SECTIONNINE

GEOLOGY AND SEISMICITY

This section describes the major geologic regions that could be affected by project construction and operation and the potential environmental consequences of the alternatives.

9.1 AFFECTED ENVIRONMENT

The following paragraphs summarize the geologic conditions and hazards that may be encountered during the construction and implementation of the alternatives for the San Luis Drainage Feature Re-evaluation. The geologic environment is discussed in greater detail in Appendix H. The focus of this section is the geologic and seismic characteristics of the Great Valley and the Coast Ranges geomorphic provinces, which may influence the comparison of a the action alternatives due to the geologic conditions and potential geologic hazards associated with these regions.

9.1.1 Regulatory Background

Several Federal and State regulations govern geology, seismicity, and soils in California. The Federal actions include the Earthquake Hazard Reduction Act of 1977, Executive Order 12699 on Seismic Safety of Federal Buildings, and the Uniform Building Code (superceded in California by the California Building Code). The State actions include the Alquist-Priolo Act, the Field Act, the California Building Code, and the Seismic Hazards Mapping Act. Some State agencies, including California Department of Transportation (Caltrans) and California Department of Water Resources (DWR), Division of Safety of Dams, have their own actions covering seismic and geologic hazards. In addition, municipalities and counties can have general or specific plans that may include the need for permitting. The regulatory background governing geology, seismicity, and soils is discussed further in Section 4.6.

9.1.2 Geologic Setting

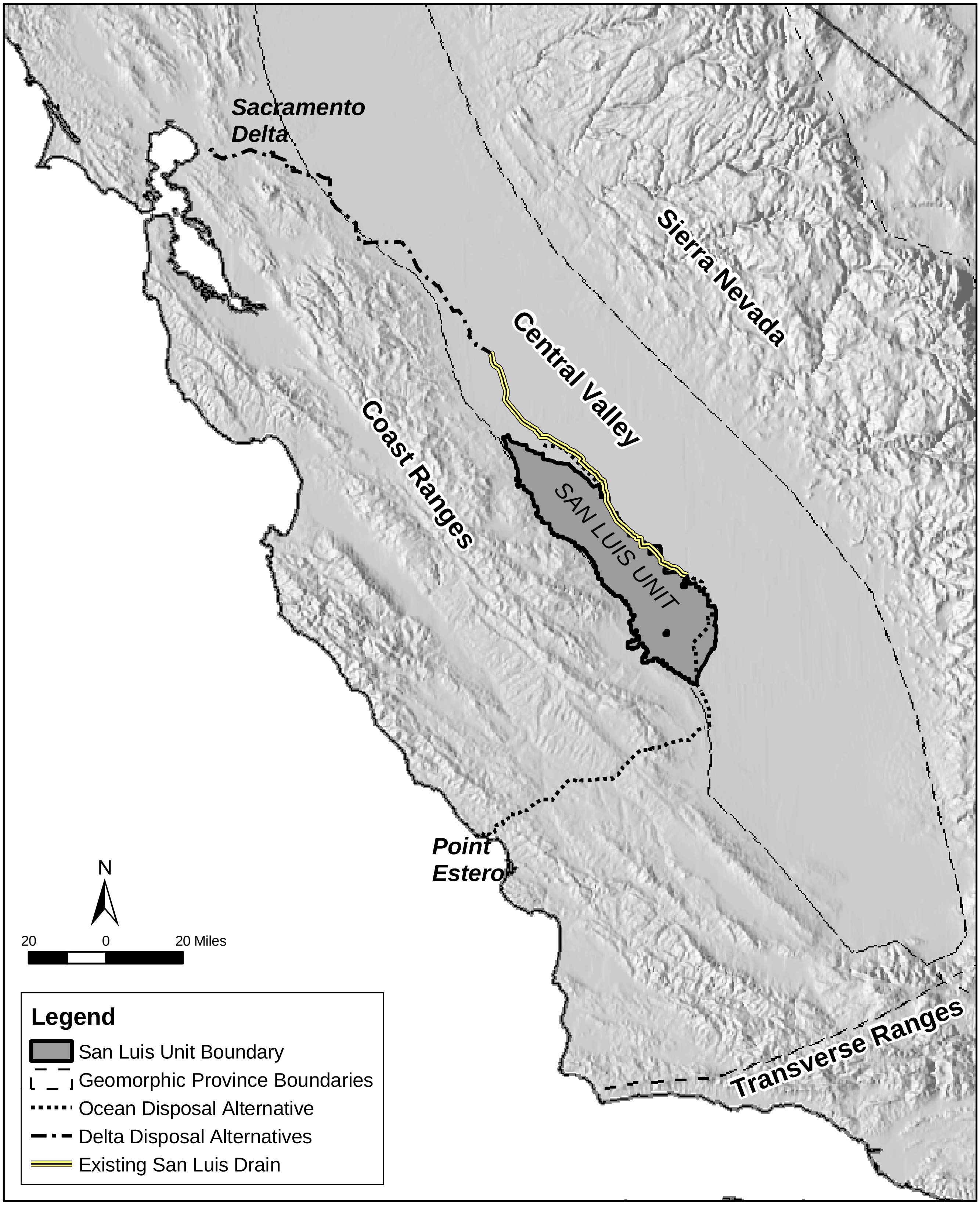
The existing San Luis Drain is situated near the western margin of San Joaquin Valley (Figure 9-1), which comprises the southern region of the Great Valley geomorphic province (Harden 1998). The Great Valley province is one of the largest agricultural basins in the world and includes Sacramento Valley in the north and San Joaquin Valley in the south, separated by the San Joaquin-Sacramento River Delta (the Delta). Further detail of the geologic setting within the project area is described in Appendix H.

San Joaquin Valley is a topographic and structural basin with the axis offset to the west (Figure 9-2), and with a gentle topographic downward slope to the north. The valley encompasses approximately 25,900 km^2 (10,000 square miles) and is bounded to the east by the Sierra Nevada Range, to the west by the Central Coast Ranges (Figure 9-3A), to the south by the Tehacapi Mountains of the Transverse Ranges geomorphic province, and to the north by the Delta. A veneer of Quaternary alluvial and lacustrine sediments cover the Cenozoic rocks of the Great Valley (Figures 9-3B through 9-3F). In central San Joaquin Valley these deposits consist mostly of unconsolidated silty sands, poorly graded sands, clayey sands, silts, and sandy clays at shallow depths. The silty sands, clayey sands, and poorly graded sands tend to be the major water-bearing units beneath the valley (Ferriz 2001). Along the western and southern boundaries of the valley, farming in some areas has ceased due to the buildup of salts and Se in the soil (see Section 6.1). Concentrations of salts and Se within the western and southern areas of the valley will likely increase over time should drainage service within these areas not be implemented.

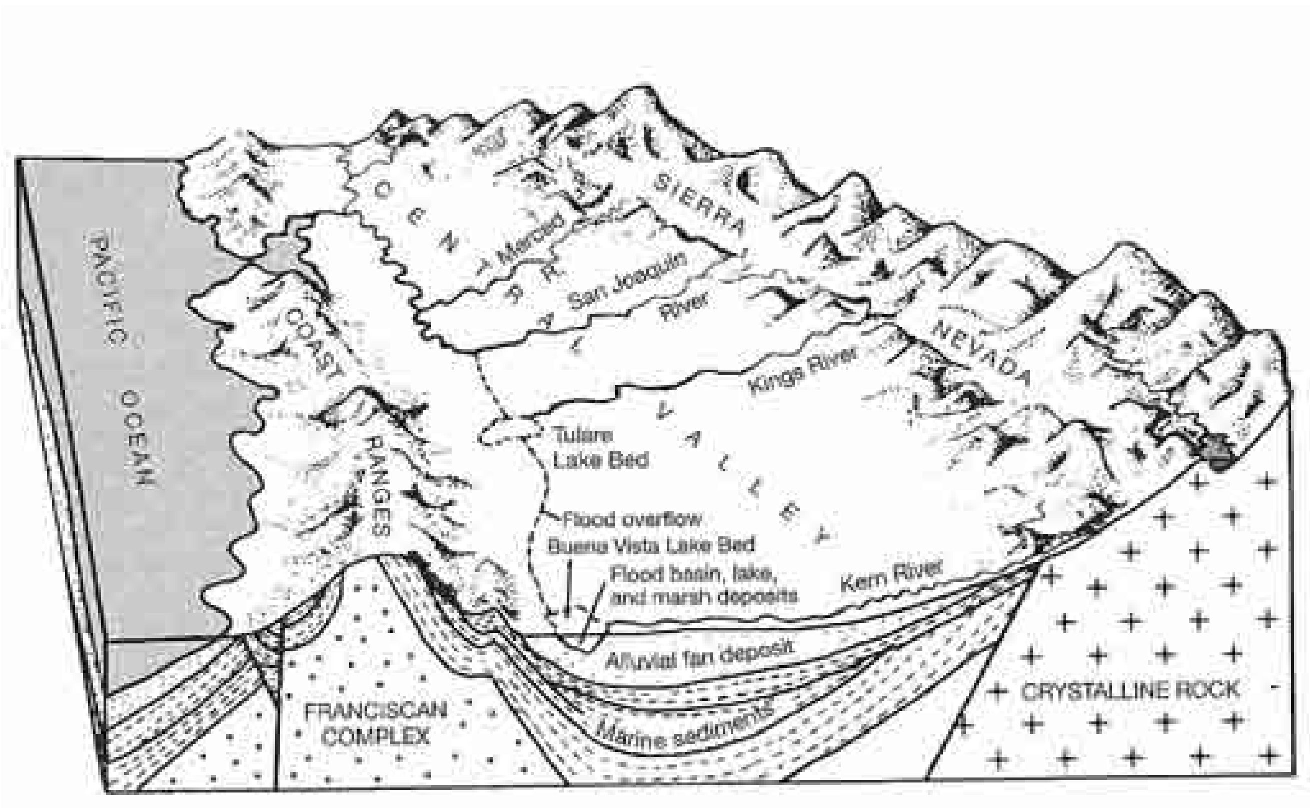
Overdraft of shallow groundwater beginning in the 1920s resulted in dramatic subsidence within several areas of southern San Joaquin Valley (Holzer 1984). Through the importation of large amounts of surface water beginning in 1968 from the California Aqueduct, and other irrigation projects, overdraft of the groundwater supplies decreased sharply.

The Ocean, Delta-Chipps Island, and Delta-Carquinez Disposal Alternatives all traverse the Coast Ranges geomorphic province (Figure 9-1). The Coast Ranges are underlain by uplifted and intensely deformed Upper Jurassic (150 million years old) and younger rocks of the Franciscan ophiolite complex and the Salinian metamorphic and granitic complex, which are in fault contact with the less deformed Great Valley sediments (Figure 9-3E). The Coast Ranges are characterized by elongate topographic and lithologic strips underlain by discrete basement blocks separated by major structural discontinuities (Appendix H).

The California Coast Ranges are a domain of right-lateral strike-slip faulting (Figure 9-4), dominated by the San Andreas fault system, which accommodates the majority of the plate motion between the Pacific and North American plates (Wallace 1990). In addition to the right-lateral strike-slip deformation, a component of compression oriented normal to the plate boundary is transferred to the region east of the main strike-slip faults as east-west to east-northeast-directed crustal shortening. This transference is accommodated as a series of folds and thrusts along the Coast Range-Sierran Block (CRSB) boundary zone located along the western margin of the Great Valley (Wakabayashi and Smith 1994). These thrusts and folds trend subparallel to the faults of the San Andreas system.

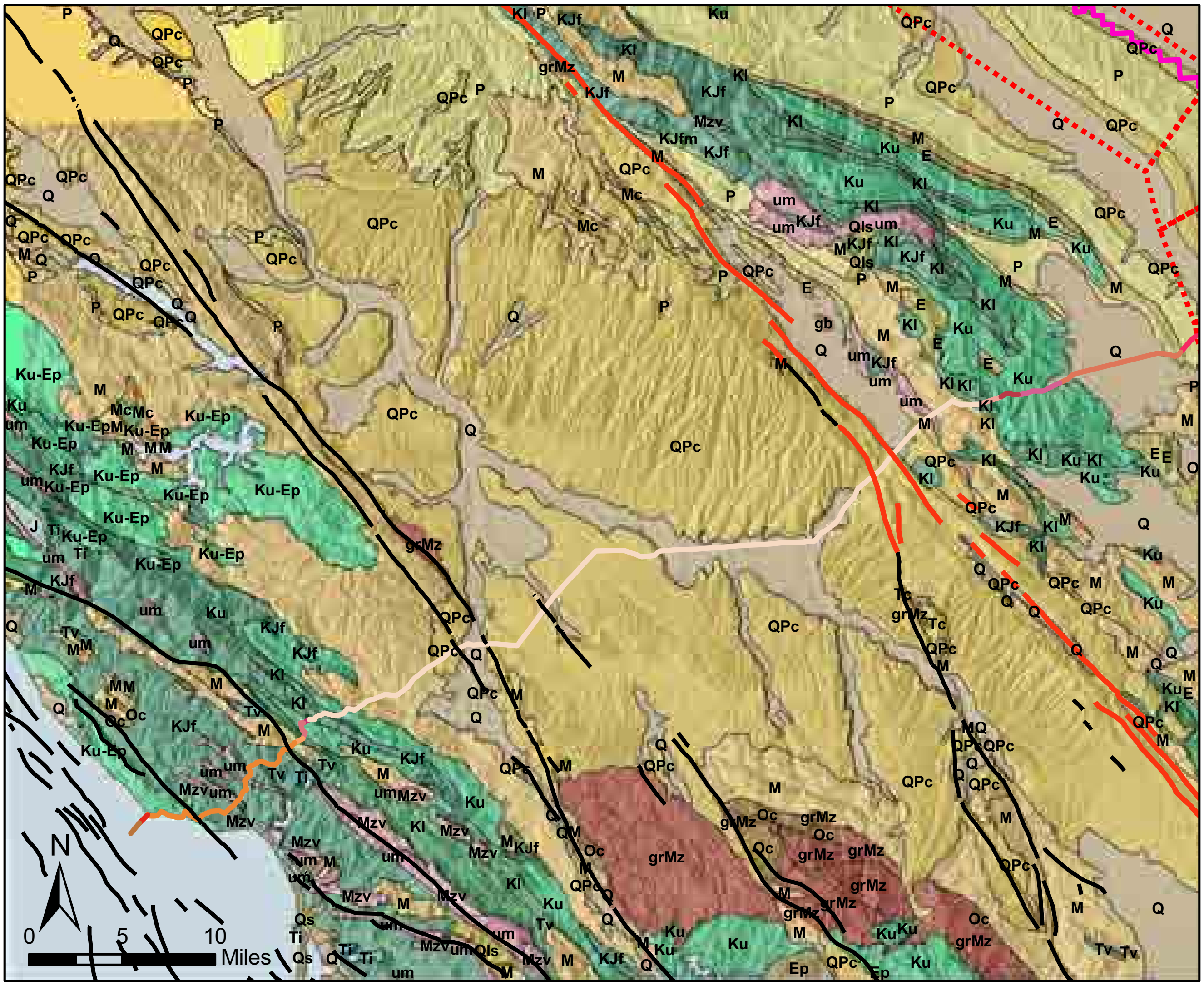


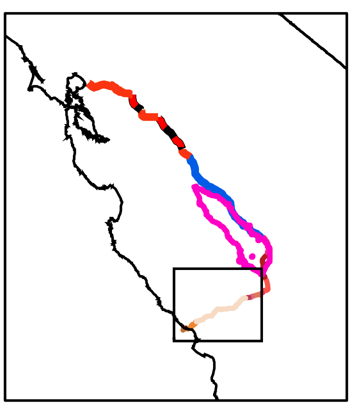
San Luis Drainage Feature Re-evaluation 17324004	Geomorphic Provinces	Figure 9-1



