Chapter 9
Geology and Seismicity

9.1 Affected Environment/Environmental Setting

This section of Chapter 9 describes the existing geologic and seismologic conditions and the associated potential geologic, seismic, and geotechnical hazards in the Sacramento–San Joaquin Delta (Delta) and Suisun Marsh area (Figure 1-9 in Chapter 1, *Introduction*). The information presented is based on existing information from published and unpublished sources. Specifically, the regional and site information was compiled from maps and reports published by various agencies, researchers, and consultants, including the California Department of Water Resources (DWR), CALFED Bay-Delta Program (CALFED), U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), and California Geological Survey (CGS, formerly California Division of Mines and Geology). This section describes the environmental setting for the following areas, each of which has the potential to be affected by BDCP activities.

- Geologic setting focuses on the subsurface soils and the underlying bedrock units, including existing natural levee and channel deposits. Near-surface soils are fully discussed in Chapter 10, *Soils*, which describes surface erosion, subsidence processes, and other soil hazards. Mineral resources that could be affected by construction and operation of the BDCP alternatives are fully discussed in Chapter 26, *Mineral Resources*.
- Seismologic setting describes historical seismic events and the ground shaking potential during earthquakes.
- Geologic and seismic hazards, including surface fault rupture, seismic-induced liquefaction, and slope instability and ground failure, are identified. Potential levee instability and breaches related to geologic processes that could result in flooding are also described. See Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismic and Climate Change Risks to SWP/CVP Water Supplies*, for additional discussion of levee stability.

Additionally, the federal and state regulatory settings for the identified geologic and seismic hazards are presented with a listing of applicable design codes.

The setting information for geology and seismicity, except where otherwise noted, is derived from the geology and seismicity appendix that was included in the conceptual engineering reports (CERs) prepared for the BDCP.

- *Conceptual Engineering Report—Isolated Conveyance Facility—All Tunnel Option* (California Department of Water Resources 2010a).
- *Conceptual Engineering Report—Isolated Conveyance Facility—Pipeline/Tunnel Option*—Addendum (California Department of Water Resources 2010b).
- *Conceptual Engineering Report—Isolated Conveyance Facility—East Option* (California Department of Water Resources 2009a).
- *Conceptual Engineering Report—Isolated Conveyance Facility—East Option—Addendum* (California Department of Water Resources 2010c).

- *Conceptual Engineering Report—Isolated Conveyance Facility—West Option* (California Department of Water Resources 2009b).
- *Conceptual Engineering Report—Isolated Conveyance Facility—West Option—Addendum* (California Department of Water Resources 2010d).
- *Option Description Report—Separate Corridors Option* (California Department of Water Resources 2010e).

9.1.1 Potential Environmental Effects Area

The Plan Area (the area covered by the BDCP) consists of the Delta and Suisun Marsh which lie within California's Central Valley, which is approximately 465 miles long and 40–60 miles wide. The valley is bound by the Sierra Nevada on the east and the Coast Ranges on the west (Figure 9-1). Paleogeographic reconstructions of this region indicate that Miocene sedimentation was similar to a modern fore-arc basin (a sea floor depression between a subduction zone and an associated volcanic arc), shedding arkosic (granular quartz and feldspar or mica) and volcanoclastic sediment westward from the continent. (Figure 9-2 presents a geologic time scale.) In the mid-Pliocene Epoch, a shift in plate tectonics triggered uplift of the Coast Ranges, which gradually closed the southern marine outlet to the basin. By the late Pliocene, sub-aerial conditions prevailed throughout the valley, resulting from marine regression (i.e., where shoreline shifts oceanward, exposing formerly submerged areas) and sedimentation from the west. During Pleistocene Epoch, the valley separated from the Pacific Ocean and developed internal drainage, the modern outlet being the Carquinez Strait, through which the Sacramento River flows to the San Francisco Bay (Lettis and Unruh 1991, pp. 164–176).

The historical Delta formed approximately 5,000 years ago at the inland margin of the San Francisco Bay Estuary as two overlapping geomorphic units. The Sacramento River Delta comprises about 30% of the total area and was influenced by the interaction of rising sea level and river floods that created channels, natural levees, and marsh plains. During large river flood events, silt and sand were deposited adjacent to the river channel, forming natural levees above the marsh plain. In contrast, the larger San Joaquin River Delta, located in the central and southern portions of the Delta and having relatively small flood flows and low sediment supply, formed as an extensive, levee free freshwater tidal marsh dominated by tidal flows and organic soil (peat and muck) accretion (Atwater and Belknap 1980). Because the San Joaquin River Delta had less well-defined levees, sediment were deposited more uniformly across the floodplain during high water, creating an extensive tule marsh with many small branching tributary channels. As a result of the different amounts of inorganic sediment supply, the peat and muck of the San Joaquin River Delta grade northward into peaty mud and then into mud as it approaches the natural levees and flood basins of the Sacramento River Delta (Atwater and Belknap 1980).

9.1.1.1 Regional Geology

The Great Valley is a northwest-trending structural basin, separating the primarily granitic rock of the Sierra Nevada from the primarily Franciscan Formation rock of the California Coastal Range (Norris and Webb 1990). The basin is filled with an approximately 3- to 6-mile-thick layer of sedimentary deposits deposited by streams originating in the Sierra Nevada, Coast Ranges, and South Cascade Range, and flowing to the San Francisco Bay. Figure 9-3 is a geologic map of the Plan Area and vicinity. (Detailed geologic mapping is not available for the entire Plan Area. Figure 9-3 is primarily based on relatively detailed mapping derived from Atwater [1982] and covers most of the Delta. The geology of the remaining areas [e.g., Suisun Marsh and southern end of the Delta] is based on regional geologic mapping derived from the California Division of Mines and Geology. Figure 9-3 also shows the primary conveyance alignments subdivided into segments; these segments provide the basis for the discussion of potential effects in Section 9.3, *Environmental Consequences*. Figure 9-4, which is based on boring logs, shows a cross-section of the stratigraphy of the sediment generally oriented along the Alternative 1A tunnel alignment.

The Delta received thick accumulations of sediment from the Sierra Nevada to the east and the Coast Ranges to the west after the Cretaceous and most of Tertiary Periods. The Delta has experienced several cycles of deposition, nondeposition, and erosion that has resulted in the accumulation of thick, poorly consolidated to unconsolidated sediment overlying the Cretaceous and Tertiary formations since late Quaternary Period. Shlemon and Begg (1975) believe that the peat and muck in the Delta began to form about 11,000 years ago at the start of the current phase of sea level rise, which started at the beginning of the Holocene Epoch. This rise created tule marshes that covered most of the Delta. These organic soils formed from the accumulated detritus of the tules and other marsh vegetation.

As the Suisun Marsh formed, plant detritus slowly accumulated, compressing the saturated underlying base material. Mineral sediment were added to the organic material by tidal action and during floods. Generally, mineral sediment deposition decreased with distance from the sloughs and channels (Miller et al. 1975). Suisun Marsh soils are termed “hydric” because they formed under prolonged saturated soil conditions. The soil adjacent to the sloughs is mineral soil with less than 15% organic matter content, and although classified as “poorly drained,” they are better drained than the more organic soil situated farther from the sloughs.

Suisun Marsh organic soil is found farthest from the sloughs and at the lowest elevations. They have greater than 50% organic matter content. Other common soils in the Suisun Marsh belong to the Valdez series, which formed on alluvial fans and contain very low amounts of organic matter. Valdez series soils are found primarily on Grizzly Island (Miller et al. 1975).

Suisun Marsh is bordered by upland soil that is non-hydric and contains very little organic matter. The marsh was originally formed by the deposition of silty alluvium from floodwaters of Suisun Slough, Montezuma Slough, and the Sacramento–San Joaquin Rivers network. The top layer in the Suisun Marsh area is mainly peat, muck, and young bay mud, underlain by a sand aquifer. The sand is a windblown dune deposit.

The surface geologic units over the Delta, Suisun Marsh, and adjoining areas include peaty and other organic soils, alluvium, levee and channel deposits, dune sand, older alluvium, and bedrock (Figure 9-3).

9.1.1.2 Local Geology

A geologic map of the Plan Area is provided in Figure 9-3. It was necessary to use different sources to compile the geologic map and descriptions of the geologic map units (Tables 9-1 through 9-5) presented in this report. The primary map used in Figure 9-3 is the geologic map created by Atwater (1982), which provides the greater detail but does not cover the entire Plan Area. Regional geologic maps (Wagner et al. 1981; Wagner and Bortugno 1982; Wagner et al. 1991) were therefore used to fill in the remaining parts of the Plan Area. Except where noted, the text descriptions provided in Tables 9-1 through 9-4 are taken directly (i.e., verbatim) from the work done by Graymer et al. (2002) because this work, although it did not cover as much of the Plan Area as Atwater, provides the most recent and relevant general descriptions of the geologic units that occur in the Plan Area. Because Graymer et al.

and Atwater used different names for geologic units, Tables 9-1 through 9-4 include approximate correlations between the terminology in Graymer's et al. and Atwater's maps.

9.1.1.2.1 Peat and Organic Soils

The tule marshes created by sea level rise covered most of the Delta and led to the formation of peat and muck. The thickness of organic soils in the Delta generally ranges from about 55 feet near Sherman Island to almost nonexistent toward the southern part of the Delta (Real and Knudsen 2009). The Suisun Marsh area is generally underlain by thick organic soils and peat (more than 40 feet thick in some places near Grizzly Bay).

Over the years, these soils have been given various designations. For example, in 1935 the University of California Agricultural Experiment Station mapped the surface soils using such names as Staten peaty muck, Egbert muck, or Sacramento mucky loam. More recently, these organic and high organic matter mineral soils were labeled on geologic maps as peaty muds and were mapped by the USGS (Graymer et al. 2002) as Holocene Bay mud deposits and Delta mud deposits, as described in Table 9-1. Atwater mapped the Delta mud deposits as "Peat and Mud of Delta Wetlands and Waterways" (map symbol Qpm). Bay mud deposits do not appear within the limits of the Atwater map (Atwater 1982) (Figure 9-3).

Table 9-1. Mapped Peaty Mud

Map Unit Name	Map Symbol	Description[a]	Approximate Correlation to Atwater[b]
Bay mud deposits (Holocene)	Qhbm	Water-saturated estuarine mud, predominantly gray, green, blue, and black clay and silty clay underlying marshlands and tidal mud flats of San Francisco Bay and Carquinez Strait. The mud also contains lenses of well-sorted, fine sand and silt, a few shelly layers (oysters), and peat. The mud interfingers with and grades into fine-grained fan deposits at the distal edge of Holocene fans. This unit is time-transgressive and generally occupies the area between the modern shoreline and the historical limits of tidal marsh	Not applicable
Delta mud deposits (Holocene)	Qhdm	Mud and peat with minor silt and sand deposited at or near sea level in the Sacramento/San Joaquin River Delta. Much of the area underlain by this unit is now dry because of construction of dikes and levees and below sea level due to compaction and deflation of the now unsaturated delta sediment.	Qpm

Source: Graymer et al. 2002.

[a] Descriptions are taken directly from Graymer et al. 2002.

[b] This correlation is only an approximation provided by the chapter author to aid the reader. It is not a scientific or peer-reviewed analysis.

9.1.1.2.2 Alluvium

Alluvium is sediment deposited by a river or other running water, and is typically composed of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. A river continually picks up and drops solid particles of rock and soil from its bed throughout its length.

Where river flow is fast, more particles are picked up than dropped. Where the river flow is slow, more particles are dropped than are picked up. Areas where more particles are dropped are called *alluvial plains* or *floodplains*, and the dropped particles are called *alluvium*. Even small streams make alluvial deposits, but it is in the floodplains and deltas of large rivers where large, geologically substantial alluvial deposits are found. The mapped Holocene alluvial deposits found in the Delta and Suisun Marsh are described in Table 9-2.

Table 9-2. Mapped Alluvium

Map Unit Name	Map Symbol	Description[a]	Approximate Correlation to Atwater[b]
Younger Alluvium (late Holocene)	Qhay	Loose sand, gravel, silt, and clay deposited in active depositional environments and judged to be less than 1,000 years old based on geomorphic expression or historic records of deposition.	Atwater mapped according to drainage basin and Graymer et al. according to type of alluvium, so correlation is very general: Qyp, Qym, Qya, Qymc
Alluvium (Holocene)	Qha	Sand, silt, and gravel deposited in fan, valley fill, terrace, or basin environment. Mostly undissected by later erosion. Typically mapped in smooth, flat valley bottoms in medium-sized drainages and other areas where geomorphic expression is insufficient to allow differentiation of depositional environment.	
Terrace (Holocene)	Qht	Moderately well sorted sand, silt, gravel, and minor clay deposited in point bar and overbank settings. These deposits are as much as 10 m above the historic flood plain, but mostly undissected by later erosion.	
Alluvial Fan Deposits (Holocene)	Qhf	Moderately to poorly sorted and moderately to poorly bedded sand, gravel, silt, and clay deposited where streams emanate from upland regions onto more gently sloping valley floors or plains. Holocene alluvial fan deposits are mostly undissected by later erosion. In places, Holocene deposits may only form a thin layer over Pleistocene and older deposits.	
Fine-Grained Alluvial Fan Deposits (Holocene)	Qhff	Mostly silt and clay with interbedded lenses of sand and minor gravel deposited at the distal margin of large alluvial fan complexes.	
Alluvium (Holocene and late Pleistocene)	Qa	Sand, silt, and gravel deposited in fan, valley fill, terrace, or basin environments. Similar to unit Qha, this unit is mapped where deposition may have occurred in either Holocene or late Pleistocene time. In Yolo County, this unit includes the Modesto and Riverbank Formations as mapped by Helley and Barker (1979).	Same as above but also includes Qm, Qr, Qry, and Qro (Table 9-5)
Terrace Deposits (Holocene and late Pleistocene)	Qt	Moderately sorted to well-sorted, moderately bedded to well-bedded sand, gravel, silt, and minor clay deposited on relatively flat, undissected stream terraces. Similar to unit Qht, this unit is mapped where deposition may have occurred in either Holocene or late Pleistocene time.	Not mapped as a separate unit by Atwater (see Qht)
Alluvial Fan Deposits (Holocene and late Pleistocene)	Qf	Poorly sorted, moderately to poorly bedded sand, gravel, silt, and clay deposited in gently sloping alluvial fans. Similar to unit Qhf, this unit is mapped where deposition may have occurred in either Holocene or late Pleistocene time.	Atwater mapped according to drainage basin and

Map Unit Name	Map Symbol	Description[a]	Approximate Correlation to Atwater[b]
Alluvium (late Pleistocene)	Qpa	Poorly to moderately sorted sand, silt, and gravel in the Capay area (Esparto quadrangle). This unit is mapped on gently sloping to level alluvial fan or terrace surfaces where separate fan, terrace, and basin deposits could not be delineated. Late Pleistocene age is indicated by depth of stream incision, development of alfisols and lack of historical flooding.	Graymer et al. according to type of alluvium, so correlation is very general: Qo, Qom, Qoa, Qomc
Alluvial Fan Deposits (late Pleistocene)	Qpf	Poorly sorted, moderately to poorly bedded sand, gravel, silt, and clay deposited in gently sloping alluvial fans. Late Pleistocene age is indicated by erosional dissection and development of alfisols. These deposits are about 10% denser and have 50% greater penetration resistance than unit Qhf (California Department of Conservation 2000).	
Basin Deposits (late Pleistocene)	Qpb	As mapped by Atwater (1982), older alluvium widely but sparsely exposed at the toe of the Putah Creek fan (Dozier quadrangle), most commonly in basins between stream-built ridges of younger alluvium.	
Pediment Deposits (late and early Pleistocene)	Qop	Thin deposits of sand, silt, clay, and gravel on broad, planar erosional surfaces. These deposits are extremely dissected, have well-developed soils, and are mostly tens or hundreds of meters above the current depositional surface.	
Alluvium (late and early Pleistocene)	Qoa	Sand, silt, clay, and gravel deposits with little or none of the original geomorphic expression preserved. Moderately to extremely dissected, in places tens or hundreds of meters above the current depositional surface, and capped by well-developed soils. In Yolo County, this unit includes the Red Bluff Formation as mapped by Helley and Barker (1979).	

Source: Graymer et al. 2002.
Note: Geologic units are listed in order of age (youngest to oldest).
[a] Descriptions are taken directly from Graymer et al. 2002.
[b] This correlation is only an approximation provided by the chapter author to aid the reader. It is not a scientific or peer-reviewed analysis.

Atwater (1982) did not differentiate the alluvial deposits into alluvium, terrace, and fan deposits. As shown on Figure 9-3, these deposits are instead collectively mapped as Quaternary alluvium named according to the non-glaciated drainage basins from which the sediment was derived. Within each basin, the alluvial deposits are called out by age: Qy indicating younger alluvium and Qo indicating older alluvium. The Qy (Qyp, Qym, Qya, and Qymc) alluvial deposits on the Atwater map correspond to the units listed in Table 9-2, which begin with Qh or Q to indicate Holocene to Holocene-to-Pleistocene-aged deposits. Similarly, the Qo (Qop, Qom, Qoa, and Qomc) alluvial deposits are listed in Table 9-2, with Qp indicating Pleistocene-aged alluvial deposits. Qch and Qcr, as mapped on the Atwater map, consist of alluvial deposits from the Corral Hollow and Calaveras creek drainage basins, respectively, and they are not broken out by age of deposits (Atwater 1982).

9.1.1.2.3 Levee and Channel Deposits

The ability of a river to carry sediment varies greatly with its flow volume and velocity. When a river floods over its banks, the water spreads out, slows down, and deposits its load of suspended sediment.

Fine-grained sediment are deposited further from the channel, where coarser sediment are deposited nearer the channel. Over time, the river's banks are built up above the level of the rest of the floodplain. The resulting low ridges are called natural levees. Artificial, or human-made, levees are built to prevent flooding of lands along the river; these confine flow, resulting in higher and faster water flow than would occur naturally. Artificial levees impact sedimentation in the modern Delta. Natural and artificial levee deposits have been mapped and are described in Table 9-3. Atwater did not separately map artificial channel, levee, and stream deposits. The natural levee, floodplain, and flood basin deposits listed in Table 9-3 are designated as Ql, Qfp, and Qb, respectively, on the Atwater map (Atwater 1982).

Table 9-3. Mapped Levee and Channel Deposits

Map Unit Name	Map Symbol	Description[a]	Approximate Correlation to Atwater[b]
Artificial Channel Deposits (Historic)	ac	Modified stream channels, usually where streams have been straightened and realigned. Deposits in artificial channels range from concrete in lined channels to sand and gravel similar to natural stream channel deposits (Qhc).	Not applicable
Artificial Levee Fill (Historic)	alf	Man-made deposit of various materials and ages, forming artificial levees as much as 20 ft (6.5 m) high. Some are compacted and quite firm, but fills made before 1965 are almost everywhere not compacted and consist simply of dumped materials. Levees bordering waterways of the Sacramento/San Joaquin Delta, mudflats, and large streams were first emplaced as much as 150 years ago. The distribution of levee fill conforms to levees shown on the most recent U.S. Geological Survey 7.5-minute quadrangle maps	Not applicable
Stream Channel Deposits (Holocene)	Qhc	Loose sand, gravel, and cobbles with minor clay and silt deposited within active, natural stream channels.	Not mapped as a separate unit by Atwater.
Natural Levee Deposits (Holocene)	Qhl	Moderately- to well-sorted sand with some silt and clay deposited by streams that overtop their banks during flooding. Natural levees are often identified by their low, channel-parallel ridge geomorphology.	Ql
Floodplain Deposits (Holocene)	Qhfp	Medium- to dark-gray, dense, sandy to silty clay. Lenses of coarser material (silt, sand, and pebbles) may be locally present. Flood plain deposits usually occur between levee deposits (Qhl) and basin deposits (Qhb) and are prevalent in the Walnut Creek-Concord Valley, much of which is south of the map area.	Qfp
Floodbasin Deposits (Holocene)	Qhfb	Firm to stiff silty clay, clayey silt, and silt, commonly with carbonate nodules and locally with black spherules (Mn and (or) Fe oxides). The deposits laterally grade into peaty mud and mud of tidal wetlands (unit Qhdm). Locally, the deposits are veneered with silty, reddish-brown alluvium of historic age, some of which may have resulted from hydraulic mining in the Sierra Nevada during the late 1800s.	Qb

Source: Graymer et al. 2002.

Note: Geologic units are listed in order of age (youngest to oldest).

[a] Descriptions are taken directly from Graymer et al. 2002.

[b] This correlation is only an approximation provided by the chapter author to aid the reader. It is not a scientific or peer-reviewed analysis.

9.1.1.2.4 Dune Sand Deposits

Dune sand deposits consist of very well-sorted fine to medium grained eolian (wind deposited) sand. Holocene sand may discontinuously overlie the latest Pleistocene sand, both of which may form a mantle of varying thicknesses over older materials. Most of the deposits are thought to be associated with the latest Pleistocene to early Holocene periods of low sea level, during which large volumes of fluvial (i.e., pertaining to a river or stream) and glacially-derived sediment from the Sierra were blown into the dunes. Dune sand deposits are described in Table 9-4. The Atwater map refers to these dune sand as eolian deposits (Qe, Qm2e, and Qoe) (Atwater 1982).

Table 9-4. Mapped Dune Sand Deposits

Map Unit Name	Map Symbol	Description[a]	Approximate Correlation to Atwater[b]
Dune Sand (early Holocene and latest Pleistocene)	Qds	Very well sorted fine- to medium-grained eolian sand. They occur mainly in two large northwest-southeast trending sheets, as well as many small hills, most displaying Barchan morphology. Dunes display as much as 30 m of erosional relief and are presently being buried by basin deposits (Qhb) and delta mud (Qhdm). They probably began accumulating after the last interglacial high stand of sea-level began to recede about 79 ka (Imbrie et al., 1984; Martinson et al., 1987; Hendy and Kennett, 2000), continued to form when sea level dropped to its Wisconsin minimum about 18 ka, and probably ceased to accumulate after sea level reached its present elevation (about 6 ka). Atwater (1982) recognized buried paleosols in the dunes, indicating periods of nondeposition.	Qe, Qm2e, Qoe

Source: Graymer et al. 2002.

Note: ka = thousand years.

[a] Descriptions are taken directly from Graymer et al. 2002.

[b] This correlation is only an approximation provided by the chapter author to aid the reader. It is not a scientific or peer-reviewed analysis.

9.1.1.2.5 Older Alluvium

The older alluvium consists of the Pleistocene-aged Modesto and Riverbank formations that were deposited during separate episodes of glacially-derived sediment from the glaciated core of the Sierra Nevada (Lettis and Unruh 1991; Marchand 1977:39–50; Cherven and Graham 1983).

Lithologically, the two units are nearly identical arkosic fine-grained alluvium from the Sierra Nevada. However, the upper Modesto frequently has finer-grained silt and sand with a notable eolian component at the surface, capped by a weakly developed soil. The Riverbank is coarser gravel and sand capped by a very well developed soil. The timing of their deposition remains uncertain, but the Riverbank is probably Illinoian (roughly 300,000—130,000 years bp), while the Modesto is probably Late Wisconsin to early Holocene (roughly 21,000 to 10,000 years bp).

The Pleistocene Mokelumne River channels that deposited older alluvium show little relation to the present stream. Whereas the modern river channels meander in its floodplain and carry fine-grained sediment, the Pleistocene rivers cut deep, canyon-like channels into underlying, older fan deposits.

These ancient rivers had greater hydraulic force and carried glacially derived boulders and cobbles much farther downstream than the present river (Shlemon 1971). The older alluvial units are described in Table 9-5. These glacial deposits do not appear within the limits of the Graymer et al. map (2002).

Table 9-5. Mapped Older Alluvium

Map Unit Name	Map Symbol	Description
Modesto Formation	Qm	Material ranges from loose sand (probably eolian), to fluvial loose sand and silt, to compact silt and very fine sand.
Riverbank Formation	Qr	Riverbank Formation, undivided.
Riverbank Formation	Qry	Younger unit of Riverbank Formation.
Riverbank Formation	Qro	Older unit of Riverbank Formation.

Source: Atwater 1982.
Note: Geologic units are listed in order of age (youngest to oldest).

9.1.1.2.6 Bedrock Units

The above-described relatively poor-consolidated to unconsolidated Quaternary deposits overlie Cretaceous-to-Tertiary-age sedimentary bedrock, which is generally deeper than 1,000 feet in the Delta (Brocher 2005). These older sedimentary rocks consist primarily of interbedded marine sandtone, shale, and conglomerate. However, deposition of shallow marine, terrestrial, and volcanoclastic sediments predominated by the late Tertiary period. Immediately adjacent to the broader delta-fan-estuary system, rock outcrops of the early Pliocene Montezuma formation of the Vacaville Assemblage can be found in the Montezuma Hills, north of the western Delta area. This sedimentary rock comprises the easternmost outcrops of the northeastern Diablo Range south of the western Delta area (Graymer et al. 2002).

9.1.1.3 Regional and Local Seismicity

The California Coast Ranges physiographic province lies along the complex boundary between two tectonic plates: the North American Plate and the Pacific Plate. The geologic and tectonic conditions in the Delta and Suisun Marsh have been, and continue to be, controlled primarily by the interaction of these two massive blocks of the Earth's crust. Under the current tectonic regime, the Pacific Plate moves northwestward relative to the North American Plate at a rate of about 1.57 inches (40 millimeters) per year (Working Group on California Earthquake Probabilities 2003). Although relative motion between these two plates is predominantly lateral (strike-slip), an increase in convergent motion along the plate boundary within the past few million years has resulted in the formation of mountain ranges and structural valleys of the Coast Ranges province (DeCourten 2008).

The San Andreas fault system dominates the seismicity of the region, and it comprises several major faults including the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, and Greenville faults. In addition to these major faults, many other named and unnamed regional faults accommodate relative motion between the plates and relieve compressional stresses that also act along the plate boundary.

The Delta and Suisun Marsh are in the eastern portion of the greater San Francisco Bay region, one of the most seismically active areas in the United States. Since 1800, several earthquakes with magnitudes greater than 6.5 have occurred in the immediate San Francisco Bay Area, including the 1868 magnitude 6.8 earthquake on the Hayward fault, the 1906 magnitude 7.9 San Francisco earthquake on the San Andreas fault, and the more recent 1989 magnitude 6.9 Loma Prieta earthquake that occurred in the Santa Cruz Mountains. Figure 9-5 depicts the recorded historical seismicity in the San Francisco Bay region from 1800 to 2006.

9.1.1.3.1 Delta

Figure 9-5 indicates that the San Francisco Bay Area and Delta region have generally experienced low-level seismicity since 1800. No earthquakes with magnitude greater than 5.0 have been observed in the Delta. Buildings constructed in accordance with the California Building Code (CBC) are not expected to experience major damage caused by an earthquake with a magnitude smaller than 5.0.

As discussed in the following sections, the known active seismic sources located within the Delta area are mostly blind thrust faults (described below).

9.1.1.3.2 Suisun Marsh

Similar to the Delta, Suisun Marsh has experienced low-level seismicity since 1800. A few earthquakes with magnitudes between 3.0 and 4.9 were recorded in the proximity of the Pittsburgh–Kirby Hills fault (Figure 9-5). Some of these seismic events may have occurred on the fault.

Two earthquakes (the 1892 Vacaville-Winters and the 1983 Coalinga earthquakes) have been associated with the Coast Ranges-Sierran Block (CRSB) seismic zone, a complex-dipping thrust fault zone that goes through the Delta and Suisun Marsh area. The epicenter of the 1892 Vacaville-Winters earthquake was approximately 8 miles west of the Delta and Suisun Marsh. The epicenter of the 1983 Coalinga earthquake was approximately 110 miles south of the Delta. Both of these seismic events had a magnitude greater than 6.5.

In 2003, the Working Group on California Earthquake Probabilities (WGCEP) calculated a 62% probability for one or more large earthquakes (magnitude 6.7 or greater) to occur in the San Francisco Bay region between 2002 and 2032). This estimate includes a 27% probability for one or more earthquakes of magnitude 6.7 or greater to take place along the nearby Hayward–Rodgers Creek fault over the same period. Because no major earthquakes have occurred in the San Francisco Bay region over the last several years, this probability will increase with time because of the strain that builds up along the faults (Working Group on California Earthquake Probabilities 2003).

The earthquake source model adopted by WGCEP in the 2003 study includes both the major regional faults and the background seismicity. Because of uncertainties associated with the source data, multiple earthquake source models were considered, and weights were assigned to these models based on expert opinion.

9.1.1.3.3 Past Earthquake Ground Motion Intensity and Damage

The San Francisco Bay region has been subjected to damaging ground shaking during past earthquakes. Table 9-6 lists the largest earthquakes that have affected the San Francisco Bay region since 1868 and the damage caused by these earthquakes, as described in the seismic study (California Department of Water Resources 2007a).

Table 9-6. Largest Earthquakes Having Affected the San Francisco Bay Region

Date	Intensity	Fault	Location	Damage Incurred
October 21, 1868	M_L = 6.8	Southern Hayward	San Francisco Bay Area, San Jose	Heavy damage sustained in towns along the Hayward fault in the eastern San Francisco Bay Area.
April 19 and 21, 1892	**M** = 6.2 to 6.5	CRSB Seismic Zone	Winters/ Vacaville	Damage to the communities of Vacaville, Dixon, and Winters, and the surrounding rural areas. Brick buildings were damaged and one man was killed by falling bricks.
March 31, 1898	MMI = VIII or greater M_L = 6.7	(no data)	Mare Island in San Pablo Bay	Buildings damaged in areas around the San Francisco Bay Area.
April 18, 1906	**M** = 7.9	San Andreas	San Francisco	Widespread damage in northern California. Ground shaking and fire caused the deaths of more than 3,000 people and injured approximately 225,000 people.
May 2, 1983	**M** = 6.4	CRSB Seismic Zone	Coalinga	$10 million in property damage and injured 94 people.
April 24, 1984	**M** = 6.2	Calaveras	Morgan Hill	$7.5 million in damage. In San Jose, cracks formed in some walls, plaster fell, many items were thrown from store shelves, and some chimneys cracked.
October 17, 1989	**M** = 6.9	San Andreas	Santa Cruz Mountains	$6 billion damage, 62 deaths, 3,500 injured, and 12,000 people displaced from homes.
October 30, 2007	**M** = 5.6	Calaveras	Northeast of San Jose	Strong shaking, no damage reported.

Source: California Department of Water Resources 2010a.

Notes:

CRSB = Coast Ranges–Sierran Block.

M_L = Richter Magnitude.

M = Moment Magnitude.

MMI = Modified Mercalli Intensity.

The Richter Magnitude is a measure of the total energy released during an earthquake. The Moment Magnitude Scale is more precise than the Richter scale because it is based on the area of the fault moving at the same moment as an earthquake. Because magnitude does not describe the extent of the damage, its usefulness is limited to an approximation of whether the earthquake is large, small, or medium-sized. Earthquakes can also be described by their intensity, or the degree of damage or observable effects caused by an earthquake at a particular location. The Modified Mercalli Scale is divided into 12 degrees, each identified by a Roman numeral.