Source: Harden, 1998

San Luis Drainage Feature Re-evaluation	Schematic Cross-Section of San Joaquin Valley	Figure 9-2
17324004		





Legend

Delta Disposal Alternatives

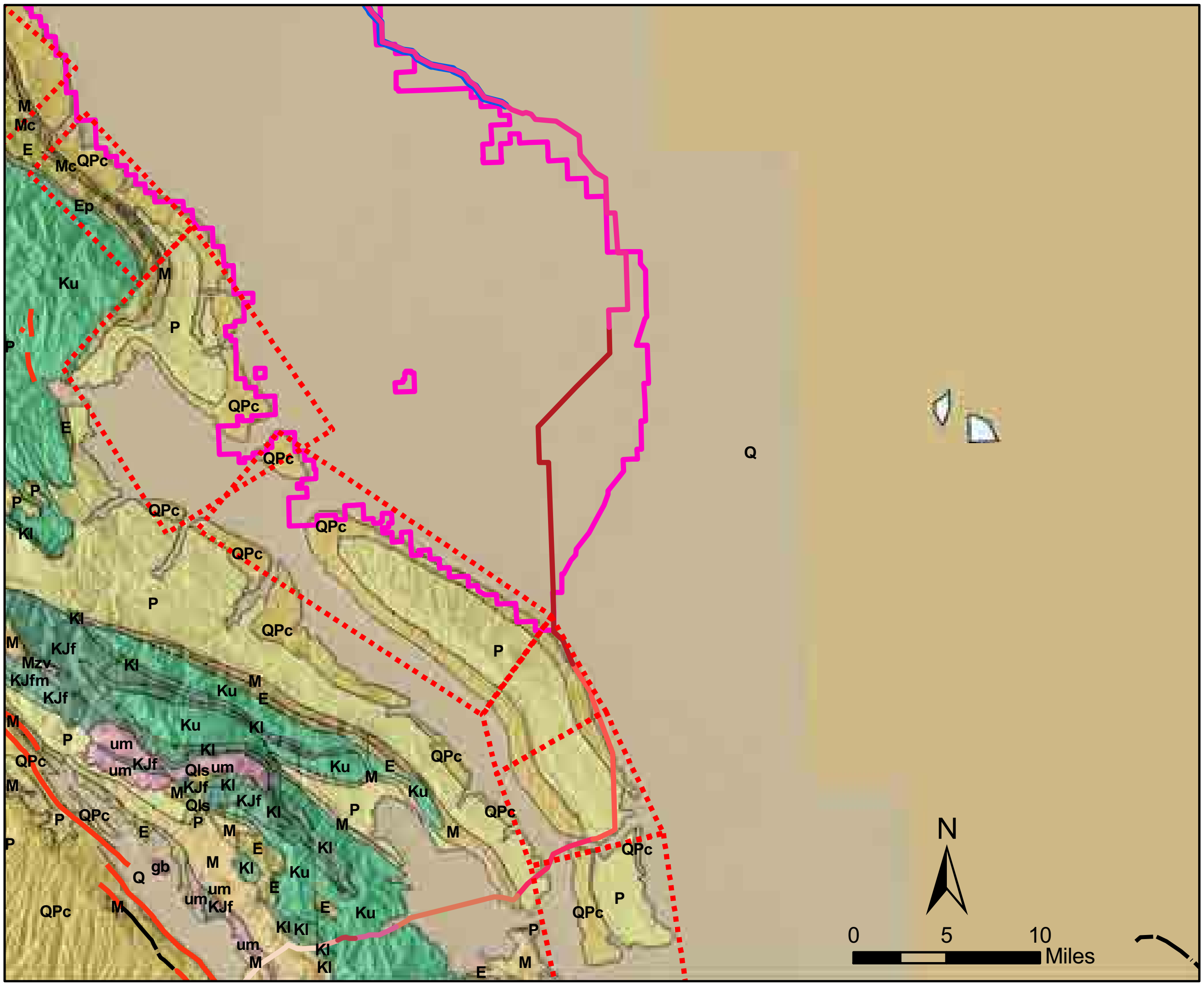
- Canal
- Pipe

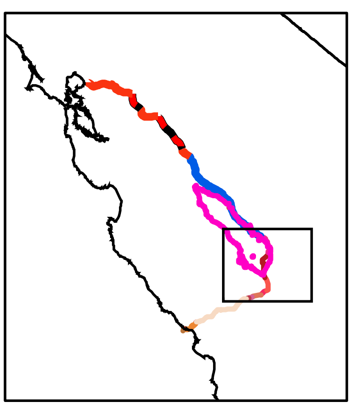
Ocean Disposal Alternative

- Bluestone Tunnel
- Buried Outfall Pipeline
- Central-South Reuse Areas Pipeline
- Cottontail Pipeline
- Kettleman City Pipeline Reach 1
- Kettleman City Pipeline Reach 2
- Kettleman City Pipeline Reach 3
- Kettleman City Pipeline Reach 4
- Kettleman City Pipeline Reach 5
- North Districts Reuse Area Pipeline
- North-Central Reuse Areas Pipeline
- Paso Robles Pipeline
- Santa Lucia Tunnel
- Santa Rita Siphon
- Santa Rita Tunnel
- South Reuse Area Pipeline
- Suspended Outfall Pipeline
- San Luis Unit Boundary
- Existing San Luis Drain

Refer to Figure 9-3F for Geologic Legend

San Luis Drainage Feature Re-evaluation	Geologic Map (1 of 5)	Figure 9-3A
17324004		





Legend

Delta Disposal Alternatives

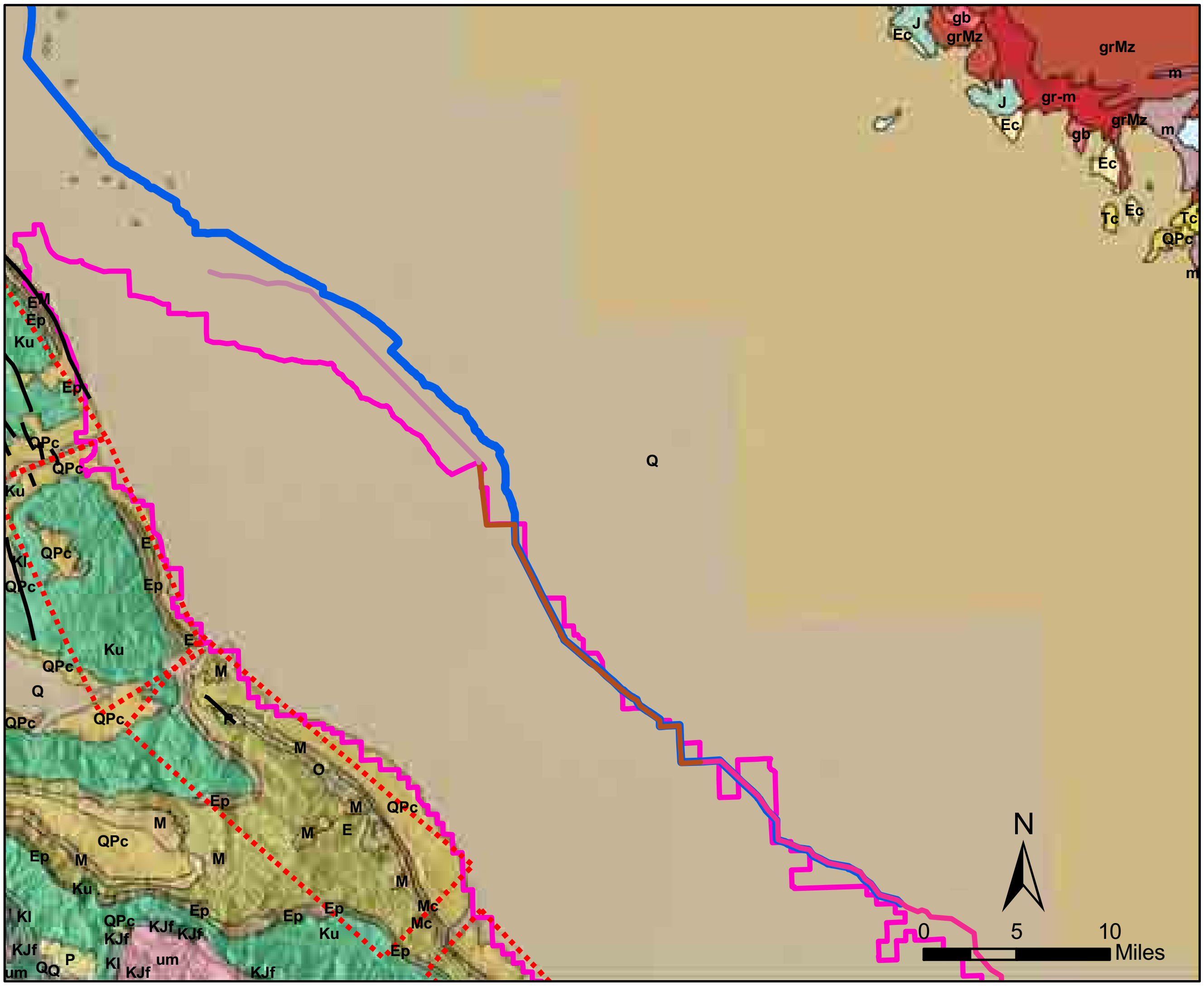
- Canal
- Pipe

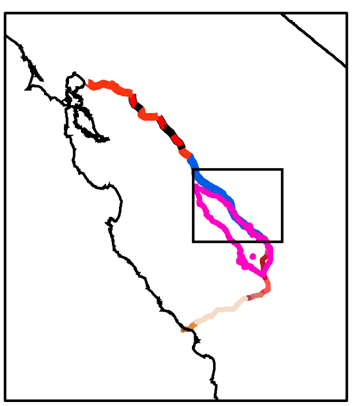
Ocean Disposal Alternative

- Bluestone Tunnel
- Buried Outfall Pipeline
- Central-South Reuse Areas Pipeline
- Cottontail Pipeline
- Kettleman City Pipeline Reach 1
- Kettleman City Pipeline Reach 2
- Kettleman City Pipeline Reach 3
- Kettleman City Pipeline Reach 4
- Kettleman City Pipeline Reach 5
- North Districts Reuse Area Pipeline
- North-Central Reuse Areas Pipeline
- Paso Robles Pipeline
- Santa Lucia Tunnel
- Santa Rita Siphon
- Santa Rita Tunnel
- South Reuse Area Pipeline
- Suspended Outfall Pipeline
- San Luis Unit Boundary
- Existing San Luis Drain

Refer to Figure 9-3F for Geologic Legend

San Luis Drainage Feature Re-evaluation	Geologic Map (2 of 5)	Figure 9-3B
17324004		