Damage resulting from earthquake ground shaking is typically estimated by Modified Mercalli Intensity (MMI). MMI is a measure of ground shaking that is based on the effects of earthquakes on people and buildings at a particular location. An MMI VII or greater indicates damaging effects on people and buildings.

Seismologists believe it is likely that the Delta and Suisun Marsh will experience periodic minor to moderate earthquakes (magnitude 6.5 or greater) in the next 50 years. A magnitude 6.5 or greater earthquake on the major seismic sources in the San Francisco Bay region would affect the Delta and Suisun Marsh with moderate to strong ground shaking, and could potentially induce damage in these areas. Strong ground shaking is typically expressed in terms of high peak ground accelerations (the maximum acceleration by a soil particle at the ground surface during an earthquake).

9.1.1.3.4 Active Seismic Sources

Seismic sources or faults can generally be described by one of three activity classes as defined by CGS: active, potentially active, or inactive. Active describes historical and Holocene faults that have had displacements within the past 11,000 years. Potentially active describes faults showing evidence of displacements during Quaternary time (the past 1.6 million years). Pre-Quaternary age faults with no subsequent offset are classified as inactive. An inactive classification by CGS does not mean that a fault will not rupture in the future, but only that it has not been shown to have ruptured within the past 1.6 million years. Seismiologists assume that the probability of fault rupture by inactive faults is low. For this reason, only the potential seismic impacts from active or potentially active faults are discussed in this chapter.

A recent seismic study (California Department of Water Resources 2007a) considered four categories of active and potentially active seismic sources.

- Crustal fault
- Thrust fault
- Seismic zone
- Subduction zone

The characterization of these seismic sources is based on the latest geologic, seismologic, and paleoseismic data, and the current understanding of fault behaviors is based mainly on the works of the Working Group on Northern California Earthquake Potential (WGNCEP), WGCEP, and CGS seismic source model used in the USGS National Seismic Hazard Maps (Working Group on Northern California Earthquake Potential 1996; Working Group on California Earthquake Probabilities 2003; Cao et al. 2003).

Key characteristics of the seismic sources important to the Delta and Suisun Marsh earthquake hazard potential are summarized as follows:

Crustal Faults

The time-independent and time-dependent source models of active and potentially active seismic sources in the San Francisco Bay region were considered in the seismic study (California Department of Water Resources 2007a). The time-independent model assumes a Poissonian process (i.e., a statistical probability distribution that characterizes discrete events occurring independently of one another in time) for earthquake occurrence that is independent of the time since the last earthquake. In contrast, in a time-dependent model, the likelihood of having an earthquake at a specific future time depends on the elapsed time since the last earthquake; the longer the elapsed time is, the greater the likelihood will be. In this study, the time-dependent source models were applied to only seven major faults based on the rates of characteristic (maximum) events developed by WGCEP (2003). These seven faults are the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust.

The approximate locations of the active and potentially active seismic sources in the San Francisco Bay region and the Delta and Suisun Marsh are plotted in Figure 9-5. The surficial crustal faults known to cross the Delta and Suisun Marsh are the Pittsburgh–Kirby Hills and the Concord–Green Valley faults. The Pittsburgh–Kirby Hills fault is mapped crossing the Suisun Marsh from near the Fairfield at the north to the Pittsburg at the south. The Concord–Green Valley fault crosses along the western part of Suisun Marsh. The Cordelia fault terminates close to the northern boundary of the Suisun Marsh.

Other major crustal faults in the San Francisco Bay region that have the potential for generating substantial earthquake ground shaking in the Delta and Suisun Marsh include the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, and Greenville. The San Andreas, Hayward–Rodgers Creek, and Calaveras faults are regional seismic sources that, although large distances away from the Delta and Suisun Marsh, can induce considerable ground shaking because of their potential for generating large-magnitude earthquakes.

The maximum earthquake moment magnitudes, closest distances to the Delta and Suisun Marsh, long-term geologic slip rates, and faulting mechanism assigned to these major active faults are presented in Table 9-7. Earthquake moment magnitude is a measure of earthquake size based on the energy released. This definition was developed in the 1970s to replace the Richter magnitude scale, and it is considered a better representation of earthquake size. The geologic slip rate is the rate that the sides of fault move with respect to one another. It is used to predict the frequencies of future earthquakes. Faulting style describes the direction of movements and relative magnitudes of various forces acting along the fault. A strike-slip faulting style indicates lateral sliding of the sides of a fault past each other.

Table 9-7. Characteristics of Major Seismic Sources in San Francisco Bay Region

Fault (closest to farthest)	Distance from Delta and Suisun Marsh[a] (miles)	Slip Rate[b] (inch/year)	Maximum Earthquake[b] (moment magnitude)	Faulting Style
Concord–Green Valley	0.0	0.20 ± 0.12	6.7	Strike-slip
Pittsburgh–Kirby Hills	0.0	0.02 ± 0.08	6.7	Strike-slip
Greenville	6.2	0.16 ± 0.08	6.9	Strike-slip
Hayward–Rodgers Creek	12.4	0.35 ± 0.08	7.3	Strike-slip
Calaveras	16.8	0.16 ± 0.79	6.9	Strike-slip
San Andreas	30.0	0.94 ± 0.12	7.9	Strike-slip

Source: California Department of Water Resources 2007a.

[a] Closest distance from fault trace to Delta and Suisun Marsh.

[b] Largest values assigned by California Department of Water Resources 2007a.

Thrust Faults

The seismic sources underlying the Delta and Suisun Marsh are mostly "blind" thrusts (Table 9-8). A blind thrust is a seismic source that is not expected to rupture to the ground surface during an earthquake event, but is still capable of producing large and damaging ground shaking. The known blind thrusts in the Delta include the Midland, Montezuma Hills, Thornton Arch, West Tracy, and Vernalis faults. The Black Butte and Midway faults are thrust faults, with a discernible geomorphic expression/trace at the surface.

Table 9-8. Characteristics of Thrust Faults in the Delta and Suisun Marsh

Fault (closest to farthest)	Probability of Activity	Slip Rate (inch/year)	Maximum Earthquake (moment magnitude)	Faulting Style
Thornton Arch	0.2	0.002–0.006	6.0–6.5	Reverse-oblique*
Montezuma Hills	0.5	0.002–0.02	6.0–6.5	Reverse-oblique
Vernalis	0.8	0.003–0.02	6.25–6.75	Reverse-oblique
Southern Midland	0.8	0.004–0.04	6.6	Reverse-oblique
West Tracy	0.9	0.07–0.5	6.25–6.5	Reverse-oblique
Black Butte and Midway	1.0	0.004–0.04	6.25–6.75	Reverse-oblique
Northern Midland	1.0	0.004–0.04	6.0–6.5	Reverse-oblique

Source: California Department of Water Resources 2007a; Fugro Consultants 2011.

* A reverse-oblique faulting style describes fault movements where one side of a fault moves upward relative to the other side (up-dipping) with some components of lateral movement as a result of compression in the crust.

The Midland fault is an approximately north-striking fault that dips to the west and underlies the central region of the Delta area. The fault is at least 37 miles long, and gas explorations conducted in the area indicate that it is not exposed at the ground surface (California Division of Oil and Gas 1982). The Midland fault is divided into a Northern Midland fault zone, which characterizes the northwest-striking fault splays north of Rio Vista, and a Southern Midland fault, which extends southward to near Clifton Court Forebay. (The area (rather than a defined trace) referred to as the Northern Midland fault zone is so-named because it encompasses numerous right-stepping northwest-striking splays of the Midland fault.)

The Montezuma Hills seismic source is modeled as a source zone between the Delta and Suisun Marsh near Rio Vista. The zone extends southward to the Sherman Island area and has been defined to capture the potential active structures that may be responsible for the uplift of the Montezuma Hills (California Department of Water Resources 2007a).

The Thornton Arch seismic zone has been defined to represent the possible existence of active buried structures near the Thornton and West Thornton-Walnut Grove gas field near the Delta Cross Channel area. After considering the best available evidence to date, the seismic study adopted a low probability of activity and a low slip rate for this zone. The probability of activity is a measure of certainty, based on the available data, that a seismic source is active (California Department of Water Resources 2007a). The probability scale ranges from 0 to 1.0, with a probability of 1.0 strongly suggesting an active fault.

The West Tracy, Vernalis, Black Butte, and Midway faults are parts of the CRSB seismic zone (California Department of Water Resources 2007a). As described previously in this section, the CRSB is a complex zone of thrust faulting that defines the boundary between the Coast Ranges block to the west and the Sierran basement rocks of the Sacramento and San Joaquin Valleys. The West Tracy fault is mapped beneath the southwestern part of the Clifton Court Forebay and western part of the Byron Tract Forebay. It has a total length of about 9.5 miles. Multiple east-dipping splays of the fault may exist in the hanging wall (i.e., upthrown block) west of the Clifton Court Forebay, some of which are underneath the intake channel to the Banks Pumping Plant (Fugro Consultants 2011). The fault strikes in a northwest–southeast direction and dips westward moderately to steeply to the west. The Vernalis fault is mapped at the southern end of the Delta area, extending between Tracy and Patterson, at a minimum length of about 19.2 miles. Similar to the West Tracy fault, the Vernalis fault is a moderately to steeply west-dipping fault (California Department of Water Resources 2007a). The Black Butte fault is a northwest–southeast striking fault approximately 6 miles southeast of Tracy. It dips moderately to steeply to the west. The Midway fault similarly strikes northwest–southeast and is separated from the northwest end of the Black Butte fault by an *en echelon* step across a small west–northwest-trending anticline. The seismic study (California Department of Water Resources 2007a) characterized the Black Butte and Midway faults as a single structure.

The probabilities of activity, maximum earthquake magnitudes, and long-term geologic slip rates assigned to these blind thrusts are presented in Table 9-8.

Seismic Zones

To account for seismicity not associated with known faults, such as random or floating earthquakes, two regional seismic zones—the Coast Ranges and Central Valley seismic zones—were developed for the seismic study. The maximum earthquake magnitudes assigned to these seismic zones are 6.5 ± 0.3 moment magnitude. The recurrences of various earthquake magnitudes were estimated using the historical seismicity recorded in each of the two seismic zones after removing events within 10-kilometer-wide corridors along known faults (to avoid double counting seismic events that occurred on the faults). Both the uniform and gridded seismicity source models were used to model the uncertainty associated with earthquake location. In the uniform model, earthquakes are assumed to occur everywhere within the zone with equal probability. For the gridded seismicity model, the rates of earthquakes at a particular location within the zone are estimated using the seismicity recorded around the location. A Gaussian (normal) filter was used to “smooth” the data and to assign greater weights to nearby seismicity (California Department of Water Resources 2007a).

Subduction Zone

A subduction zone consists of interface and intraslab seismic sources. The interface seismic source is along the convergent plate boundary, while the intraslab is a deeper seismic source on the subducting plate.

The Cascadia subduction zone extends from Cape Mendocino, California, to Vancouver Island, British Columbia. Although this seismic zone is a large distance from the Delta and Suisun Marsh, its contributions to the ground shaking cannot be ignored because of its potential for generating very large-magnitude earthquakes (earthquakes with moment magnitudes of about 9.0).

A large-magnitude earthquake tends to produce strong, long-period motions even at large distances from the energy source. Long-period ground motions are important for assessments of linear structures, such as tunnels and levee deformations.

Because of the distances from the Delta and Suisun Marsh, only the very large (megathrust) events of the interface were considered in the seismic study (California Department of Water Resources 2007a). The Wong and Dober (2007) megathrust model was adopted, with a maximum moment magnitude of 9 ± 0.5 and a recurrence interval of 450 ± 150 years. An alternative model was considered by USGS for the Cascadia interface (Peterson et al. 2008). The 2007 USGS model considers two weighted fault rupture scenarios.

- Megathrust events (magnitude 9.0 ± 0.2) that rupture the entire interface zone every 500 years (weight of 0.67).
- Smaller events (magnitude 8.0 to 8.7) that float over the interface zone and rupture the entire zone over a period of about 500 years (weight of 0.33).

9.1.1.4 Geologic and Seismic Hazards

The geologic and seismic hazards discussed in this section include surface fault rupture, earthquake ground shaking, seismic-induced liquefaction and its related soil instability, and slope instability.

9.1.1.4.1 Surface Fault Ruptures

Fault Trace and Rupture Zones

The Alquist-Priolo (AP) Earthquake Fault Zoning Act, passed in 1972, required the establishment of earthquake fault zones (known as S*pecial Studies Zones* prior to January 1, 1994) along known active faults in California. The state guidelines for assessing fault rupture hazards are explained in CGS Special Publication 42, which is discussed in detail under Section 9.2, *Regulatory Setting*. Strict regulations for development in these fault zones are enforced to reduce the potential for damage resulting from fault displacement.

Special Publication 42 shows that the only AP fault zones occurring in the Plan Area are those for the Green Valley and Cordelia faults. The active Green Valley fault crosses the southwestern corner of the Suisun Marsh Restoration Opportunity Area (ROA) and the active Cordelia fault extends approximately 1 mile into the northwestern corner of the Suisun Marsh ROA.

As discussed previously, the Delta is underlain by blind thrusts that are considered active or potentially active, but they are not expected to rupture to the ground surface. Blind thrust fault ruptures generally terminate before they reach the surface. They may produce ground manifestations (i.e., below ground shear zone and/or ground surface bulging) during breaking, but in most cases, no clear surface ruptures.

Those faults that could cause ground deformation at the surface but not surface rupture are discussed in the following section.

Fault Offsets

An estimate of fault offset (displacement during a seismic event) is important for assessing possible future effects. The amount of fault offset depends mainly on earthquake magnitude and location along the fault trace. Fault offset can take place on a single fault plane, or displacements can be distributed over a narrow zone. Fault rupture can also be caused by rupture on a neighboring fault (secondary fault rupture).

Empirical relationships are typically used to estimate fault offsets. The relationships provide estimates of fault displacements, such as average and maximum offsets, as a function of fault parameters. The average and maximum fault offsets for the Concord and Pittsburgh–Kirby Hills faults (Table 9-9) were estimated using the relationships of Wells and Coppersmith (1994).

Table 9-9. Estimated Fault Rupture Offsets for Concord and Pittsburgh Hills Faults

Fault	Maximum Earthquake (moment magnitude)	Average Offset[a] (inch)	Maximum Offset[a] (inch)	Faulting Style
Concord[b]	6.7	10.6–38.6	13.4–63	Strike-slip
Pittsburgh–Kirby Hills	6.7	10.6–38.6	13.4–63	Strike-slip

Source: Estimated using the relationships of Wells and Coppersmith (1994).

[a] The range represents values ±1 standard deviation.

[b] The maximum magnitude of the Concord–Green Valley fault system was used.

Although the Midland fault is characterized as a blind thrust, there seems to be anomalous relief near the base of the peat (or top of the sand layer) across the fault traces. The available data indicate a modest 6.6–9.8 foot west-side-up step at the base of the peat across the surface trace of the Midland fault (California Department of Water Resources 2007a).

Fault offset characteristics of the West Tracy fault are provided in Table 9-8. The West Tracy fault appears to contain secondary east-dipping splays (branches) in the hanging wall (i.e., overhanging block) of the fault, positioned west of the Clifton Court Forebay, some of which are beneath the intake channel to the Banks Pumping Plant. The CGS and USGS show the West Tracy fault as not being active. However, Fugro Consultants (2011) indicate that the fault may have experienced movement within the past 35,000 years and therefore would be potentially active. If movement occurred along the fault, uplift of the hanging wall of the fault could cause surface deformation in the western part of the Clifton Court Forebay and the Byron Tract Forebay. Additionally, slippage of the fault splays could cause surface rupture immediately west of the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011).

9.1.1.4.2 Earthquake Ground Shaking

The potential of earthquake ground shaking in the Delta was evaluated in the seismic study using the Probabilistic Seismic Hazard Analysis (PSHA) method (California Department of Water Resources 2007a). This method permits the explicit treatment of uncertainties in source geometry and parameters, as well as ground motion estimation. In a PSHA, the probabilities of exceeding various levels of ground motion at a site are calculated by considering seismic source locations and geometry, rates of various earthquake magnitudes, and ground motion attenuation from the energy source to the site. The uncertainties associated with source parameters and ground motion estimation are incorporated in the analysis using a logic tree approach that uses multiple parameter values.

The standard PSHA assumes a Poissonian process for earthquake occurrences or a time-independent earthquake recurrence model. In the seismic study, however, a time-dependent recurrence model was used to calculate the earthquake potential (California Department of Water Resources 2007a). The time-independent PSHA analysis was also performed for comparison purposes.

In a time-dependent model, the time of the last earthquake is used to estimate earthquake recurrence interval or frequency (a non-Poissonian process). Because many of the San Francisco Bay region seismic sources do not have sufficient information on the times of last earthquakes, only seven of the major faults were characterized using the time-dependent model: the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust. Therefore, the overall model used in the seismic study is not a pure time-dependent model.

Empirical earthquake ground motion attenuation relationship is used to estimate the horizontal Peak Ground Acceleration (PGA) and the 5% damped spectral accelerations. The ground motion attenuation relationship describes the attenuation of seismic waves with distance to the source as a function of source parameters such as magnitude, rupture width, faulting style, and site condition. Multiple relationships are commonly used to account for the uncertainty associated with ground motion predictions. The PGA and spectral accelerations are engineering parameters representing the intensity of seismic waves (ground motion) at various frequencies.

The seismic study used the Next Generation Attenuation (NGA) relationships developed for western United States earthquakes for the crustal faults, blind thrusts, and seismic zones discussed previously (California Department of Water Resources 2007a). At the time of the seismic study, only three of the NGA relationship models were available, and these were used with equal weights (Chiou and Youngs 2006; Campbell and Bozorgnia 2007; Boore and Atkinson 2007). For the Cascadia subduction zone, the seismic study used the relationships of Youngs et al. (1997) and Atkinson and Boore (2003).

The PSHA was conducted at six selected locations in the Delta area (Clifton Court, Delta Cross Channel, Montezuma Slough, Sacramento, Sherman Island, and Stockton) for four different years: 2005, 2050, 2100, and 2200. The selected sites represent the north, south, east, west and central regions of the Delta and the western-most section of the Plan Area. The results are expressed in terms of hazard curves that relate the intensity of ground motion (PGA and response spectral accelerations) to annual exceedance probability (probability that a specific value of ground motion intensity will be exceeded). The distributions of hazard curve (the 5th, 15th, mean, median [50th], 85th, and 95th percentile hazard curves) were calculated at the six selected locations for PGA and 1.0-second spectral acceleration. The seismic hazard analysis was performed for a stiff soil site condition, with an average shear-wave velocity of 1,000 feet per second (ft/sec) in the top 100 feet, or 30 meters (V_{s100ft}).

The results of PSHA indicate that ground shaking hazards in the Delta area are not sensitive to the assumed recurrence model (whether a time-dependent or time-independent model is used). This is true because the hazards are dominated by the nearby Delta seismic sources (time-independent sources), and not by the time-dependent major seismic source in the region.

Controlling Seismic Sources

The seismic sources expected to dominate the ground motions at a specific location (known as *controlling seismic sources*) vary depending on the location, ground motion probability level (or return period), and ground motion frequency (or period). Table 9-10 summarizes the controlling seismic sources at the six selected sites in 2005 for PGA and 1.0-second spectral acceleration at ground motion return periods of 100 and 2,475 years.

Table 9-10. Controlling Seismic Sources in 2005

Location	PGA	1.0-second Spectral Acceleration
100-Year Return Period		
Clifton Court	Southern Midland Mt. Diablo	Mt. Diablo Hayward–Rodgers Creek
Delta Cross Channel	Southern Midland Northern Midland Zone	Mt. Diablo
Montezuma Slough	Concord–Green Valley	Concord–Green Valley
Sacramento	Northern Midland Zone	Mt. Diablo San Andreas
Sherman Island	Southern Midland	Southern Midland Hayward–Rodgers Creek San Andreas
Stockton	Southern Midland Hayward–Rodgers Creek Calaveras	Hayward–Rodgers Creek San Andreas
2,475-Year Return Period		
Clifton Court	Southern Midland	Southern Midland
Delta Cross Channel	Southern Midland Northern Midland Zone	Cascadia Subduction Zone Southern Midland
Montezuma Slough	Pittsburg-Kirby Hills	Pittsburg-Kirby Hills
Sacramento	Northern Midland Zone	Cascadia Subduction Zone
Sherman Island	Southern Midland Montezuma Hills Zone	Southern Midland
Stockton	Southern Midland	Cascadia Subduction Zone

Source: California Department of Water Resources 2007a.
Note: PGA = Peak Ground Acceleration

Additionally, the controlling seismic sources in 2200 are similar to those in 2005 except for the 1.0-second spectral acceleration; the San Andreas fault becomes a major contributor to the site hazards because of the high potential for a repeat of a 1906-type major earthquake event. The controlling seismic sources in 2050 and 2100 are similar to the sources identified for 2005 and 2200.

Site Soil Amplifications

Thick deposits of peaty and soft soil tend to amplify earthquake ground motions, especially for the long-period motions such as the 1.0-second spectral acceleration. The earthquake ground motions developed for the Delta and Suisun Marsh as part of the seismic study are applicable for a stiff soil site condition. Therefore, these motions are expected to change as they propagate upward through the peaty and soft soil from the stiffer alluvium underlying the Delta and Suisun Marsh. Based on CALFED Bay-Delta Program (2000), the acceleration amplification factor from the stiff base layer to the levee crown is in the order of 1 to 2.

72-Year Return Period Peak Ground Motion

The calculated mean PGA and 1.0-second spectral acceleration values for a 72-year ground motion return period (or an annual frequency of 0.01388) in 2005 and 2200 are presented in Table 9-11.

The calculated ground motions in 2050 and 2100 are between these values. The 72-year return period corresponds to approximately a 50% probability of exceedance in 50 years. The ground motions were calculated for a stiff soil condition with an average shear-wave velocity of 1,000 ft/sec in the top 100 feet.

Table 9-11. Calculated Mean Peak Ground Motions at Selected Sites for Various Return Periods (for Stiff Soil Site, V_{s100ft} = 1,000 ft/sec)

	Return Period									
	72 years		144 years		475 years		975 years		2,475 years	
Location	2005	2200	2005	2200	2005	2200	2005	2200	2005	2200
Mean Peak Ground Acceleration in g										
Clifton Court	0.18	0.21	0.24	0.27	0.39	0.41	0.49	0.51	0.66	0.67
Delta Cross Channel	0.13	0.14	0.16	0.18	0.24	0.25	0.29	0.29	0.36	0.36
Montezuma Slough	0.23	0.27	0.31	0.34	0.46	0.49	0.57	0.60	0.74	0.75
Sacramento	0.11	0.12	0.14	0.14	0.20	0.20	0.24	0.24	0.29	0.29
Sherman Island	0.20	0.23	0.27	0.29	0.41	0.43	0.49	0.52	0.64	0.66
Stockton	0.12	0.13	0.15	0.17	0.22	0.23	0.25	0.27	0.31	0.33
Mean 1.0-second Spectral Acceleration in g (5% damping)										
Clifton Court	0.20	0.24	0.28	0.32	0.46	0.50	0.60	0.63	0.83	0.85
Delta Cross Channel	0.15	0.17	0.20	0.23	0.30	0.33	0.37	0.40	0.48	0.50
Montezuma Slough	0.24	0.29	0.33	0.38	0.53	0.57	0.66	0.71	0.89	0.93
Sacramento	0.13	0.15	0.17	0.19	0.26	0.28	0.32	0.34	0.42	0.44
Sherman Island	0.22	0.26	0.29	0.34	0.46	0.50	0.59	0.62	0.78	0.80
Stockton	0.14	0.17	0.19	0.22	0.28	0.31	0.34	0.38	0.44	0.47

Source: California Department of Water Resources 2007a.
Note: g = acceleration due to gravity, 32.2 ft/sec^2

144-Year Return Period Ground Motion

The calculated mean PGA and 1.0-second spectral acceleration values for a 144-year ground motion return period (or an annual frequency of 0.00694) in 2005 and 2200 are presented Table 9-11. The calculated ground motions in 2050 and 2100 are between these values (not shown in the table). The 144-year return period corresponds to approximately 30% probability of exceedance in 50 years.

475-Year Return Period Ground Motion

The calculated mean PGA and 1.0-second spectral acceleration values for a 475-year ground motion return period (or an annual frequency of 0.0021) in 2005 and 2200 are presented in Table 9-11. The calculated ground motions in 2050 and 2100 are between these values (not shown in the table). The 475-year return period corresponds to approximately 10% probability of exceedance in 50 years.

975-Year Return Period Ground Motion

The calculated mean PGA and 1.0-second spectral acceleration values for a 975-year ground motion return period (or an annual frequency of 0.00102) in 2005 and 2200 are presented in Table 9-11. The calculated ground motions in 2050 and 2100 are between these values (not shown in the table). The 975-year return period corresponds to approximately 5% probability of exceedance in 50 years.

2,475-Year Return Period Ground Motion

The calculated mean PGA and 1.0-second spectral acceleration values for a 2,475-year ground motion return period (or an annual frequency of 0.0004) in 2005 and 2200 are presented in Table 9-11. The calculated ground motions in 2050 and 2100 are between these values (not shown in the table). The 2,475-year return period corresponds to approximately 2% probability of exceedance in 50 years.

The data in Table 9-11 indicate that ground motion decreases from west to east as the distance to the San Andreas fault system increases. Also, the calculated ground motions are not sensitive (they only increase slightly) to the assumed time interval from the last major earthquake (from 2005 to 2200).

The 2008 USGS National Seismic Hazard Maps provide the values of PGA and 1.0-second spectral acceleration for the 475- and 2,475-year return periods. Table 9-12 compares the ranges of PGA and 1.0-second spectral acceleration calculated in the seismic study (California Department of Water Resources 2007a) to those estimated from the USGS maps (U.S. Geological Survey 2009).

Table 9-12. Comparison of Ground Motions Calculated in the Seismic Study to Estimated 2008 USGS Mapped Values

Ground Motion Return Period	Range of Mean Peak Ground Acceleration in g		Range of Mean 1.0-second Spectral Acceleration in g (5% damping)	
	DWR (2007a)[a]	USGS 2008 Maps[b]	DWR (2007a)[a]	USGS 2008 Maps[b]
475 years	0.20–0.46	0.20–0.40	0.26–0.53	0.14–0.30
2,475 years	0.29–0.74	0.30–0.70	0.42–0.89	0.25–0.50

Source: California Department of Water Resources 2007a; U.S. Geological Survey 2009.
DWR = California Department of Water Resources
g = acceleration due to gravity, 32.2 ft./sec^2
USGS = U.S. Geological Survey
[a] Ranges of calculated ground motion at the six selected sites in the Delta (V_{s100ft} = 1,000 ft/sec)
[b] Approximate ranges of ground motion over the Delta (V_{s100ft} = 2,500 ft/sec)

The 2008 USGS maps were developed for a reference site condition with an average shear-wave velocity of 2,500 ft/sec (about 760 meters per second) in the top 100 feet (Petersen et al. 2008). Consequently, the mapped values cannot be directly compared to those calculated in the seismic study, which assumed a site condition with an average shear-wave velocity of 1,000 ft/sec (California Department of Water Resources 2007a).

9.1.1.4.3 Liquefaction

Liquefaction is a process whereby strong ground shaking causes loose and saturated soil sediment to lose strength and to behave as a viscous fluid. This process can cause excessive ground deformations, failures, and temporary loss of soil bearing capacity, resulting in damage to structures and levees. Ground failures can take the forms of lateral spreading, excessive differential and/or total compaction or settlement, and slope failure. Liquefaction can also increase the potential for buoyancy to buried structures (causing them to float to the ground surface) and cause an increase in lateral earth pressure. The Delta and Suisun Marsh are underlain at shallow depths by various channel deposits and recent silty and sandy alluvium. Some of the existing levee materials also consist of loose, silty, and sandy soil.

Where saturated, these soil of the levee embankment and the soil of their foundations locally may be susceptible to liquefaction during earthquakes.

Soil liquefaction is also a function of ground motion intensity and shaking duration. Longer ground shaking, even at a lower intensity, may cause liquefaction as the soil is subject to more repeated cycles of loading. Longer duration shaking is typically associated with larger magnitude earthquakes, such as earthquakes that occur on the San Andreas, Hayward, and Calaveras faults.

Historical Occurrences of Liquefaction

Ground manifestation associated with liquefaction during the 1906 San Francisco earthquake was reported in three locations within and in the vicinity of the Plan Area. Youd and Hoose (1978) reported settlements up to 11 feet, south of Fairfield along the Southern Pacific Railway through the Suisun Marsh; ground settlement of several inches was reported at the Southern Pacific Bridge Crossing over the San Joaquin River in Stockton; and settlement of 3 feet was reported at a bridge crossing over Middle River approximately 10 miles west of Stockton (Youd and Hoose 1978). No ground manifestations were reported in the Delta and Suisun Marsh during the more recent 1989 Loma Prieta earthquake (Knudsen et al. 2000).

Conditions Susceptible to Liquefaction

Along the Delta and Suisun Marsh levees, loose silty and sandy soil are present in the levee embankments and in the underlying foundation soil. When saturated, such soil is susceptible to liquefaction during earthquake events. Since the levees are constructed (not naturally occurring), the loose, silty and sandy soil comprising the levees are likely to be more continuous than those present in the foundation of the levee (CALFED Bay-Delta Program 2000). Areas with larger lateral continuity of liquefied soil are expected to experience more ground failure. The available data also indicate that the levees protecting Sherman Island have extensive layers of liquefiable sandy soil, more so than other levees in the Delta and Suisun Marsh (CALFED Bay-Delta Program 2000). See Chapter 6, *Surface Water*, for more information.

Liquefaction Hazard Mapping

No official Seismic Hazard Zone maps for liquefaction potential have been developed by CGS or the USGS for the Delta. Also, maps of liquefaction hazard (i.e., the susceptibility of the geologic or soil materials and ground water levels to liquefaction combined with shaking levels anticipated for a given earthquake scenario) have not been prepared for the entire Delta area. However, a preliminary analysis of the risk of levee failure caused by liquefaction-induced seismic shaking was prepared for the CALFED Levee System Integrity Program (Torres et al. 2000). Torres et al. (2000) estimated the magnitude and recurrence intervals of peak ground accelerations throughout the Delta. Then, based on local knowledge and limited geotechnical information, they identified and mapped Damage Potential Zones (Figure 9-6). The Damage Potential Zones specifically are based on the “fragility” of existing levees as affected by seismically induced liquefaction considering levee characteristics, levee foundation soil characteristics, and seismic shaking factors. Consequently, the map should not be construed as a liquefaction hazard map. The map shows that the highest potential levee damage could occur in the central Delta and Sherman Island.