Legend

Delta Disposal Alternatives

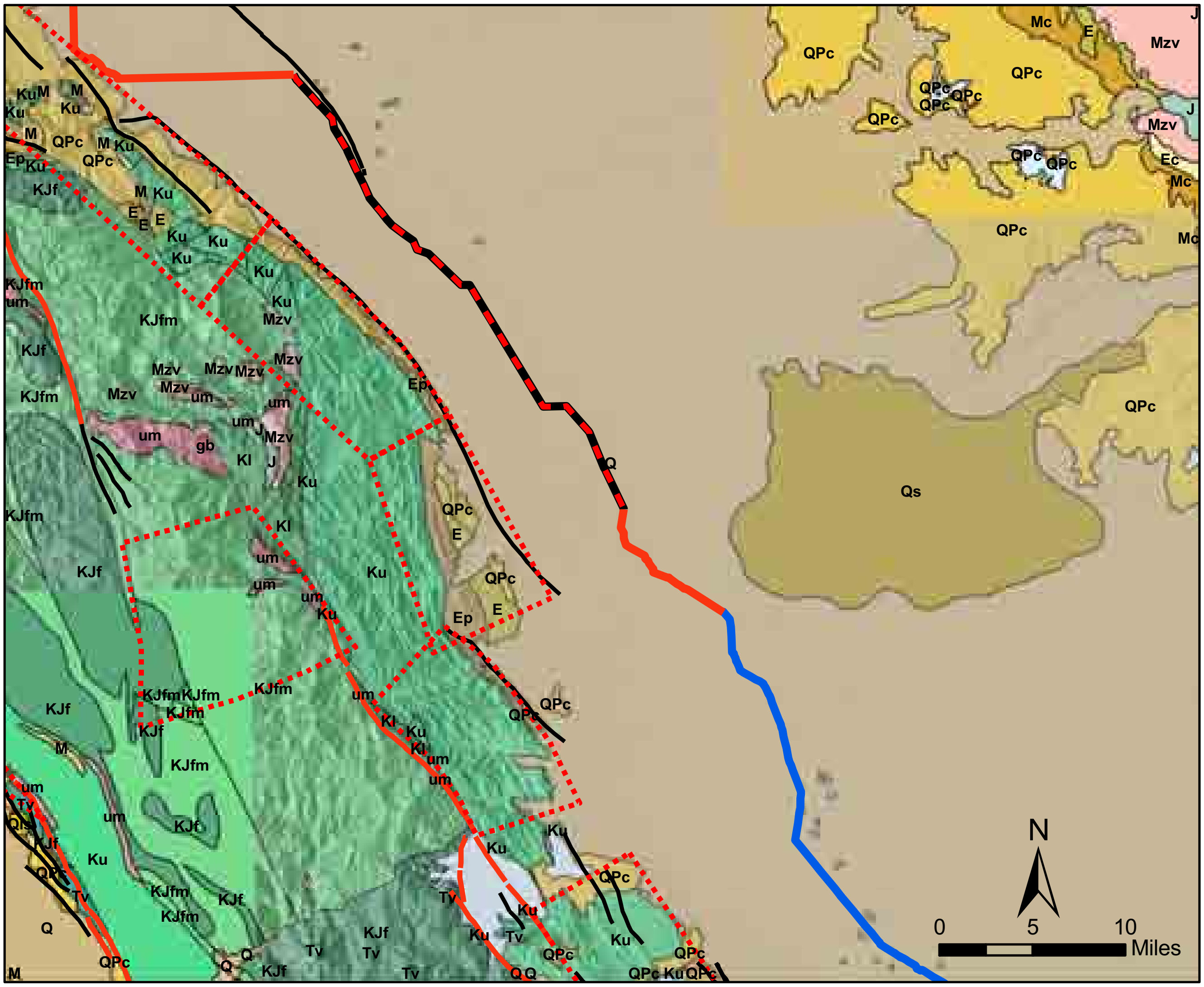
- Canal
- Pipe

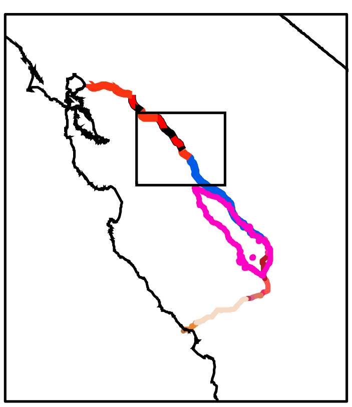
Ocean Disposal Alternative

- Bluestone Tunnel
- Buried Outfall Pipeline
- Central-South Reuse Areas Pipeline
- Cottontail Pipeline
- Kettleman City Pipeline Reach 1
- Kettleman City Pipeline Reach 2
- Kettleman City Pipeline Reach 3
- Kettleman City Pipeline Reach 4
- Kettleman City Pipeline Reach 5
- North Districts Reuse Area Pipeline
- North-Central Reuse Areas Pipeline
- Paso Robles Pipeline
- Santa Lucia Tunnel
- Santa Rita Siphon
- Santa Rita Tunnel
- South Reuse Area Pipeline
- Suspended Outfall Pipeline
- San Luis Unit Boundary
- Existing San Luis Drain

Refer to Figure 9-3F for Geologic Legend

San Luis Drainage Feature Re-evaluation	Geologic Map (3 of 5)	Figure 9-3C
17324004		





Legend

Delta Disposal Alternatives

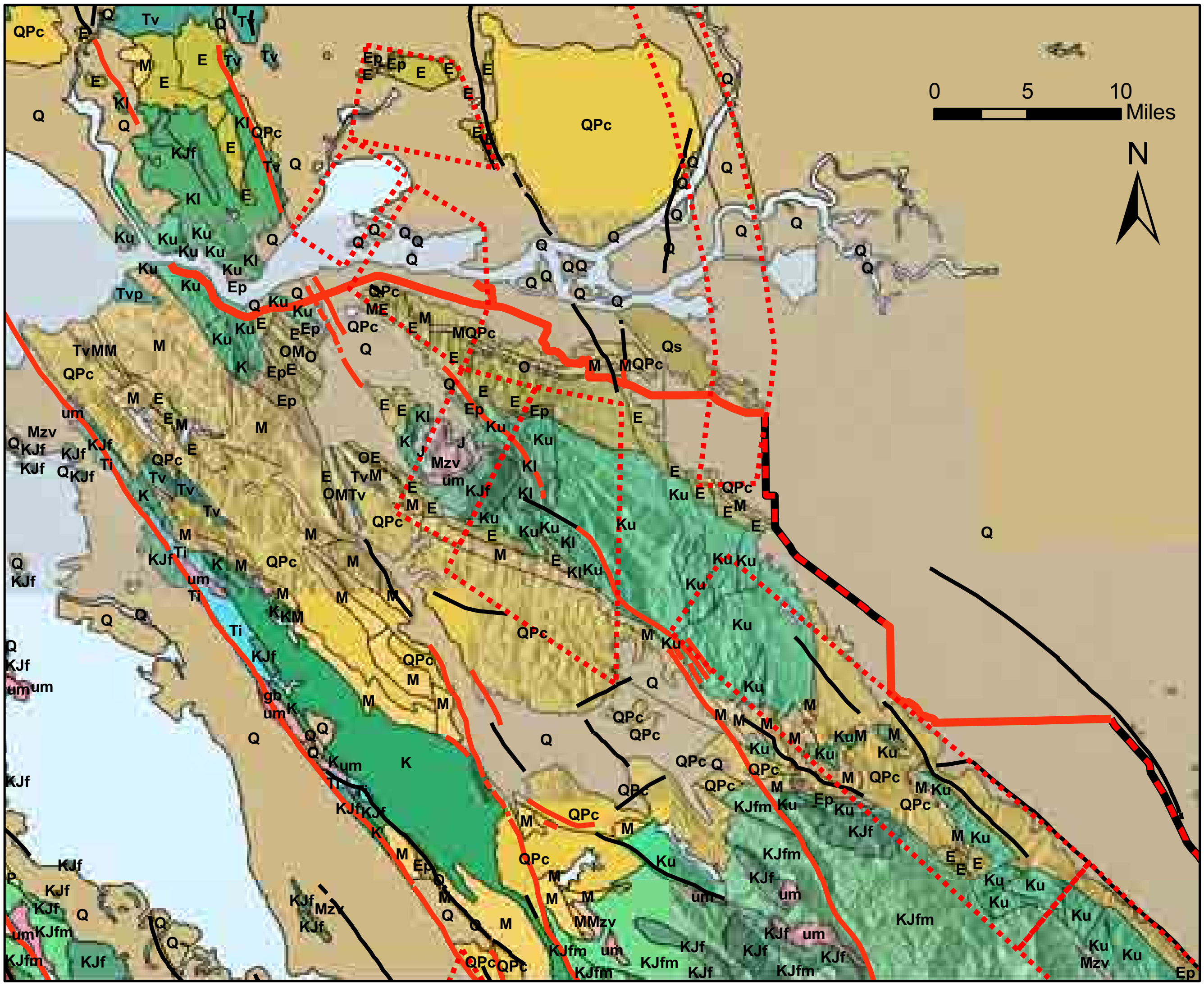
- Canal
- Pipe

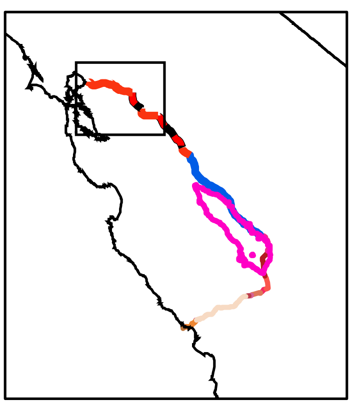
Ocean Disposal Alternative

- Bluestone Tunnel
- Buried Outfall Pipeline
- Central-South Reuse Areas Pipeline
- Cottontail Pipeline
- Kettleman City Pipeline Reach 1
- Kettleman City Pipeline Reach 2
- Kettleman City Pipeline Reach 3
- Kettleman City Pipeline Reach 4
- Kettleman City Pipeline Reach 5
- North Districts Reuse Area Pipeline
- North-Central Reuse Areas Pipeline
- Paso Robles Pipeline
- Santa Lucia Tunnel
- Santa Rita Siphon
- Santa Rita Tunnel
- South Reuse Area Pipeline
- Suspended Outfall Pipeline
- San Luis Unit Boundary
- Existing San Luis Drain

Refer to Figure 9-3F for Geologic Legend

San Luis Drainage Feature Re-evaluation	Geologic Map (4 of 5)	Figure 9-3D
17324004		





Legend

Delta Disposal Alternatives

- Canal
- Pipe

Ocean Disposal Alternative

- Bluestone Tunnel
- Buried Outfall Pipeline
- Central-South Reuse Areas Pipeline
- Cottontail Pipeline
- Kettleman City Pipeline Reach 1
- Kettleman City Pipeline Reach 2
- Kettleman City Pipeline Reach 3
- Kettleman City Pipeline Reach 4
- Kettleman City Pipeline Reach 5
- North Districts Reuse Area Pipeline
- North-Central Reuse Areas Pipeline
- Paso Robles Pipeline
- Santa Lucia Tunnel
- Santa Rita Siphon
- Santa Rita Tunnel
- South Reuse Area Pipeline
- Suspended Outfall Pipeline
- San Luis Unit Boundary
- Existing San Luis Drain

Refer to Figure 9-3F for Geologic Legend

San Luis Drainage Feature Re-evaluation	Geologic Map (5 of 5)	Figure 9-3E
17324004		

Holocene (Active) faults
Pre-Holocene faults
Active Blind Thrusts

Cenozoic Sedimentary Rocks

- Q, Alluvium (mostly Holocene); Quaternary nonmarine & marine
- QPc, Plio-Pleistocene nonmarine; Pliocene nonmarine
- Qg, Glacial deposits
- Qls, Selected large landslide deposits
- Qs, Extensive sand dune deposits
- P, Pliocene marine
- M+KJfs, Miocene marine-Franciscan schist
- M, Miocene marine
- M?, Miocene marine?
- Mc, Miocene nonmarine
- O, Oligocene marine
- Oc, Oligocene nonmarine
- Oc?, Oligocene nonmarine?
- E, Eocene marine
- E-Ep, Eocene-Paleocene marine
- Ec, Eocene nonmarine
- Ep, Paleocene marine
- Tc, Tertiary nonmarine, undivided

Mesozoic, Paleozoic, Precambrian Sedimentary and Metasedimentary Rocks

- TK, Tertiary-Cretaceous Coastal Belt rocks
- K, Cretaceous marine undivided (in part nonmarine)
- K?, Cretaceous marine undivided (in part nonmarine)?
- KJf, Franciscan Complex
- KJfm, Franciscan melange
- KJfs, Franciscan schist
- Kl, Lower Cretaceous marine
- Kl?, Lower Cretaceous marine?
- Ku, Upper Cretaceous marine
- Ku-Ep, Upper Cretaceous marine-Paleocene marine
- Ku?, Upper Cretaceous marine?
- J, Jurassic marine
- J?, Jurassic marine?
- Tr, Triassic marine
- Pm, Permian marine
- C, Carboniferous marine
- D, Devonian marine
- SO, Silurian and/or Ordovician marine
- Ca, Cambrian marine
- Pz, Paleozoic marine, undivided
- ls, Limestone of probable Paleozoic or Mesozoic age
- pC, Precambrian rocks, undivided
- sch, Schist of various types and ages

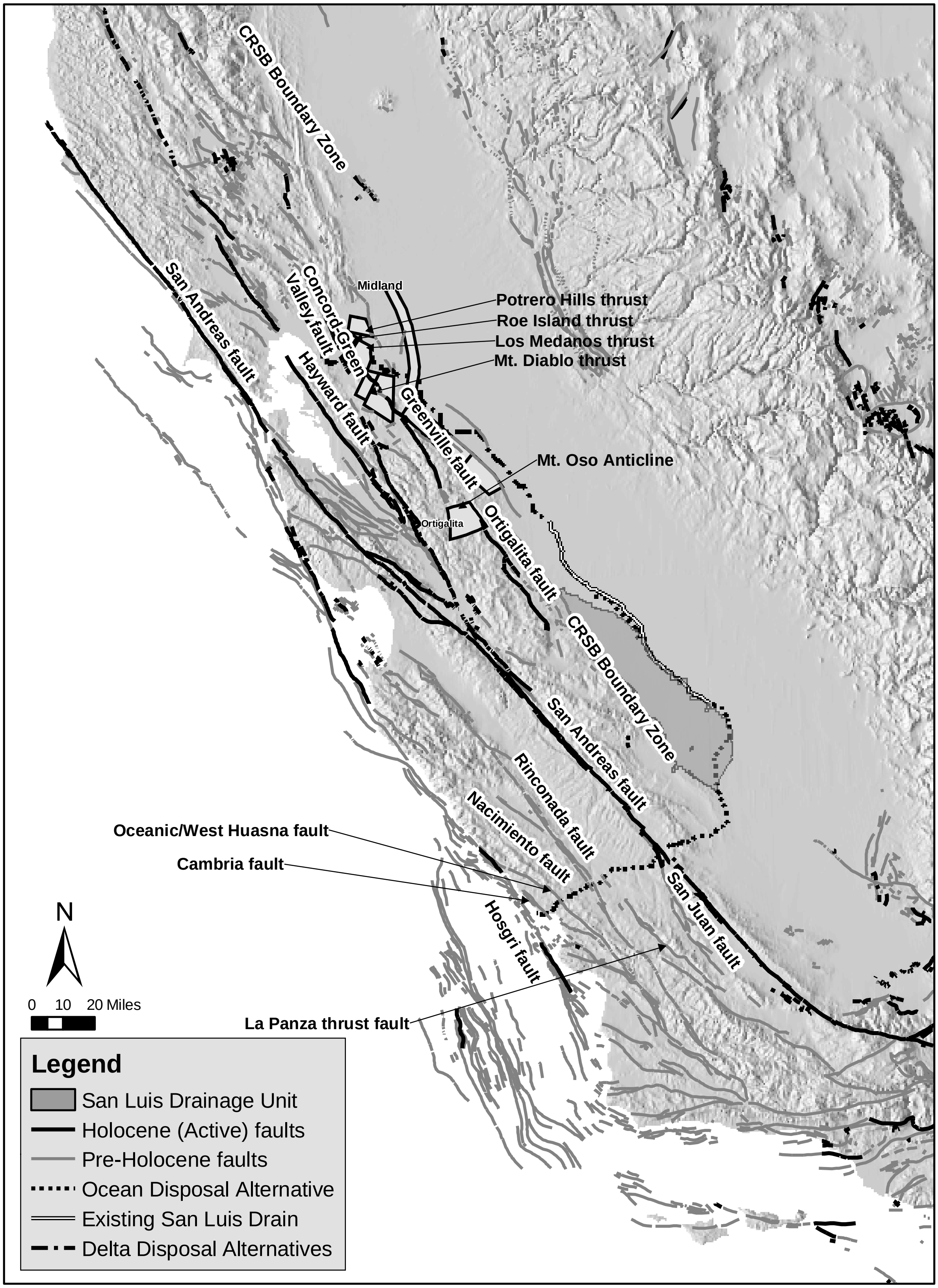
Cenozoic Volcanic Rocks

- Qrv, Recent (Holocene) volcanic flow rocks(or predominantly flow rocks)
- Qrvp, Recent (Holocene) pyroclastic rocks and volcanic mudflow deposits
- Qv, Quaternary volcanic flow rocks (or predominantly flow rocks)
- Qv?, Quaternary volcanic flow rocks (or predominantly flow rocks)?
- Qvp, Quaternary pyroclastic rocks and volcanic mudflow deposits
- Qvp?, Quaternary pyroclastic rocks and volcanic mudflow deposits?
- Ti, Tertiary intrusive rocks
- Tv, Tertiary volcanic flow rocks (or predominantly flow rocks)
- Tvp, Tertiary pyroclastic rocks and volcanic mudflow deposits

Cenozoic-Precambrian Plutonic, Metavolcanic, and Mixed Rocks

- grCz, Cenozoic (Tertiary) granitic rocks
- grCz?, Cenozoic (Tertiary) granitic rocks?
- gr-m, Granitic and metamorphic rocks, undivided, of pre-Cenozoic age
- gb, Mesozoic gabbroic rocks
- grMz?, Mesozoic granitic rocks?
- um, Ultramafic rocks, chiefly Mesozoic
- Mzv, Mesozoic volcanic and metavolcanic rocks; Franciscan volcanic rocks
- grMz, Mesozoic granitic rocks
- mv, Undivided pre-Cenozoic metavolcanic rocks
- m, Undivided pre-Cenozoic metasedimentary and metavolcanic rocks
- grPz, Paleozoic and Permo- Triassic granitic rocks
- Pzv, Paleozoic metavolcanic rocks
- grpC, Precambrian granitic rocks
- grpC?, Precambrian granitic rocks?
- pCc, Precambrian igneous and metamorphic rock complex
- gr, Undated granitic rocks

San Luis Drainage Feature Re-evaluation	Legend	Figure 9-3F
17324004		



URS Corporation L:\Projects\San Luis Drainage\MXD\Soils and Geology\F_9-4 Faults.mxd Date: 5/21/2003 11:35:39 AM Name: dhwrigh0

San Luis Drainage Feature Re-evaluation	Active Faults	Figure 9-4
17324004		

9.1.3 Seismicity

The historical earthquake record for San Joaquin Valley and much of California only extends back to the mid-1800s, coinciding with the influx of miners and settlers during the Gold Rush (Wong and Ely 1983). Until adequate seismographic coverage came into existence in Southern California in the 1930s, earthquake detection was generally limited to those events that produced felt or physical effects. Earthquakes as small as Richter local magnitude (M_L) 3 were probably not completely observed throughout San Joaquin Valley until about 1960. Thereafter, seismographic coverage in Southern California improved significantly and, currently, earthquakes as small as M_L 1.5 can be detected for most portions of the San Joaquin Valley.

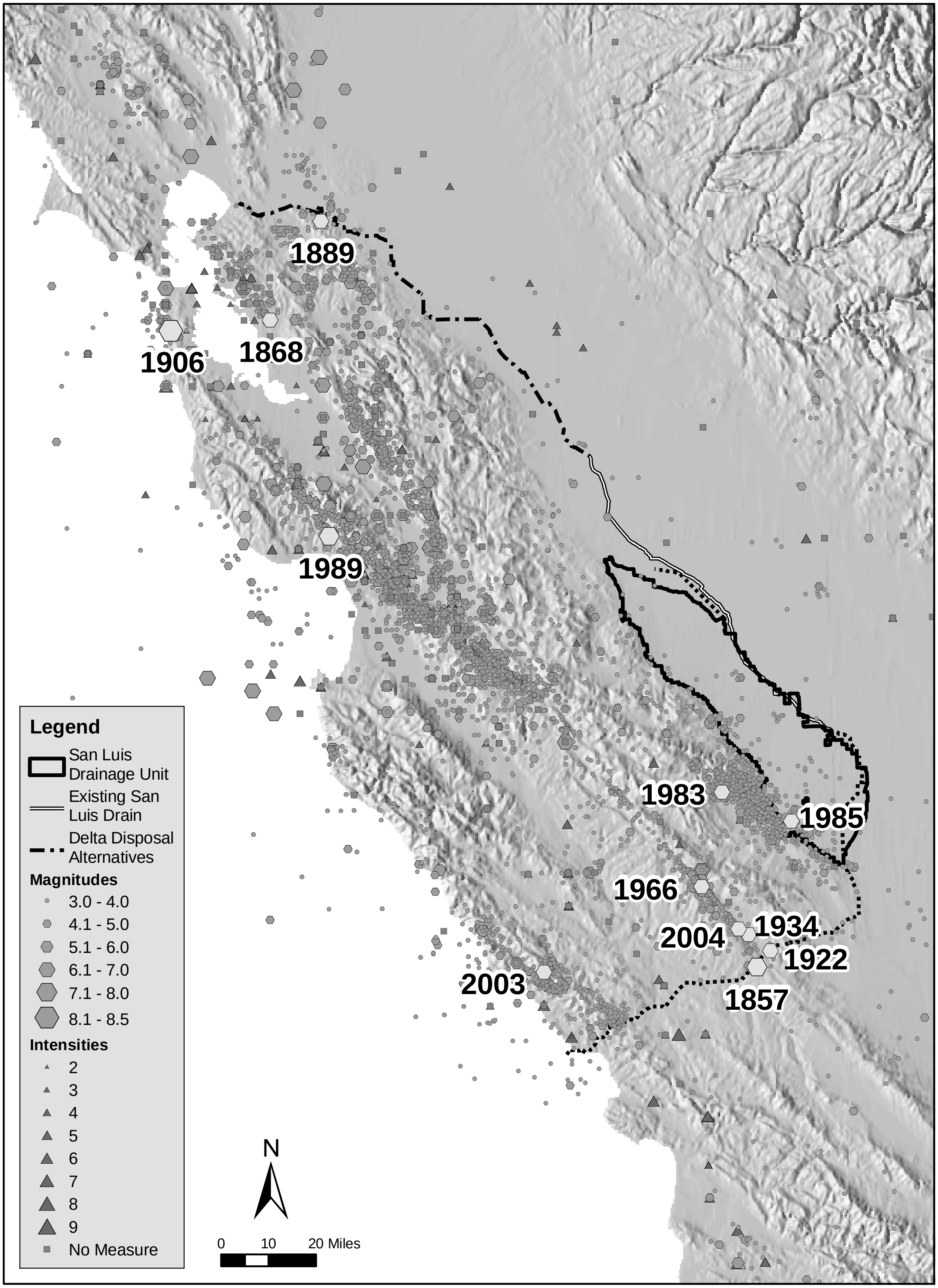
The project area is located in a region that historically has not been seismically active (Figure 9-5). The largest historical earthquakes have generally occurred along the valley margins. The current seismicity along the margins of the Central Valley and within the Coast Ranges provinces is characterized by linear alignments of epicenters along the main faults in the San Andreas fault system, most prominently the San Andreas, Calaveras, Hayward, Nacimiento, and Hosgri faults (Figure 9-5). Seismicity along the western margin of the Central Valley (the CRSB boundary) is more diffuse and clustered as aftershock sequences around the epicenters of the Coalinga and Kettleman Hills mainshocks. The seismicity of the project area is discussed in greater detail in Appendix H.

9.1.4 Significant Faults

Southern San Joaquin Valley is surrounded by a number of active and potentially active faults (Figure 9-4), some of which have generated large, damaging earthquakes during historic time. The most significant of these are listed in Table 9-1, along with estimates of the maximum earthquake for each fault.

The dominant active fault structure in this region is the San Andreas fault. The fault extends from the Gulf of California, Mexico, to Point Delgada on the Mendocino Coast in Northern California, a total distance of 1,200 km (746 miles). The San Andreas fault accommodates about 75 percent of the motion between the Pacific and North American plates. This fault is the largest active fault in California and is responsible for two of the largest known earthquakes in California during historical time, the 1857 moment magnitude (**M**) 8 Fort Tejon and the 1906 **M** 7.9 San Francisco earthquake (Wallace 1990). The Ocean Disposal Alternative crosses the San Andreas fault at the boundary between the Parkfield and Cholame segments. This part of the fault ruptured during the 1857 Fort Tejon earthquake. Estimates of lateral displacement during this earthquake are at least 7 meters (23 feet) (Grant and Sieh 1993). The Parkfield segment most recently ruptured during a **M** 6 event on September 9, 2004 (http://www.cisn.org/special/evt.04.09.28/).

Other active faults, including the Hayward, Concord-Green Valley, CRSB boundary thrusts, Mount Diablo, Greenville, Ortigalita, Rinconada, Oceanic-West Huasna, and Hosgri faults, are all capable of generating large, damaging earthquakes. These and other active faults are discussed in greater detail in Appendix H.



San Luis Drainage Feature Re-evaluation	Historical Seismicity M $\geq$ 3 and Significant Earthquakes 1864 - 2005	Figure 9-5
17324004		

Table 9-1
Major Active Faults

Fault	Style of Faulting[a]	Fault Length (km)[b]	Maximum Credible Earthquake (M)[c]	Slip Rate (mm/yr)
San Andreas	SS	305	8	34 ± 3
Hayward – Rodgers Creek	SS	150	7½	9 ± 2
Concord-Green Valley	SS	56	7	5 ± 2
CRSB	R	25-30	6¾	1.5 ± 1.0
Mt. Diablo	R	25	6¾	4.1 ± 1.4
Greenville	SS		7	2 ± 1
Ortigalita	SS	100	7½	1.0 ± 0.5
Mt. Oso	R	25	6¾	unknown
San Juan	SS	86	7¼	unknown
La Panza	R	71	7¼	unknown
Rinconada	SS	128	7½	1
Nacimiento	SS	86	7¼	unknown
Oceanic/West Huasna	R	28	6¾	unknown
Cambria	R	63	7	unknown
Hosgri	SS	120	7½	1 – 3

Notes:
[a] SS: strike-slip; R: reverse
[b] maximum rupture length
[c] Moment magnitude

Sources: Working Group on California Earthquake Probabilities (1999); Working Group on Northern California Earthquake Potential (1996).

9.1.5 Geologic and Seismic Hazards

This section of the EIS considers the potential geologic hazards that may be encountered in the project area. The hazards considered include surface fault rupture, earthquake ground shaking, liquefaction, landsliding/mass wasting, uplift and subsidence, seiches and tsunamis, expansive soils, and erosion.

9.1.5.1 Surface Fault Rupture

Surface fault rupture is defined as slip on a fault plane that has propagated upward to, and is offsetting or disturbing, the earth’s surface. Offset on a fault intersecting the ground surface can create a discrete step or fault scarp (Stewart and Hancock 1990) if fault slip occurs on a single fault plane or within a narrow fault zone. If fault slip is accommodated over a broader area, then the deformation may be manifest as a zone of fracturing and ground cracking with minor amounts of offset on individual fractures; however, the cumulative offset across the entire zone may be significant. Surface faulting may also arise as a secondary effect from other geologic processes. Secondary surface faulting can be triggered by aquifer compaction and subsidence or by the effects of strong ground shaking triggering slip on neighboring faults. Surface fault rupture has occurred on a number of faults within the study region during the last 10,000 years.

The State of California delineates zones around active faults under the Alquist-Priolo Earthquake Fault Zone Act (Hart 1994) in order to mitigate for the effects of surface faulting. The State defines an active fault as a fault showing evidence for rupture during the Holocene (the last 11,000 years). The project route crosses two faults zoned by the State as being active; the San Andreas and Concord-Green Valley faults. Fault parameters and slip-per-event estimates are presented in Table 9-2. Other active faults crossed by the proposed route are the CRSB fault zone and the Midland fault. Both of these fault zones comprise a series of blind thrusts. These are reverse faults, which although active, do not rupture to the surface. However, these, and other active faults (Table 9-1), because of their proximity to the pipeline alignment, can generate potentially significant ground motions along the route but are not considered ground rupture hazards.

The Ocean Disposal Alternative also crosses the San Juan, Rinconada, Nacimiento, Oceanic-West Huasna, and Cambria faults. None of those faults is zoned by the State of California under the Alquist-Priolo Act and, therefore, are not considered by the State to constitute a potential surface faulting hazard. The 2003 San Simeon earthquake, which may have been generated by rupture of the Oceanic fault, was not accompanied by surface fault rupture.