Liquefaction hazard maps prepared by the Association of Bay Area Governments have been prepared for the greater San Francisco Bay Area, including the Suisun Marsh and the western and northwestern parts of the Delta. Figure 9-6 shows that the liquefaction hazard in the Suisun Marsh ROA is mostly medium to high, the southern half of the west conveyance option is mostly medium to low, and part of the Cache Slough ROA is medium to low (Association of Bay Area Governments 2011).Areas not assigned a hazard/damage potential class on Figure 9-6 either were not evaluated or are assumed to have less than low hazard/damage potential.

9.1.1.4.4 Areas Susceptible to Slope Instability

A landslide is a mass of rock, soil, and/or debris that has been displaced downslope by sliding, flowing, or falling. Landslides include cohesive block glides and disrupted slumps that have formed by the translation or rotation of slope materials along one or more planar or curve-planar surfaces. Soil creep is the slow, imperceptible downslope movement of weak soil and soft rock under the force of gravity.

Landslides occur when shear stresses within a soil or rock mass exceed the available shear strength of the mass. Failure may occur when stresses that act on a slope increase, internal strength of a slope decreases, or a combination of both. Increased stresses can be caused by an increase in weight of the overlying slope materials (by saturation), addition of material (surcharge) to the slope, application of external loads (foundation loads, for example), or seismic loading (application of an earthquake-generated agitation to a structure).

Slope soil shear strength (the internal resistance of a soil to shear stress) can be reduced through erosion and/or undercutting or removal of supporting materials at the slope toe as a result of scouring (concentrated erosion by streamflow), increased pore water pressure within the slope, and weathering or decomposition of supporting soil. Zones of low shear strength within the slope are generally associated with the presence of certain clay, bedding, or fracture surfaces. The various factors and processes that contribute to an unstable slope or levee in the Delta and Suisun Marsh are explained in Chapter 6, *Surface Water*.

Strong earthquake ground shaking often causes landslides, particularly in areas already susceptible to landslides because of other non-seismic factors, including the presence of existing landslide deposits and water-saturated slope materials. Failure of steep slopes, collapse of natural streambanks, and reactivation of existing landslides may occur extensively during a major earthquake.

Historical Occurrences of Landslides and Levee Failure

Since 1900, at least 158 levee failures or breaches have been reported that resulted in flooding the Delta and Suisun Marsh islands and tracts. (California Department of Water Resources 2010f) Earthquake ground shaking is not linked to any of these levee breaches. The dominant causes of the levee breaches are believed to have been water overtopping levees during high tides, erosion, piping and seepage though the levee embankment and foundation soil, and burrowing animals. (California Department of Water Resources 2007b)

Because the topography of the Delta and Suisun Marsh is nearly level, the potential of landslides at locations outside the levees is considered low. No maps or records on the historical occurrences of slope failure are readily available for areas outside the levees.

Areas Susceptible to Landslides and Debris Flows

The known areas susceptible to slope failure within the Delta and Suisun Marsh primarily are along the levee system and channel banks. Maps of those levees and channel banks that are particularly subject to mass failure have not been prepared.

Because of their steep slopes, the Potrero Hills, the area west of Interstate I-680, and the western slopes of the Montezuma Hills within the Suisun Marsh ROA likely have a greater relative potential for landslides and debris flows (a shallow, moving mass of rock fragments, soil, and mud) than the remainder of the Plan Area, although it is not known if any significant landslides or debris flows have occurred in these areas.

A map in the Solano County General Plan, Public Health and Safety Element (Solano County 2008) shows landslide susceptibility for the western part of the county. The landslide susceptibility ranges from "least susceptible" to "most susceptible" in the part of the Plan Area west of I-680. The area east of I-680 in the northwestern part of the Suisun Marsh is rated as "least susceptible". The other parts of the county, including the Montezuma Hills and Potrero Hills, appear not to have been evaluated for landslide susceptibility.

Existing landslides (but not landslide susceptibility/hazard) have been mapped for all of Alameda County (Roberts et al. 1999). Within and adjoining the Plan Area, the map shows one relatively small landslide located east of the Delta Mendota Canal and southwest of Mountain House Creek.

In San Joaquin County, the sloping areas in the vicinity of the Plan Area exist southwest of the Plan Area. The San Joaquin County General Plan (San Joaquin County 1992) shows no areas that are subject to landslides within the Plan Area.

Landslide Hazard Maps Prepared by California Geological Survey

No official Seismic Hazard Zone maps for earthquake-induced landslide potential have been developed by CGS for the Delta and Suisun Marsh. The closest available maps are those for the Las Trampas Ridge USGS 7.5' quadrangle, southwest of the Delta and Suisun Marsh, and the Livermore and Altamont USGS 7.5' quadrangles, south of the Delta and Suisun Marsh. The coverage areas of these maps are outside of the Plan Area.

9.1.1.4.5 Ground Failure and Seismic-Induced Soil Instability

Compaction and Settlement

Earthquake ground motions can cause compaction and settlement of soil deposits because of rearrangement of soil particles during shaking. The amount of settlement depends on ground motion intensity and duration and degree of soil compaction; looser soil subjected to higher ground shaking will settle more. Empirical relationships are commonly used to provide estimates of seismic-induced settlement. In these relationships, ground shaking can be represented by PGA and magnitude, and soil compaction is typically measured by Standard Penetration Test (SPT) (i.e., an *in-situ* dynamic penetration test that measures the density of granular soil) blow-counts or N-values. Excessive total and differential settlements can cause damage to buried structures, including utilities, which in turn may initiate larger failure to levees and other above-ground facilities.

Loss of Bearing Capacity

Liquefaction can also result in temporary loss of bearing capacity in foundation soil, which has the potential to cause foundation, pipeline, and tunnel failures during and immediately after an earthquake event.

Lateral Spreading

Soil lateral spreading, or horizontal movement, can be initiated during an earthquake event. Liquefaction-induced lateral spreading could occur even on gently sloping grounds or flat ground with a nearby free face (e.g., a steep stream bank or other slope) when the underlying soil liquefies. The amount of horizontal movement depends on ground motion intensity, the ground's slope, soil properties, and conditions of lateral constraint (free-face or non-free-face condition).

Increased Lateral Pressures

Liquefaction can increase lateral earth pressures on walls and buried structures. As soil liquefies, earth lateral pressure will approach that of a fluid-like material.

Buoyancy

Liquefaction can cause buried pipes and structures to become buoyant. The potential for buoyancy caused by liquefaction is typically determined using site-specific data at the planned locations of buried pipes and structures.

9.1.1.4.6 Tsunami and Seiche

No known maps of tsunami hazard are available for the Delta or Suisun Marsh areas. Tsunami hazard mapping closest to the Plan Area appears to be the tsunami inundation maps prepared by the California Department of Conservation (2009) that extend east to about the Benicia Bridge. That mapping shows at tsunami inundation area on the shores of the Sacramento River, extending east of the Benicia Bridge to the edge of the base map (i.e., the Benicia 7.5' quadrangle). The hazard maps show the "maximum considered tsunami runup from a number of extreme, yet realistic tsunami sources". On the Benicia quadrangle, the inundation areas extend over mud flats and tidal marshes, which are presumed to have an elevation at or within approximately 3 feet above sea level. Because the inundation zone is close to sea level, it appears that substantial tsunami effects extending into the Suisun Marsh and Delta are mostly attenuated in the San Francisco Bay. Tsunami effects to the east of the Benicia Bridge are presumed to be further attenuated in the Suisun and Grizzly bays.

Historic records of the Bay Area indicate that 19 tsunamis were recorded in San Francisco Bay during the period of 1868 to 1968. The maximum wave height recorded at the Golden Gate tide gage was 7.4 feet (Contra Costa County 2009).

Based on a tsunami wave runup of 20 feet at the Golden Gate, the 2009 (Contra Costa) Countywide Comprehensive Transportation Plan indicates that tsunami attenuation in the San Francisco Bay would diminish the height of the wave to approximately 10 feet along the Richmond shoreline. East of Point Pinole, the wave height would diminish to approximately one-tenth of that (i.e., 2 feet) at the Golden Gate (Contra Costa Transportation Agency 2009).

Based on the above information and on professional judgment, the effects of a tsunami in the Suisun Marsh and Delta are expected to be minimal.

A seismically induced seiche is a rhythmic standing wave in a partly or fully enclosed body of water caused by seismic waves generated by a landslide, earthquake-induced ground acceleration, or ground offset. Elongate and deep (relative to width) bodies of water seem most likely to be subject to seiches, and earthquake wave orientation may also play a role in seiche formation. The "sloshing" waves generated can reach tens of feet high and have devastating effects on people and property. Seiches can temporarily flood a shoreline in a manner similar to tsunami; however, their destructive capacity is not as great. Seiches may cause overtopping of impoundments such as dams, particularly when the impoundment is in a near-filled condition, releasing flow downstream. Earthquakes occurring miles away can produce seiches in local bodies of water which could overtop and damage levees and dams and cause water to inundate surroundings (Contra Costa County 2009). In 1868, an earthquake along the Hayward fault in the San Francisco Bay Area generated a seiche along the Sacramento River (County of Sacramento 1993).

Based on professional judgment, with the exception of the Clifton Court Forebay and the Byron Tract Forebay, the hazard of a seiche occurring in the Plan Area is expected to be low because of the lack of existing and proposed (e.g., intermediate forebay) deep, narrow, and enclosed water bodies and distance from seismic sources capable of generating strong ground motions.

Fugro Consultants, Inc. (2011) identified the potential for strong ground motions along the West Tracy fault to cause a seiche of an unspecified wave height to occur in the Clifton Court Forebay, assuming that this fault is potentially active. Since the fault also extends under the Byron Tract Forebay, a seiche could also potentially occur in the Byron Tract Forebay.

9.2 Regulatory Setting

9.2.1 Federal Plans, Policies, and Regulations

9.2.1.1 U.S. Geological Survey Quaternary Faults

USGS maintains the database of Quaternary fault and fold parameters (U.S. Geological Survey 2009). The database is periodically updated to reflect the latest data available and current understanding of fault behaviors. These parameters were used to develop the National Seismic Hazard Maps.

9.2.1.2 U.S. Geological Survey National Seismic Hazard Maps

USGS provides probabilistic seismic hazard maps for the 48 conterminous states, including the Delta and Suisun Marsh area (U.S. Geological Survey 2009). These maps depict contour plots of PGA and spectral accelerations at selected frequencies for various ground motion return periods. The USGS National Seismic Hazard Maps are updated periodically and have been adopted by many building and highway codes as the minimum design requirements.

9.2.1.3 U.S. Geological Survey Landslide Hazard Program

USGS provides information regarding the causes of ground failure and mitigation strategies to reduce long-term losses from landslide hazards. The information is useful for understanding the nature and scope of ground failures and improving the mitigation strategies.

9.2.1.4 U.S. Army Corps of Engineers EC 1165-2-211

In July 2009, the Corps issued EC 1165-2-211, a water resource policy mandating that every Corps coastal activity influenced by tidal waters include potential relative sea-level change in the starting water surface elevation, where appropriate. To conform, projects must determine how sensitive plans and designs are to rates of future local mean sea-level change, how this sensitivity affects calculated risk, and what design or operations and maintenance measures should be implemented to minimize adverse consequences while maximizing beneficial effects.

The Project is not a Corps activity subject to EC 1165-2-211; however, the Project will include maintenance operations that will require placement of levee materials as necessary to maintain freeboard in response to actual sea-level rise rates.

9.2.2 State Plans, Policies, and Regulations

9.2.2.1 Delta Plan

The Delta Reform Act requires that the Delta Plan promote effective emergency response and emergency preparedness and promote appropriate land use to attempt to reduce risks to people, property, and State interest in the Delta (Water Code section 85305). The Delta Reform Act requires the Delta Plan to recommend priorities for State investments in Delta levees. In response, the Delta Plan has adopted policy RR P1, *Prioritization of Statement Investments in Delta Levees and Risk Reduction*.

The hope is that implementation of Policy RR P1 will provide adequate protection to freshwater aqueducts passing through the Delta and the primary freshwater channel pathways through the Delta against floods and other risks of failures as well as prevent water deliveries to East Bay Municipal Utilities District, Contract Costa Water District, the CVP and the SWP from being interrupted by floods or earthquakes.

9.2.2.2 California Division of Safety of Dams

The DSOD has oversight and approval authority for structures that are considered dams under the Water Code. Some levees are "dams" as defined by California Water Code section 6002, and as such, are required to meet DSOD's standards and design review requirements. Dams under DSOD jurisdiction are artificial barriers that are at least 25 feet high or have an impounding capacity of at least 50 acre feet. Water Code section 6004(c) specifically excludes structures in the Sacramento-San Joaquin Delta "…if the maximum possible water storage elevation of the impounded water does not exceed four feet above mean sea level, as established by the United States Geological Survey 1929 Datum."

Certain elements of various BDCP Alternatives could be subject to DSOD jurisdiction depending on the size and volume of water stored (i.e., the intermediate forebay, the Byron Tract Forebay, repairs or alterations to certain levees that might fall within DSOD jurisdiction).

9.2.2.3 Liquefaction and Landslide Hazard Maps (Seismic Hazards Mapping Act)

The Seismic Hazards Mapping Act of 1990 (California Public Resources Code Sections 2690 to 2699.6) was passed following the Loma Prieta earthquake to reduce threats to public health and safety by identifying and mapping known seismic hazard zones in California. The act directs the CGS of the Department of Conservation to identify and map areas prone to earthquake hazards of liquefaction, earthquake-induced landslides, and amplified ground shaking. The purpose of the maps is to assist cities and counties in fulfilling their responsibilities for protecting public health and safety. The Act requires site-specific geotechnical investigations be conducted identifying the seismic hazard and formulating mitigation measures prior to permitting most developments designed for human occupancy within areas prone to liquefaction and earthquake-induced landslides (also known as a Zone of Required Investigation). Cities and counties are required to incorporate the Seismic Hazard Zone Maps into their Safety Elements and the Act requires sellers of real property to disclose to buyers if property is in a seismic hazard Zone of Required Investigation.

As of January 2012, 119 official seismic hazard zone maps showing areas prone to liquefaction and earthquake-induced landslides had been published in California, and more are scheduled. Most of the mapping has been performed in southern California and the San Francisco Bay Area. Twenty-nine official maps for the San Francisco Bay Area have been released, with preparation of 10 additional maps for San Mateo, Santa Clara, Alameda, and Contra Costa Counties planned or in progress. None of these planned or in-progress maps will cover the Plan Area. Accordingly, the Seismic Hazards Mapping Act requirements will not affect the project unless and until the area is mapped.

Review by the local agency is required for proposed construction sites located in the mapped seismic hazard zones. Site-specific geologic investigations and evaluations are carried out to identify the extent of hazards, and appropriate mitigation measures are incorporated in the development plans to reduce potential damage.

9.2.2.4 Alquist-Priolo Earthquake Fault Zones

The AP Earthquake Fault Zoning Act was passed in 1972 (California Public Resources Code Section 2621 et seq.). Similar to the Seismic Hazards Mapping Act, its main purposes are to identify known active faults in California and to prevent the construction of buildings used for human occupancy on the surface trace of active faults. For the purpose of this act, a fault is considered active if it displays evidence of surface displacement during Holocene time (approximately during the last 11,000 years).

The act directs CGS to establish the regulatory zones, called AP Earthquake Fault Zones, around the known surface traces of active faults and to publish maps showing these zones. Each fault zone extends approximately 200 to 500 feet on each side of the mapped fault trace to account for potential branches of active faults.

CGS Special Publication 42 (Bryant and Hart 2007) states that in the absence of a site-specific faulting study, the areas within 50 feet of the mapped fault should be considered to have the potential for surface faulting and, therefore, no structure for human occupancy should be in these areas. Construction of buildings intended for human occupancy within the fault zone boundaries is strictly regulated, and site-specific faulting investigations are required.

Title 14 of the California Code of Regulations, Section 3601(e), defines buildings intended for human occupancy as those that would be inhabited for more than 2,000 hours per year. If none of the facilities included within the proposed project design meet this definition, this act would not apply.

9.2.2.5 Assembly Bill 1200 (Chapter 573, Statutes of 2005)

Assembly Bill 1200 directed DWR and the California Department of Fish and Wildlife to prepare a report on evaluating the potential effects on water supplies derived from the Delta from a variety of stressors, including continuous land subsidence, earthquakes, floods, and climate change,. The bill also requires the studies of possible improvements and options (ranking of possible options) for the water-related issues in the next 50, 100, and 200 years when determining effects on the Delta.

In response to the bill, DWR and the California Department of Fish and Wildlife have issued a report, Risks and Options to Reduce Risks to Fishery and Water Supply Uses of the Sacramento/San Joaquin

Delta, dated January 2008. This report summarizes the potential risks to water supplies in the Sacramento and San Joaquin Delta attributable to future subsidence, earthquakes, floods and climate change, and identifies improvements to reduce the effects and options to deliver water.

9.2.2.6 Regulatory Design Codes and Standards for Project Structures

State and federal design codes and standards will regulate construction of the many structures that are part of the BDCP. These codes and standards establish minimum design and construction requirements, including design and construction of concrete and steel structures, levees, tunnels, pipelines, canals, buildings, bridges and pumping stations. They also establish construction requirements for temporary activities such as shoring of excavations and site grading. The codes and standards are intended to ensure structural integrity and to protect public health and safety. The codes and standards are developed by federal and state agencies with the participation of engineering boards or associations, and professional engineering societies. They are based on the performance history of structures under real conditions, including surface and subsurface geologic conditions and variable regional conditions such as flooding and seismic events. The following state and federal codes and standards will dictate the minimum design and construction requirements for the various elements of the BDCP water conveyance facilities and the structural aspects of other conservation measures. The minimum design and construction requirements act as performance standards for engineers and construction contractors. Because the design and construction parameters of these codes and standards are intended to reduce the potential for structural damage or risks to human health due to the geologic and seismic conditions that exist within the Plan Area and the surrounding region, their use is considered an environmental commitment of the agencies implementing the BDCP. This commitment is discussed further in Appendix 3B, *Environmental Commitments*.

- American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for LRFD [load and resistance factor] Seismic Bridge Design, 1st Edition, 2009.
  - Geotechnical seismic design guidelines are consistent with the philosophy for structure design that loss of life and serious injury due to structure collapse are minimized, to the extent possible and economically feasible.
  - These guide specifications adopt:
    - 7 percent probability of exceedance in 75 years (i.e., the same as 5 percent probability of exceedance in 50 years and an approximately 1,000 year recurrence interval) for development of a design spectrum.
    - the NEHRP Site Classification system and include site factors in determining response spectrum ordinates
    - a 1.5 safety factor (how much extra load beyond what is intended a structure will actually take or be required to withstand) for minimum support length requirement to ensure sufficient conservatism.
- American Railway Engineering and Maintenance-of-Way Association Manual for Railway Engineering, Volume 2, Chapter 9, *Seismic Design for Railway Structures*, 2008.
  - Provides recommended practices and guidelines for railway design in seismically active areas as well as recommended practices for post-earthquake response, including inspections.
  - Three performance limit states are given for seismic design of railroad bridges.

        - The serviceability limit state requires that the structure remain elastic during Level 1 ground motion (motion that has a reasonable probability of being exceeded during the life of the bridge). Only moderate damage and no permanent deformations are acceptable.
        - The ultimate limit state requires that the structure suffer only readily detectable and repairable damage during Level 2 ground motion (motion that has a low probability of being exceeded during the life of the bridge).
        - The survivability limit state requires that the bridge not collapse during Level 3 ground motion (motion for a rare, intense earthquake). Extensive damage may be allowed. For some structures, the railroad may elect to allow for irreparable damage, and plan to replace the bridges following a Level 3 event.
    - No seismic analysis is necessary for locations where a base acceleration of 0.1 g or less is expected with a 475-year return period. However, it is good practice to detail structures for seismic resistance if they are in potentially active areas.
    - Structures classified as “important” (discussed in Section 1.3.3) should be designed to resist higher seismic loads than nonimportant structures.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
    - Provides requirements for general structural design and includes means for determining dead, live, soil, flood, wind, snow, rain, atmospheric ice, and earthquake loads, and their combinations that are suitable for inclusion in building codes and other documents.
    - The intent of the seismic provisions in ASCE 7-05 is to provide a low probability of collapse for buildings experiencing the Maximum Considered Earthquake (MCE) shaking. MCE shaking is defined either as that shaking having a 2% probability of exceedance in 50 years (2,475 year mean recurrence interval) or at sites near major active fault, 150% of the median shaking resulting from a characteristic magnitude earthquake on that fault, whichever is less.
    - Nonstructural components (including architectural, mechanical, electrical, and plumbing equipment) and their supports and attachments that are permanently attached to a structure must be designed and constructed to resist the effects of the earthquakes motions in accordance with the code.
    - Provides Seismic Hazards Maps developed by USGS. Section 13.2.1 requires that mechanical and electrical equipment manufacturers provide certification that components are seismically qualified. Section 13.3.1 determines the magnitudes of horizontal and vertical seismic forces. Use Ip = 1.5 for mechanical equipment and 1.75 for electrical equipment in Occupancy Category IV for critical facilities as discussed in Section 4.3.5
- California Building Standards Code, 2010 (Title 24 California Code of Regulations).
    - Provides seismic design requirements in the design and construction of buildings, associated facilities and equipment. This code applies to all building occupancies, and related features and equipment throughout the state, and contains requirements to the structural, mechanical, electrical, and plumbing systems, and requires measures for energy conservation, green design, construction and maintenance, fire and life safety, and accessibility.
- Caltrans (California Department of Transportation) Seismic Design Criteria (SDC), Version 1.6, Nov 2010.

- The SDC is a compilation of new and existing seismic design criteria for Ordinary bridges (a bridge that spans less than 300 feet and is built on soil that is not susceptible to liquefaction, lateral spreading, or scour. The document is an update of all the Structure Design (SD) design manuals on a period basis to reflect the current state of practice for seismic bridge design.
    - These specifications are meant to guarantee that an Ordinary bridge will remain standing but may suffer significant damage requiring closure when ground shaking (defined as ground motion time histories or response spectrum), liquefaction, lateral spreading, surface fault rupture, and tsunami occur.
    - The criteria contained within the SDC are the minimum requirements for seismic design.

- California Code of Regulations, Title 8.
  - Section 3203 (Cal/OSHA Workplace Injury and Illness Prevention Program) states that a workplace or construction sites must devise and implement an Injury and Illness Prevention Program (IIPP) for all employees within the organization. The 8 required IIPP elements are:
    - Responsibility (e.g., supervisors are responsible for all accidents on their job or under their supervision, supervisors are responsible for the inspection of work areas, equipment and other potential accident producing conditions daily, employees are responsible for ensuring that machine guards are used and maintained in good condition and reporting to the supervisor if a guard is in questionable condition, etc.)
    - Compliance (e.g., supervisors must take disciplinary action when necessary to enforce safety rules and practices, etc.)
    - Communication (e.g., company policy to maintain open communication between management and employees on matters pertaining to safety, company will provide current safety news and activities, safety reading materials, signs, posters, and/or a bulletin board and will hold regular safety meetings)
    - Hazard Assessment (e.g., Managers, supervisors, and employees will report any hazardous conditions or activities noted as a result of a formal weekly and/or monthly inspections or during daily routine operations to the appropriate job site foreman or superintendent.)
    - Accident/Exposure Investigation (e.g., each supervisor/foreman has a prominent role in promptly conducting an accident investigation and must collect the facts, determine the sequence of events that resulted in the accident, identify action to prevent recurrence, and provide follow-up to ensure that corrective action was effective)
    - Hazard Correction (e.g., all hazards will be corrected as soon as identified and a record of hazard abatement will be kept in the main office to track the steps taken to correct the hazardous condition)
    - Training and Instruction (e.g., all new employees must undergo an initial orientation on job site safety rules and code of safe work practices. All employees must participate in scheduled safety meetings which are conducted weekly by the site foreman on all job sites and additional training as job duties or work assignments are expanded or changed)
    - Recordkeeping (e.g., hazard reports, employee-training records, etc. will be kept at the main office)
  - Section 1509 requires that every employer shall adopt a written Code of Safe Practices (8 CCR 1938, Appendix A) which related to the employer's operations. Also, supervisory employees

must conduct Toolbox or Tailgate safety meetings, or equivalent, with their crews at least every 10 working days to emphasize safety.

- DWR (California Department of Water Resources) Division of Safety of Dams (DSOD) *Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters*, 2002.
    - The loading criteria for jurisdictional dam facilities are determined using the DSOD criteria as follows:
        - The statistical level of ground motion for design (50^{th}- or 84^{th}-percentile) is determined from the DSOD Hazard Matrix (Table 2-2) based upon the consequence of failure (Total Class Weight obtained from DSOD) and the slip rate of the causative fault (obtained from a Seismic Hazard Assessment).
        - The Minimum Earthquake PGA parameter of 0.15g to 0.25g now applies to all new and existing jurisdictional dams undergoing re-evaluation in California (new and existing dams undergoing re-evaluation must resist a horizontal force of 0.15g to 0.25g).
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
    - Provides engineering criteria and guidance for the design, evaluation, operation, and maintenance of levees and floodwalls that provide an urban level of flood protection (i.e., 200-year level of flood protection) in California, as well as for determining design water surface elevations (DWSE) along leveed and unleveed streams. Flood Safety Plan is required for all agencies working at or near levee
    - Requires analysis of seismic vulnerability of the levee system for 200-year return period ground motions to meet the urban level of flood protection.
    - Frequently loaded levees (and floodwalls), such as many levees in the Sacramento-San Joaquin Delta, are required to have seismic stability sufficient to maintain the integrity of the levee and its internal structures without significant deformation. In most cases, for frequently loaded levees with less than 5 feet of freeboard, earthquake-induced deformations should be limited to less than 3 feet of total deformation and about 1 foot of vertical displacement.
    - For intermittently loaded levees (and floodwalls), if seismic damage from 200-year-return-period ground motions is expected after the urban level of flood protection is achieved, a post-earthquake remediation plan is required as part of a flood safety plan that is developed in coordination with pertinent local, State, and federal agencies.
- DWR Division of Engineering State Water Project—Seismic Loading Criteria Report, Sept 2012.
    - Provides DWR design guidelines in selecting appropriate seismic loading criteria for a wide variety of SWP facilities including dams, canals, pipelines, tunnels, check structures, bridges, buildings, pumping and power plants, and utility overcrossings. The seismic design load shall be selected based on the criticality of a facility and consequences of failure. Most critical facilities are expected to be functional immediately after an earthquake and thereby should experience very limited damage. Other facilities may be considered less critical such that they are designed to incur some damage but still return to some level of function in a specified timeframe.
- DWR Delta Seismic Design, June 2012.
    - This report serves to provide literature search of Delta specific design criteria and application of load to structures. It's a compilation of existing state of practice for the seismic design of the

type of hydraulic structures as well as recommended guidelines for design criteria associated with future hydraulic structures in the Delta.

- Federal Highway Administration Seismic Retrofitting Manual for Highways Structures, Parts 1 and 2, 2006.
    - The manual recommends a performance-based methodology for retrofitting highway bridges. It defines different performance expectations for bridges of varying importance while subject to four different levels of seismic hazard. The manual goes on and provides more details for defining minimal, significant, and sustained damages. It is worth noting that the performance levels are varying with level of earthquake ground motion, bridge importance and anticipated service life (ASL). Two ground motion levels (lower level – 100 year return period and upper level – 975 year return period), two importance classifications (Standard and Essential), and three service life categories (ASL l, 2, and 3) are defined.
    - Minimum performance levels for retrofitted bridges:

	Bridge Importance and Service Life Category					
	Standard			Essential		
Earthquake Ground Motion	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level Ground Motion 50 percent probability of exceedance in 75 years; return period is about 100 years.	PL0	PL3	PL3	PL0	PL3	PL3
Upper Level Ground Motion 7 percent probability of exceedance in 75 years; return period is about 1,000 years.	PL0	PL1	PL1	PL0	PL1	PL2

Notes:

1. Anticipated Service Life categories are:
    a. ASL 1: 0-15 years
    b. ASL 2: 16-50 years
    c. ASL 3: greater than 50 years
2. Performance Levels are:
    a. PL0 – No minimum level of performance is recommended.
    b. PL1 – Life safety. Significant damage is sustained during an earthquake and service is significantly disrupted, but life safety is assured. The bridge may need to be replaced after a large earthquake.
    c. PL2 – Operational. Damage sustained is minimal and full service for emergency vehicles should be available after inspection and clearance of debris. Bridge should be reparable with or without restrictions on traffic flow.
    d. PL3 – Fully operational. Damage sustained is negligible and full service is available for all vehicles after inspection and clearance of debris. Any damage is repairable without interruption to traffic.
3. Earthquake ground motion levels
    a. The "lower level" earthquake ground motion is one that has a reasonable likelihood of occurrence within the life of the bridge (assume to be 75 years) (i.e., it represents a relatively small but likely ground motion)
    b. The "upper level" earthquake ground motion has a finite, but remote, probability of occurrence within the life of the bridge; i.e., it represents a large but unlikely ground motion.
4. An "essential" bridge is one that satisfies one or more of the following conditions:
    a. Required to provide secondary life safety (provides access to local emergency services such as hospitals or cross routes that provide secondary life safety.
    b. Loss of the bridge would create a major economic impact
    c. Formally defined by a local emergency plan as critical (enables civil defense, fire departments, and public health agencies to respond immediately to disaster situations)
    d. Serves as a critical link in the security and/or defense roadway network.
    e. A "standard" bridge is everything not "essential"

- State of California Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), Sea-Level Rise Interim Guidance Document, 2010
  - This document provides guidance for incorporating sea-level rise (SLR) projections into planning and decision making for projects in California. Using Year 2000 as a baseline, the Sea-Level Rise Projections in California range between 10 to 17 inches by year 2050 and between 18 to 29 inches by year 2070.
  - Underestimating SLR in the project design will result in harmful realized impacts such as flooding. Harmful impacts are more likely to occur if the project design is based upon a low projection of SLR and less likely if higher estimates of SLR are used. In situations with high consequences (high impacts and/or low adaptive capacity), using a low SLR value involves a higher degree of risk. (examples of harmful impacts that might result from underestimating SLR include damage to infrastructure, contamination of water supplies due to saltwater intrusion, and inundation of marsh restoration projects located too low relative to the tides).
  - As of the date of the guidance document, the State Coastal Conservancy (SCC) and the State Lands Commission (SLC) have adopted, and the Delta Vision Blue Ribbon Task Force Independent Science Board has recommended, the use of 55 inches (140 cm) of SLR for 2100. The SCC and the SLC also adopted a policy of using 16 inches (41 cm) as the estimate of SLR for 2050. Agencies may select other values depending on their particular guiding policies and considerations related to risk, ability to incorporate phased adaptation into design and other factors.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
  - This procedure covers the geotechnical practice for levee evaluation, analysis, design, construction and maintenance of levees in accordance with Sacramento District and USACE guidance and regulation. Sacramento District standard practice may differ from published USACE guidance.
  - Standard Levee Geometry – The minimum levee section should have a 3H:1V waterside slope, a minimum 20 ft. wide crown for main line levees, major tributary levees, and bypass levees, a minimum 12 ft. wide crown for minor tributary levees, a 3H:1V landside slope, a minimum 20 ft. wide landside easement, and a minimum 15 ft. waterside easement. Existing levees with landside slopes as steep as 2H:1V may be used in rehabilitation projects if landside slope performance has been good. Easements are necessary for maintenance, inspection, and floodfight access.
  - Typically a seepage berm should be designed as a semipervious berm with a drainage layer. Seepage berms should have a minimum width of 4 times the maximum levee height in a reach. The maximum seepage berm width should typically be 300 ft. A seepage berm will typically vary from about 5 ft. thick at the levee toe to about 3 ft. thick at the berm toe.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
  - This document provides guidelines or methodology for the design and construction of earth levees.
  - The manual is general in nature and not intended to supplant the judgment of the design engineer on a particular project.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.

  - The manual provides guidance in evaluating and assessing the ground motions, site characterization, structural response, functional consequences, and potential hazards in the design and construction of Civil Work projects including dams and levees.
  - The seismic design for new projects and the seismic evaluation or reevaluation for existing projects should be accomplished in accordance with this regulation. This regulation applies to all projects which have the potential to malfunction or fail during major seismic events and cause hazardous conditions related to loss of human life, appreciable property damage, disruption of lifeline services, or unacceptable environmental consequences. The scope of each seismic study should be aimed at assessing the ground motions, site characterization, structural response, functional consequences, and potential hazards in a consistent, well-integrated, and cost-effective effort that will provide a high degree of confidence in the final conclusions.
  - Survival of operating equipment and utility lines is as essential as survival of the structural and geotechnical features of the project.
- USACE Engineering and Design – Earthquake Design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6053, 2007.
  - This manual provides guidance for performance-based design and evaluation of concrete hydraulic structures (CHS). It introduces procedures that show how to design or evaluate a hydraulic structure to have a predictable performance for specified levels of seismic hazard. Traditional design and evaluation procedures may still be used for feasibility and screening purposes. However, for critical facilities, they should be followed by the procedures of this manual to prevent sudden collapse even though the structure may suffer severe damage, to limit damage to a repairable level, or to maintain functionality immediately after the earthquake.
  - This manual contains mandatory requirements at the end of each chapter. These requirements usually pertain to critical elements of the design and evaluation, such as loads and load combinations, to analytical procedures used to determine force and displacement demands, and to methods used to determine member strength and displacement capacities. The purpose of the mandatory requirements is to assure that the structure meets minimum safety and performance objectives.
  - Performance requirements for stability shall be in accordance with EM 1110-2-2100, *Stability Analysis of Concrete Structures*.
- USACE Engineering and Design—General Design and Construction Considerations for Earth and Rock-Fill Dams, EM 1110-2-2300, 2004.
  - This manual provides guidance on the design and construction, and performance monitoring of and modifications to embankment dams. The manual presents general guidance and is not intended to supplant the creative thinking and judgment of the designer for a particular project.
  - To meet the dam safety requirements, the design, construction, operation, and modification of an embankment dam must comply with the following technical and administrative requirements:
    - Technical requirements

    - The dam, foundation, and abutments must be stable under all static and dynamic loading conditions
    - Seepage through the foundation, abutments, and embankment must be controlled and collected to ensure safe operation. The intent is to prevent excessive uplift pressures, piping of materials, sloughing, removal of material by solution, or erosion of this material into cracks, joints, and cavities. In addition, the project purpose may impose a limitation on allowable quantity of seepage. The design should include seepage control measures such a foundation cutoffs, adequate and nonbrittle impervious zones, transition zones, drainage material and blankets, upstream impervious blankets, adequate core contact area, and relief wells.
    - The freeboard must be sufficient to prevent overtopping by waves and include an allowance for settlement of the foundation and embankment.
    - The spillway and outlet capacity must be sufficient to prevent over-topping of the embankment by the reservoir.
  - Administrative requirements
    - Environmental responsibility
    - Operation and maintenance manual
    - Monitoring and surveillance plan
    - Adequate instrumentation to monitor performance
    - Documentation of all the design, construction, and operational records
    - Emergency Action Plan: Identification, notification, and response subplan
    - Schedule for periodic inspections, comprehensive review, evaluation, and modifications as appropriate.
- The following criteria must be met to ensure satisfactory earth and rock-fill structures:
  - Technical requirements
    - The embankment, foundation, and abutments must be stable under all conditions of construction and reservoir operation including seismic
    - Seepage through the embankment, foundation and abutments must be controlled and collected to prevent excessive uplift pressures, piping, sloughing, removal of material by solution, or erosion of this material into cracks, joints, and cavities. In addition, the project purpose may impose a limitation on allowable quantity of seepage. The design should include seepage control measures such a foundation cutoffs, adequate and nonbrittle impervious zones, transition zones, drainage blankets, upstream impervious blankets, and relief wells.
    - The freeboard must be sufficient to prevent overtopping by waves and include an allowance for settlement of the foundation and embankment as well as for seismic effects where applicable.
    - The spillway and outlet capacity must be sufficient to prevent over-topping of the embankment.

- USACE Engineering and Design—Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
    - This manual describes the development and use of response spectra for the seismic analysis of concrete hydraulic structures. The manual provides guidance regarding how earthquake ground motions are characterized as design response spectra and how they are then used in the process of seismic structural analysis and design. The manual is intended to be an introduction to the seismic analysis of concrete hydraulic structures.
    - The design and evaluation of hydraulic structures for earthquake loading must be based on appropriate criteria that reflect both the desired level of safety and the nature of the design and evaluation procedures (ER 1110-2-1806). The first requirement is to establish earthquake ground motions to be used as the seismic input by considering safety, economics, and the designated operational functions. The second involves evaluating the earthquake performance of the structure to this input by performing a linear elastic dynamic analysis based on a realistic idealization of the structure, foundation, and water.
        - For an operating basis earthquake (OBE) that can reasonably be expected to occur within the service life of the project (that is, with a 50 percent probability of exceedance during the service life), structures located in regions of high seismicity should essentially respond elastically to the event with no disruption to services, but limited localized damage is permissible and should be repairable. In such cases, a low to moderate level of damage can be expected.
        - For a maximum design earthquake (MDE) which is a maximum level of ground motion for which a structure is designed or evaluated, the associated performance requirement is the that the project performs without catastrophic failure, such as uncontrolled release of a reservoir, although severe damage or economic loss may be tolerated. The damage during an MDE event could be substantial, but should not be catastrophic in terms of loss of life, economics, and social and environmental impacts.
        - For critical structures (structures of high downstream hazard whose failure during or immediately following an earthquake could result in loss of life), the MDE is set equal to the MCE (the greatest earthquake that can reasonably be expected to be generated by a specific source on the basis of seismological and geological evidence). For other than critical structures, the MDE is selected as a lesser earthquake than the MCE.
- USACE Engineering and Design—Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005.
    - This manual establishes and standardizes stability criteria for use in the design and evaluation of the many various types of concrete structures common to Corps of Engineers civil works projects. As used in this manual, the term "stability" applies to external global stability (sliding, rotation, flotation and bearing), not to internal stability failures such as sliding on lift surfaces or exceedance of allowable material strengths. The manual prescribes the safety factors, which govern stability requirements for the structure for various load combinations.
- USACE Engineering and Design—Structural Design and Evaluation of Outlet Works, EM 1110-2-2400, 2003.
    - This manual provides guidance for the planning and structural design and analysis of intake structures and other outlet works features used on US Army Corps of Engineers projects for the

purpose of flood control, water supply, water quality and temperature control, recreation, or hydropower.

- The following are minimum required safety factors for seismic sliding analysis:
  - OBE = 1.7 for critical structures, and 1.3 for other structures
  - MDE = 1.3 for critical structures, and 1.1 for other structures
- The associated performance level with the OBE is the requirement that the structure will function within the elastic range with little or no damage and without interruption of function.
- The MDE is the maximum level of ground motion for which the structure is designed or evaluated. The tower may be damaged but retains its integrity. The purpose of the MDE is to protect against economic losses from damage or loss of services. Ordinarily the MDE is defined for intake towers as a ground motion having a 10 percent probability of exceedance during the service life of 100 years.

- USACE Engineering and Design—Structural Design and Evaluation of Outlet Works, EM 1110-2-2400, 2003.
  - This manual provides guidance for the planning and structural design and analysis of intake structures and other outlet works features used on the U.S. Army Corps of Engineers projects for the purpose of flood control, water supply, water quality and temperature control, recreation, or hydropower.
  - Seismic design for new towers and the evaluation of existing towers must demonstrate that the tower has adequate strength, ductility, and stability to resist the specified earthquake ground motions. The ultimate strength or capacity of new and existing towers will be determined using the principles and procedures described in EM 1110-2-2104. Capacities are based on ultimate strength, or the nominal strength multiplied by a capacity reduction factor. Intake tower sections shall have the strength to resist load combinations involving dead load, live load, and earthquake load.
- USACE Engineering and Design—Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
  - This manual describes the procedures for the linear-elastic time-history dynamic analysis and development of acceleration time-histories for seismic design and evaluation of concrete hydraulic structures. It provides guidance on the formulation and performance of the linear-elastic time-history dynamic analyses and how the earthquake input time-histories are developed and applied.
  - Design and safety evaluation earthquakes for concrete hydraulic structures are the OBE and the MDE as required by ER 1110-2-1806.
    - The OBE is defined in ER 1110-2-1806 as an earthquake that can reasonably be expected to occur within the service life of the project, that is, with a 50 percent probability of exceedance during the service life. The associated performance requirement is that the project function with little or no damage, and without interruption of function. The purpose of the OBE is to protect against economic losses from damage or loss of service.
    - The MDE is defined in ER 1110-2-1806 as the maximum level of ground motion for which a structure is designed or evaluated. The associated performance requirement is that the

project performs without catastrophic failure, such as uncontrolled release of a reservoir, although severe damage or economic loss may be tolerated.

- For critical structures, ER 1110-2-1806 requires the MDE to be set equal to the MCE. Critical structures are defined as structures whose failure during or immediately following an earthquake could result in loss of life. The MCE is defined as the greatest earthquake that can reasonably be expected to be generated by a specific source on the basis of seismological and geological evidence (ER 1110-2-1806)
- For other than critical structures the MDE is selected as a less severe earthquake than the MCE, which provides for an economical design meeting specified safety standards. In these cases, the MDE is defined as that level of ground motion having as a minimum a 10 percent probability in exceedance in 100 years.

- USACE Slope Stability, EM 1110-2-1902, 2003.
  - This engineer manual (EM) provides guidance for analyzing the static stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock. Methods for analysis of slope stability are described and are illustrated by examples in the appendixes. Criteria are presented for strength tests, analysis conditions, and factors of safety. The criteria in this EM are to be used with methods of stability analysis that satisfy all conditions of equilibrium. Methods that do not satisfy all conditions of equilibrium may involve significant inaccuracies and should be used only under the restricted conditions described herein. This manual is intended to guide design and construction engineers, rather than to specify rigid procedures to be followed in connection with a particular project.
  - Minimum Required Factors of Safety: New Earth and Rock-Fill Dams

Analysis Condition	Required Minimum Factor of Safety	Slope
End-of-Construction (including staged construction)	1.3	Upstream and Downstream
Long-term (steady seepage, maximum storage pool, spillway crest or top of gates)	1.5	Downstream
Maximum surcharge pool	1.4	Downstream
Rapid drawdown	1.1–1.3	Upstream

- USACE Engineering and Design—Settlement Analysis, EM 1110-1-1904, 1990.
  - This manual presents guidelines for calculation of vertical displacements and settlement of soil under shallow foundations (mats and footings) supporting various types of structures and under embankments.
- USACE Engineering and Design—Design of Pile Foundations, EM 1110-2-2906, 1991
  - This manual provides information, foundation exploration and testing procedures, load test methods, analysis techniques, design criteria and procedures, and construction considerations for the selection, design, and installation of pile foundations. The guidance is based on the present state of technology for pile-soil-structure-foundation interaction behavior. This manual provides design guidance intended specifically for geotechnical and structural engineers and essential information for others interested in understanding construction techniques related to

pile behavior during installation. The understanding of pile foundation behavior is actively expanding by ongoing research, prototype, model pile, and pile group testing and development of more refined analytical models. However, this manual is intended to provide examples and procedures of proven technology. This manual will be updated as changes in design and installation procedures are developed.

- The pile foundation must perform as designed for the life of the structure. Performance can be described in terms of structural displacements which may be just as harmful to a structure as an actual pile failure. The load capacity should not degrade over time due to deterioration of the pile material.
- For most hydraulic structures, designers should have a high level of confidence in the soil and pile parameters and the analysis. Therefore, uncertainty in the analysis and design parameters should be minimized rather than requiring a high factor of safety. For less significant structures, it is permissible to use larger factors of safety if it is not economical to reduce the uncertainty in the analysis and design by performing additional studies, testing, etc. Also factors of safety must be selected to assure satisfactory performance for service conditions. Failure of critical components to perform as expected can be as detrimental as an actual collapse.
- It is normal to apply safety factors to the ultimate load predicted. In general, safety factors for hydraulic structures are as follows:

		Minimum Factor of Safety	
Method of Determining Capacity	Loading Condition	Compression	Tension
Theoretical or empirical prediction to be verified by pile load test	Usual[1]	2.0	2.0
	Unusual[2]	1.5	1.5
	Extreme[3]	1.15	1.15
Theoretical or empirical prediction to be verified by pile driving analyzer	Usual[1]	2.5	3.0
	Unusual[2]	1.9	2.25
	Extreme[3]	1.4	1.7
Theoretical or empirical prediction not verified by load test	Usual[1]	3.0	3.0
	Unusual[2]	2.25	2.25
	Extreme[3]	1.7	1.7

[1] Usual loads refer to conditions which are related to the primary function of a structure and can be reasonably expected to occur during the economic service life. The loading effects may be of either a long term, constant or an intermittent, repetitive nature. Pile allowable loads and stresses should include a conservative safety factor for such conditions.

[2] Unusual loads refer to construction, operation or maintenance conditions which are of relatively short duration or infrequent occurrence. Risks associated with injuries or property losses can be reliably controlled by specifying the sequence or duration of activities, and/or by monitoring performance. Only minor cosmetic damage to the structure may occur during these conditions.

[3] Extreme loads refer to events which are highly improbable and can be regarded as emergency conditions. Such events may be associated with major accidents involving impacts or explosions and natural disasters due to earthquakes or hurricanes which have a frequency of occurrence that greatly exceeds the economic service life of the structure. The basic design concept for normal loading conditions should be efficiently adapted to accommodate extreme loading effects without experiencing a catastrophic failure. Extreme loadings may cause significant structural damage which partially impairs the operational functions and requires major rehabilitation or replacement of the structure.

- U.S. Department of the Interior and USGS Climate Change and Water Resources Management: A Federal Perspective, Circular 1331.
  - The purpose of this interagency report is to explore strategies to improve water management by tracking, anticipating, and responding to climate change. This report describes the existing and still needed underpinning science crucial to addressing the many impacts of climate change on water resources management. With sea level rising, data obtain in this report will be used in the planning and design of future hydraulic facilities and levees.
  - Advocates for the National Research Council (2004) recommendation of adopting an adaptive management framework that involves post-construction evaluations being standard for the adaptive management of projects and systems as well as ensuring that operating plans build in flexibility to adapt to potential climate conditions.

9.3 Environmental Consequences

This section describes the potential effects that could result from project construction, operation and maintenance, and restoration due to geologic and seismic-related conditions and hazards. The types of effects that are evaluated include the following.

- Exposure of people or structures to potential substantial adverse effects, including the risk of loss of property, personal injury, or death, involving the below.
  - Rupture of a known earthquake fault, as delineated on the most recent AP Earthquake Fault Zoning Map issued by the state geologist for the area or based on other substantial evidence of a known fault.
  - Strong seismic ground shaking.
  - Liquefaction.
  - Seismic-related ground failure.
  - Slope instability.
  - Soft, loose, and compressible soils.
  - Seiche, tsunami, or mudflow.
- Location relative to geologic units or soils that are unstable or that would become unstable as a result of the project and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction, or collapse.

Geologic and seismic effects on structures and construction activities associated with the BDCP would be restricted to the Plan Area, but the Plan Area could be affected by seismic conditions well outside the Plan Area. Because all conveyance and restoration activities related to the project would occur within the Plan Area, geologic and seismic conditions Upstream of the Delta and within the SWP and CVP Export Service Areas would not be affected by construction, operation, maintenance, or restoration activities. Therefore, this section does not evaluate effects in those geographic areas.

Potential adverse effects associated with near-surface soils, including erosion; subsidence caused by oxidation of organic matter; and expansive, corrosive, and compressible soils, are assessed in Chapter 10, *Soils*. Further discussion of levee stability and flooding is provided in Chapter 6, *Surface Water*.

Potential effects of irrigation-induced salt loading to soils are addressed in Chapter 8, *Water Quality,* and Chapter 14, *Agricultural Resources*. Potential effects on mineral resources are fully discussed in Chapter 26, *Mineral Resources*.

9.3.1 Methods for Analysis

This section describes the methods used to evaluate the potential for geologic and seismic hazards to affect the constructed and operational elements of the alternatives and the potential for the elements of the alternatives to increase human health risk and loss of property or other associated risks. Some of these effects would be temporary, associated with construction activities within the geographic footprint of disturbance of new facilities in the Plan Area. Other effects would be more regional in nature, associated with the presence of new structures and water operations throughout the Plan Area. Lands outside of the Plan Area are not being considered because there are no structures being proposed and because changed operations upstream and within the water user service areas do not increase geologic or seismic hazards in those areas. Both quantitative and qualitative methods were used to evaluate these effects, depending on the availability of data. Conservation and restoration activities were evaluated on a programmatic level using qualitative methods to estimate potential effects.

The impact analysis for geology and seismicity was performed primarily using information on soils and stratigraphy, area topography, subsurface conditions, and potential earthquake hazards developed for the BDCP CERs and Geotechnical Data Reports, as listed below.

- *Conceptual Engineering Report—Isolated Conveyance Facility—All Tunnel Option* (California Department of Water Resources 2010a).
- *Conceptual Engineering Report—Isolated Conveyance Facility—Pipeline/Tunnel Option—Addendum* (California Department of Water Resources 2010b).
- *Conceptual Engineering Report—Isolated Conveyance Facility—East Option* (California Department of Water Resources 2009a).
- *Conceptual Engineering Report—Isolated Conveyance Facility—East Option—Addendum* (California Department of Water Resources 2010c).
- *Conceptual Engineering Report—Isolated Conveyance Facility—West Option* (California Department of Water Resources 2009b).
- *Conceptual Engineering Report—Isolated Conveyance Facility—West Option—Addendum* (California Department of Water Resources 2010d).
- *Option Description Report—Separate Corridors Option* (California Department of Water Resources 2010e).
- *Draft Phase II Geotechnical Investigation—Geotechnical Data Report—Pipeline/Tunnel Option* (California Department of Water Resources 2011).
- *Draft Phase I Geotechnical Investigation—Geotechnical Data Report—Isolated Conveyance Facility West* (California Department of Water Resources 2010g).
- *Draft Phase I Geotechnical Investigation—Geotechnical Data Report—Isolated Conveyance Facility East* (California Department of Water Resources 2010h).

Other study results and applicable maps and information published by various regulatory agencies, researchers and consultants were also used (e.g., California Department of Water Resources 1992; CALFED Bay-Delta Program 2000; California Department of Water Resources and California Department of Fish and Wildlife 2008, Shlemon and Begg 1975; Fugro Consultants 2011). The emphasis in the impact analysis has been to identify where the existing data suggest that geologic or seismic conditions pose a potentially serious threat to structural integrity. The analysis determines whether these conditions and associated risk can be reduced to less than significant by conformance with existing codes, standards and the application of accepted, proven construction engineering practices. A range of specific design and construction approaches are normally available to address a specific circumstance. For example, the potential for liquefaction to affect structural integrity could be controlled using a range of engineering approaches, such as by removal and replacement of the liquefiable soil with engineered fill and construction of the structure on pilings founded on non-liquefiable material. Specific control measures have not been developed for all site conditions at this point in the BDCP planning process. Regardless of the control method used, the same stability criteria must be met to conform with code and standards requirements. Design solutions would be guided by relevant building codes and state and federal standards for constructing foundations, bridges, tunnels, earthworks, and all other project facilities, listed in Section 9.2.2.4, *Regulatory Design Codes and Standards for Project Structures*. This evaluation process is described in more detail below in Section 9.3.1.1. Methodologies for evaluating specific geologic and seismic hazards are further defined in Section 9.3.1.3 below.

Indirect environmental effects related to levee failure and breaches that could result in flooding are described in Chapter 6, *Surface Water*. Other resources that may be affected by the geologic and seismic conditions of the Plan Area are addressed in Chapter 7, *Groundwater*, and Chapter 10, *Soils*. Potential effects on mineral resources are discussed in Chapter 26, *Mineral Resources*.

9.3.1.1 Process and Methods of Review for Geologic and Seismic Hazards

This section describes the sequence of planning, evaluation, review and design activities that identify geologic and seismic hazards and establish approaches to avoiding or minimizing those hazards. This is the process being implemented to avoid significant hazards to structures and human health associated with the BDCP. The description of the process and methods is intended to make it clear how site-specific hazard conditions are identified and fully addressed through data collection, analysis and conformance with existing design and construction requirements.

As the BDCP and its various conservation measures have been developed by DWR in anticipation of agency and public review through the CEQA/NEPA processes, the agency has developed geologic and geotechnical information for all of the conveyance alignment alternatives. This information has been developed under the supervision of professional engineers and documented in the geotechnical data reports prepared by DWR for the project. As is appropriate for a project of this scale, these documents show project and alternative feasibility by identifying site geotechnical conditions along with associated constraints and opportunities. The geology and seismicity analyses in this chapter include review of the geotechnical data reports and other existing reports and data to determine whether significant risks might occur from implementing the BDCP.

Seismic and geologic hazards are determined to be adverse under NEPA or significant under CEQA if their related effects pose a substantial risk of damage to structures or pose a substantial human health threat. The criteria used to evaluate significance do not require the elimination of the potential for structural damage from the site's geologic and seismic conditions. Rather, the criteria require evaluation of whether site conditions can be overcome through engineering design solutions that reduce the substantial risk to people and structures. The codes and design standards referred to above ensure that buildings and structures are designed and constructed so that, while they may sustain damage during a major earthquake, the substantial risk of loss of property, personal injury or death due to structure failure or collapse is reduced. The CEQA/NEPA evaluation considers whether conformance with existing codes and standards, and application of accepted, proven construction engineering practices, would reduce the substantial risk to people and structures.

Configuration of the proposed BDCP alternatives will be determined when the CEQA/NEPA review is completed. Development of final-level design and inclusion of more detailed information would not be likely to substantially modify any CEQA/NEPA conclusions. After CEQA/NEPA document certification, the final design of structures will be developed; this will require additional subsurface geotechnical investigation to identify very localized conditions that must be reflected in the final engineering design. These geotechnical investigations will characterize, log, and test soils and bedrock at selected construction sites to further refine anticipated site responses to seismic activity and the various loads created by structures. They will also refine the design parameters that must be met. The geotechnical investigation and its recommendations will be presented in a report that is reviewed and approved by a California-registered civil engineer or a certified engineering geologist who is competent in the field of seismic hazard evaluation and mitigation. The requirements for evaluating seismic hazards other than surface fault rupture and for recommending mitigation measures that the California-registered civil engineer or certified engineering geologist or geologist must follow are specified in *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). For the BDCP, the proponents have made an environmental commitment that final design of all constructed components will meet the standards listed in Section 9.2.2.4, *Regulatory Design Codes and Standards for Project Structures* and contained in Appendix 3B, *Environmental Commitments*. The constructed components may include canals, tunnels, intake structures, pipelines, transmission lines, levees, temporary and permanent access roads, bridges, borrow areas, and spoils storage sites.

Based on the final geotechnical report and code and standards requirements, the final design of structures will be developed by the aforementioned California-registered civil engineer or California-certified engineering geologist with participation and review by the BDCP proponents, and in some cases county building departments, to ensure that design standards are met. The design and construction specifications will then be incorporated into a construction contract for implementation and required to be implemented. During project construction, new or unexpected conditions may be found that are different than shown in the detailed, site-specific geotechnical report that guides the final design. Under these circumstances, the new condition will be evaluated and an appropriate method to meet the design specification will be determined by the project's California-registered civil engineer or California-certified engineering geologist and approved by the BDCP proponents. Although new or unexpected conditions may be found, the design standards will not change.

9.3.1.2 Evaluation of Construction Activities

Construction activities for the water conveyance facilities as they are currently defined, were evaluated on a project level for potential effects relating to existing geologic hazards and to conform with federal and state regulations and guidance pertaining to geologic hazard mitigation. Construction activities in the ROAs were evaluated on a programmatic level for potential effects relating to existing geologic hazards. These effects will need to be discussed in greater detail in subsequent project-level environmental documentation after specific restoration activities are finalized.

Geologic and seismic analysis of construction-related effects included these methodologies and approaches.

- **Review of conveyance alternatives and construction methods and sequences**. The available design drawings, reports, and memoranda were reviewed, including construction methods, borrow areas, and dewatering systems.
- **Review of available site topography and conditions and soil and groundwater data**. The available data within the Plan Area, as presented in the CERs and the Geotechnical Data Reports (see list at the beginning of Section 9.3.1), were compiled and reviewed. Available soil boring logs, subsurface cross sections, soil stratigraphy, and groundwater data from the CER were used. Geology and soil maps (from the U.S. Geological Survey and Natural Resources Conservation Service) for the Plan Area were also used, with particular focus on areas where soft, loose, and compressible soils are present.
- **Evaluation of potential effects caused by geologic conditions**. Potential effects of construction activities from geologic hazards and the potential for increased risk were evaluated. Engineering design criteria were reviewed and assessed to evaluate how substantial effects were addressed.

9.3.1.2.1 Surface Fault Rupture

Two types of surface fault rupture were addressed: sudden rupture and offset during an earthquake event, and slow offset caused by long-term fault creep in the absence of an earthquake. The potential for near-surface ground disturbance was assessed for blind thrust faults because they are not expected to rupture to the ground surface as a result of fault creep or sudden offset.

The methodology for assessing surface fault rupture was based primarily on the available AP Fault Zone Maps. Additional information provided in the CERs and the available published information on fault rupture risks were also used. Areas within the footprints of each alternative located within the AP fault zones or having the potential of experiencing ground ruptures during future earthquakes were identified. For each area having fault rupture potential, the median (50th percentile) and 84th percentile fault offsets during earthquakes were determined using published empirical relationships. The long-term offset attributable to fault creep was also estimated using fault slip rate and time frame considered.

9.3.1.2.2 Earthquake Ground Shaking

For engineering design purposes, ground shaking is commonly quantified by a response spectrum, which is a plot of peak responses (acceleration, velocity, or displacement) of a single-degree-of-freedom oscillator of varying natural frequency or period. Peak acceleration response at a period of zero seconds or PGA is also widely used to characterize the level of ground motion. Earthquake ground shaking is influenced by local site topography and soil conditions. Thick deposits of soft soils (such as peaty mud) tend to amplify long-period motions, such as the response at a period of 1.0 second.

The potential exposure to ground shaking during future earthquakes and the effects to facilities within all Build Alternative footprints was evaluated using the results of the CERs. Specifically, the effects of ground motions predicted for various probabilities of exceedance during the design life of the project were addressed. Seismic study results were interpolated and extrapolated to estimate ground shaking for time periods not presented in the CERs; no new seismic ground motion calculations were performed. Comparisons to previous studies were also made to validate the ground motion estimates.

9.3.1.2.3 Liquefaction

Liquefaction hazard was assessed using the available soil data from the CERs. The assessment was performed primarily through correlations with basic soil characteristics (soil type, water content, depositional environment, and age). For areas where adequate soil engineering data were not available, additional analyses were performed, including assessments based on SPT sampler penetration blow-counts (SPT blow-counts), Cone Penetration Test (CPT) measurements, and shear-wave velocity of the soil. The liquefaction analysis (for areas where adequate soil engineering data were available) was performed for earthquake ground motions with return periods of 475 years and 975 years, corresponding to 10% and 5% probabilities of being exceeded in 50 years, respectively. The controlling earthquake magnitudes were determined from the results of the seismic study (California Department of Water Resources 2007a) and/or the U.S. Geological Survey National Seismic Hazard Mapping Program.

9.3.1.2.4 Ground Failure and Seismic-Induced Soil Instability

Compaction and Settlement

Seismic-induced ground compaction and settlements are caused by the rearrangement of soil particles during an earthquake. Soil experiencing liquefaction tends to produce an increased amount of compaction and settlement. Excessive ground compaction may lead to large differential and/or total settlement and cause damage to facilities, lifelines, and other utilities.

A study of the characteristics of the soil found along the footprint of the proposed project was performed to give a qualitative assessment as to the potential for seismic-induced soil compaction and settlement.

Loss of Bearing Capacity

Loss of soil bearing capacity results mainly from significant reduction in soil effective stresses during an earthquake. In the case of liquefaction, soil effective stresses drop to almost zero, and soil strength reaches its residual value (soil residual strength). When soil strength is not sufficient to maintain stability, large deformation occurs, leading to foundation failure and excessive soil settlements and lateral movements.

A study of the type of the soil found along the footprint of the proposed project was performed to give a qualitative assessment as to the potential for substantial loss of bearing capacity during earthquakes.

Lateral Spreading

Lateral spreading typically occurs when the soil underlying an earth slope or near a free face liquefies during an earthquake. It can occur on gently sloping ground and extend large distances from the slope's open face.

A study of the characteristics of the soil/sediment and site topography found along the footprint of the proposed project was performed to give a qualitative assessment as to the potential for soil lateral movement.

Increased Lateral Soil Pressure

When soil liquefies, it behaves as a heavy liquid and may induce increased soil lateral pressure to walls or buried pipes and tunnels. The increased soil lateral pressure was estimated using liquefied soil unit weight, which is roughly twice the unit weight of water. Even when a soil does not liquefy during a seismic event, lateral earth pressures will increase mainly because of inertia earthquake forces.

Buoyancy

As soil liquefies, it causes an increase in buoyancy pressure on buried structures or parts of facilities below the ground, similar to increased soil lateral pressure. The buoyancy forces were estimated using liquefied soil unit weight.

9.3.1.2.5 Slope Instability

Slope instability (e.g., landslides, soil creep, and debris flow) can occur as a result of gravity loads or in combination with earthquake loads. Analysis focused on areas where past instability had occurred or where water saturates slope materials to estimate the potential for slope instability. In areas where facilities may be built, new cut-and-fill slopes were identified and evaluated for stability.

A qualitative slope stability evaluation was performed based on slope inclination, soil type, and groundwater conditions. For areas where adequate soil and site data were available, slope stability was evaluated using a two-dimensional slope model and the limit-equilibrium method. Impact assessments for the existing levees are described in Chapter 6, *Surface Water*.