Table 9-2
Potential Surface Faulting Displacements

Fault	Length	Earthquake Magnitude (M)	Average Displacement[1] (meters)	Maximum Displacement[1] (meters)
San Andreas	375	7.9	6.8 ± 0.20	17.6 ± 1.2
Concord-Green Valley	56	6.9	1.3 ± 0.2	2.5 ± 0.4

[1]Calculated from empirical relationships between fault length and surface displacement (Wells and Coppersmith 1994).

9.1.5.2 Earthquake Ground Shaking

The amount of earthquake shaking at a particular site is a function of earthquake magnitude, type of earthquake source (i.e., type of fault); distance between the site and the earthquake source, geology of the site, and how earthquake waves decrease or attenuate as they travel from their source to the site in question. Typically, the larger the earthquake and the shorter the distance between the earthquake source and the site, then the greater the amount of shaking. The geologic materials through which the earthquake energy travels towards the site act to decrease, or attenuate, the amount of shaking. A number of attenuation relationships have been developed from recordings of earthquake shaking that relate earthquake size, distance from the earthquake source, and geologic conditions to the amount of shaking that can be expected at a site. The amount of shaking is expressed in terms of ‘Peak Horizontal Acceleration’ (PHA) measured in percent of ‘g’, the acceleration of gravity (approximately 980 cm/sec^2).

California has experienced numerous damaging earthquakes during historic time (Figure 9-5) (Stover and Coffman 1993; Toppozada et al. 2000). The 1868 earthquake on the Hayward fault caused widespread damage throughout the eastern San Francisco Bay area; the 1906 earthquake on the San Andreas fault caused extensive damage in San Francisco and throughout Northern California. More recently, the 1989 Loma Prieta earthquake in the Santa Cruz Mountains and the 1994 Northridge earthquake in the San Fernando Valley caused widespread damage in San Francisco Bay and Los Angeles basin regions, respectively. Locally, the M 6.5 San Simeon earthquake had its epicenter about 25 km (15 miles) north of the proposed pipeline route for the Ocean Disposal Alternative and caused significant shaking and damage, especially to unreinforced masonry buildings. A more comprehensive list of damaging earthquakes is provided in Appendix H.

To estimate the maximum shaking that might occur in a future earthquake, the ground motion parameter, PHA, is calculated using empirical attenuation relations (Abrahamson and Silva 1997; Boore et al. 1997; Campbell 1997; Sadigh et al. 1997) and the maximum earthquakes for each seismic source. To account for variations in each relation, the results of each were summed and then averaged. Closer faults or larger magnitude earthquakes result in potentially higher ground motions than more distant faults or smaller maximum earthquakes. Such an approach, which only considers the maximum earthquake and does not consider how often such an earthquake will occur, is called deterministic seismic hazard assessment, and is essentially a 'worst-case scenario' approach, which is adopted by some State agencies such as Caltrans (Mualchin 1996) and DWR, Division of Safety of Dams (Fraser 2001).

An alternative approach is probabilistic seismic hazard analysis, which is an evaluation of the likelihood that specific ground motions will be exceeded during a specific time period. The analysis can also provide ground motions with specific probabilities of being exceeded. Because probabilistic approaches incorporate earthquake frequency, they allow for risk-based decisions to be made, incorporating the lifetime of the facility and consequences of failure. This approach is used both by the USGS and California Geological Survey (CGS), to produce ground shaking hazard maps for both State and Federal use (Frankel et al. 2002; Petersen et al. 1996). Maps of probabilistic seismic hazard are used in the Uniform Building Code and various FEMA guidelines for seismic rehabilitation of buildings. Deterministic approaches do not incorporate the frequency of earthquake occurrence; therefore, they only represent single event scenarios, which can result in inappropriate ground motion levels for seismic design.

The USGS National Hazard Maps (http://geohazards.cr.usgs.gov/eq/) show that the 10 percent in 50-year (474-year return period) ground motions along the western margin of San Joaquin Valley are between 0.4 and 0.5 g (acceleration due to gravity) in the CRSB vicinity (USGS 2003; Frankel et al 2002). Away from the valley margin, in the area of the existing SLDF the ground motions are about 0.1 g. The Ocean, Delta-Carquinez, and Delta-Chipps Island Disposal Alternatives all cross areas that have the potential to experience ground motions in excess of 0.6 g and possibly as high as 0.8 to 1 g (USGS 2003; Frankel et al. 2002). Maximum recorded ground motions in the 2003 San Simeon earthquake were 0.48 g near Templeton (Hardebeck et al. 2004).

9.1.5.3 Liquefaction

Liquefaction is a phenomenon during which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction and related phenomena have been responsible for tremendous amounts of damage in historical earthquakes around the world.

Liquefaction is the transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore pressure and decreased effective stress (Youd and House 1978). Increased pore pressures in unconsolidated sediment, especially in western California, are most typically seismically induced. Observed types of ground failure resulting from liquefaction can include sand boils, lateral spreads, ground settlement, ground cracking, and ground warping (Youd and Hoose 1978).

Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. Although earthquake shaking often triggers this increase in water pressure, construction-related activities such as blasting, also can cause an increase in water pressure. When liquefaction occurs, the strength of the soil decreases, and the ability of a soil deposit to support foundations for buildings and bridges is reduced. Liquefied soil also exerts higher pressure on retaining walls, which can cause them to tilt or slide. This movement can cause settlement of the retained soil and destruction of structures on the ground surface. Increased water pressure can also trigger landslides.

Because liquefaction only occurs in saturated soil, its effects are most commonly observed in low-lying areas near waterbodies such as rivers, lakes, bays, and oceans. The effects of liquefaction may include major sliding and slumping of soil toward the water body, or more modest movements that produce tension cracks. Port and wharf facilities are often located in areas susceptible to liquefaction damage. Liquefaction-induced soil movements can push foundations out of place to the point where structures lose support or are compressed to the point of buckling.

Four kinds of ground failure commonly result from liquefaction: lateral spread, flow failure, ground oscillation, and loss of bearing strength:

- Lateral Spread

  Lateral displacement of surficial blocks of sediment as the result of liquefaction in a subsurface layer is called a lateral spread. Once liquefaction transforms the subsurface layer into a fluidized mass, gravity plus inertial forces that result from the earthquake may cause the mass to move downslope towards a cut slope or free face (such as a river channel or a canal). Lateral spreads most commonly occur on gentle slopes that range between 0.3° and 3°, and commonly displace the surface by several meters to tens of meters.

- Flow Failure

  The most catastrophic mode of ground failure caused by liquefaction, flow failure usually occurs on slopes greater than 3°. The flows are principally soil or blocks of intact material riding on a liquefied subsurface zone. Displacements are commonly tens of meters, but in favorable circumstances, have displaced material tens of miles at velocities of tens of km per hour.

- Ground Oscillation

  When liquefaction occurs at depth, but the slope is too gentle to permit lateral displacement, the soil blocks that are not liquefied may decouple from one another and oscillate on the liquefied zone. The resulting ground oscillation may be accompanied by the opening and closing of fissures and sand boils.

- Loss of Bearing Strength

  When a soil loses strength and liquefies, loss of bearing strength may occur beneath a structure, possibly causing the building to settle and tip. If the structure is buoyant, it may float upward.

Research into the process and consequences of liquefaction in past earthquakes have linked liquefaction to certain hydrologic and geologic settings, characterized by water-saturated, cohesionless, granular materials situated at depths of less than 12 meters (40 feet). The following areas are those identified as being favorable for liquefaction:

- Areas known to have experienced liquefaction during historic earthquakes.
- Areas of uncompacted fill containing liquefaction susceptible material that is saturated, nearly saturated, or may be expected to become saturated.
- Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.
- Areas containing young (less than 15,000 years) soils, with limited or no geotechnical data.

Areas traversed by the Delta Disposal Alternatives satisfy all four of the above criteria. The area around Walnut Creek on the southern bank of the Sacramento River suffered liquefaction during the 1906 **M** 7.9 San Francisco earthquake (Knudsen et al. 2000). Most of the project area that lies within the Central Valley geomorphic province satisfies the last criteria, as do stretches of the Ocean Disposal Alternative. Some liquefaction features were observed near Paso Robles and Oceana following the 2003 San Simeon earthquake, which was located near the Ocean Disposal Alternative route; most occurred in areas of artificial fill (Hardebeck et al. 2004).

9.1.5.4 Landsliding/Mass Wasting

Mass wasting is downward movement of soils and rock under gravity, including landslides, rockfalls, and debris flows. Mass wasting requires source materials, a slope, and a triggering mechanism. Source materials include fractured and weathered bedrock, unconsolidated materials, and loose soils. Steep slopes are more susceptible to mass wasting. Triggering mechanisms include earthquake shaking, heavy rainfall, erosion and undercutting of the toe of the slope.

Slides and earth flows are landslides that can pose serious hazard to property in the hillside terrain of the Coast Ranges. They tend to move slowly and, thus, rarely threaten life directly. When they move – in response to such changes as increased water content, earthquake shaking, addition of load, or removal of downslope support – they deform and tilt the ground surface. The result can be destruction of foundations, offset of roads, and breaking of underground pipes within and along the margins of the landslide, as well as overriding of property and structures downslope. Landslide hazards for the San Francisco Bay Area have been mapped by the USGS

(San Francisco Bay Landslide Mapping Team 1997) and more recently by CGS (http://gmw.consrv.ca.gov/shmp/) under the Seismic Hazard Mapping Program.

Due to the loosely to moderately consolidated condition of the sedimentary units within the central Coast Ranges, the area is highly susceptible to landslide events (Figure 9-3). Large amounts of precipitation can fall in a short amount of time, saturating the sediments and causing failure on steep slopes (Figure 9-6). Landslides and shallow soil slips are mostly observed in the northern Coast Ranges; however, flash-type flooding events tend to dominate the southern Coast Ranges and without sufficient vegetative cover (due to low annual rainfall), large-scale landslides have occurred. The Franciscan Formation is frequently associated with landslides along the Coast Ranges and accounts for the downslope transport of significant volumes of material (Norris and Webb 1990). Due to an abundant amount of serpentinite in the Franciscan Formation, shearing is prevalent and, therefore, makes the formation more susceptible to landslides. The Ocean Disposal Alternative would cross the Franciscan Formation between the edge of the Kettleman Hills and Cottonwood Pass, and from near the summit of the Santa Lucia Range to the Pacific Ocean (Figure 9-3A).

9.1.5.5 Subsidence and Uplift

Land surface subsidence can result from both natural and human-made phenomena. Natural phenomena include subsidence resulting from tectonic deformation and seismically induced settlements, soil subsidence due to consolidation, subsidence due to oxidation or dewatering of organic-rich soils, and subsidence related to subsurface cavities. Subsidence, or settlement related to human activities include subsidence caused by decreased pore pressure due to the withdrawal of subsurface fluids, including water and hydrocarbons.

Land subsidence in San Joaquin Valley became a major issue beginning in the late 1960s (Figure 9-7). Overdrafting of shallow groundwater resources has caused the water table to drop from just below the surface in many areas to nearly 30.5 meters (100 feet) below ground surface in central San Joaquin Valley and over 61 meters (200 feet) in southern San Joaquin Valley. Land subsidence has occurred on nearly 13,500 km^2 (5,212 square miles) of land, approximately 50 percent of San Joaquin Valley land mass, and ground-surface elevations in areas have dropped as much as 10 meters (33 feet) in the last 80 years (Poland and Lofgren 1984).

Three types of land subsidence have been documented in the valley: (1) subsidence due to the compaction of aquifer units from excessive withdrawal of groundwater; (2) hydrocompaction, subsidence due to the compaction of fine-grained moisture-deficient deposits when water is applied; and (3) subsidence due to the extraction of oil deposits beneath the surface (Poland and Lofgren 1984). The first two types of subsidence described are most commonly encountered along the existing San Luis Drain and the potential route for the San Luis Drain extension and other related conveyance (pipelines and canals) to reuse and treatment facilities.