9.3.1.2.6 Soft, Loose, and Compressible Soils

The team used both geographic information system (GIS) data and available geology and soil maps to identify areas with soft, loose, and compressible soil within the footprints of each of the alternatives. The thicknesses of these soils were estimated using available geotechnical exploration data.

9.3.1.2.7 Seismic-Induced Seiche and Tsunami

The basis for determining the hazard for seismically induced seiche and tsunami is discussed Section 9.1.1.3.

9.3.1.3 Evaluation of Operations

The potential for operation of the proposed facilities to directly or indirectly affect geologic hazards or increase risks associated with geologic hazards was evaluated. The potential for adverse effects caused by operation of the conveyance facilities was identified, and maintenance plans to address the effects were evaluated.

Analysis methodologies and approaches for operation-related effects include review of the facilities and their operations and evaluation of effects (including erosion, soil/slope instability, groundwater fluctuation, and facility failures) caused by operation.

9.3.2 Determination of Effects

The effects of the BDCP alternatives on geologic and seismic risks may result from both construction and operation of project features. This effects analysis assumes that an action alternative would result in an adverse effect (under NEPA) or a significant impact (under CEQA) if it exposes people or structures to a substantially greater potential for loss of property, personal injury or death from the following effects.

- Earthquake fault rupture.
- Strong seismic ground shaking.
- Liquefaction.
- Seismic-related ground failure.
- Slope instability (landslides).
- Soft, loose and compressible soils.
- Seiche, tsunami, or mudflow.

For the purposes of this analysis, "substantially greater potential for loss, injury or death" is defined as any circumstance in which construction or operational activities have an increased likelihood of resulting in direct property loss, personal injury or death of individuals. Potential effects caused by subsidence, expansive and corrosive soils, and other such hazards are described in Chapter 10, *Soils*. Potential flooding effects are described in Chapter 6, *Surface Water*.

9.3.2.1 Compatibility with Plans and Policies

Constructing the proposed water conveyance facility (CM1) and implementing CM2–CM22 could potentially result in incompatibilities with plans and policies related to geologic/seismic hazards. Section 9.2, *Regulatory Setting*, provides an overview of federal, state, regional and agency-specific plans and policies applicable to seismic safety and levee stability. This section summarizes ways in which BDCP is compatible or incompatible with those plans and policies. Potential incompatibilities with local plans or policies do not necessarily translate into adverse environmental effects under NEPA or CEQA. Even where an incompatibility "on paper" exists, it does not by itself constitute an adverse physical effect on the environment, but rather may indicate the potential for a proposed activity to have a physical effect on the environment. The relationship between plans, policies, and regulations and impacts on the physical environment is discussed in Chapter 13, *Land Use*, Section 13.2.3.

Government Code Section 65302(g)(1) requires a seismic safety and safety element in all city and county general plans. The effect of this section is to require cities and counties to take seismic and safety hazards into account in their planning programs. The basic objective is to reduce loss of life, injuries, damage to property, and economic and social dislocations resulting from future earthquakes or other natural disasters. Generally, these local plans require mitigation of potential impacts of geologic hazards through development and building review, maintaining compatible land uses and appropriate construction techniques. Additionally, development projects are to conform with state seismic and building standards in the design and siting of critical facilities. Implementing a selected BDCP alternative could require construction of structures on or near blind faults. However, as discussed below under Impacts GEO-1 through GEO-16, construction and operation of the BDCP alternatives are not expected to create any additional seismic or geologic risk to lives or property. The BDCP proponents would implement an environmental commitment to conform with relevant state codes and standards to avoid creating any additional impacts from geologic/seismic hazards. Additionally, prior to construction, a California-registered civil engineer or California-certified engineering geologist would conduct site-specific evaluation for potential hazards and recommend measures in a geotechnical report to address hazards such as ground settlement or collapse from dewatering and potential liquefaction. These environmental commitments ensure the BDCP is compatible with the mission and goals of relevant general plans.

The Delta Plan, discussed generally in Section 9.2.2.1, has adopted policy RR P1, *Prioritization of Statement Investments in Delta Levees and Risk Reduction*. This policy covers any proposed action that involves discretionary State investments in Delta flood risk management, including levee operations, maintenance, and improvements, such as BDCP. The Delta Stewardship Council, in consultation with DWR, the Central Valley Flood Protection Board, and the California Water Commission, developed priorities for interim funding that include emergency preparedness, response, and recovery, as well as Delta levees funding. This policy prioritizes localized flood protection for existing urban areas by providing 200-year flood protection; protecting water quality and water supply conveyance in the Delta, especially levees that protect freshwater aqueducts and the primary channels that carry fresh water through the Delta; and protecting existing and providing for a net increase in channel-margin habitat. All of the levee alterations required by the BDCP alternatives meet this description. Therefore, the BDCP alternatives are compatible with the Delta Plan policies relevant to this resource area.

9.3.3 Effects and Mitigation Approaches

9.3.3.1 No Action Alternative

The No Action Alternative is the future condition at 2060 that would occur if none of the action alternatives were approved and if no change from current management direction or the level of management intensity of existing programs by federal, state, and local agencies occurred. The No Action Alternative considers changes in risk from geology and seismicity that would take place as a result of the continuation of existing plans, policies, and operations, as described in Chapter 3, *Description of Alternatives*. The No Action Alternative includes projects and programs with defined management or operational plans, including facilities under construction as of February 13, 2009, because those actions would be consistent with the continuation of existing management direction or level of management for plans, policies, and operations by the BDCP proponents and other agencies. The No Action Alternative assumptions also include projects and programs that are permitted or are assumed to be constructed by 2060. The No Action Alternative would result in the following effects on geology and seismicity.

9.3.3.1.1 Earthquake-Induced Ground Shaking, Liquefaction, and Slope Instability

Under the No Action Alternative, it is anticipated that the current hazard resulting from earthquake-induced ground shaking from regional and local faults would persist. This would continue to present a risk of levee failure and subsequent flooding of Delta islands, with a concomitant influx of seawater into the Delta, thereby adversely affecting water quality and water supply. The effects of flooding of Delta islands and consequently on water quality and supply are described in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies* and Chapter 6, *Surface Water*.

It is also anticipated that the current hazard of earthquake-induced liquefaction triggered by regional and local faults would persist. Liquefaction would continue to present a risk of levee failure and subsequent flooding of Delta islands, with concomitant water quality and water supply effects from seawater intrusion as described in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*.

The current hazard of earthquake-induced slope instability (e.g., levee failure) triggered by regional and local faults would continue under the No Action Alternative. Slope instability associated with non-engineered levees would continue to present a risk of levee failure and subsequent flooding of Delta islands. Ongoing and reasonably foreseeable future projects in parts of the Delta are expected to upgrade the levees to a "flood-safe" condition under the 100-year return flood elevation. However, these projects would provide very little levee foundation strengthening and improvements directed at improving the stability of the levees to better withstand ground shaking, liquefaction, and slope instability.

9.3.3.1.2 Tsunami and Seiche

Under the No Action Alternative, it is anticipated that the current hazard resulting from tsunami and seismically induced seiche on Delta and Suisun Marsh levees would continue. As reported above, the hazard of a substantial tsunami affecting the Delta and the Suisun Marsh appears to be minor because of their distance from the Pacific Ocean and the attenuating effect of San Francisco and Suisun bays. With respect to the hazard of a seiche, the existing water bodies in the Delta and Suisun Marsh tend to be wide and shallow. This geometry and distance to seismic sources generally are not conducive to the occurrence of a substantial seismically induced seiche, as described in Section 9.1.1.3. However, because of its proximity to the potentially active West Tracy fault, there is a potential hazard for a seiche to occur in the Clifton Court Forebay (Fugro Consultants 2011).

9.3.3.1.3 Ongoing Plans, Policies, and Programs

The programs, plans, and projects included under the No Action Alternative are summarized in Table 9-13, along with their anticipated effects on geology and seismicity. Although not specifically directed at mitigating potential damage to levees caused by a tsunami and seiche, the ongoing and reasonably foreseeable future projects directed to upgrade levees to a "flood-safe" condition under the 100-year return flood elevation or projects involving other similar levee improvements identified in Table 9-13 below may provide some benefit to withstanding the potential effect of a tsunami and seiche.

In total, the plans and programs would result in a beneficial effect on an undetermined extent of levees in the Delta. Under the No Action alternative, these plans, policies, and programs would be deemed to have an indirect and beneficial effect upon the potential hazard of tsunami and seiche in the Delta due to improvements in levee infrastructure as a part of implementation of these projects or programs.

9.3.3.1.4 Climate Change and Catastrophic Seismic Risks

The Delta and vicinity is within a highly active seismic area, with a generally high potential for major future earthquake events along nearby and/or regional faults, and with the probability for such events increasing over time. Based on the location, extent and non-engineered nature of many existing levee structures in the Delta area, the potential for significant damage to, or failure of, these structures during a major local seismic event is generally moderate to high. In the instance of a large seismic event, levees constructed on liquefiable foundations are expected to experience large deformations (in excess of 10 feet) under a moderate to large earthquake in the region. There would potentially be loss, injury or death resulting from ground rupture, ground shaking and liquefaction, (See Appendix 3E, *Potential Seismic and Climate Change Risks to SWP/CVP Water Supplies* for more detailed discussion).

***CEQA Conclusion*:** In total, the plans and programs would result in a beneficial effect on an undetermined extent of levees in the Delta. Under the No Action alternative, these plans, policies, and programs would be deemed to have an indirect and beneficial effect upon the potential hazard of tsunami and seiche in the Delta. These plans and programs, however, would not decrease the risks associated with climate change or a catastrophic seismic event, as discussed above and more thoroughly in Appendix 3E, *Seismic and Climate Change Risks to SWP/CVP Water Supplies.*

Table 9-13. Effects on Geology and Seismicity from the Plans, Policies, and Programs for the No Action Alternative

Agency	Program/Project	Status	Description of Program/Project	Effects on Geology and Seismicity
USACE	Delta Dredged Sediment Long-Term Management Strategy	Ongoing	Maintaining and improving channel function, levee rehabilitation, and ecosystem restoration.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
DWR	In-Delta Storage Project	Planning phase	Strengthening of existing levees and construction of embankments inside levees.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
West Sacramento Area Flood Control Agency and USACE	West Sacramento Levee Improvements Program	Planning phase	Improvements to levees protecting West Sacramento to meet local and federal flood protection criteria.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
DWR	Levee Repair-Levee Evaluation Program	Ongoing	Repair of state and federal project levees.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
DWR	Delta Levees Flood Protection Program	Ongoing	Levee rehabilitation projects in the Delta.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
DWR, DFW, USACE	CALFED Levee System Integrity Program	Planning phase	Levee maintenance and improvement in the Delta.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
DWR	Central Valley Flood Management Planning Program	Planning phase	Among other management actions, involves levee raising and construction of new levees for flood control purposes.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
SAFCA, Central Valley Flood Protection Board, USACE	Flood Management Program	Ongoing	South Sacramento Streams Project component consists of levee, floodwall, and channel improvements.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.
NMFS/USFWS	2008 and 2009 Biological Opinion	Ongoing	The Biological Opinions issued by NMFS and USFWS establish certain RPAs and RPMs to be implemented. Some of the RPAs require habitat restoration which may require changes to existing levees and channel improvements.	No direct effect on eliminating risks from earthquakes, groundshaking, liquefaction and slope instability. Indirect effect of improving resistance to tsunami and seiche.

9.3.3.2 Alternative 1A—Dual Conveyance with Pipeline/Tunnel and Intakes 1–5 (15,000 cfs; Operational Scenario A)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

Earthquakes could be generated from local and regional seismic sources during construction of the Alternative 1A water conveyance facilities. Seismically induced ground shaking could cause collapse of facilities at the construction sites.

The potential for experiencing earthquake ground shaking during construction in 2020 (during the project's near-term implementation stage) was estimated using the results of the seismic study (California Department of Water Resources 2007a). The seismic study also computed seismic ground shaking hazards at six locations in the Delta for 2005, 2050, 2100, and 2200. The results of these analyses show that the ground shakings in the Delta are not sensitive to the elapsed time since the last major earthquake (i.e., the projected shaking hazard results for 2005, 2050, 2100, and 2200 are similar).

Table 9-14 lists the expected PGA and 1.0-second spectral acceleration (S_a) values in 2020 at selected facility locations along the Alternative 1A alignment. For the construction period, a ground motion return period of 72 years was assumed, corresponding to approximately 50% probability of being exceeded in 50 years. Values were estimated for a stiff soil site, as predicted in the seismic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No computational modeling was conducted for 2020 in the seismic study, so the ground shaking that was computed for 2005 was used to represent the construction near-term period (i.e., 2020).

Table 9-14. Expected Earthquake Ground Motions at Locations of Selected Major Facilities during Construction (2020)—Alternative 1A

	72-Year Return Period Ground Motions (during construction)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake Locations[c]	0.11	0.14	0.13	0.21
Tunnel Location near Venice Island[d]	0.20	0.26	0.22	0.35
Clifton Court Forebay / Byron Tract Forebay	0.18	0.23	0.20	0.32

g = gravity
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.3 and 1.6 were applied to PGA and 1.0-sec S_a values, respectively (adjustments from a stiff soil site to a soft soil site).
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island site were used.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted in the seismic study would increase if no major events take place on these faults through 2020. The effect could be substantial because seismically-induced ground shaking could cause loss of property or personal injury at the Alternative 1A construction sites (including intake locations, pipelines from intakes to the intermediate forebay, the tunnel, and the Byron Tract Forebay) as a result of collapse of facilities. For example, facilities lying directly on or near active blind faults, such as the concrete batch plant and fuel station on Tyler Island and Byron Tract Forebay for Alternative 1A may have an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Figure M3-1 in the Mapbook Volume.

However, during construction, all active construction sites would be designed and managed to meet the safety and collapse-prevention requirements of the relevant state codes and standards listed earlier in this chapter and expanded upon in Appendix 3B, *Environmental Commitments*, for the above-anticipated seismic loads. In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during construction:

- DWR Division of Engineering State Water Project—Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design—Earthquake Design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6053, 2007.
- USACE Engineering and Design—Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- USACE Engineering and Design—Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence). The safety requirements could include shoring, specified slope angles, excavation depth restrictions for workers, lighting and other similar controls. Conformance with these standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. The California Department of Industrial Relations Division of Operational Safety and Health (Cal-OSHA) requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites. Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking that is estimated to occur and the resultant ground motion anticipated at Alternative 1A construction sites, including the intake locations, the tunnel, the pipelines and the forebays, could cause collapse or other failure of project facilities while under construction. For example, facilities lying directly on or near active blind faults, such as the concrete batch plant and fuel station on Tyler Island and the Byron Tract Forebay for Alternative 1A may have an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conforming with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conforming with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals. This risk would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Settlement of excavations could occur as a result of dewatering at Alternative 1A construction sites with shallow groundwater. Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. This can be anticipated at all intake locations (Sites 1–5) and pumping plant sites adjacent to the Sacramento River, where 70% of the dewatering for Alternative 1A would take place. All of the intake locations and adjacent pumping plants for Alternative 1A are located on alluvial floodbasin deposits, alluvial floodplain deposits and natural levee deposits. Similar dewatering may be necessary where intake and forebay pipelines cross waterways and major irrigation canals east of the Sacramento River and north of the proposed intermediate forebay. The conveyance pipeline between Intake 1 and tunnel 1 crosses three canals or ditches. Two of these would be a half mile south of the facility grounds for Intake 1 (or nearer) and the other would be about 0.4 miles north northwest of Scribner Road. The conveyance pipeline between Intake 3 and the intermediate forebay crosses five canals or ditches. Three are 0.6 miles southeast of the facility grounds for Intake 3 (or nearer). The other two are both less than 0.25 miles north of the connection with the intermediate forebay. Conveyance pipelines constructed for Intakes 2, 4, and 5 would not be anticipated to intersect with waterways or major irrigation canals.

Dewatering can stimulate settlement in excavation and tunneling sites. The settlement could cause the slopes of excavations to fail. This potential effect could be substantial because settlement or collapse during dewatering could result in collapse of excavations at the construction sites.

NEPA Effects: The hazard of settlement and subsequent collapse of excavations would be evaluated by assessing site-specific geotechnical and hydrological conditions at intake locations and adjacent pumping plants, as well as where intake and forebay pipelines cross waterways and major irrigation canals. A California-registered civil engineer or California-certified engineering geologist would recommend measures in a geotechnical report to address these hazards, such as seepage cutoff walls and barriers, shoring, grouting of the bottom of the excavation, and strengthening of nearby structures, existing utilities, or buried structures. As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. See Appendix 3B, *Environmental Commitments.* In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from settlement or collapse at the construction site caused by dewatering during construction:

- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built in such a way that settlement is minimized. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to conform with appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in settlement or collapse caused by dewatering at construction sites. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR or their contractors would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (see Appendix 3B, *Environmental Commitments*). Conforming with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. This risk would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

Two types of ground settlement could be induced during tunneling operations: large settlement and systematic settlement. Large settlement occurs primarily as a result of over-excavation by the tunneling shield. The over-excavation is caused by failure of the tunnel boring machine to control unexpected or adverse ground conditions (for example, running, raveling, squeezing, and flowing ground) or operator error. Minor settlement occurrences may not be discernible while large settlement can range from interruption of utilities to hindrance of road access. Below the surface, large settlement can lead to the creation of voids and/or sinkholes above the tunnel. This settlement can also affect the ground surface. While this could potentially cause property loss or personal injury above the tunneling operation, instances of large settlement are extremely unlikely to occur due to pre-construction measures and other protective strategies and safety practices during construction. Site-specific geotechnical investigations are needed to design the extent and type of ground improvement that may be required. Ground improvement would be required to facilitate support of tunnel shafts, control groundwater at the locations of the shafts, prevent development of undesired tunnel-induced surface settlements and provide pre-defined zones for TBM maintenance interventions. The types of ground improvement that would be considered include jet-grouting, permeation or compaction grouting, and ground freezing. The choice usually depends on ground conditions and the methods preferred by the contractor. Additionally, the use of earth pressure balance (EPB) tunnel boring machines (TBMs) decreases the potential for over-excavation. EPB machines hold the excavated tunnel spoils in a pressurized chamber behind the cutter head. This chamber is used to counterbalance earth pressures. Pressure is held at the tunnel face by carefully controlling the rate of spoils withdrawal from the chamber using a screw auger while the machine is pushed forward. The use of an EPB TBM enables the construction of tunnels in soft ground conditions and a high water table. The TBM shield supports the walls and roof of the excavation until the precast segmental liner is erected at the end of the shield. The pressure at the face is maintained by the controlled release of excavated material via a screw conveyor. Reusable tunnel material (RTM) is discharged into cars or onto conveyors to be removed off site. Proper use of the EPB technique allows only the removal of the theoretically correct amount of material, thus greatly reducing the potential of surface settlement.

Systematic settlement usually results from ground movements that occur before tunnel supports can exit the shield and the tunnel to make full contact with the ground. Soil with higher silt and clay content tend to experience less settlement than sandy soil. A deeper tunnel induces less ground surface settlement because a greater volume of soil material is available above the tunnel to fill any systematic void space.

The geologic units in the area of the Alternative 1A pipeline/tunnel alignment are shown on Figure 9-3 and summarized in Table 9-15. The characteristics of each unit would affect the potential for settlement during tunneling operations. Segments 1 and 3 contain higher amounts of sand than the other segments, so they pose a greater risk of settlement.

Given the likely design depth of the tunnel, the potential for excessive systematic settlement expressed at the ground surface caused by tunnel installation is thought to be relatively low. Operator errors or highly unfavorable/unexpected ground conditions could result in larger settlement. Large ground settlements caused by tunnel construction are almost always the result of using inappropriate tunneling equipment (incompatible with the ground conditions), improperly operating the machine, or encountering sudden or unexpected changes in ground conditions.

Table 9-15. Surficial Geology Underlying Alternative 1A/Pipeline/Tunnel Alignment by Segments

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 and Segment 2	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qro	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well sort sand, gravel, silt and minor clay
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
Segment 3	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 4	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qpm	Delta mud: mud and peat with minor silt or sand
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt.
Segment 5 and Segment 6	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 7	Qpm	Delta mud: mud and peat with minor silt or sand
	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 8	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.

Sources: Hansen et al. 2001 and Atwater 1982.

[a] The segments are shown on Figure 9-3.

NEPA Effects: The potential effect could be substantial because ground settlement could occur during the tunneling operation. However, during detailed project design, a site-specific subsurface geotechnical evaluation would be conducted along the pipeline/tunnel alignment to verify or refine the findings of the preliminary geotechnical investigation. The tunneling equipment and drilling methods would be reevaluated and refined based on the results of the investigations, and field procedures for sudden changes in ground conditions (e.g., excavate and replace soft soil; staged construction to allow soft soil to gain strength through consolidation) would be implemented to minimize or avoid ground settlement. A California-registered civil engineer or California-certified engineering geologist would recommend measures to address these hazards, such as specifying the type of tunnel boring machine to be used in a given segment. The results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). The geotechnical report will contain site-specific evaluations of the seismic hazard affecting the project, and will identify portions of the project site containing seismic hazards. The report will also identify any known off-site seismic hazards that could adversely affect the site in the event of an earthquake and make recommendations for appropriate mitigation as required by 14 CCR 3724(a).

As described in Section 9.3.1*, Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as USACE design measures. See Appendix 3B, *Environmental Commitments.* In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from ground settlement above the tunneling operation during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

As described in Impacts GEO-1 and GEO-2, DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement. DWR would also ensure that the design specifications are properly executed during construction. DWR has made this conformance and monitoring process an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*).

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of ground settlement. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. This risk would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

Excavation of borrow material could result in failure of cut slopes and application of temporary spoils and RTM at storage sites could cause excessive settlement in the spoils at the construction sites leading to collapse of slopes. Soil and sediment, especially those consisting of loose alluvium and soft peat or mud, would be particularly prone to failure and movement. Additionally, groundwater is expected to be within a few feet of the ground surface in these areas; this may make excavations more prone to failure.

Borrow and spoils areas for construction of intakes, sedimentation basins, pumping plants, forebays, and other supporting facilities would be sited near the locations of these structures (generally within 10 miles). Along the pipeline/tunnel alignment, selected areas would also be used for disposing of the byproduct (RTM) of tunneling operations. Table 9-16 describes the geology of these areas as mapped by Atwater (1982) (Figure 9-3).

Table 9-16. Geology Underlying Borrow/Spoils and Reusable Tunnel Material Storage Areas—Alternative 1A

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 Borrow/Spoils Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Segment 2 Borrow/Spoils Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 9 Borrow/Spoils Area	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand and gravel
Segment 2 Reusable Tunnel Material Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Segment 4 Reusable Tunnel Material Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 5 and Segment 6 Reusable Tunnel Material Area	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 7 Reusable Tunnel Material Area	Qfp	Floodplain deposits: dense, sandy to silty clay

Source: Hansen et al. 2001; Atwater 1982.

[a] The segments are shown on Figure 9-3.

NEPA Effects: The potential effect could be substantial because excavation of borrow material and the resultant cutslopes and potential failure of spoils/RTM fill slopes could cause injury of workers at the construction sites.

Excavations in borrow areas would be designed to avoid excessive ground movements on adjacent areas and soil “boiling” (i.e., upwelling of groundwater) at the bottom of the excavation. Spoils would be placed in 12-inch lifts with proper compaction and stored no higher than 12 feet above preconstruction ground elevation with maximum side slopes of 5H:1V. During design, the potential for native ground settlement below the spoils would be evaluated by a geotechnical engineer using site-specific geotechnical and hydrological information. The use of shoring, seepage cutoff walls, and ground modifications to prevent slope instability, soil boiling, or excessive settlement would be considered in the design.

In addition to the risk of slope failure at borrow sites and spoils and RTM sites, there are also potential impacts on levee stability resulting from construction of Alternative 1A water conveyance facilities. The intakes would be sited along the existing Sacramento River levee system, requiring reconstruction of levees to provide continued flood management. At each intake pumping plant site, a new setback levee (ring levee) would be constructed. The space enclosed by the setback levee would be filled up to the elevation of the top of the setback levee, creating a building pad for the adjacent pumping plant.

As discussed in Chapter 3, *Description of the Alternatives*, the new levees would be designed to provide an adequate Sacramento River channel cross section and to provide the same level of flood protection as the existing levee and would be constructed to geometries that meet or exceed PL 84-99 standards. CALFED and DWR have adopted PL 84-99 as the preferred design standard for Delta levees. Transition levees would be constructed to connect the existing levees to the new setback levees. A typical new levee would have a broad-based, generally asymmetrical triangular cross section. The levee height considered wind and wave erosion. As measured from the adjacent ground surface on the landside vertically up to the elevation of the levee crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the levee (toe of levee to toe of levee) would range from approximately 180 to 360 feet. The minimum crest width of the levee would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. Cut-off walls would be constructed to avoid seepage, and the minimum slope of levee walls would be three units horizontal to one unit vertical. All levee reconstruction will conform with applicable state and federal flood management engineering and permitting requirements.

Depending on foundation material, foundation improvements would require excavation and replacement of soil below the new levee footprint and potential ground improvement. The levees would be armored with riprap—small to large angular boulders—on the waterside. Intakes would be constructed using a sheetpile cofferdam in the river to create a dewatered construction area that would encompass the intake site. The cofferdam would lie approximately 10–35 feet from the footprint of the intake and would be built from upstream to downstream, with the downstream end closed last. The distance between the face of the intake and the face of the cofferdam would be dependent on the foundation design and overall dimensions. The length of each temporary cofferdam would vary by intake location, but would range from 740 to 2,440 feet. Cofferdams would be supported by steel sheet piles and/or king piles (heavy H-section steel piles). Installation of these piles may require both impact and vibratory pile drivers. Some clearing and grubbing of levees would be required prior to installation of the sheet pile cofferdam, depending on site conditions. Additionally, if stone bank protection, riprap, or mature vegetation is present at intake construction site, it would be removed prior to sheet pile installation.

As described in Section 9.3.1, *Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from failure of excavations and settlement. DWR also has committed to ensure that the design specifications are properly executed during construction. In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from settlement/failure of cutslopes of borrow sites and failure of soil or RTM fill slopes during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1A would not create an increased likelihood of loss of property or injury of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures (geotextile fabrics, rock revetments, riprap, or other material), seepage reduction measures, and overall mass. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures, seepage reduction measures, and overall mass. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

Pile driving and other heavy equipment operations would cause vibrations that could initiate liquefaction and associated ground movements in places where soil and groundwater conditions are present to allow liquefaction to occur. The consequences of liquefaction could be manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. These consequences could cause loss of property or personal injury and could damage nearby structures and levees.

The lateral extent (or influenced distance) of damage potential caused by pile driving and heavy equipment operations depends on many factors, including soil conditions, the piling hammer used, frequency of piling, and the vibration tolerance of structures and levees.

Pile driving would be conducted at the intakes, where, based on boring logs, soil materials subject to liquefaction (e.g., saturated, poorly graded sand) are present. During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data (e.g., California Department of Water Resources 2010a, 2010b, 2011) to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil bearing capacity and extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as (SPT) blow counts, (CPT) penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake (i.e., the earthquake that is expected to produce the strongest level of ground shaking at a site to which it is appropriate to design a structure to withstand). If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

NEPA Effects: The potential effect could be substantial because construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction.

During design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. The potential effects of construction vibrations on nearby structures, levees, and utilities would be evaluated using specific piling information (such as pile type, length, spacing, and pile-driving hammer to be used). In areas determined to have a potential for liquefaction, the California-registered civil engineer or California-certified engineering geologist would develop design strategies and construction methods to ensure that pile driving and heavy equipment operations do not damage facilities under construction and surrounding structures, and do not threaten the safety of workers at the site (e.g., compaction grouting, which consists of pumping a thick grout mixture into the soil under high pressure forming a grout bulb which compacts the surrounding soil by displacement; removal and replacement of liquefaction susceptible soil; etc.). As shown in Figure 9-6, the area south of the Sacramento River all the way across Woodward Island, which Alternative 1A crosses through, has medium to medium-high potential for levee liquefaction damage. Two fuel stations, a concrete batch plant, as well as a barge unloading facility are located in this medium to medium-high potential for levee liquefaction damage area. Design strategies may include predrilling or jetting, using open-ended pipe piles to reduce the energy needed for pile penetration, using cast-in-place-drill-hole (CIDH) piles/piers that do not require driving, using pile jacking to press piles into the ground by means of a hydraulic system, or driving piles during the drier summer months. Field data collected during design also would be evaluated to determine the need for and extent of strengthening levees, embankments, and structures to reduce the effect of vibrations. These construction methods would conform with current seismic design codes and requirements, as described in Appendix 3B, *Environmental Commitments*. Such design standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) that the construction methods recommended by the geotechnical engineer are included in the design of project facilities and construction specifications to minimize the potential for construction-induced liquefaction. DWR also has committed to ensure that these methods are followed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from construction-related ground motions:

- USACE Engineering and Design–Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to construction method recommendations and other applicable specifications would ensure that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals due to construction-related ground motion and resulting potential liquefaction in the work area. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from construction-related ground motion and resulting potential liquefaction in the work area and the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*). The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

According to the available AP Fault Zone Maps, none of the Alternative 1A facilities would cross or be within any known active fault zones. However, numerous AP fault zones have been mapped west of the conveyance alignment (Figure 9-5). The closest AP fault zone would be the Greenville fault, located approximately 7.6 miles west of the conveyance facilities. Because none of the Alternative 1A constructed facilities would be within any of the fault zones (which include the area approximately 200 to 500 feet on each side of the mapped surface trace to account for potential branches of active faults), the potential that the facilities would be directly subject to fault offsets is negligible.

In the Delta, active or potentially active blind thrust faults were identified in the seismic study. Segments 3, 4, and 5 of the Alternative 1A conveyance alignment (Figure 9-3) would cross the Thornton Arch fault zone. The western part of the proposed Byron Tract Forebay adjacent to the Clifton Court Forebay is underlain by the West Tracy fault. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). If the West Tracy fault is potentially active, it could cause surface deformation in the western part of the Clifton Court Forebay. Because the western part of the Byron Tract Forebay is also underlain by the hanging wall of the fault, this part of the forebay may also experience uplift and resultant surface deformation (Fugro Consultants 2011). In the seismic study (California Department of Water Resources 2007a), the Thornton Arch and West Tracy blind thrusts have been assigned 20% and 90% probabilities of being active, respectively. The depth to the Thornton Arch blind fault is unknown. The seismic study indicates that the West Tracy fault dies out as a discernible feature within approximately 3,000 to 6,000 feet below ground surface (bgs) [in the upper 1- to 2-second depth two-way time, estimated to be approximately 3,000 to 6,000 feet using the general velocity function as published in the Association of Petroleum Geologists Pacific Section newsletter (Tolmachoff 1993)].