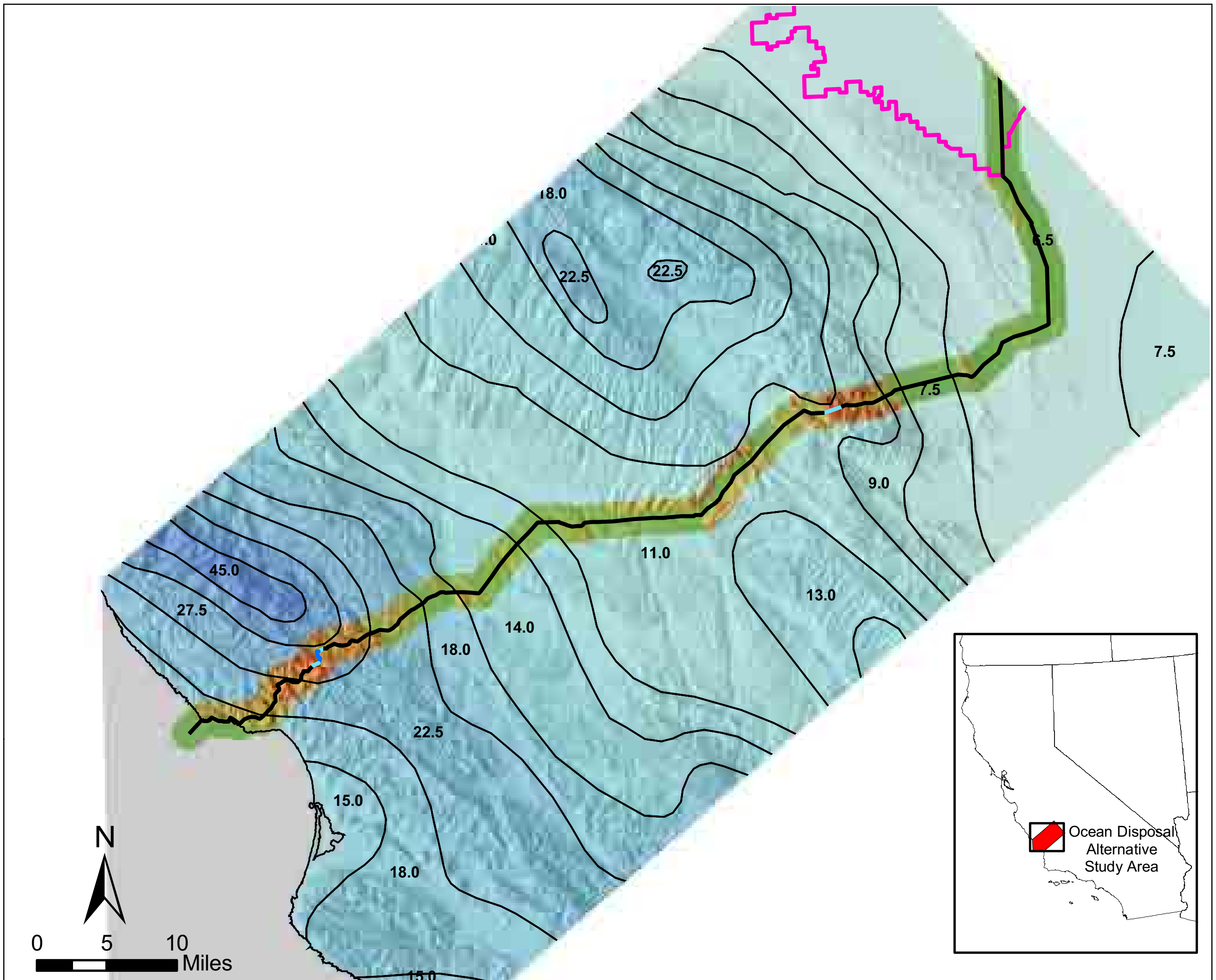
Overdrafting of groundwater supplies has been occurring since the middle 1920s when agriculture became the main industry in San Joaquin Valley. Shallow groundwater was easy to tap into. With the invention of the electric pump and abundant water supplies, farmers were encouraged to convert the native land and grow more crops on a yearly basis. The continued pumping of groundwater eventually caused a reduction in pore pressure within the water-bearing, coarse-grained sediments beneath the valley. Through the years, more groundwater was pumped and used for irrigation than what was naturally recharged through yearly flooding and precipitation. As the water was drained from the aquifer, the sediments compacted and permanently reduced the pore space within the formation. The compaction of these coarse-grained sedimentary units caused the majority of the land subsidence in San Joaquin Valley. The location of the existing San Luis Drain and the route of the San Luis Drain extension trend through the areas that were heavily affected by this type of land subsidence (Figure 9-7). However, since the importation of surface water for irrigation, the rate of land subsidence due to the draining of aquifers has declined sharply (Poland and Lofgren 1984).

Subsidence has also occurred in the Delta region. The area was originally covered by peat bogs, which were removed for agricultural purposes. The removal of the peat through oxidation/burning, wind-blown fine-grained sediments, and aquifer dewatering has lowered the ground surface in the Delta area by as much as 7 meters (23 feet). Large dikes have been constructed to hold back yearly floodwaters of the Sacramento, American, and San Joaquin rivers. However, the potential conveyance alignment for the Delta Disposal Alternatives appears to be mostly located to the south and west of the areas affected by the land subsidence in the Delta region (Norris and Webb 1990).

To a lesser extent, hydrocompaction has occurred in several localized areas along western San Joaquin Valley. Hydrocompaction occurs after fine-grained clay sediments deposited above the groundwater table via mudflows are dried out due to low rainfall. Once water is applied for the first time, the clay bond in these sediments weakens and the fine-grained deposits compact. Hydrocompaction has occurred along approximately 65 km (40 miles) of the California Aqueduct, which trends along western San Joaquin Valley and is situated near the potential alignment of the Delta aqueduct and the San Luis Drain extension. Prior to the construction of the California Aqueduct, the fine-grained soils along the proposed route were watered thoroughly so that the soils would compact (Poland and Lofgren 1984).

Subsidence due to the extraction of oil deposits occurs primarily in southern San Joaquin Valley (Kern County) and only occurs in localized areas where large amounts of oil have been pumped from the underlying strata.

Tectonic land level changes were observed following the 1983 Coalinga earthquake (Stein and Ekström 1992). Detailed leveling surveys following the earthquake revealed uplift of up to 0.5 meter (1.6 feet) approximately 10 km (6.2 miles) northeast of and subsidence of 50 mm (2 inches) in the area surrounding the town of Coalinga.



Legend

Ocean Disposal Alternative Alignment

- Tunnels
- Pipelines
- Santa Rita Siphon
- San Luis Unit Boundary

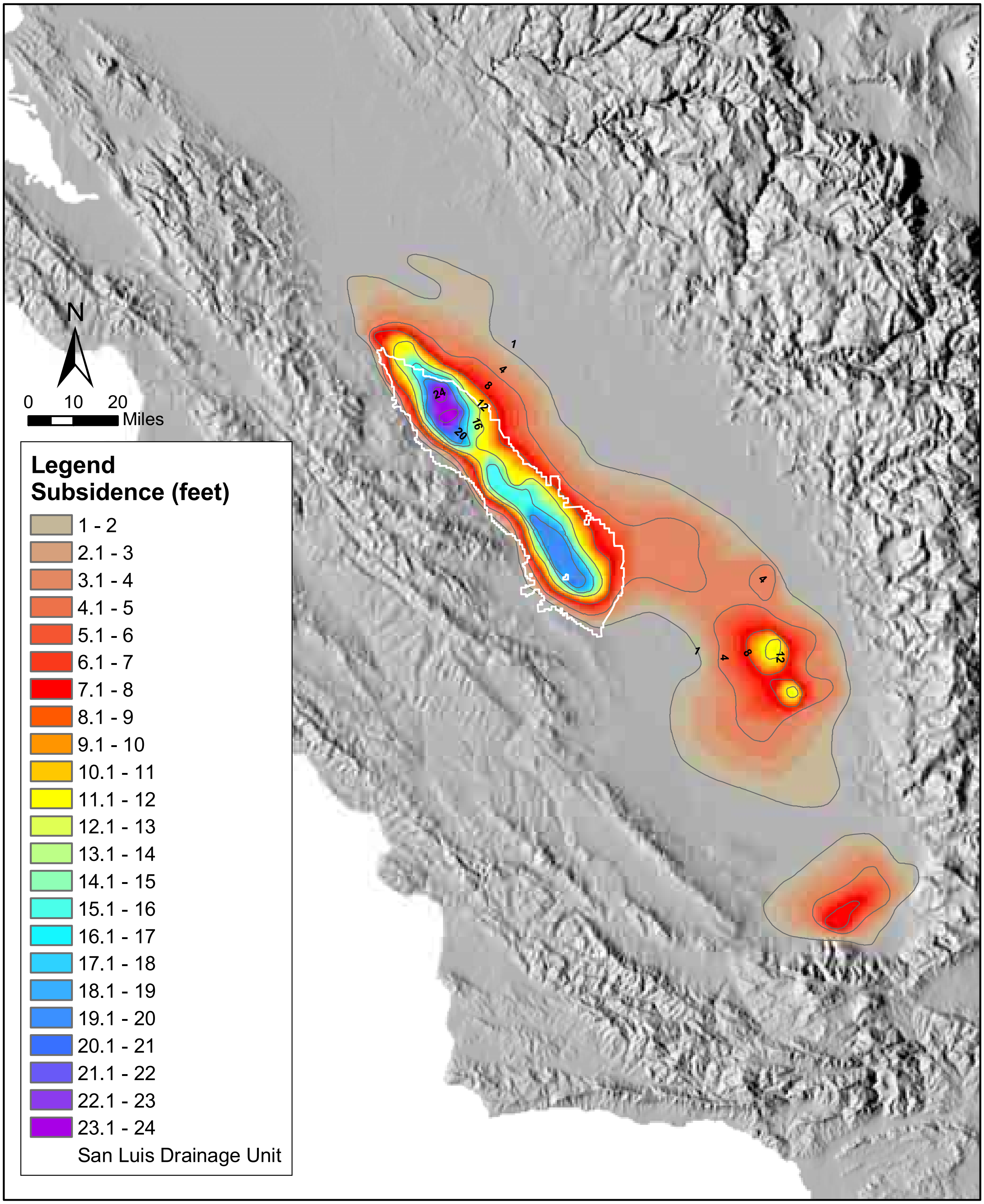
Slope (degrees)

- 0 - 5
- 5.1 - 10
- 10.1 - 20
- > 20

Annual Precipitation (inches)

5	12.5	25
5.5	13	27.5
6.5	14	30
7	15	32.5
7.5	17	35
8	17.5	37.5
9	18	40
11	22.5	45

San Luis Drainage Feature Re-evaluation 17324004	Potential Slope Instability Along Ocean Disposal Alternative	Figure 9-6



San Luis Drainage Feature Re-evaluation	Subsidence	Figure 9-7
17324004		

9.1.5.6 Tsunami and Seiche

A "tsunami" (Japanese word meaning "harbor wave") is a water wave or a series of waves generated by an impulsive displacement of the surface of the ocean or other water body. Tsunamis can travel across oceanic basins and cause damage several thousand km from their sources. Most tsunamis are caused by a rapid vertical movement along a break in the earth's crust, i.e., a tectonic fault rupture on the bottom of the ocean resulting in displacement of the column of water directly above it. The majority of tsunamis are triggered by earthquake rupture along subduction zones. The catastrophic tsunami that struck the Indian Ocean on December 26, 2004, is one such example. Other causes of tsunamis include subaqueous and subaerial landslides, volcanic eruptions and meteor impacts. The 1964 Alaska earthquake generated a tsunami that caused widespread damage along the coastline of northern California. Paleoseismic investigations have also shown that tsunamis resulting from earthquakes on the subduction zone beneath Japan and the Cascadia subduction zone in the Pacific Northwest have also inundated the Pacific coast states (Atwater et al. 1995). An increasing body of evidence is showing that tsunamis have repeatedly affected the coast of central California (Borrero et al. 2001).

A seiche is a periodic oscillation or "sloshing" of water in a lake or an enclosed basin such as San Francisco Bay. The period of oscillation can range from minutes to hours. Seiches can be caused by the same mechanisms that induce tsunamis.

9.1.5.7 Expansive Soils

Expansive soils contain mixed-layer clay minerals that increase and decrease in volume upon wetting and drying, respectively. Expansive soils are common throughout California and can cause damage to foundations and slabs unless properly treated during construction. The shrink-swell capacity of expansive soils can result in differential movement beneath foundations.

Expansive soils commonly contain smectite mixed-layer clays and exhibit a vertisol texture. Such soils are found throughout the Central Valley province, in particular in San Joaquin Valley. Soils of the San Joaquin, Panoche, and Tulare associations are the most likely to contain mixed layer clays.

9.1.5.8 Erosion

Erosion is the gradual wearing away of land by water, wind, and weathering. Erosion is a natural geological process, but more rapid soil erosion results from poor land-use practices, leading to the loss of fertile topsoil and to the silting of dams, lakes, rivers, and harbors.

Wind erosion may occur on any soil where the surface is dry, unprotected by vegetation (to bind it at root level and shelter the surface) and consists of light particles. Transport mechanisms include straightforward picking up of dust and soil particles by the airflow and the dislodging or abrasion of surface material by the effect of particles already airborne.

Three classes of water erosion exist: (1) splash erosion occurs when raindrops strike bare soil, causing it to splash, as mud, to flow into spaces in the soil, and to turn the upper layer of soil into a structureless, compacted mass that dries with a hard, largely impermeable crust; (2) surface flow occurs when soil is removed with surface runoff during heavy rain; and (3) channelized flow occurs when a flowing mixture of water and soil cuts a channel, which is then deepened by further scouring.

9.1.6 Geologic Resources of Recreational, Commercial, or Scientific Value

The action alternatives have the potential to affect the geologic environment, in particular, the energy, mineral, and paleontological resources. A summary of these resources is presented below. Geologic resources of potential recreational, commercial, or scientific value in the project vicinity that could be affected include aggregate and gas reserves.

9.1.6.1 Sand and Gravel Resources

The Quaternary deposits along the western margin of the Central Valley may be potential aggregate resources. None of these resources are currently being exploited.

9.1.6.2 Crushed Rock Aggregate Resources

No working crushed rock aggregate operations exist within the project area or along the In-Valley or Out-of-Valley Disposal Alternative alignments.

9.1.6.3 Hydrocarbons

Several known hydrocarbon (oil and gas) resources exist within the immediate project area (DOGG 2001). The Ocean Disposal Alternative crosses the Kettleman North oil field. The Holm and Turk anticline oil fields are also located within the project area. The Delta Disposal Alternatives cross several small gas fields, including the Vernalis and Tracy field on the southern side of the Delta.

9.1.6.4 Geothermal Resources

No known geothermal resources exist within the immediate project area (DOGG 2001).

9.1.6.5 Economic Resources

No known significant mineral resources exist beneath the project area other than potential sand and gravel deposits.

9.1.6.6 Unique or Outstanding Geologic and Geomorphic Features

The project area of the Central Valley and the Coast Ranges does not contain any unique geological formations, geological features, or geomorphological features. The stratigraphy and geologic features along the western margin of San Joaquin Valley are common to the entire Central Valley. Likewise, the geology and geomorphology along the Disposal Alternative routes through the Coast Ranges do not encounter any geologic features that cannot be found elsewhere in the Coast Ranges.

9.2 ENVIRONMENTAL CONSEQUENCES

This section describes how the implementation of new conveyance and other drainwater management facilities would be affected by the geologic hazards previously identified.