It appears that the potential of having any shear zones, bulging, or both at the depths of the pipeline/tunnel is low because the depth to the blind thrust faults is generally deep and there is no credible evidence to indicate that the faults could experience displacement within the depth of the pipeline/tunnel.

NEPA Effects: The effect would not be adverse because no active faults extend into the Alternative 1A alignment. Additionally, although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 1A alignment, they do not present a hazard of surface rupture based on available information, including the AP Earthquake Fault Zone Map showing faults capable of surface rupture (Figure 9-5).

However, because there is limited information regarding the depths of the Thornton Arch and West Tracy blind thrusts, seismic surveys would be performed on the blind thrust during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. The geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis,* such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*). For construction of the water conveyance facilities, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1A would not create an increased likelihood of loss of property or injury in the event of ground movement in the vicinity of the Thornton Arch fault zone and West Tracy, blind thrust would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1A conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. Therefore, there would be no adverse effect.

CEQA Conclusion**:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, they do not present a hazard of surface rupture based on available information. Conformance to applicable design specifications and standards would ensure that operation of Alternative 1A would not create an increased likelihood of loss of property or injury of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone and West Tracy, blind thrust would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1A conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

Earthquake events may occur on the local and regional seismic sources during operation of the Alternative 1A water conveyance facilities. The ground shaking could damage pipelines, tunnels, intake Table 9-17 shows that the proposed facilities would be subject to moderate-to-high earthquake ground shaking through 2025. All facilities would be designed and constructed in accordance with the requirements of the design guidelines and building codes described in Appendix 3B. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize damage potential facilities, pumping plants, and other facilities disrupting the water supply through the conveyance system. In an extreme event of strong seismic shaking, uncontrolled release of water from damaged pipelines, tunnels, intake facilities, pumping plants, and other facilities could cause flooding, disruption of water supplies to the south, inundation of structures, property loss, and injury. These effects are discussed more fully in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*.

Table 9-17 lists the expected PGA and 1.0-S_a values in 2025 at selected facility locations. For early long-term, earthquake ground motions with return periods of 144 years and 975 years were estimated from the results presented in the seismic study (California Department of Water Resources 2007a). The 144-year and 975-year ground motions correspond to the OBE (i.e., an earthquake that has a 50% probability of exceedance in a 100-year period (which is equivalent to a 144-year return period event) and the MDE (i.e., an earthquake that causes ground motions that have a 10% chance of being exceeded in 100 years) design ground motions, respectively. Values were estimated for a stiff soil site (as predicted in the seismic study), and for the anticipated soil conditions at the facility locations. No seismic study results exist for 2025, so the ground shaking estimated for the 2050 were used for Early Long-term (2025).

Table 9-17. Expected Earthquake Ground Motions at Locations of Selected Major Facilities in the Early Long-Term (2025)—Alternative 1A

	144-year Return Period Ground Motions (OBE)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake Locations[c]	0.14	0.15	0.19	0.30
Tunnel Location near Venice Island[d]	0.30	0.33	0.31	0.50
Clifton Court Forebay/Byron Tract Forebay	0.28	0.31	0.30	0.48
	975-year Return Period Ground Motions (MDE)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[e]	Stiff Soil[a]	Local Soil[e]
Intake Locations[c]	0.24	0.24	0.33	0.53
Tunnel Location near Venice Island[d]	0.50	0.50	0.60	0.96
Clifton Court Forebay/Byron Tract Forebay	0.50	0.50	0.61	0.98

g = gravity
MDE = maximum design earthquake
OBE = operating basis earthquake
PGA = Peak Ground Acceleration
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.1 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island were used.
[e] Site-adjusted factors of 1.0 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.

This potential effect could be substantial because strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities and result in loss of property or personal injury. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the conveyance system could cause flooding and inundation of structures. Please refer to Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

The structure of the underground conveyance facility would decrease the likelihood of loss of property or personal injury of individuals from structural shaking of surface and subsurface facilities along the Alternative 1A conveyance alignment in the event of strong seismic shaking. The conveyance pipeline will be lined with precast concrete which will be installed continuously following the advancement of a pressurized tunnel boring machine. The lining consists of precast concrete segments inter-connected to maintain alignment and structural stability during construction. Reinforced concrete segments are precast to comply with strict quality control. High performance gasket maintains water tightness at the concrete joints, while allowing the joint to rotate and accommodate movements during intense ground shaking. Precast concrete tunnel lining (PCTL) has been used extensively in seismically active locations such as Japan, Puerto Rico, Taiwan, Turkey, Italy and Greece. The adoption of PCTL in the United States started about 20 years ago, including many installations in seismically active areas such as Los Angeles, San Diego, Portland and Seattle. PCTL provides better seismic performance than conventional tunnels for several reasons:

- higher quality control using precast concrete
- better ring-build precision with alignment connectors
- backfill grouting for continuous ground to tunnel support
- segment joints provide flexibility and accommodate deformation during earthquakes
- high performance gasket to maintain water tightness during and after seismic movement

Reviewing the last 20 years of PCTL seismic performance histories, it can be concluded that little or no damage to PCTL was observed for major earthquakes around the world. Case studies of the response of PCTL to large seismic events have shown that PCTL should not experience significant damage for ground acceleration less than 0.5g (Dean et al. 2006). The design PGA for a 975-year return period is 0.49g (California Department of Water Resources 2010i, Table 4-4). Based on this preliminary data, the Delta tunnels can be designed to withstand the anticipated seismic loads.

Design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the conveyance features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical report will contain site-specific evaluations of the seismic hazard affecting the project, and will identify portions of the project site containing seismic hazards. The report will also identify any known off-site seismic hazards that could adversely affect the site in the event of an earthquake and make recommendations for appropriate mitigation as required by 14 CCR 3724(a). The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Design strategies could include measures such as slope stabilization and removing or replacing liquefaction-prone soil during grading, site strengthening through dynamic compaction methods, deep densification of the soil through blasting, or other site improvement methods.

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards are an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction. See Appendix 3B, *Environmental Commitments.*

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project–Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design–Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design–Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

NEPA Effects: Conformance with the aforementioned standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from structural shaking of surface and subsurface facilities along the Alternative 1A conveyance alignment in the event of strong seismic shaking. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities and result in loss of property or personal injury. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the Alternative 1A water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

Earthquake-induced ground shaking could cause liquefaction, resulting in soil slumping or lateral spreading and subsequent damage to or breaching of water conveyance structures and facilities. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. Failure of tunnels, pipelines, levees, bridges, and other structures and facilities could result in loss of property or personal injury, and disrupt SWP and CVP water supply deliveries. The potential for adverse impacts from flooding as a result of levee or dam failure is also discussed in Chapter 6, *Surface Water*.

The native soil underlying Alternative 1A facilities consist of various channel deposits and recent silty and sandy alluvium at shallow depths. The available data along the southern portion of the conveyance (from approximately Potato Slough to Clifton Court Forebay) show that the recent alluvium overlies peaty or organic soil, which in turn is underlain by layers of mostly sandy and silty soil (Real and Knudsen 2009). Soil borings advanced by DWR along the northern portion of the conveyance (from approximately Potato Slough to Intake 1) show the surface soil as being similar to the range reported for the southern portion, but locally containing strata of clayey silt and lean clay. Because the borings were made over water, peat was usually absent from the boring logs (California Department of Water Resources 2011). This may be because the peat had floated from the bottom of the waterways over time, or may be because the absence of peat indicates that the watercourse's present course has not deviated greatly since the late Pleistocene.

The silty and sandy soil deposits underlying the peaty and organic soil over parts of the Delta are late-Pleistocene age dune sand, which are liquefiable during major earthquakes. The tops of these materials are exposed in some areas, but generally lie beneath the peaty soil at depths of about 10–40 feet bgs along the pipeline/tunnel alignment (Real and Knudsen 2009). Liquefaction hazard mapping by Real and Knudsen (2009), which covers only the southwestern part of the Plan Area, including the part of the alignment from near Isleton to the Palm Tract, indicates that the lateral ground deformation potential would range from <0.1 to 6.0 feet. Liquefaction-induced ground settlement during the 1906

San Francisco earthquake was also reported near Alternative 1A facilities at a bridge crossing over Middle River just north of Woodward Island (Youd and Hoose 1978). Local variations in thickness and lateral extent of liquefiable soil may exist, and they may have important influence on liquefaction-induced ground deformations.

NEPA Effects: Figure 9-6 shows that the Alternative 1A alignment has no substantial levee damage potential from liquefaction in its extreme northern part and low to medium-high levee damage potential throughout the remainder of the Plan Area.

Because the tunnel invert would be at depths of 100–160 feet bgs, the potential effects on these facilities due to liquefaction is judged to be low. However, the surface and near-surface facilities that would be constructed at the access road, intake, pumping plant, and forebay areas would likely be founded on liquefiable soil.

The potential effect could be substantial because seismically induced ground shaking could cause liquefaction, which could result in loss of property or personal injury, and damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures.

In the process of preparing final facility designs, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to further assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high “fines” (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

During final design, site-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, a California-registered civil engineer or California-certified engineering geologist would develop design measures and construction methods to meet design criteria established by building codes and construction standards to ensure that the design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, and using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods). The results of the site-specific evaluation and California-registered civil engineer or California-certified engineering geologist’s recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE‘s *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design requirements is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from liquefaction and associated hazards. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project–Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design–Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003
- USACE Engineering and Design–Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- USACE Engineering and Design–Design of Pile Foundations, EM 1110-2-2906, 1991
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of liquefaction and associated ground movements would not create an increased likelihood of loss of property, personal injury or death of individuals from structural failure resulting from seismic-related ground failure along the Alternative 1A conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the Alternative 1A water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

Alternative 1A would involve excavation that creates new cut-and-fill slopes and construction of new embankments and levees. As a result of ground shaking and high soil-water content during heavy rainfall, existing and new slopes that are not properly engineered and natural stream banks could fail and cause damage to facilities. Levees can fail for several reasons: 1) high velocities of water flow can result in high rates of erosion and erode and overtop a levee; 2) the higher velocities of water flow can also lead to higher rates of erosion along the inner parts of levees and lead to undercutting and clumping of the levee into the river. Heavy rainfall or seepage into the levee from the river can increase fluid pressure in the levee and lead to slumping on the outer parts of the levee. If the slumps grow to the top of the levee, large sections of the levee may slump onto the floodplain and lower the elevation of the top of the levee, leading to overtopping; 3) increasing levels of water in the river will cause the water table in the levee to rise which will increase fluid pressure and may result in seepage and eventually lead to internal erosion called piping. Piping will erode the material under the levee, undermining it and causing its collapse and failure.

With the exception of levee slopes and natural stream banks, the topography along the Alternative 1A conveyance alignment is nearly level to very gently sloping. The areas that may be susceptible to slope failure are along existing levee slopes, and at intakes, pumping plants, forebay, and certain access road locations. Outside these areas, the land is nearly level and consequently has a negligible potential for slope failure. Based on review of topographic maps and a landslide map of Alameda County (Roberts et al. 1999), the conveyance facilities would not be constructed on, nor would it be adjacent to, slopes that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures built on these slopes could be damaged or fail entirely as a result of slope instability. As discussed in Impact SW-2 in Chapter 6, *Surface Water*, operation of the water conveyance features under Alternative 1A would not result in an increase in potential risk for flood management compared to existing conditions. Peak monthly flows under Alternative 1A in the locations considered were similar to or less than those that would occur under existing conditions. Since flows would not be substantially greater, the potential for increased rates of erosion or seepage are low. For additional discussion on the possible exposure of people or structures to impacts from flooding due to levee failure, please refer to Impact SW-6 in Chapter 6, *Surface Water*.

During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. The design criteria would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As discussed in Chapter 3, *Description of the Alternatives*, the foundation soil beneath slopes, embankments, or levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill also would be used to construct new slopes, embankments, and levees. Surface and internal drainage systems would be installed as necessary to reduce erosion and piping (internal erosion) potential.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Section 9.3.1, *Methods for Analysis*, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.* The design requirements would be presented in a detailed geotechnical report. Conformance with these design requirements is an environmental commitment by DWR to ensure that slope stability hazards would be avoided as the water conveyance features are operated. DWR would ensure that the geotechnical design recommendations are included in the design of cut and fill slopes, embankments, and levees to minimize the potential effects from slope failure. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic shaking or from high-pore water pressure:

- DWR Division of Engineering State Water Project–Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 1A conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures built on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. The measures would be described in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil*

Works Projects. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the Alternative 1A water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Therefore, the potential hazard of loss of property or personal injury as a result of a tsunami on the water conveyance facilities is low.

Similarly, with the exception of the Clifton Court Forebay and the Byron Tract Forebay, the potential for a substantial seiche to take place in the Plan Area that would cause loss of property or personal injury in the construction areas is considered low because seismic and water body geometry conditions for a seiche to occur near conveyance facilities are not favorable. Fugro Consultants, Inc. (2011) identified the potential for a seiche of an unspecified wave height to occur in the Clifton Court Forebay, caused by strong ground motions along the underlying West Tracy fault, assuming that this fault is potentially active. Since the fault also exists in the immediate vicinity of the Byron Tract Forebay, a seiche could also occur in the Byron Tract Forebay.

NEPA Effects: The effect of a tsunami generated in the Pacific Ocean would not be adverse because the distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low (i.e., less than 2 feet) tsunami wave height to reach the Delta (Contra Costa Transportation Agency 2009). With the assumption of an 18-inch sea level rise at mid-century, the tsunami effect would not be adverse since the attenuating effect of the San Francisco Bay (a 100-year return period tsunami wave run-up elevation at Golden Gate Bridge of 8.2 feet NGVD) would dissipate as it moves east toward the East Bay and the Delta. By the time it reaches the East Bay it would be half as high (City and County of San Francisco 2011). As it moves to the Delta, the wave run-up is likely low (3.5 feet or less) tsunami wave height.

Because the majority of the region's faults are strike-slip faults, a tsunami is not expected to be a major threat as a result of a regional earthquake. The primary tsunami threat along the central California coast is from distant earthquakes along subduction zones elsewhere in the Pacific basin, including Alaska. Since 1877, Alaska earthquakes have produced tsunami run-ups in the Bay Area nine times or on average, every 28 years. Historically, the run-ups from these events have been less than 1 foot (City and County of San Francisco 2011).

In most parts of the Plan Area, the effects of a seiche would not be adverse because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay. The effect could be adverse because the waves generated by a seiche could overtop the Byron Tract Forebay and Clifton Court Forebay embankments, causing erosion of the embankments and subsequent flooding in the vicinity.

However, design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would determine the peak ground acceleration caused by movement of the West Tracy fault and the maximum probable seiche wave that could be generated by the ground shaking. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard, as well as the hazard of a seiche overtopping the Clifton Court Forebay embankment and subsequent adverse effect on the Byron Tract Forebay embankment, would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that the adverse effects of a seiche are controlled to an acceptable level while the forebay facility is operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and consequent seiche waves. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from tsunami or seiche:

- U.S. Department of the Interior and USGS Climate Change and Water Resources Management: A Federal Perspective, Circular 1331.
- State of California Sea-Level Rise Task Force of CO-CAT, Sea-Level Rise Interim Guidance Document, 2010
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes provide guidance on estimating the effects of climate change and sea level rise and associated effects when designing a project and ensuring that a project is able to respond to these effects.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the Byron Tract Forebay embankment would be designed and constructed to contain and withstand the anticipated maximum seiche wave height and would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 1A conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required.

Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height and potential seiche wave overtopping of the Clifton Court Forebay and Byron Tract Forebay embankments as the Alternative 1A water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 1A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect to groundwater surface elevations caused by canal seepage. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Alternative 1A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. There would be no impact. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

According to the available AP Earthquake Fault Zone Maps, only the Suisun Marsh ROA could be affected by rupture of an earthquake fault. The active Green Valley fault crosses the southwestern corner of the ROA. The active Cordelia fault extends approximately 1 mile into the northwestern corner of the ROA. Rupture of these faults could damage levees and berms constructed as part of the restoration, which could result in failure of the levees and flooding of otherwise protected areas.

Within the Delta, active or potentially active blind thrust faults were identified in the seismic study (California Department of Water Resources 2007a). The extreme southeastern corner of the Suisun Marsh is underlain by the Montezuma blind thrust zone. Parts of the Cache Slough and Yolo Bypass ROAs are underlain by part of the North Midland blind thrust zone. The Cosumnes/Mokelumne River and East Delta ROAs are underlain by the Thornton Arch zone. Although these blind thrusts are not expected to rupture to the ground surface during earthquake events, they may produce ground or near-ground shear zones, bulging, or both. In the seismic study (California Department of Water Resources 2007a), the Thornton Arch blind thrust was assigned a 20% probability of being active. The depth to the Thornton Arch blind fault is unknown. Based on limited geologic and seismic survey information, it appears that the potential of having any shear zones, bulging, or both at the sites of the habitat levees is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect of implementing the conservation measures in the ROAs could be substantial because rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and cause damage or failure of ROA facilities, including levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

Because there is limited information regarding the depths of the blind faults mentioned above, seismic surveys would be performed in the vicinity of the faults as part of final design. These surveys would be used to verify fault depths where levees and other features would be constructed. Collection of this depth information would be part of broader, design-level geotechnical studies prepared by a geotechnical engineer licensed in the state of California to support all aspects of site-specific project design. The studies would assess site-specific conditions at and near all the project facility locations, including the nature and engineering properties of all soil horizons and underlying geologic strata, and groundwater conditions. The geotechnical engineers' information would be used to develop final engineering solutions to any hazardous condition, consistent with the code and standards requirements of federal, state and local oversight agencies. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that risks from a fault rupture are minimized as conservation levees are constructed and maintained. The hazard would be controlled to a safe level by following the proper design standards.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of ground movement in the vicinity of the blind thrusts underlying the ROAs would not jeopardize the integrity of the levees and other features constructed in the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

Earthquake events may occur on the local and regional seismic sources at or near the ROAs. Because of its proximity to these faults, the Suisun Marsh ROA would be especially subject to ground shaking caused by the Concord-Green Valley fault. The Cache Slough ROA would be subject to shaking from the Northern Midland fault zone, which underlies the ROA. Although more distant from these sources, the other ROAs would be subject to shaking from the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust faults and the more proximate blind thrusts in the Delta.

Among all the ROAs, the Suisun Marsh ROA would be most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31–0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11–0.26 g. The ground shaking could damage levees and other structures, and in an extreme event cause levees to fail such that protected areas flood.

NEPA Effects: All temporary facilities would be designed and built to meet the safety and collapse-prevention requirements for the above-anticipated seismic loads. Therefore, this effect is considered not adverse. No additional mitigation measures are required. All facilities would be designed and constructed in accordance with the requirements of the design measures described in

Chapter 3, *Description of the Alternatives*. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize the potential of damage. Design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the levees and other features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical engineer's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are implemented.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project features and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of seismic shaking would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Amongst all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31–0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11–0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

New structural features are proposed at the ROAs, such as levees as part of CM4, setback levees as part of CM5 and CM6, and experimental ramps and fish ladders at the Fremont Weir as part of CM2. Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of these levees and other features constructed at the restoration areas. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), and increased lateral soil pressure. Failure of levees and other structures could result in loss or injury, as well as flooding of otherwise protected areas in Suisun Marsh and behind new setback levees along the Sacramento and San Joaquin Rivers and in the South Delta ROA.

The ROAs vary with respect to their liquefaction hazard (Figure 9-6). The Suisun Marsh ROA generally has a moderate or high liquefaction hazard. The liquefaction damage potential among the other ROAs, as well as where setback levees would be constructed along the Old, Middle, and San Joaquin Rivers under CM5 and CM6, is generally low to medium.

NEPA Effects: The potential effect could be substantial because earthquake-induced liquefaction could damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

During final design of conservation facilities, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content is less susceptible to liquefaction.

During final design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, the engineer would develop design parameters and construction methods to meet the design criteria established to ensure that design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods), and conforming with current seismic design codes and requirements. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic-related ground failure:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during construction and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in loss or injury, as well as flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Implementation of CM2–CM7, would involve breaching, modification or removal of existing levees and construction of new levees and embankments. CM4 which provides for the restoration of up to 65,000 acres of tidal perennial aquatic, tidal mudflat, tidal freshwater emergent wetland, and tidal brackish emergent wetland natural communities within the ROAs involves the greatest amount of modifications to levees. Levee modifications, including levee breaching or lowering, may be performed to reintroduce tidal exchange, reconnect remnant sloughs, restore natural remnant meandering tidal channels, encourage development of dendritic channel networks, and improve floodwater conveyance.

Levee modifications could involve the removal of vegetation and excavation of levee materials. Excess earthen materials could be temporarily stockpiled, then re-spread on the surface of the new levee slopes where applicable or disposed of offsite. Any breaching or other modifications would be required to be designed and implemented to maintain the integrity of the levee system and to conform with flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies. Those agencies may include USACE, DWR, CVFPB, and other flood management agencies. For more detail on potential modifications to levees as a part of conservation measures, please refer to Chapter 3, *Description of Alternatives*.

New and existing levee slopes and stream/channel banks could fail and could damage facilities as a result of seismic shaking and as a result of high soil-water content during heavy rainfall.

With the exception of levee slopes, natural stream banks, and part of the Suisun Marsh ROA, the topography of ROAs is nearly level to gently sloping. The areas that may be susceptible to slope failure are along existing Sacramento and San Joaquin River and Delta island levees and stream/channel banks, particularly those levees that consist of non-engineered fill and those streambanks that are steep and consist of low strength soil.

The structures associated with conservation measures would not be constructed in, nor would they be adjacent to, areas that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in flooding of otherwise protected areas.

As outlined in Chapter 3, *Description of Alternatives*, erosion protection measures and protection against related failure of adjacent levees would be taken where levee breaches were developed. Erosion protection could include geotextile fabrics, rock revetments, riprap, or other material selected during future evaluations for each location. Aggregate rock could be placed on the remaining levees to provide an access road to the breach location. Erosion protection measures would also be taken where levee lowering is done for the purposes of allowing seasonal or periodic inundation of lands during high flows or high tides to improve habitat or to reduce velocities and elevations of floodwaters. To reduce erosion potential on the new levee crest, a paved or gravel access road could be constructed with short (approximately 1 foot) retaining walls on each edge of the crest to reduce undercutting of the roadway by high tides. Levee modifications could also include excavation of watersides of the slopes to allow placement of slope protection, such as riprap or geotextile fabric, and to modify slopes to provide levee stability. Erosion and scour protection could be placed on the landside of the levee and continued for several feet onto the land area away from the levee toe. Neighboring levees could require modification to accommodate increased flows or to reduce effects of changes in water elevation or velocities along channels following inundation of tidal marshes. Hydraulic modeling would be used during subsequent analyses to determine the need for such measures.

New levees would be constructed to separate lands to be inundated for tidal marsh from non-inundated lands, including lands with substantial subsidence. Levees could be constructed as described for the new levees at intake locations. Any new levees would be required to be designed and implemented to conform with applicable flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies, which may include USACE, DWR, CVFPB, and local flood management agencies.

Additionally, during project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As discussed in Chapter 3, *Description of the Alternatives*, foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, *Description of the Alternatives*, such as USACE‘s *Design and Construction of Levees* and USACE’s *EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from landslides or other slope instability:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion: Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: The distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low tsunami wave height to reach the Suisun Marsh and the Delta. Conditions for a seiche to occur at the ROAs are not favorable. Therefore, the effect would not be adverse.

CEQA Conclusion: Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.3 Alternative 1B—Dual Conveyance with East Alignment and Intakes 1–5 (15,000 cfs; Operational Scenario A)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

Earthquakes could be generated from local and regional seismic sources during construction of the Alternative 1B water conveyance facilities. Seismically induced ground shaking could cause injury of workers at the construction sites as a result of collapse of facilities.

The potential for experiencing earthquake ground shaking during construction in 2020 (during the project's near-term implementation stage) was estimated using the results of the seismic study (California Department of Water Resources 2007a). The seismic study also computed seismic ground shaking hazards at six locations in the Delta for 2005, 2050, 2100, and 2200. The results of these analyses show that ground shaking in the Delta is not sensitive to the elapsed time since the last major earthquake (that is, the projected shaking hazard results for 2005, 2050, 2100, and 2200 are similar).

Table 9-18 lists the expected PGA and 1.0-S_a values in 2020 at selected facility locations along the Alternative 1B alignment. As with Alternative 1A, ground motions with a return period of 72 years and computed for 2005 are used to represent near-term (i.e., 2020) construction period motions for Alternative 1B.

Table 9-18. Expected Earthquake Ground Motions at Locations of Selected Major Facilities during Construction (2020)—Alternative 1B

	72-year Return Period Ground Motions			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake and Fish Screen Area[c]	0.11	0.14	0.13	0.21
Siphon Location near Neugebaur Road in Stockton[d]	0.12	0.16	0.14	0.22
Clifton Court Forebay / Byron Tract Forebay	0.18	0.23	0.20	0.32

g = gravity
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.3 and 1.6 were applied to PGA and 1.0-sec Sa values, respectively (adjustments from a stiff soil site to a soft soil site).
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Stockton site were used.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted by the seismic study would increase if no major events occur on these faults through 2020. The effect would be adverse because seismically induced ground shaking could cause loss of property or personal injury at the Alternative 1B construction sites (including intake locations, pipelines between transition structures and canal transition structures, the canal, bridge crossings along the conveyance alignment, and the Byron Tract Forebay) as a result of collapse of facilities. The Byron Tract Forebay is located near an active blind fault and the portion of the canal located east of Locke, as well as the portion of the canal which lies between Beaver Slough and Hog Slough, lie directly over an active blind fault and within the Thornton Arch Zone, resulting in an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Mapbook Figure M3-2.

However, during construction, all active construction sites would be designed and managed to meet the safety and collapse-prevention requirements of the relevant state codes and standards listed earlier in this chapter and expanded upon in Appendix 3B, *Environmental Commitments* for the above-anticipated seismic loads.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design – Earthquake Design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6053, 2007.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence). The safety requirements could include shoring, specified slope angles, excavation depth restrictions for workers, lighting and other similar controls. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury from structural or earth failure. The relevant codes and standards represent performance standards that must be met by DWR and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking that is estimated to occur and the resultant ground motion anticipated at Alternative 1B construction sites, including the canal, pipelines and the forebays, could cause collapse or other failure of project facilities while under construction. For example, facilities lying directly on or near active blind faults, such as the Byron Tract Forebay as well as along the canal near Locke and between Beaver Slough and Hog Slough, may have in an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals. This risk would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Settlement of excavations could occur as a result of construction dewatering if proven construction and dewatering methods and earthwork practices are not carried out. The settlement could cause the slopes of excavations to fail. This hazard is most likely to be present at the intake and pumping plant locations and the canal alignment. The preliminary dewatering analysis results indicate that the majority (more than 90%) of the dewatering needs for Alternative 1B construction would be associated with canal construction (i.e., for the excavation of the canal foundation). The proposed canal for Alternative 1B is located on alluvial floodbasin deposits, alluvial floodplain deposits, natural levee deposits, dredge soils, and the Modesto Formation. Similar dewatering may be necessary where intakes and conveyance pipelines cross waterways and major irrigation canals. The conveyance pipeline between Intake 3 and the canal crosses three canals or ditches. All are 0.3 miles southeast of the facility grounds for Intake 3 (or nearer). The conveyance pipeline between Intake 5 and the canal crosses three canals or ditches. These crossings occur approximately 0.25 miles, 0.5 miles, and 0.75 miles southeast and east southeast of the facility grounds for Intake 5. Conveyance pipelines construction for Intakes 1, 2, and 4 would not be anticipated to intersect with waterways or major irrigation canals.

Dewatering can stimulate settlement in excavation and tunneling sites. The settlement could cause the slopes of excavations to fail.

NEPA Effects: This potential effect could be substantial because settlement or collapse during dewatering could cause injury of workers at the construction sites as a result of collapse of excavations. The hazard of settlement and subsequent collapse of excavations would be evaluated by assessing site-specific geotechnical and hydrological conditions along the canal, as well as where intakes and conveyance pipelines cross waterways and major irrigation canals. A California-registered civil engineer or California-certified engineering geologist would recommended measures in a geotechnical report to address these hazards, such as seepage cutoff walls and barriers, shoring, grouting of the bottom of the excavation, and strengthening of nearby structures, existing utilities, or buried structures. As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. See Appendix 3B, *Environmental Commitments*. In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from settlement or collapse at the construction site caused by dewatering during construction:

- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built in such a way that settlement is minimized. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. Therefore, there would be no adverse effects.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1B would not create an increased likelihood of direct loss, injury or death of individuals from settlement or collapse caused by dewatering. This risk would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

Two types of ground settlement could be induced during construction of alternative 1B tunnel siphons: large settlement and systematic settlement. Large settlement occurs primarily as a result of over-excavation by the tunneling shield. The over-excavation is caused by failure of the tunnel boring machine to control unexpected or adverse ground conditions (for example, running, raveling, squeezing, and flowing ground) or operator error. Large settlement can lead to the creation of voids and/or sinkholes above the tunnel siphon. In extreme circumstances, the settlement effects could translate to the ground surface, potentially causing loss of property or personal injury above the tunnel siphon construction.

Systematic settlement usually results from ground movements that occur before tunnel supports can exit the shield and the tunnel to make full contact with the ground. Soil with higher silt and clay content tend to experience less settlement than sandy soil. Additional ground movements can occur with the deflection of the tunnel siphon supports and over-excavation caused by steering/plowing of the tunnel boring machine at horizontal and vertical curves. A deeper tunnel siphon induces less ground surface settlement because a greater volume of soil material is available above the tunnel siphon to fill any systematic void space.

The geologic units in the area of the Alternative 1B alignment are shown on Figure 9-3 and summarized in Table 9-19. The characteristics of each unit would affect the potential for settlement during tunnel siphon construction. Segments 4, 5, 6, 7, 8 and 9, located south east of Locke and running down to Fourteenmile Slough, contain higher amounts of loose and fine sand than the other segments, so they pose a greater risk of settlement.

Given the likely design depth of the tunnel siphon, the potential for excessive systematic settlement expressed at the ground surface caused by tunnel siphon construction is thought to be relatively. Operator errors or highly unfavorable/unexpected ground conditions could result in larger settlement. Large ground settlements caused by tunnel siphon construction are almost always the result of using inappropriate tunneling equipment (incompatible with the ground conditions), improperly operating the machine, or encountering sudden or unexpected changes in ground conditions.

NEPA Effects: The potential effect could be substantial because ground settlement could occur during the tunnel siphon construction. During detailed project design, a site-specific subsurface geotechnical review would be conducted along the water conveyance facility alignment to verify or refine the findings of the preliminary geotechnical investigation. The tunneling equipment and drilling methods would be reevaluated and refined based on the results of the investigations, and field procedures for sudden changes in ground conditions would be implemented to minimize or avoid ground settlement. A California-registered civil engineer or California-certified engineering geologist would recommend measures to address these hazards, such as specifying the type of tunnel boring machine to be used in a given segment. The results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular, *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as USACE design measures. See Appendix 3B, *Environmental Commitments*.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from ground settlement above the tunneling operation during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Table 9-19. Geology of Alternative 1B/East Alignment by Segments

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qr, Qry and Qro	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well-sorted sand, gravel, silt, and minor clay
Segment 2	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qry	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well-sorted sand, gravel, silt, and minor clay
Segment 3 (Tunnel Siphon Segment)	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Segment 4	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qr	Riverbank Formation: alluvial fans from glaciated basins consisting of moderately sorted to well sorted sand, gravel, silt and minor clay
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
Segment 5, Segment 6, Segment 7, and Segment 8	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
Segment 9	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
	Qm2e	Eolian sand: well sorted fine- to medium-grained sand
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 10 (Tunnel Siphon Segment)	Qds	Dredge soils, post 1900
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 11	Qds	Dredge soils, post 1900
	Qpm	Delta mud: mud and peat with minor silt or sand
	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 12 and Segment 13	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 14 (Tunnel Siphon Segment)	Qfp	Floodplain deposits: dense sandy to silty clay

Source: Hansen et al. 2001 and Atwater 1982.
[a] The segments are shown on Figure 9-3.

As described in detail in Impacts GEO-1 and GEO-2, DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement. DWR would also ensure that the design specifications are properly executed during construction. DWR has made this conformance and monitoring process an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*).

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of ground settlement. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunnel siphon construction could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. This risk would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

Excavation of borrow material could result in failure of cut slopes and application of temporary spoils and RTM at storage sites could cause excessive settlement in the spoils, potentially causing injury of workers at the construction sites. Soil and sediment, especially those consisting of loose alluvium and soft peat or mud, would particularly be prone to failure and movement. Additionally, groundwater is expected to be within a few feet of the ground surface in these areas, this may make excavations more prone to failure.

Borrow and spoils areas for construction of the canal foundation, intakes, sedimentation basins, pumping plants, forebays, and other supporting facilities would be sited near the locations of these structures (generally within 10 miles). Along the alignment, selected areas would also be used for disposing of the byproduct (RTM) of tunnel siphon construction. Table 9-20 describes the geology of these areas as mapped by Atwater (1982) (Figure 9-3).

1 **Table 9-20. Geology of Alternative 1B Borrow/Spoils and Resuable Tunnel Material Areas by Segments**

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 Borrow/Spoils Area	Ql	Natural Levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qoe	Older eolian deposits
	Qr, Qry and Qro	Riverbank Formation: alluvial fans from glaciated basins which consist of moderately-sorted to well-sorted sand, gravel, silt and minor clay
Segment 2 Borrow/Spoils Area	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qry	Riverbank Formation: alluvial fans from glaciated basins consisting of moderately-sorted to well-sorted sand, gravel, silt and minor clay
Segment 4 Borrow/Spoils Area	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
Segment 5, Segment 7, and Segment 8 Borrow/Spoils Area	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
Segment 9 Borrow/Spoils Area	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 11 Borrow/Spoils Area	Qds	Dredge soils, post 1900
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 12 and Segment 13 Borrow/Spoils Area	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 3 Resuable Tunnel Material Area	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Ql	Natural Levee deposits: moderately to well-sorted sand, with some silt and clay.
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qr	Riverbank Formation: alluvial fans from glaciated basins consisting of moderately sorted to well sorted sand, gravel, silt and minor clay
Segment 10 Resuable Tunnel Material Area	Qm	Modesto Formation: loose sand and silt to compact silt and very fine sand
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
Segment 14 Resuable Tunnel Material Area	Qfp	Floodplain deposits: dense, sandy to silty clay

Source: Hansen et al. 2001 and Atwater 1982.

[a] The segments are shown on Figure 9-3.

2

NEPA Effects: The potential effect could be substantial because excavation of borrow material and the resultant cutslopes and potential failure of spoils/RTM fill slopes could cause injury of workers at the construction sites.

Excavations in borrow areas would be designed to avoid excessive ground movements on adjacent areas and soil "boiling" (i.e., upwelling of groundwater) at the bottom of the excavation. Spoils would be placed in 12-inch lifts with proper compaction and stored no higher than 12 feet above preconstruction ground elevation with maximum side slopes of 5H:1V. During design, the potential for native ground settlement below the spoils would be evaluated by a geotechnical engineer using site-specific geotechnical and hydrological information. The use of shoring, seepage cutoff walls, and ground modifications to prevent slope instability, soil boiling, or excessive settlement would be considered in the design.

In addition to the risk of slope failure at borrow sites and spoils and RTM sites, there are also potential impacts on levee stability resulting from construction of Alternative 1B water conveyance facilities. The intakes would be sited along the existing Sacramento River levee system, requiring reconstruction of levees to provide continued flood management. At each intake pumping plant site, a new setback levee (ring levee) would be constructed. The space enclosed by the setback levee would be filled up to the elevation of the top of the setback levee, creating a building pad for the adjacent pumping plant.

As discussed in Chapter 3, *Description of the Alternatives*, the new levees would be designed to provide an adequate Sacramento River channel cross section and to provide the same level of flood protection as the existing levee and would be constructed to geometries that meet or exceed PL 84-99 standards. CALFED and DWR have adopted PL 84-99 as the preferred design standard for Delta levees. Transition levees would be constructed to connect the existing levees to the new setback levees. A typical new levee would have a broad-based, generally asymmetrical triangular cross section. The levee height considered wind and wave erosion. As measured from the adjacent ground surface on the landside vertically up to the elevation of the levee crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the levee (toe of levee to toe of levee) would range from approximately 180 to 360 feet. The minimum crest width of the levee would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. Cut-off walls would be constructed to avoid seepage, and the minimum slope of levee walls would be three units horizontal to one unit vertical. All levee reconstruction will conform with applicable state and federal flood management engineering and permitting requirements.

Depending on foundation material, foundation improvements would require excavation and replacement of soil below the new levee footprint and potential ground improvement. The levees would be armored with riprap—small to large angular boulders—on the waterside. Intakes would be constructed using a sheetpile cofferdam in the river to create a dewatered construction area that would encompass the intake site. The cofferdam would lie approximately 10–35 feet from the footprint of the intake and would be built from upstream to downstream, with the downstream end closed last. The distance between the face of the intake and the face of the cofferdam would be dependent on the foundation design and overall dimensions. The length of each temporary cofferdam would vary by intake location, but would range from 740 to 2,440 feet. Cofferdams would be supported by steel sheet piles and/or king piles (heavy H-section steel piles). Installation of these piles may require both impact and vibratory pile drivers. Some clearing and grubbing of levees would be required prior to installation of the sheet pile cofferdam, depending on site conditions. Additionally, if stone bank protection, riprap, or mature vegetation is present at intake construction site, it would be removed prior to sheet pile installation.

As described in Section 9.3.1, *Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from failure of excavations and settlement. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from settlement/failure of cutslopes of borrow sites and failure of soil or RTM fill slopes during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1B would not create an increase likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures (geotextile fabrics, rock revetments, riprap, or other material), seepage reduction measures, and overall mass. Therefore, there would be no adverse effect.

CEQA Conclusion: Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures, seepage reduction measures, and overall mass. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

Pile driving and other heavy equipment operations would cause vibrations that could initiate liquefaction and associated ground movements in places where soil and groundwater conditions are present to allow liquefaction to occur. The consequences of liquefaction could be manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. These consequences could damage nearby structures and levees.

The lateral extent (or influenced distance) of damage potential caused by pile driving and heavy equipment operations depends on many factors, including soil conditions, the piling hammer used, frequency of piling, and the vibration tolerance of structures and levees.

Pile driving would be conducted at the intakes, where, based on boring logs, soil materials subject to liquefaction (e.g., saturated, poorly graded sand) are present. During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data (e.g., California Department of Water Resources 2009a, 2010i) to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil bearing capacity and extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake (i.e., the earthquake that is expected to produce the strongest level of ground shaking at a site to which it is appropriate to design a structure to withstand). If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

NEPA Effects: The potential effect could be substantial because construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites.

During design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. The potential effects of construction vibrations on nearby structures, levees, and utilities would be evaluated using specific piling information (such as pile type, length, spacing, and pile-driving hammer to be used). In areas determined to have a potential for liquefaction, the California-registered civil engineer or California-certified engineering geologist would develop design strategies and construction methods to ensure that pile driving and heavy equipment operations do not damage facilities under construction and surrounding structures and do not threaten the safety of workers at the site. As shown in Figure 9-6, the area from Disappointment Slough to Holt which Alternative 1B crosses through has medium to medium-high potential for levee liquefaction damage. Several siphons and a pumping plant north of Holt are located in this medium to medium-high potential for levee liquefaction damage area. Design measures may include predrilling or jetting, using open-ended pipe piles to reduce the energy needed for pile penetration, using CIDH piles/piers that do not require driving, using pile jacking to press piles into the ground by means of a hydraulic system, or driving piles during the drier summer months. Field data collected during design also would be evaluated to determine the need for and extent of strengthening levees, embankments, and structures to reduce the effect of vibrations. These construction methods would conform with current seismic design codes and requirements, as described in Chapter 3, *Description of the Alternatives*. Such design standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) that the construction methods recommended by the geotechnical engineer are included in the design of project facilities and construction specifications to minimize the potential for construction-induced liquefaction. DWR also has committed to ensure that these methods are followed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from construction-related ground motions:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to construction methods recommendations and other applicable specifications would ensure that construction of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals due to construction-related ground motion and resulting potential liquefaction in the work area. The effect would not be adverse.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, DWR has committed to conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1A would not create an increased likelihood of loss of property, personal injury or death of individuals from construction-related ground motion and resulting potential liquefaction in the work area, and the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*). The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

According to the available AP Earthquake Fault Zone Maps, none of the Alternative 1B facilities would cross or be within any known active fault zones. However, numerous AP fault zones have been mapped west of the conveyance alignment (Figure 9-5). The closest AP fault zone would be the Greenville fault, located approximately 13 miles west of the Alternative 1B conveyance alignment. Because none of the Alternative 1B constructed facilities would be within any of the fault zones (which include the area approximately 200 to 500 feet on each side of the mapped surface trace to account for potential branches of active faults), the potential that the facilities would be directly subject to fault offsets is negligible.

In the Delta, active or potentially active blind thrust faults were identified in the seismic study. Segments 2, 3, 4, and 5 of Alternative 1B conveyance alignment would cross the Thornton Arch fault zone. The western part of the proposed Byron Tract Forebay adjacent to the Clifton Court Forebay is underlain by the West Tracy fault. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). Assuming that the West Tracy fault is potentially active, it could cause surface deformation in the western part of the Clifton Court Forebay. Because the western part of the Byron Tract Forebay is also underlain by the hanging wall of the fault, this part of the forebay may also experience uplift and resultant surface deformation (Fugro Consultants 2011). In the seismic study (California Department of Water Resources 2007a), the Thornton Arch and West Tracy blind thrusts have been assigned 20% and 90% probabilities of being active, respectively. The depth to the Thornton Arch blind fault is unknown. The seismic study indicates that the West Tracy fault dies out as a discernible feature within approximately 3,000 to 6,000 feet bgs (in the upper 1 to 2 second depth two-way time, estimated to be approximately 3,000 to 6,000 feet using the general velocity function as published in the Association of Petroleum Geologists Pacific Section newsletter [Tolmachoff 1993]).

It appears that the potential of having any shear zones, bulging, or both at the depths of the tunnel siphons is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect would not be adverse because no active faults capable of surface rupture extend into the Alternative 1B alignment. Additionally, although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 1B alignment, based on available information, they do not present a hazard of surface rupture.

However, because of the limited information regarding the depths of the Thornton Arch and West Tracy blind thrusts, seismic surveys would be performed on the faults during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. The geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*).

For construction of the water conveyance facilities, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1B conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. Therefore, there would be no adverse effect.

CEQA Conclusion: There are no active fault capable of surface rupture that extend into the Alternative 1B alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 1B alignment, based on available information, they do not present a hazard of surface rupture.

Conformance to applicable design specifications and standards would ensure that operation of Alternative 1B would not create an increased likelihood of loss of property, injury or death of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone or West Tracy blind thrusts would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1B conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

Earthquake events may occur on the local and regional seismic sources during operation of the Alternative 1B water conveyance facilities. The ground shaking could damage the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities disrupting the water supply through the conveyance system. In an extreme event of strong seismic shaking, uncontrolled release of water from the damaged canal, pipelines, tunnel siphons, intake facilities, pumping plants, and other facilities could cause flooding, disruption of water supplies to the south, and inundation of structures. These effects are discussed more fully in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*. The potential of earthquake ground shaking in the early long-term (2025) was estimated using the results of the seismic study (California Department of Water Resources 2007a). Table 9-21 lists the expected PGA and 1.0-S_a values for early long-term. Earthquake ground shakings for the OBE (144-year return period) and MDE (975-year return period) were estimated for the stiff soil site, as predicted in the seismic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No seismic study results exist for 2025, so the ground shakings estimated for 2050 were used for early long-term.

Table 9-21 shows that the proposed facilities would be subject to moderate-to-high earthquake ground shakings in the Early Long-term through 2025. All facilities would be designed and constructed in accordance with the requirements of the design measures described in Appendix 3B, *Environmental Commitments*. Site-specific geotechnical information would be used to further assess the effect of local soil on the OBE and MDE ground shakings and to develop design criteria to minimize the potential of damage.

NEPA Effects: The potential effect could be substantial because strong ground shaking could damage pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the conveyance system could cause flooding and inundation of structures. Please refer to Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

Design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the conveyance features to withstand the peak ground acceleration caused by fault movement in the region. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards.

Table 9-21. Expected Earthquake Ground Motions at Locations of Selected Major Facilities in the Early Long-Term (2025)—Alternative 1B

	144-year Return Period Ground Motions (OBE)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake Locations[c]	0.14	0.15	0.19	0.30
Tunnel Siphon Location near Venice Island[d]	0.30	0.33	0.31	0.50
Clifton Court Forebay / Byron Tract Forebay	0.28	0.31	0.30	0.48
	975-year Return Period Ground Motions (MDE)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[e]	Stiff Soil[a]	Local Soil[e]
Intake Locations[c]	0.24	0.24	0.33	0.53
Tunnel Siphon Location near Venice Island[d]	0.50	0.50	0.60	0.96
Clifton Court Forebay / Byron Tract Forebay	0.50	0.50	0.61	0.98

g = gravity
MDE = maximum design earthquake
OBE = operating basis earthquake
PGA = Peak Ground Acceleration
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.1 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island were used.
[e] Site-adjusted factors of 1.0 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction. See Appendix 3B, *Environmental Commitments*.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003

- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

Conformance with these standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1B would not create an increased likelihood of loss of property, personal injury or death of individuals from strong seismic shaking of surface and subsurface facilities along the Alternative 1B conveyance alignment. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt SWP and CVP water supply deliveries through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the Alternative 1B water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

Earthquake-induced ground shaking could cause liquefaction, resulting soil slumping or lateral spreading and subsequent damage to or breaching of water conveyance structures and facilities. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. Failure of the canal, tunnel and culvert siphons, pipelines, levees, bridges, and other structures and facilities could result in loss or injury and disrupt SWP and CVP water supply deliveries. The potential for impacts from flooding as a result of levee or dam failure is also discussed in Chapter 6, *Surface Water*.

The native soils underlying Alternative 1B facilities consist of floodplain, natural levee, eolian sand, and flood basin deposits, along with more consolidated Modesto Formation materials locally. The more recently-deposited, sandy materials would be more prone to liquefaction. Figure 9-6 shows that the Alternative 1B alignment has no substantial liquefaction damage potential in its northern part and low to medium-high damage potential in its central and southern parts from Disappointment Slough down to the proposed Byron Tract Forebay.

NEPA Effects: The potential effect could be substantial because seismically induced ground shaking could cause liquefaction, which could result in damage to the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. Please refer to Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

In the process of preparing final facility designs, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to further assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high “fines” (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

During final design, site-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, a California-registered civil engineer or California-certified engineering geologist would develop design measures and construction methods to meet design criteria established by building codes and construction standards to ensure that the design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, and using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods). The results of the site-specific evaluation and California-registered civil engineer or California-certified engineering geologist's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design requirements is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from liquefaction and associated hazard. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of liquefaction and associated ground movements would not create an increased likelihood of loss of property, personal injury or death of individuals from structural failure resulting from seismic-related ground failure along the Alternative 1B conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion**:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood effects.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the Alternative 1B water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

Alternative 1B would involve excavation that creates new cut-and-fill slopes and construction of new embankments and levees. As a result of ground shaking and high soil-water content during heavy rainfall, existing and new slopes that are not properly engineered and natural stream banks could fail. Levees can fail for several reasons: 1) high velocities of water flow can result in high rates of erosion and erode and overtop a levee; 2) the higher velocities of water flow can also lead to higher rates of erosion along the inner parts of levees and lead to undercutting and clumping of the levee into the river. Heavy rainfall or seepage into the levee from the river can increase fluid pressure in the levee and lead to slumping on the outer parts of the levee. If the slumps grow to the top of the levee, large sections of the levee may slump onto the floodplain and lower the elevation of the top of the levee, leading to overtopping; 3) increasing levels of water in the river will cause the water table in the levee to rise which will increase fluid pressure and may result in seepage and eventually lead to internal erosion called piping. Piping will erode the material under the levee, undermining it and causing its collapse and failure.

With the exception of levee slopes and natural stream banks, the topography along the Alternative 1B conveyance alignment is nearly level to very gently sloping. The areas susceptible to slope failure are along existing levee slopes and at intake, pumping plant, forebay, and certain access road locations. Outside these areas, the land is nearly level and consequently has a negligible potential for slope failure.

Based on review of topographic maps, the conveyance facilities would not be constructed on, nor would it be adjacent to, slopes that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. As discussed in Impact SW-2 in Chapter 6, *Surface Water*, operation of the water conveyance features under Alternative 1B would not result in an increase in potential risk for flood management compared to existing conditions. Peak monthly flows under Alternative 1B in the locations considered were similar to or less than those that would occur under existing conditions. Since flows would not be substantially greater, the potential for increased rates of erosion or seepage are low. For additional discussion on the possible exposure of people or structures to a significant risk of loss or injury from flooding due to levee failure, please refer to Impact SW-6 in Chapter 6, *Surface Water*.

During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. The design criteria would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As discussed in Chapter 3, *Description of the Alternatives*, the foundation soil beneath slopes, embankments, or levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill also would be used to construct new slopes, embankments, and levees. Surface and internal drainage systems would be installed as necessary to reduce erosion and piping (internal erosion) potential.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Section 9.3.1, *Methods for Analysis*, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.* The design requirements would be presented in a detailed geotechnical report. Conformance with these design requirements is an environmental commitment by DWR to ensure that slope stability hazards would be avoided as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of cut and fill slopes, embankments, and levees to minimize the potential effects from slope failure. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic shaking or from high-pore water pressure:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not create an increased likelihood of loss of property or injury of individuals along the Alternative 1B conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. The measures would be described in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the Alternative 1B water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Therefore, the potential hazard of loss of property or personal injury as a result of a tsunami on the water conveyance facilities is low.

Similarly, with the exception of the Clifton Court Forebay and the Byron Tract Forebay, the potential for a substantial seiche to take place in the Plan Area is considered low because seismic and water body geometry conditions for a seiche to occur near conveyance facilities are not favorable. Fugro Consultants, Inc. (2011) identified the potential for a seiche of an unspecified wave height to occur in the Clifton Court Forebay, caused by strong ground motions along the underlying West Tracy fault, assuming that this fault is potentially active. Since the fault also exists in the immediate vicinity of the Byron Tract Forebay, a seiche could also occur in the Byron Tract Forebay.

NEPA Effects: The effect of a tsunami generated in the Pacific Ocean would not be adverse because the distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low (i.e., less than 2 feet) tsunami wave height to reach the Delta (Contra Costa Transportation Agency 2009).

In most parts of the Plan Area, the effects of a seiche would not be adverse because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay. The effect could be adverse because the waves generated by a seiche could overtop the Byron Tract Forebay and Clifton Court Forebay embankments, causing erosion of the embankments and subsequent flooding in the vicinity.

However, design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would determine the peak ground acceleration caused by movement of the West Tracy fault and the maximum probable seiche wave that could be generated by the ground shaking. The engineer's recommended measures to address this hazard, as well as the hazard of a seiche overtopping the Clifton Court Forebay embankment and subsequent adverse effect on the Byron Tract Forebay embankment, would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that the adverse effects of a seiche are controlled to an acceptable level while the forebay facility is operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and in construction specifications to minimize the potential effects from seismic events and consequent seiche waves. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from tsunami or seiche:

- U.S. Department of the Interior and USGS Climate Change and Water Resources Management: A Federal Perspective, Circular 1331.
- State of California Sea-Level Rise Task Force of the CO-CAT, Sea-Level Rise Interim Guidance Document, 2010.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes provide guidance on estimating the effects of climate change and sea level rise and associated effects when designing a project and ensuring that a project is able to respond to these effects.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the Byron Tract Forebay embankment would be designed and constructed to contain and withstand the anticipated maximum seiche wave height and would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 1B conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required.

Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height and potential seiche wave overtopping of the Clifton Court Forebay and Byron Tract Forebay embankments as the Alternative 1B water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

If unlined canals (as opposed to lined canals) would be constructed, seepage from the sideslopes and bottom of the unlined canals could occur where the normal water level in the canal is higher than the water surface elevation of the adjacent areas. The seepage could raise the water table on the landside of the embankments through more permeable lenses of sand and/or gravel in the foundation soil. Increased water table levels may increase the likelihood of ground settlement and earthquake-induced liquefaction.

NEPA Effects: The effect would be adverse because seepage from an unlined canal could raise the water table in the area adjacent to the canal and increase the hazard of liquefaction in the vicinity.

However, the amount of seepage from the canal is not expected to be substantial because the canal foundation and surface materials, derived from local borrow areas, would be selected based on site-specific geotechnical evaluations. An engineer would design the canal to prevent excessive loss of water from seepage. Additionally, control of excessive seepage may be accomplished through the installation of a slurry cutoff wall in the canal. A cutoff wall would be most effective in areas where the canal is constructed in relatively permeable materials, such as layers of permeable sand and gravels. Additional measures that could be implemented to offset the effects of seepage water include the following:

- Use of a drainage ditch parallel to the canal to control seepage. Water in the drainage ditch would then be pumped into the sloughs or back into the canal.
- Installation of pressure-relief wells to collect subsurface water and direct it into the parallel drainage ditch.

As indicated above and in Chapter 3, *Description of the Alternatives*, engineers would use site-specific geotechnical and hydrological information to design the canal, and the design would conform with the current standards and construction practices specified by USACE and DWR design standards. As described in Section 9.3.1, *Methods for Analysis*, such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*). For construction of the canal and any required seepage control measures, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects.* These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the canal design to minimize the potential excessive seepage. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury as a result of ground failure resulting from unlined canal seepage:

- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of potential excessive seepage and resulting soil instability.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the applicable design specifications and standards would ensure that the hazard of seepage from the canal would not cause an excessive increase in the water surface elevation in areas adjoining the canal resulting in ground failure. Therefore, the effect would not be adverse.

CEQA Conclusion**:** Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures, there would be no increased likelihood of loss of property, personal injury or death of individuals from ground failure caused by increased groundwater surface elevations. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

According to the available AP Earthquake Fault Zone Maps, only the Suisun Marsh ROA could be affected by rupture of an earthquake fault. The active Green Valley fault crosses the southwestern corner of the ROA. The active Cordelia fault extends approximately one mile into the northwestern corner of the ROA. Rupture of these faults could damage levees and berms constructed as part of the restoration, which could result in failure of the levees and flooding of otherwise protected areas.

Within the Delta, active or potentially active blind thrust faults were identified in the seismic study (California Department of Water Resources 2007a). The extreme southeastern corner of the Suisun

Marsh ROA is underlain by the Montezuma blind thrust zone. Parts of the Cache Slough and Yolo Bypass ROAs are underlain by part of the North Midland blind thrust zone. The Cosumnes/Mokelumne River and East Delta ROAs are underlain by the Thornton Arch zone. Although these blind thrusts are not expected to rupture to the ground surface during earthquake events, they may produce ground or near-ground shear zones, bulging, or both. In the seismic study (California Department of Water Resources 2007a), the Thornton Arch blind thrust was assigned a 20% probability of being active. The depth to the Thornton Arch blind fault is unknown. Based on limited geologic and seismic survey information, it appears that the potential of having any shear zones, bulging, or both at the depths of the habitat levees is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect of implementing the conservation measures in the ROAs could be substantial because rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and cause damage or failure of ROA facilities, including levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

Because there is limited information regarding the depths of the blind faults mentioned above, seismic surveys would be performed in the vicinity of the faults as part of final design. These surveys would be used to verify fault depths where levees and other features would be constructed. Collection of this depth information would be part of broader, design-level geotechnical studies prepared by a licensed engineer to support all aspects of site-specific project design. The studies would assess site-specific conditions at and near all the project facility locations, including the nature and engineering properties of all soil horizons and underlying geologic strata, and groundwater conditions. The engineer's information would be used to develop final engineering solutions to any hazardous condition, consistent with the code and standards requirements of federal, state and local oversight agencies. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that risks from a fault rupture are minimized as conservation levees are constructed and maintained. The hazard would be controlled to a safe level by following the proper design standards.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.

- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of ground movement in the vicinity of the blind thrusts underlying the ROAs would not jeopardize the integrity of the levees and other features constructed in the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion**:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

Earthquake events may occur on the local and regional seismic sources at the ROAs. Because of its proximity to these faults, the Suisun Marsh ROA would be especially subject to ground shaking caused by the Concord-Green Valley fault. The Cache Slough ROA would be subject to shaking from the Northern Midland fault zone, which underlies the ROA. Although more distant from these sources, the other ROAs would be subject to shaking from the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust faults and the more proximate blind thrusts in the Delta.

Among all the ROAs, the Suisun Marsh ROA would be most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. The ground shaking could damage levees and other structures, and in an extreme event cause levees to fail such that protected areas flood.

NEPA Effects: All temporary facilities would be designed and built to meet the safety and collapse-prevention requirements for the above-anticipated seismic loads. Therefore, this effect is considered not adverse. No additional mitigation measures are required. All facilities would be designed and constructed in accordance with the requirements of the design measures described in Chapter 3, *Description of the Alternatives*. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize the potential of damage.

Design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the levees and other features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical engineer's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are implemented.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project features and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.

- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of seismic shaking would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR‘s Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE‘s *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

New structural features are proposed at the ROAs, such as levees as part of CM4, setback levees as part of CM5 and CM6, and experimental ramps and fish ladders at the Fremont Weir as part of CM2. Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees and other features constructed at the restoration areas. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), and increased lateral soil pressure. Failure of levees and other features could result in flooding of otherwise protected areas in Suisun Marsh and behind new setback levees along the Sacramento and San Joaquin Rivers and in the South Delta ROA.

The ROAs vary with respect to their liquefaction hazard (Figure 9-6). The Suisun Marsh ROA generally has a moderate liquefaction hazard. The liquefaction damage potential among the other ROAs is generally low to medium.

NEPA Effects: The potential effect could be substantial because earthquake-induced liquefaction could damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

During final design of conservation facilities, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high “fines” (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

During final design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, the engineer would develop design parameters and construction methods to meet the design criteria established to ensure that design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods), and conforming with current seismic design codes and requirements, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE‘s *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic-related ground failure:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995

- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during implementation and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Implementation of CM2–CM7, would involve breaching, modification or removal of existing levees and construction of new levees and embankments. CM4 which provides for the restoration of up to 65,000 acres of tidal perennial aquatic, tidal mudflat, tidal freshwater emergent wetland, and tidal brackish emergent wetland natural communities within the ROAs involves the greatest amount of modifications to levees. Levee modifications, including levee breaching or lowering, may be performed to reintroduce tidal exchange, reconnect remnant sloughs, restore natural remnant meandering tidal channels, encourage development of dendritic channel networks, and improve floodwater conveyance.

Levee modifications could involve the removal of vegetation and excavation of levee materials. Excess earthen materials could be temporarily stockpiled, then re-spread on the surface of the new levee slopes where applicable or disposed of offsite. Any breaching or other modifications would be required to be designed and implemented to maintain the integrity of the levee system and to conform with flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies. Those agencies may include USACE, DWR, CVFPB, and other flood management agencies. For more detail on potential modifications to levees as a part of conservation measures, please refer to Chapter 3, *Description of Alternatives*.

New and existing levee slopes and stream/channel banks could fail and could damage facilities as a result of seismic shaking and as a result of high soil-water content during heavy rainfall. With the exception of levee slopes, natural stream banks, and part of the Suisun Marsh ROA, the topography of ROAs is nearly level to gently sloping. The areas that may be susceptible to slope failure are along existing Sacramento and San Joaquin River and Delta island levees and stream/channel banks particularly those levees that consist of non-engineered fill and those streambanks that are steep and consist of low strength soil.

The structures associated with conservation measures would not be constructed in, nor would they be adjacent to, areas that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in flooding of otherwise protected areas.

As outlined in Chapter 3, *Description of Alternatives*, erosion protection measures and protection against related failure of adjacent levees would be taken where levee breaches were developed. Erosion protection could include geotextile fabrics, rock revetments, riprap, or other material selected during future evaluations for each location. Aggregate rock could be placed on the remaining levees to provide an access road to the breach location. Erosion protection measures would also be taken where levee lowering is done for the purposes of allowing seasonal or periodic inundation of lands during high flows or high tides to improve habitat or to reduce velocities and elevations of floodwaters. To reduce erosion potential on the new levee crest, a paved or gravel access road could be constructed with short (approximately 1 foot) retaining walls on each edge of the crest to reduce undercutting of the roadway by high tides. Levee modifications could also include excavation of watersides of the slopes to allow placement of slope protection, such as riprap or geotextile fabric, and to modify slopes to provide levee stability. Erosion and scour protection could be placed on the landside of the levee and continued for several feet onto the land area away from the levee toe. Neighboring levees could require modification to accommodate increased flows or to reduce effects of changes in water elevation or velocities along channels following inundation of tidal marshes. Hydraulic modeling would be used during subsequent analyses to determine the need for such measures.

New levees would be constructed to separate lands to be inundated for tidal marsh from non-inundated lands, including lands with substantial subsidence. Levees could be constructed as described for the new levees at intake locations. Any new levees would be required to be designed and implemented to conform with applicable flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies, which may include USACE, DWR, CVFPB, and local flood management agencies.

Additionally, during project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As required by design standards and building codes (see Appendix 3B, *Environmental Commitments*), foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from landslides or other slope instability:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.µ

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levee and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion**:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

The distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low tsunami wave height to reach the Suisun Marsh and the Delta. Conditions for a seiche to occur at the ROAs are not favorable. Therefore, the effect would not be adverse.