9.2.1 Evaluation Criteria

Effects would be considered significant if they:

- Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving surface fault rupture, earthquake ground shaking, liquefaction, subsidence, uplift, expansive soils, mass wasting, erosion, and tsunami or seiche;
- Situate structures on a geologic unit or soil that is unstable, or that could become unstable as a result of the action alternatives, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse;
- Result in substantial soil erosion or the loss of topsoil; or
- Prevent future access to geologic features and resources of economic or scientific value.

9.2.2 Assessment Methods

Information about the project area's geologic and seismic history and resources was developed from reviews of the relevant geologic databases, and literature, including an extensive collection of earlier project-related documentation, maps, and reports. Published and peer-reviewed scientific reports and papers by academic, government, and industry scientists, geologic maps published by USGS and CGS (formerly Division of Mines and Geology), hazard maps prepared by Federal agencies (e.g., FEMA), U.S. Department of Agriculture soil survey reports, and the safety elements of local authority general plans provided the majority of the information for this study.

9.2.3 No Action Alternative

The No Action Alternative would consist of reasonably foreseeable future conditions without drainage service alternatives. Under the No Action Alternative approximately 109,100 acres of land would be retired from irrigation. Some reuse due to the existing Grassland Bypass Project would occur, and existing pilot projects that could utilize reuse and treatment systems would continue in the area.

The existing San Luis Drain would be in use until 2009 and is subject to one documented geologic hazard, land subsidence. Two types of land subsidence are most commonly encountered along the existing Drain: reduction of pore space from overpumping of groundwater resources and hydrocompaction. Subsidence due to oil extraction has been documented in southern San Joaquin Valley near Bakersfield and should not be an issue with the No Action Alternative.

Topographically, San Joaquin Valley slopes downward in elevation northward toward the Delta region; the southern portion of the Drain is located at a topographically higher elevation than the northern portion. This slope allows the existing Drain to be gravity fed and does not require uphill pumping of the agricultural wastewater. It is likely that certain portions of the existing Drain have been affected at some point by land subsidence. However, the amount of land subsidence around these portions of the existing Drain may not have been significant enough to alter the grade of the drainage route. Since the importation of surface water to this area, the rate of land subsidence has diminished and would have no effect to the existing Drain by the 2009 closure date.

The No Action Alternative may also be subject to strong earthquake shaking and the attendant affects of liquefaction, seiche, and mass wasting. The **M** 6.4 1983 Coalinga earthquake caused extensive structural damage in and around the town of Coalinga. Other effects included damage to canals and canal linings resulting from lateral spreading and liquefaction. Similar effects can be expected for a future earthquake located along the CRSB. A repeat of the 1857 earthquake on the San Andreas fault would also result in widespread strong shaking over much of the project area. Liquefaction would be widespread in sandy and silty materials and would be exacerbated if a large earthquake were to occur during the winter when the groundwater elevation increases due to higher precipitation. Water retention structures, including holding ponds, may also be subject to damage from seiches of impounded water and liquefaction/lateral spreading of poorly constructed earth embankments.

No new collection facilities would be constructed; therefore, the likelihood of affecting geologic resources of economic or scientific value would be negligible.

9.2.4 In-Valley Disposal Alternative

The two types of land subsidence that could affect this alternative are pore space compaction and hydrocompaction. This alternative's location is south and upgradient from the existing Drain. This alternative would use pumps to lift the water from the existing Drain and from new drains (including the proposed Delta-Mendota Canal drain) to the reuse facilities. Land subsidence within this area could change the grade of the potential aqueduct that would be used to convey drainwater to the reuse facilities. The reused drainwater would be conveyed via pipeline or canal to treatment and/or disposal facilities. Detailed geotechnical investigations for this alternative would likely be required along the proposed conveyance alignments to evaluate the potential for subsidence of these sediments prior to construction. In addition, topographic data could be used in connection with USGS historical benchmark data to determine the amount of historical subsidence in areas along the potential routes and near the reuse facilities. For those areas with subsidence, careful management of groundwater resources (both pumping and injection rates) would minimize the effect. Groundwater resources are currently managed through local agency compliance with plans developed under AB 3030, Groundwater Management Act, 1992. The potential alignment should not be influenced by the oil extraction land subsidence, since it mostly occurs in southern San Joaquin Valley near Bakersfield.

This alternative's collection system and treatment facilities would be subject to heave from expansive soils where soils of the San Joaquin, Panoche, and Tulare associations are encountered. This effect would be considered significant. Geotechnical investigations are needed to determine the specifically affected components. Removing and/or treating such soils would minimize the effect of shrink/swell behavior; with this mitigation, no significant effect would occur. Construction activities for evaporation basins may result in increased erosion and runoff during earthwork. However, as these activities are transient, the effect to the geologic environment is considered to be minimal. Construction-related erosion, especially during construction of evaporation basins where large volume earthwork may be required, may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive runoff. With this mitigation, no significant effect would occur.

Strong earthquake shaking from either the CRSB or the San Andreas fault also has the potential to affect this alternative. However, by employing current engineering design standards, it is unlikely that this alternative would be affected significantly by an earthquake.

9.2.5 In-Valley/Groundwater Quality Land Retirement Alternative

The In-Valley/Groundwater Quality Land Retirement Alternative consists of retiring all the lands in Westlands with Se concentration greater than 50 ppb in the shallow groundwater and lands acquired by Westlands (that could be brought into production with drainage service, Table 2.3-1). It would also retire 10,000 acres in Broadview Water District in the Northerly Area. Total land retirement is 92,592 acres (44,106 acres for the In-Valley Disposal Alternative plus an additional 48,486 acres).

Lands remaining in production within the drainage-impaired area would be eligible for drainage service. The collection, treatment, and disposal of drainwater collected from drained lands would be similar to that described for the In-Valley Disposal Alternative (for RO treatment, Se biotreatment, the evaporation basins, and conveyance), but at a slightly reduced scale due to greater land retirement than under the In-Valley Disposal Alternative.

Similar to the In-Valley Disposal Alternative, the two types of land subsidence that could affect this alternative are pore space compaction and hydrocompaction. Effects from expansive soils and earthquake shaking and effects from construction activities for evaporation basins that may result in increased erosion and runoff during earthwork are similar to the In-Valley Disposal Alternative.

9.2.6 In-Valley/Water Needs Land Retirement Alternative

The In-Valley/Water Needs Land Retirement Alternative would retire enough lands to meet the internal water use needs of the San Luis Unit or 193,956 acres (44,106 acres plus 149,850 additional acres). This value would include lands with Se concentrations greater than 20 ppb in Westlands, lands acquired by Westlands (that could be brought into production with drainage service, Table 2.3-1) and 10,000 acres in Broadview Water District.

Lands remaining in production within the drainage-impaired area would be eligible for drainage service. The collection, treatment, and disposal of drainwater collected from drained lands would be similar to that described for the In-Valley Disposal Alternative for RO treatment, Se biotreatment, the evaporation basins, and conveyance, but at a reduced scale due to large-scale land retirement.

Similar to the In-Valley Disposal Alternative, the two types of land subsidence that could affect this alternative are pore space compaction and hydrocompaction. Effects from expansive soils and strong earthquake shaking and effects from construction activities for evaporation basins that may result in increased erosion and runoff during earthwork are similar to the In-Valley Disposal Alternative.

9.2.7 In-Valley/Drainage-Impaired Area Land Retirement Alternative

The In-Valley/Drainage-Impaired Area Land Retirement Alternative would retire 308,000 acres (44,106 plus 263,894 acres), including all of the drainage-impaired lands in Westlands – approximately 298,000 acres. The Northerly Area (non-Westlands) is excluded from land retirement except for 10,000 acres in Broadview Water District. Drainage collection, treatment, and disposal facilities would not be needed in the Westlands drainage-impaired areas.

Lands remaining in production within the Northerly drainage-impaired area would be eligible for drainage service. The collection, treatment, and disposal of drainwater collected from drained lands would be scaled down to one reuse facility, one RO/Se treatment facility, and one evaporation basin.

Similar to the In-Valley Disposal Alternative, the two types of land subsidence that could affect this alternative are pore space compaction and hydrocompaction. Effects from expansive soils and strong earthquake shaking and effects from construction activities for the evaporation basin that may result in increased erosion and runoff during earthwork are similar to the In-Valley Disposal Alternative.

9.2.8 Ocean Disposal Alternative

The potential route for this alternative through the Coast Ranges crosses several major fault zones including the San Andreas, Riconada, and Nacimento faults. In addition, the potential alignment also crosses several smaller faults. Of the three major fault zones identified, the San Andreas is listed as the only historically active fault zone (ruptured during the 1857 Fort Tejon earthquake) and the only fault zoned by the State of California under the Alquist-Priolo Act. Significant displacement (up to 7 meters [23 feet]) along the San Andreas fault zone could cause the PVC-constructed aqueduct for this alternative to fail. This effect would be significant. However, pipelines generally perform well during fault displacement provided they are not placed under compression. Crossing the fault at an oblique angle to the direction of motion at an appropriate orientation would ensure that the pipeline fault crossing would undergo extension. The pipeline fault crossing should also be designed to withstand up to 7 meters (23 feet) of coseismic displacement across the San Andreas fault and smaller but still significant displacements across the other major faults, or employ mitigation measures such as seismic shut-off valves that would prevent spillage following a surface-rupturing earthquake.

The San Andreas fault has generated several large earthquakes during historic time, including a series of events along the Parkfield segment, approximately 6.2 km (10 miles) north of the potential route. These earthquakes ranged from **M** 5.8 to 6.0 between 1922 and 2004. To the south, the 1857 **M** 8 Fort Tejon earthquake, that was felt over much of the State. In addition, the offshore Hosgri fault, the Nacimiento fault, and the CRSB are all potential sources of strong earthquake shaking that may affect the Ocean Disposal Alternative. The Oceanic-West Huasna fault, which crosses the proposed pipeline route, is a candidate for the source of the 2003 M 6.5 San Simeon earthquake. No surface faulting was associated with that event, so the source is uncertain. A number of smaller faults are identified along the potential route; however, because no evidence for late Quaternary movement exists, it is unlikely that any of these faults could cause a major disruption of this route.

The potential for strong ground shaking associated with earthquakes in the southern Coast Ranges would likely require significant engineering measures for the construction of this alternative. Shaking from the San Simeon earthquake, for example, triggered liquefaction near Paso Robles and Oceana, numerous rockfalls in areas of steep topography, settlement and cracking of roads, bridges, and dams, some extensional cracking along ridge tops where seismic energy can be concentrated, as well as damage to largely unreinforced masonry buildings in Paso Robles and elsewhere. To mitigate the effects of shaking, the pipeline should be constructed to withstand the probable coseismic ground motions as determined by seismic hazard analysis. The engineering measures would also have to take into account the 34 mm (1.34 inches) of creep that occurs along the creeping section of the San Andreas fault zone on an annual basis and incorporate measures to mitigate for right-lateral coseismic offsets on the order of 7 meters (23 feet) at the San Andreas fault crossing. Such measures can include orienting the pipeline to cross the fault at an oblique angle such that the pipeline only experiences extension not compression, which might cause it to buckle; constructing the pipeline above ground across faults and supporting it on sliding supports, as was done for the trans-Alaska Pipeline; adding U-shaped sections to provide flexibility and accommodate relative motion; installing isolation valves with emergency bypasses; anchoring the pipeline to the ground at fault crossing; strengthening the pipeline at fault crossings; and others.

In addition, this alternative's conveyance route passes through the Coast Ranges. This region, especially right near the coast, includes extremely steep terrain, which increases its susceptibility to mass wasting effects. The route passes through the Franciscan Formation between the edge of Kettleman Hills and Cottonwood Pass, and from near the summit of the Santa Lucia Range to the Pacific Ocean. The Franciscan Formation is susceptible to landslides and accounts for the majority of rock and soil material that moves downslope during landslide events in the Coast Ranges, especially in areas of steep topography. Significant geotechnical studies, including slope stability, and soil compaction characteristics, would have to be conducted for the pump stations on this route, especially if the locations of the pump stations are on or beneath a potentially unstable slope. Potential problem areas could then be mitigated by appropriate slope stability design. Mitigation options include (1) rerouting to avoid unstable slopes, (2) grading to improve slope stability through replacement of unstable soil, (3) reinforcement or strengthening the slope with soil reinforcement, retaining walls, deep foundations, geosynthetics, and/or soil nails/tiebacks, and (4) reinforcing structures or isolating them from ground deformation through the use of piles or compaction grouting.

Site-specific geotechnical investigations would also be required to identify and subsequently mitigate for areas of potential liquefaction and lateral spreading where the route crosses areas of unconsolidated Quaternary deposits. Options for mitigating liquefaction hazard include soil reinforcement, the use of shallow or deep foundations to avoid the liquefiable layer, densification, drainage, reinforcement of the soil, hardening or mixing to improve the cohesive properties of the soil, removal and replacement of liquefiable sediment, and permanent dewatering.

Facilities along the coast may also be subject to potential tsunami hazard. These facilities would have to be designed to withstand potential inundation without collapse, or be situated at elevations above the potential inundation zone.

This alternative's In-Valley collection/conveyance facilities would be subject to heave from expansive soils where soils of the San Joaquin, Panoche, and Tulare associations are encountered, a significant effect. Geotechnical investigations are needed to determine the specifically affected components. Removing and/or treating such soils would minimize the effect of shrink/swell behavior; with this mitigation, no significant effect would occur.

Construction activities for pumping plants, tunnels, pipelines, and aqueducts may result in increased erosion and runoff during earthwork. However, as these activities are transient, the effect to the geologic environment is considered to be minimal. Construction-related erosion may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding of slopes to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive slope runoff. With this mitigation, no significant effect would occur.

9.2.9 Delta Disposal Alternatives

The Delta Disposal Alternatives should not be greatly affected by land subsidence since hydrocompaction and pore space compaction mostly occurs south of the Los Banos, California area. Their potential conveyance alignment appears to be mostly located to the south and west of the areas affected by the land subsidence in the Delta region (Norris and Webb 1990). Subsidence due to oil resource extraction mostly occurs in southern San Joaquin Valley and is not an issue with the Delta Disposal Alternatives.

The potential conveyance does not appear to cross any major faults identified within central San Joaquin Valley. However, the conveyance trends roughly parallel to the CRSB at distances of about 10 to 15 km (6.2 to 9.3 miles) and the San Andreas fault system located between 60 and 90 km (37 and 56 miles) to the west. In addition, near San Luis Reservoir, the proposed alignment is approximately 24 km (15 miles) east of the Ortigalita fault and trends roughly parallel to the fault zone. A large earthquake associated with any of these seismic sources has the potential to disrupt the Delta Disposal Alternatives. However, by employing present engineering design standards, it is unlikely that the potential aqueduct would be affected by an earthquake.

Along northern San Joaquin Valley near the Delta, the potential alignment is located approximately 16 km (10 miles) east of the Greenville fault zone, which trends northwest through the city of Livermore. Although the potential route does not cross the Greenville fault zone, it could be affected or disrupted by any strong earthquake shaking caused by a large earthquake. Other seismic sources in this area that have the potential to affect the Delta Disposal Alternatives include the Mount Oso and Mount Diablo blind thrusts and the Midland fault. Again, by employing present engineering design standards, it is unlikely that the potential aqueduct would be affected by an earthquake.

The Delta-Chipps Island Disposal Alternative's alignment does not appear to cross any major fault zones that present a potential surface faulting hazard. However, the Delta-Carquinez Strait Disposal Alternative's route would cross the Concord fault, which extends beneath the Sacramento River and beyond to the north where it becomes the Green Valley fault. The Concord fault is estimated to have both approximately 3.4 mm (0.134 inch) of horizontal, right-lateral fault creep and approximately 0.45 mm of uplift on the eastern side of the fault per year. Recent studies indicate that the fault has caused approximately 20 meters (66 feet) of offset in the last 6,000 years. This rate offset is unlikely to cause a significant effect to the Delta-Carquinez Strait Disposal Alternative's pipeline. However, engineering design should ensure that creep would not affect the pipeline over its estimated lifetime. In addition, the pipeline fault crossing should also be designed to withstand several meters of coseismic displacement or employ mitigation measures such as seismic shut-off valves that would prevent spillage following a surface-rupturing earthquake.

In addition to the Concord-Green Valley fault, a number of other active faults, including the Calaveras and Hayward faults, are capable of generating large, damaging earthquakes. However, by employing current engineering design standards, it is unlikely that these disposal alternatives would be affected by an earthquake.

This alternative's In-Valley collection system and RO treatment facilities would be subject to heave from expansive soils where soils of the San Joaquin, Panoche, and Tulare associations are encountered, a significant effect. Geotechnical investigations are needed to determine the specifically affected components. Removing and/or treating such soils would minimize the effect of shrink/swell behavior; with this mitigation, no significant effect would occur.

Construction activities for pumping plants, pipelines, and aqueducts may result in increased erosion and runoff during earthwork. However, as these activities are transient, the effect to the geologic environment is considered to be minimal. Construction-related erosion may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding of slopes to provide a vegetation cover or by the use of straw bales, Visquene plastic cover, and temporary drainage measures to prevent excessive slope runoff. With this mitigation, no significant effect would occur.

9.2.10 Cumulative Effects

Cumulative effects are those that result from the incremental effects of an action added to other past, present, and reasonably foreseeable future actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time. The action alternatives would not affect access to potential geologic resources of either scientific or economic value. The action alternatives would have no effect on the seismic hazard potential for the region and, thus, the cumulative effects would be negligible.

9.2.11 Environmental Effects Summary

9.2.11.1 No Action Alternative

- Existing facilities would be subject to potential strong earthquake shaking. Facilities designed to current building and seismic design codes should not suffer significant damage.
- The No Action Alternative with possible unplanned discharges or seepage of stormwater runoff into the existing San Luis Drain may result in significant erosion in areas where runoff overwhelms existing drainage conveyance capacity.
- Liquefaction and lateral spreading resulting from earthquake activity has the potential to affect existing facilities. If facilities are designed to current building and seismic design codes, no significant damage would occur.
- The existing San Luis Drain does not prevent access to any geologic resources.

9.2.11.2 In-Valley Disposal Alternative

- This alternative with its RO/Se biotreatment plants, pipelines, evaporation basins, and reuse facilities would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer damage. No significant effect would occur.
- This alternative with its RO/Se biotreatment plants, pipelines, evaporation basins, and reuse facilities would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- This alternative would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.
- Construction-related erosion, especially during construction of evaporation basins where large volume earthwork may be required, may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive runoff. With this mitigation, no significant effect would occur.

9.2.11.3 In-Valley/Groundwater Quality Land Retirement Alternative

- This alternative with its RO/Se biotreatment plants, pipelines, evaporation basins, and reuse facilities would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer significant damage. No significant effect would occur.
- This alternative with its RO/Se biotreatment plants, evaporation basins, and reuse facilities would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- This alternative would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.
- Construction-related erosion, especially during construction of evaporation basins where large volume earthwork may be required, may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and

temporary drainage measures to prevent excessive runoff. With this mitigation, no significant effect would occur.

9.2.11.4 In-Valley/Water Needs Land Retirement Alternative

- This alternative with its RO/Se biotreatment plants, pipelines, evaporation basins, and reuse facilities would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer significant damage. No significant effect would occur.
- This alternative with its RO/Se biotreatment plants, evaporation basins, and reuse facilities would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- This alternative would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.
- Construction-related erosion, especially during construction of evaporation basins where large volume earthwork may be required, may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive runoff. With this mitigation, no significant effect would occur.

9.2.11.5 In-Valley/Drainage-Impaired Area Land Retirement Alternative

- This alternative with its single RO/Se biotreatment plant, pipelines, evaporation basin, and reuse facilities would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer significant damage. No significant effect would occur.
- This alternative with its single RO/Se biotreatment plant, evaporation basin, and reuse facilities would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- This alternative would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.

- Construction-related erosion, especially during construction of the Northerly Area evaporation basin where large volume earthwork may be required, may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive runoff. With this mitigation, no significant effect would occur.

9.2.11.6 Ocean Disposal Alternative

- This alternative would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to significant surface fault rupture hazard at the San Andreas crossing. Historical rupture along this section of the fault involved at least 7 meters (23 feet) of lateral displacement. Pipelines generally perform very well during fault displacement provided they are not placed under compression. Crossing the fault at properly oriented oblique angle to the direction of motion would ensure that the pipeline fault crossing would undergo extension. With this and other mitigation techniques to accommodate fault displacement, no significant effect would occur.
- This alternative would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- This alternative would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- This alternative would be exposed to potential slope instability, especially in areas of Franciscan bedrock, a significant effect. Detailed engineering geologic investigations along the route would identify potential problem areas that could then be mitigated by appropriate slope stability design. With this mitigation, no significant effect would occur.
- This alternative would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.
- Construction-related erosion may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding of slopes to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive slope runoff. With this mitigation, no significant effect would occur.
- This alternative would be exposed to tsunami hazards at Point Estero, a significant effect. Situating facilities above potential inundation zones or burying pipelines to a sufficient depth to avoid erosion would mitigate the effects tsunami waves. With this mitigation, no significant effect would occur.

9.2.11.7 Delta Disposal Alternatives

- These alternatives would be exposed to potential earthquake strong motions. Facilities would be designed to current building and seismic design codes and should not suffer significant damage. No significant effect would occur.
- These alternatives would be exposed to significant surface fault rupture hazard at the Concord-Green Valley fault crossing. Pipelines generally perform very well during fault displacement provided they are not placed under compression. Crossing the fault at a properly oriented oblique angle to the direction of motion would ensure that the pipeline fault crossing would undergo extension. With this mitigation, no significant effect would occur.
- These alternatives would be exposed to potential liquefaction resulting from earthquake strong motions. Facilities designed to current building and seismic design codes should not suffer significant damage. No significant effect would occur.
- These alternatives would be exposed to potential subsidence, a significant effect. Careful management of groundwater resources (pumping and injection rates) would minimize the effect. With this mitigation, no significant effect would occur.
- These alternatives would be subject to heave from expansive soils, a significant effect. Removing and/or treating such soils would minimize the effect of shrink/swell behavior. With this mitigation, no significant effect would occur.
- Construction-related erosion may be significant during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding of slopes to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive slope runoff. With this mitigation, no significant effect would occur.

Tables 9-3 through 9-10 summarize the effects of geology and seismicity on the No Action Alternative and the action alternatives.

Table 9-3
Summary Comparison of Effects of No Action Alternative

Affected Resource and Area of Potential Effect	No Action Alternative Compared to Existing Conditions
Earthquake Ground Shaking	No damage if designed to current codes.
Surface Fault Rupture	No effect.
Liquefaction and Lateral Spreading	No damage if designed to current codes.
Landsliding/Mass Wasting	No effect.
Subsidence/Uplift	No damage if careful management of groundwater resources.
Expansive Soils	No damage if soils removed and/or treated.
Erosion	Runoff may overwhelm San Luis Drain. Possible effect.
Geologic Resources of Economic and Scientific Value	No effect.
Tsunami or Seiche	No effect.

Table 9-4
Summary Comparison of Effects of
In-Valley Disposal Alternative

Affected Resource and Area of Potential Effect	In-Valley Disposal Compared to No Action	In-Valley Disposal Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No significant effect.	No effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation=no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

Table 9-5
Summary Comparison of Effects of
In-Valley/Groundwater Quality Land Retirement Alternative

Affected Resource and Area of Potential Effect	In-Valley/Groundwater Quality Land Retirement Alternative Compared to No Action	In-Valley/Groundwater Quality Land Retirement Alternative Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No significant effect.	No effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

Table 9-6
Summary Comparison of Effects of
In-Valley/Water Needs Land Retirement Alternative

Affected Resource and Area of Potential Effect	In-Valley/Water Needs Land Retirement Alternative Compared to No Action	In-Valley/Water Needs Land Retirement Alternative Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No significant effect.	No effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

Table 9-7
Summary Comparison of Effects of
In-Valley/Drainage-Impaired Area Land Retirement Alternative

Affected Resource and Area of Potential Effect	In-Valley/Drainage-Impaired Area Land Retirement Alternative Compared to No Action	In-Valley/Drainage-Impaired Area Land Retirement Alternative Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No significant effect.	No effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

Table 9-8
Summary Comparison of Effects of Ocean Disposal Alternative

Affected Resource and Area of Potential Effect	Ocean Disposal Compared to No Action	Ocean Disposal Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No damage if pipeline fault crossing undergoes extension. Significant effect; with mitigation = no significant effect.	No damage if pipeline fault crossing undergoes extension. Adverse effect; with mitigation = no effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No damage if appropriate slope stability designed. Significant effect; with mitigation = no significant effect.	No damage if appropriate slope stability designed. Adverse effect; with mitigation = no effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No damage if facilities sited above inundation zone or pipeline buried. Significant effect; with mitigation = no significant effect	No damage if facilities sited above inundation zone or pipeline buried. Adverse effect; with mitigation = no effect.

Table 9-9
Summary Comparison of Effects of Delta-Chipps Island Disposal Alternative

Affected Resource and Area of Potential Effect	Delta-Chipps Island Disposal Compared to No Action	Delta-Chipps Island Disposal Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Surface Fault Rupture	No damage if pipeline fault crossing undergoes extension. Significant effect; with mitigation = no significant effect.	No damage if pipeline fault crossing undergoes extension. Adverse effect; with mitigation = no effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

Table 9-10
Summary Comparison of Effects of Delta-Carquinez Strait Disposal Alternative

Affected Resource and Area of Potential Effect	Delta-Carquinez Strait Disposal Compared to No Action	Delta-Carquinez Strait Disposal Compared to Existing Conditions
Earthquake Ground Shaking	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. Possible effect.
Surface Fault Rupture	No damage if pipeline fault crossing undergoes extension. Significant effect; with mitigation = no significant effect.	No damage if pipeline fault crossing undergoes extension. Adverse effect; with mitigation = no effect.
Liquefaction and Lateral Spreading	No damage when designed to current codes. No significant effect.	No damage when designed to current codes. No effect.
Landsliding/Mass Wasting	No significant effect.	No effect.
Subsidence/Uplift	No damage if groundwater resources are carefully managed. Significant effect; with mitigation = no significant effect.	No damage if groundwater resources are carefully managed. Adverse effect; with mitigation = no effect.
Expansive Soils	No damage if soils removed and/or treated. Significant effect; with mitigation = no significant effect.	No damage if soils removed and/or treated. Adverse effect; with mitigation = no effect.
Construction-Related Erosion	No damage if excessive runoff prevented. Significant effect; with mitigation = no significant effect.	No damage if excessive runoff prevented. Adverse effect; with mitigation = no effect.
Geologic Resources of Economic and Scientific Value	No significant effect.	No effect.
Tsunami or Seiche	No significant effect.	No effect.

9.2.12 Mitigation Recommendations

The greatest effect on the action alternatives from the geologic environment would be from **landsliding, surface fault rupture, and subsidence/uplift**, depending on which alternative is evaluated. The effects of these potential hazards may be addressed through mitigation measures designed to eliminate or reduce their adverse effects:

- Detailed engineering geologic investigations along the conveyance routes would identify potential problem areas for appropriate slope stability design
- Pipelines subject to fault displacement should not be placed under compression.
- Pipelines subject to fault displacement should be designed to cross the fault at a properly oriented oblique angle to the direction of motion to ensure that the pipeline fault crossing would undergo extension.

To minimize the potential for heave and shrink/swell behavior from **expansive soils** (where soils of the San Joaquin, Panoche, and Tulare associations are encountered), removing and/or treating such soils is recommended.

The action alternatives may all result in adverse effects to the geologic environment through disturbance of soils during construction and the potential for **erosion** during periods of stormwater runoff. Erosion of soils during construction can be minimized by temporary hydroseeding of slopes to provide a vegetation cover or by the use of straw bales, visquene plastic cover, and temporary drainage measures to prevent excessive slope runoff.

It is assumed that all action alternative facilities would be designed to current building and seismic design codes.