CEQA Conclusion**:** Based on recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.4 Alternative 1C—Dual Conveyance with West Alignment and Intakes W1–W5 (15,000 cfs; Operational Scenario A)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

Earthquakes could be generated from on local and regional seismic sources during construction of the Alternative 1C water conveyance facilities. Seismically induced ground shaking could cause injury of workers at the construction sites as a result of collapse of facilities.

The potential for experiencing earthquake ground shaking during construction in 2020 (during the project's near-term implementation stage) was estimated using the results of the seismic study (California Department of Water Resources 2007a). The study also computed seismic ground shaking hazards at six locations in the Delta for 2005, 2050, 2100, and 2200. The results of these analyses show that the ground shakings in the Delta are not sensitive to the elapsed time since the last major earthquake (that is, the projected shaking hazard results for 2005, 2050, 2100, and 2200) are similar.

Table 9-22 lists the expected PGA and 1.0-S_a values in 2020 at selected facility locations along the Alternative 1C alignment. As with Alternative 1B, ground motions with a return period of 72 years and computed for 2005 were used to represent near-term (i.e., 2020) construction period motions for Alternative 1C.

Table 9-22. Expected Earthquake Ground Motions at Locations of Selected Major Facilities during Construction (2020)—Alternative 1C

	72-year Return Period Ground Motions			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake and Fish Screen Area[c]	0.11	0.14	0.13	0.21
Tunnel Location between Bradford Island and Webb Tract[d]	0.20	0.26	0.22	0.35
Clifton Court Forebay/Byron Tract Forebay	0.18	0.23	0.20	0.32

g = gravity

S_a = second spectral acceleration

[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.

[b] Site-adjusted factors of 1.3 and 1.6 were applied to PGA and 1.0-sec S_a values, respectively (adjustments from a stiff soil site to a soft soil site).

[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.

[d] The results of California Department of Water Resources 2007a for the Sherman Island were used.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted by the study would increase if no major events occur on these faults through 2020. The effect would be adverse because seismically induced ground shaking could cause collapse of facilities. For example, the concrete batch plant and fuel station on Bradford Island, several siphons, a fuel station and concrete batch plant west of Clifton Court Forebay, the entire length of the water conveyance from the middle of Ryer Island down to the Byron Tract Forebay for Alternative 1C all lie on or near the Southern Midland fault, a single, potentially seismogenic fault; or the West Tracy fault. Both are active blind faults, resulting in an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Mapbook Figure M3-3.

However, during construction, all active construction sites would be designed and managed to meet the safety and collapse-prevention requirements of the relevant state codes and standards listed earlier in this chapter and expanded upon in Appendix 3B, *Environmental Commitments* for the above-anticipated seismic loads. In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design – Earthquake Design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6053, 2007.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence). The safety requirements could include shoring, specified slope angles, excavation depth restrictions for workers, lighting and other similar controls. Conformance with these standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by DWR and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements to protect worker safety are the principal measures that would be enforced at construction sites. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking that is estimated to occur and the resultant ground motion anticipated at Alternative 1C construction sites, including the canal, pipelines and the forebays, could cause collapse or other failure of project facilities while under construction. For example, the concrete batch plant and fuel station on Bradford Island, several siphons, a fuel station and concrete batch plant west of Clifton Court Forebay, the entire length of the water conveyance from the middle of Ryer Island down to the Byron Tract Forebay for Alternative 1C all lie on or near the Southern Midland fault, a single, potentially seismogenic fault; or the West Tracy fault. Both are active blind faults, resulting in an increased likelihood of direct loss or injury at these sites in the event of seismically-induced ground shaking. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals. This risk would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Settlement of excavations could occur as a result of construction dewatering if proven construction and dewatering methods and earthwork practices are not carried out. The settlement could cause the slopes of excavations to fail. This hazard is most likely to be present at the intake and pumping plant locations and the canal alignment. The preliminary dewatering analysis results indicate that the majority (more than 90%) of the dewatering needs for Alternative 1C construction would be associated with canal construction (i.e., for the excavation of the canal foundation). The proposed canal for Alternative 1C is located on alluvial floodbasin deposits, alluvial floodplain deposits, natural levee deposits, peat and muck, and the Modesto Formation. Similar dewatering may be necessary where conveyance pipelines cross waterways and major irrigation canals. The conveyance pipeline between Intake 1 and the canal crosses 5 canals or ditches, Winchester Lake, and Elk Slough. The intersections with Winchester Lake and one of the canals or ditches occur about 0.4 miles west of the Sacramento River. The crossing of Elk Slough occurs approximately 0.8 miles southwest of the slough's confluence with the Sacramento River. The pipeline crosses 3 canals or ditches north of S. River Road, east and west of Rose Road. The final intersection with a canal or ditch is about 0.3 miles north of Clarksburg Road, west of the community of Clarksburg. The intake pipeline and conveyance pipeline associated with Intake 2 would each intersect one canal or ditch. Both of these intersection points would be less than 0.1 mile south of County Road 141 on Merritt Island. The intake pipeline and conveyance pipeline associated with Intake 3 would each intersect one canal or ditch. Both of these intersection points would be less than 0.1 mile south of County Road 142 on Merritt Island.

The conveyance pipeline between Intake 4 and the canal would intersect with one canal or ditch, about 0.3 miles northwest of the facility grounds for Intake 4. The conveyance pipeline between Intake 5 and the canal would cross two canals or ditches. These lies east and southeast of Elk Slough, approximately 0.25 miles and 0.5 miles (respectively) north of the facility grounds for Intake 5.

Dewatering can stimulate settlement in excavation and tunneling sites. The settlement could cause the slopes of excavations to fail.

NEPA Effects: The potential effect could be substantial because settlement or collapse during dewatering could cause collapse of excavations.

The hazard of settlement and subsequent collapse of excavations would be evaluated by assessing site-specific geotechnical and hydrological conditions along the canal, as well as where intake and forebay pipelines cross waterways and major irrigation canals. A California-registered civil engineer or California-certified engineering geologist would recommended measures in a geotechnical report to address these hazards, such as seepage cutoff walls and barriers, shoring, grouting of the bottom of the excavation, and strengthening of nearby structures, existing utilities, or buried structures. As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. See Appendix 3B, *Environmental Commitments*.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from settlement or collapse at the construction site caused by dewatering during construction:

- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built in such a way that settlement is minimized. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

Two types of ground settlement could be induced during Alternative 1C tunnel construction: large settlement and systematic settlement. Large settlement occurs primarily as a result of over-excavation by the tunneling shield. The over-excavation is caused by failure of the tunnel boring machine to control unexpected or adverse ground conditions (for example, running, raveling, squeezing, and flowing ground) or operator error. Large settlement can lead to the creation of voids and/or sinkholes above the tunnel and the culvert siphons. In extreme circumstances, the settlement effects could translate to the ground surface, potentially causing loss of property or personal injury above the tunneling operation.

Systematic settlement usually results from ground movements that occur before tunnel supports can exit the shield and the tunnel to make full contact with the ground. Soil with higher silt and clay content tend to experience less settlement than sandy soil. Additional ground movements can occur with the deflection of the tunnel supports and over-excavation caused by steering/plowing of the tunnel boring machine at horizontal and vertical curves. A deeper tunnel induces less ground surface settlement because a greater volume of soil material is available above the tunnel to fill any systematic void space.

The geologic units in the area of the Alternative 1C alignment are shown on Figure 9-3 and summarized in Table 9-23. The characteristics of each unit would affect the potential for settlement during tunnel construction. Segment 4, located from the middle of Ryer Island running south to just west of Summer Lake, is primarily where the tunnel portion of Alternative 1C lies.

Table 9-23. Geology of Alternative 1C/West Alignment by Segments

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 and Segment 2	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Segment 3	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 4 (Tunnel Portion)	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qpm	Delta mud: mud and peat with minor silt or sand
	Qds	Dredge soils, post 1900
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
Segment 5, Segment 6, and Segment 7	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
Segment 8, Segment 9 and Segment 10	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
Segment 11	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 12	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
Byron Tract Forebay (Northwest of Clifton Court Forebay Location)	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel

Source: Hansen et al. 2001 and Atwater 1982.
[a] The segments are shown on Figure 9-3.

Given the likely design depth of the tunnel and the culvert siphons, the potential for excessive systematic settlement expressed at the ground surface caused by tunnel installation is thought to be relatively low. Operator errors or highly unfavorable/unexpected ground conditions could result in larger settlement. Large ground settlements caused by tunnel construction are almost always the result of using inappropriate tunneling equipment (incompatible with the ground conditions), improperly operating the machine, or encountering sudden or unexpected changes in ground conditions.

NEPA Effects: The potential effect could be substantial because ground settlement could occur during the tunneling operation. During detailed project design, a site-specific subsurface geotechnical evaluation would be conducted along the water conveyance facility alignment to verify or refine the findings of the preliminary geotechnical investigation. The tunneling equipment and drilling methods would be reevaluated and refined based on the results of the investigations, and field procedures for sudden changes in ground conditions would be implemented to minimize or avoid ground settlement. A California-registered civil engineer or California-certified engineering geologist would recommend measures to address these hazards, such as specifying the type of tunnel boring machine to be used in a given segment. The results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008).

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from ground settlement above the tunneling operation during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

As described in detail in Impacts GEO-1 and GEO-2, DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement. DWR would also ensure that the design specifications are properly executed during construction. DWR has made this conformance and monitoring process an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*).

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of ground settlement. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. This risk would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

Excavation of borrow material could result in failure of cut slopes and application of temporary spoils and RTM at storage sites could cause excessive settlement in the spoils, potentially causing injury of workers at the construction sites. Soil and sediment, especially those consisting of loose alluvium and soft peat or mud, would particularly be prone to failure and movement. Additionally, groundwater is expected to be within a few feet of the ground surface in these areas, this may make excavations more prone to failure.

Borrow and spoils areas for construction of the canal foundation, intakes, sedimentation basins, pumping plants, forebays, and other supporting facilities would be sited near the locations of these structures (generally within 10 miles). Along the alignment, selected areas would also be used for disposing of the byproduct (RTM) of tunnel construction. Table 9-24 describes the geology of these areas as mapped by Atwater (1982) (Figure 9-3).

Table 9-24. Geology of Alternative 1C Borrow/Spoils and Reusable Tunnel Material Areas by Segments

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 and Segment 2 Borrow/Spoils	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Segment 3 Borrow/Spoils	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 6, Segment 7, Segment 8 and Segment 9 Borrow/Spoils	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
Segment 10 Borrow/Spoils	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
Segment 11 and Segment 12 Borrow/Spoils	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
Segment 4 Resuable Tunnel Material Area	Qpm	Delta mud: mud and peat with minor silt or sand
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel

Source: Hansen et al. 2001 and Atwater 1982.
[a] The segments are shown on Figure 9-3.

NEPA Effects: The potential effect could be substantial because excavation of borrow material and the resultant cutslopes and potential failure of spoils/RTM fill slopes could cause injury of workers at the construction sites.

Excavations in borrow areas would be designed to avoid excessive ground movements on adjacent areas and soil "boiling" (i.e., upwelling of groundwater) at the bottom of the excavation. Spoils would be placed in 12-inch lifts with proper compaction and stored no higher than 12 feet above preconstruction ground elevation with maximum side slopes of 5H:1V. During design, the potential for native ground settlement below the spoils would be evaluated by a geotechnical engineer using site-specific geotechnical and hydrological information. The use of shoring, seepage cutoff walls, and ground modifications to prevent slope instability, soil boiling, or excessive settlement would be considered in the design. As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*.

In addition to the risk of slope failure at borrow sites and spoils and RTM sites, there are also potential impacts on levee stability resulting from construction of Alternative 1C water conveyance facilities. The intakes would be sited along the existing Sacramento River levee system, requiring reconstruction of levees to provide continued flood management. At each intake pumping plant site, a new setback levee (ring levee) would be constructed. The space enclosed by the setback levee would be filled up to the elevation of the top of the setback levee, creating a building pad for the adjacent pumping plant.

As discussed in Chapter 3, *Description of the Alternatives*, the new levees would be designed to provide an adequate Sacramento River channel cross section and to provide the same level of flood protection as the existing levee and would be constructed to geometries that meet or exceed PL 84-99 standards. CALFED and DWR have adopted PL 84-99 as the preferred design standard for Delta levees. Transition levees would be constructed to connect the existing levees to the new setback levees. A typical new levee would have a broad-based, generally asymmetrical triangular cross section. The levee height considered wind and wave erosion. As measured from the adjacent ground surface on the landside vertically up to the elevation of the levee crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the levee (toe of levee to toe of levee) would range from approximately 180 to 360 feet. The minimum crest width of the levee would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. Cut-off walls would be constructed to avoid seepage, and the minimum slope of levee walls would be three units horizontal to one unit vertical. All levee reconstruction will conform with applicable state and federal flood management engineering and permitting requirements.

Depending on foundation material, foundation improvements would require excavation and replacement of soil below the new levee footprint and potential ground improvement. The levees would be armored with riprap—small to large angular boulders—on the waterside. Intakes would be constructed using a sheetpile cofferdam in the river to create a dewatered construction area that would encompass the intake site. The cofferdam would lie approximately 10–35 feet from the footprint of the intake and would be built from upstream to downstream, with the downstream end closed last. The distance between the face of the intake and the face of the cofferdam would be dependent on the foundation design and overall dimensions. The length of each temporary cofferdam would vary by intake location, but would range from 740 to 2,440 feet. Cofferdams would be supported by steel sheet piles and/or king piles (heavy H-section steel piles). Installation of these piles may require both impact and vibratory pile drivers. Some clearing and grubbing of levees would be required prior to installation of the sheet pile cofferdam, depending on site conditions. Additionally, if stone bank protection, riprap, or mature vegetation is present at intake construction site, it would be removed prior to sheet pile installation.

As described in Section 9.3.1, *Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from failure of excavations and settlement. DWR also has committed to ensure that the design specifications are properly executed during construction. In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from settlement/failure of cutslopes of borrow sites and failure of soil or RTM fill slopes during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures (geotextile fabrics, rock revetments, riprap, or other material), seepage reduction measures, and overall mass. Therefore, there would be no adverse effect.

CEQA Conclusion: Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures, seepage reduction measures, and overall mass. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

Pile driving and other heavy equipment operations would cause vibrations that could initiate liquefaction and associated ground movements in places where soil and groundwater conditions are present to allow liquefaction to occur. The consequences of liquefaction could be manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. These consequences could cause loss of property or personal injury and could damage nearby structures and levees.

The lateral extent (or influenced distance) of damage potential caused by pile driving and heavy equipment operations depends on many factors, including soil conditions, the piling hammer used, frequency of piling, and the vibration tolerance of structures and levees.

Pile driving would be conducted at the intakes, where, based on boring logs, soil materials subject to liquefaction (e.g., saturated, poorly graded sand) are present. During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data (e.g., California Department of Water Resources 2009b, 2010d, 2010i) to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil bearing capacity and extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes (i.e., the earthquake that is expected to produce the strongest level of ground shaking at a site to which it is appropriate to design a structure to withstand). The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

NEPA Effects: The potential effect could be substantial because construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. During design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. The potential effects of construction vibrations on nearby structures, levees, and utilities would be evaluated using specific piling information (such as pile type, length, spacing, and pile-driving hammer to be used). In areas determined to have a potential for liquefaction, the engineer would develop design measures and construction methods to ensure that pile driving and heavy equipment operations do not damage facilities under construction and surrounding structures and do not threaten the safety of workers at the site. As shown in Figure 9-6, a majority of Alternative 1C crosses through an area classified as medium to low liquefaction hazard. Alternative 1C also runs through Brannan Island and Twitchell Island, which have medium to medium-high levee liquefaction damage potential. A barge unloading facility is located at the northern end of Brannan Island in this medium to medium-high levee liquefaction damage potential area. Design strategies may include predrilling or jetting, using open-ended pipe piles to reduce the energy needed for pile penetration, using CIDH piles/piers that do not require driving, using pile jacking to press piles into the ground by means of a hydraulic system, or driving piles during the drier summer months. Field data collected during design also would be evaluated to determine the need for and extent of strengthening levees, embankments, and structures to reduce the effect of vibrations. These construction methods would conform with current seismic design codes and requirements, as described in Chapter 3, *Description of the Alternatives*. Such design standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) recommended by the geotechnical engineer are included in the design of project facilities and construction specifications to minimize the potential for construction-induced liquefaction. DWR also has committed to ensure that these methods are followed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from construction-related ground motions:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991

- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to construction methods recommendations and other applicable specifications would ensure that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals due to construction-related ground motion and resulting potential liquefaction in the work area. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, DWR has committed to conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures. Conformance with these requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from construction-related ground motion and resulting potential liquefaction in the work area and the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*). The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

According to the available AP Earthquake Fault Zone Maps, none of the Alternative 1C facilities would cross or be within any known active fault zones. However, numerous AP fault zones have been mapped west of the conveyance alignment (Figure 9-5). The closest AP fault zone would be the Greenville fault, located approximately 8.1 miles west of the Alternative 1C conveyance facilities. The Midway fault is also mapped approximately 3.4 miles west of the Alternative 1C conveyance facilities, near the cities of Tracy and Livermore. Because none of the Alternative 1C constructed facilities would be within any of the fault zones (which include the area approximately 200 to 500 feet on each side of the mapped surface trace to account for potential branches of active faults) the potential that the facilities would be directly subject to fault offsets is negligible.

In the Delta, active or potentially active blind thrust faults were identified in the seismic study. Segment 4 of the Alternative 1C conveyance alignment would cross the Southern Midland fault and continue through the Montezuma Hills fault zone. Segment 5 and part of Segment 6 would also cross the Montezuma Hills fault zone. The western part of the proposed Byron Tract Forebay adjacent to the Clifton Court Forebay is underlain by the West Tracy fault and the southernmost segment of the Southern Midland fault. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). Assuming that the West Tracy fault is potentially active, it could cause surface deformation in the western part of the Clifton Court Forebay. Because the western part of the Byron Tract Forebay is also underlain by the hanging wall of the fault, this part of the forebay may also experience uplift and resultant surface deformation (Fugro Consultants 2011). In the seismic study, the South Midland, Montezuma Hills, and West Tracy blind thrusts were assigned 80%, 50%, and 90% probabilities of being active, respectively (California Department of Water Resources 2007a).

The depth to the Montezuma Hills faults is unknown. The seismic study (California Department of Water Resources 2007a) indicates that the West Tracy fault dies out as a discernible feature within approximately 3,000 to 6,000 feet bgs (in the upper 1 to 2 second depth two-way time, estimated to be approximately 3,000 to 6,000 feet using the general velocity function as published in the Association of Petroleum Geologists Pacific Section newsletter [Tolmachoff 1993]). This same study indicates that the tip of the Southern Midway fault is said to extend above the base of the Tertiary Markley Formation to depths of about 1.5 km or 4,900 feet, and possibly shallower. The minimum fault depth has not been determined.

It appears that the potential of having any shear zones, bulging, or both at the depths of the canal and the proposed forebay at Clifton Court is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect would not be adverse, because no active faults capable of surface rupture extend into the Alternative 1C alignment. Additionally, although the West Tracy blind thrust occurs beneath the Alternative 1C alignment, based on available information, it do not present a hazard of surface rupture.

However, because there is limited information regarding the depths of these faults, seismic surveys would be performed on the South Midland, Montezuma Hills, and West Tracy blind thrusts during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. The geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*). For construction of the water conveyance facilities, the codes and standards would include the

California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1C would not create an increased likelihood of loss of property, injury or death of individuals in the event of ground movement in the vicinity of the South Midland, Montezuma Hills, and West Tracy, blind thrusts would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1C conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. Therefore, there would be no adverse effect.

CEQA Conclusion: There are no active faults capable of surface rupture that extend into the Alternative 1C alignment. Although the Montezuma Hills, West Tracy and South Midland blind thrusts occur beneath the Alternative 1C alignment, based on available information, they do not present a hazard of surface rupture. Conformance to applicable design specifications and standards would ensure that operation of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals in the event of ground movement in these areas and would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 1C conveyance alignment or the proposed forebay and associated facilities adjacent to the Clifton Court Forebay. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

Earthquake events may occur on the local and regional seismic sources during operation of the Alternative 1C water conveyance facilities. The ground shaking could damage the canals, pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities disrupting the water supply through the conveyance system. In an extreme event of strong seismic shaking, uncontrolled release of water from the damaged canal, pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities could cause flooding, disruption of water supplies to the south, and inundation of structures. These effects are discussed more fully in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*.

The potential of earthquake ground shaking in the early long-term (2025) was estimated using the results of the seismic study (California Department of Water Resources 2007a). Table 9-25 lists the expected PGA and 1.0-S_a values in 2025 at selected facility locations for the early long-term. Earthquake ground shaking for the OBE (144-year return period) and MDE (975-year return period) was estimated for the stiff soil site, as predicted in the seiscmic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No seismic study results exist for 2025, so the ground shaking estimated for 2050 was used for the early long-term (2025).

Table 9-25 shows that the proposed facilities would be subject to moderate-to-high earthquake ground shaking in the early long-term (2025). All facilities would be designed and constructed in accordance with the requirements of the design measures described earlier in this chapter. Site-specific geotechnical information would be used to further assess the effect of local soil on the OBE and MDE ground shaking and to develop design criteria to minimize the potential of damage.

NEPA Effects: This potential effect could be substantial because strong ground shaking could damage pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the conveyance system could cause flooding and inundation of structures. Please refer to Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

Table 9-25. Expected Earthquake Ground Motions at Locations of Selected Major Facilities in the Early Long-Term (2025)—Alternative 1C

	144-year Return Period Ground Motions (OBE)			
	PGA (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake and Fish Screen Area[c]	0.14	0.15	0.19	0.30
Tunnel Location between Bradford Island and Webb Tract[d]	0.30	0.33	0.31	0.50
Clifton Court Forebay / Byron Tract Forebay	0.28	0.31	0.30	0.48
	975-year Return Period Ground Motions (MDE)			
	PGA (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[e]	Stiff Soil[a]	Local Soil[e]
Intake and Fish Screen Area[c]	0.24	0.24	0.33	0.53
Tunnel Location between Bradford Island and Webb Tract[d]	0.50	0.50	0.60	0.96
Clifton Court Forebay / Byron Tract Forebay	0.50	0.50	0.61	0.98

g = gravity
MDE = maximum design earthquake
OBE = operating basis earthquake
PGA = Peak Ground Acceleration
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.1 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island were used.
[e] Site-adjusted factors of 1.0 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.

Design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the conveyance features to withstand the peak ground acceleration caused by fault movement in the region. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. As described in in the methodology section in this chapter and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards are an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction. See Appendix 3B, *Environmental Commitments*.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

Conformance with these standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 1C would not create an increased likelihood of loss of property, personal injury or death of individuals from structural shaking of surface and subsurface facilities along the Alternative 1C conveyance alignment in the event of strong seismic shaking. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Seismically induced strong ground shaking could damage the canals, pipelines, culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the Alternative 1C water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

Earthquake-induced ground shaking could cause liquefaction, resulting soil slumping or lateral spreading and subsequent damage to or breaching of water conveyance structures and facilities. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. Failure of the canal, tunnel, culvert siphons, pipelines, levees, bridges, and other structures and facilities could result in loss and injury and disrupt SWP and CVP water supply deliveries. The potential for impacts from flooding as a result of levee or dam failure is also discussed in Chapter 6, *Surface Water*.

The native soils underlying the southern part of the Alternative 1C alignment consist primarily of alluvial fan and terrace deposits, including clay, silt, sand and gravels of variable density. The northern part of the alignment is more variable in composition, consisting of natural levee, basin, and Delta mud deposits. The central portion (Segment 4), through which the tunnel would be constructed, consists of natural levee, eolian sand, Delta mud, alluvial fans, and dredge spoils. The more recently-deposited, sandy materials would be more prone to liquefaction. Figure 9-6 shows that the Alternative 1C alignment has no substantial liquefaction damage potential in its northern part and low to medium-high damage potential in its central and southern parts.

NEPA Effects: The potential effect could be substantial because seismically induced ground shaking could cause liquefaction, which could damage pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. Please refer to Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

In the process of preparing final facility designs, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to further assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high “fines” (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

During final design, site-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, a California-registered civil engineer or California-certified engineering geologist would develop design measures and construction methods to meet design criteria established by building codes and construction standards to ensure that design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, and using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods). The results of the site-specific evaluation and California-registered civil engineer or California-certified engineering geologist's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* and *Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design requirements is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from liquefaction and associated hazard. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of liquefaction and associated ground movements would not create an increased likelihood of loss of property, personal injury or death of individuals from structural failure of surface and subsurface facilities resulting from seismic-related ground failure along the Alternative 1C conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion**:** Seismically induced ground shaking could cause liquefaction, which could result in loss of property or personal injury. Liquefaction could damage pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the Alternative 1C water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

Alternative 1C would involve excavation that creates new cut-and-fill slopes and construction of new embankments and levees. As a result of ground shaking and high soil-water content during heavy rainfall, existing and new slopes that are not properly engineered and natural stream banks could fail and cause damage to facilities. Levees can fail for several reasons: 1) high velocities of water flow can result in high rates of erosion and erode and overtop a levee; 2) the higher velocities of water flow can also lead to higher rates of erosion along the inner parts of levees and lead to undercutting and clumping of the levee into the river. Heavy rainfall or seepage into the levee from the river can increase fluid pressure in the levee and lead to slumping on the outer parts of the levee. If the slumps grow to the top of the levee, large sections of the levee may slump onto the floodplain and lower the elevation of the top of the levee, leading to overtopping; 3) increasing levels of water in the river will cause the water table in the levee to rise which will increase fluid pressure and may result in seepage and eventually lead to internal erosion called piping. Piping will erode the material under the levee, undermining it and causing its collapse and failure.

With the exception of levee slopes and natural stream banks, the topography along the Alternative 1C conveyance alignment is nearly level to very gently sloping. The areas that may be susceptible to slope failure are along existing levee slopes and at intake, pumping plant, forebay, and certain access road locations. Outside these areas, the land is nearly level and consequently has a negligible potential for slope failure.

Based on review of topographic and a landslide map of Alameda County (Roberts et al. 1999), the conveyance facilities would not be constructed on, nor would it be adjacent to, slopes that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The effect would be adverse because levee slopes and stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. As discussed in Impact SW-2 in Chapter 6, *Surface Water*, operation of the water conveyance features under Alternative 1C would not result in an increase in potential risk for flood management compared to existing conditions. Peak monthly flows under Alternative 1C in the locations considered were similar to or less than those that would occur under existing conditions. Since flows would not be substantially greater, the potential for increased rates of erosion or seepage are low. For additional discussion on the possible exposure of people or structures to a significant risk from flooding due to levee failure, please refer to Impact SW-6 in Chapter 6, *Surface Water*.

During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. The design criteria would be documented in a detailed geotechnical report prepared in accordance with the state guidelines, in particular, *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As discussed in Chapter 3, *Description of the Alternatives*, the foundation soil beneath slopes, embankments, or levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill also would be used to construct new slopes, embankments, and levees. Surface and internal drainage systems would be installed as necessary to reduce erosion and piping (internal erosion) potential.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Section 9.3.1, *Methods for Analysis*, such as USACE's *Design and Construction of Levees* and USACE*'s EM 1110-2-1902, Slope Stability.* The design requirements would be presented in a detailed geotechnical report. Conformance with these design requirements is an environmental commitment by DWR to ensure that slope stability hazards would be avoided as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of cut and fill slopes, embankments, and levees to minimize the potential effects from slope failure. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic shaking or from high-pore water pressure:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 1C conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. The measures would be described in a detailed geotechnical report prepared in accordance with the state guidelines, in particular, *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments,* such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the Alternative 1C water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Therefore, the potential hazard of loss of property or personal injury as a result of a tsunami on the water conveyance facilities is low.

Similarly, with the exception of the Clifton Court Forebay and the Byron Tract Forebay, the potential for a substantial seiche to take place in the Plan Area is considered low because seismic and water body geometry conditions for a seiche to occur near conveyance facilities are not favorable. Fugro Consultants, Inc. (2011) identified the potential for a seiche of an unspecified wave height to occur in the Clifton Court Forebay, caused by strong ground motions along the underlying West Tracy fault, assuming that this fault is potentially active. Since the fault also exists in the immediate vicinity of the Byron Tract Forebay, a seiche could also occur in the Byron Tract Forebay.

NEPA Effects: The effect of a tsunami generated in the Pacific Ocean would not be adverse because the distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low (i.e., less than 2 feet) tsunami wave height to reach the Delta (Contra Costa Transportation Agency 2009).

In most parts of the Plan Area, the effects of a seiche would not be adverse because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay. The effect could be adverse because the waves generated by a seiche could overtop the Byron Tract Forebay and Clifton Court Forebay embankments, causing erosion of the embankments and subsequent flooding in the vicinity.

However, design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would determine the peak ground acceleration caused by movement of the West Tracy fault and the maximum probable seiche wave that could be generated by the ground shaking. The engineer's recommended measures to address this hazard, as well as the hazard of a seiche overtopping the Clifton Court Forebay embankment and subsequent adverse effect on the Byron Tract Forebay embankment, would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that the adverse effects of a seiche are controlled to an acceptable level while the forebay facility is operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and consequent seiche waves. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury tsunami or seiche:

- U.S. Department of the Interior and USGS Climate Change and Water Resources Management: A Federal Perspective, Circular 1331.
- State of California Sea-Level Rise Task Force of the CO-CAT, Sea-Level Rise Interim Guidance Document, 2010.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes provide guidance on estimating the effects of climate change and sea level rise and associated effects when designing a project and ensuring that a project is able to respond to these effects.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the Byron Tract Forebay embankment would be designed and constructed to contain and withstand the anticipated maximum seiche wave height and would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 1C conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required.

Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height and potential seiche waver overtopping of the Clifton Court Forebay and Byron Tract Forebay embankments as the Alternative 1C water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

If an unlined canal (as opposed to a lined canal) was constructed, seepage from the sideslopes and bottom of the canal could occur where the normal water level in the canal is higher than the water surface elevation of the adjacent areas. The seepage could raise the water table on the landside of the embankments through more permeable lenses of sand and/or gravel in the foundation soil. Increased water table levels may increase the likelihood of ground settlement and earthquake-induced liquefaction.

NEPA Effects: The effect would be adverse because seepage from an unlined canal could raise the water table in the area adjacent to the canal and increase the hazard of liquefaction in the vicinity.

However, the amount of seepage from the canal is not expected to be substantial because the canal foundation and surface materials, derived from local borrow areas, would be selected based on site-specific geotechnical evaluations. An engineer would design the canal to prevent excessive loss of water from seepage. Additionally, control of excessive seepage may be accomplished through the installation of a slurry cutoff wall in the canal. A cutoff wall would be most effective in areas where the canal is constructed in relatively permeable materials, such as layers of permeable sand and gravels. Additional measures that could be implemented to offset the effects of seepage water include the following:

- Use of a drainage ditch parallel to the canal to control seepage. Water in the drainage ditch would then be pumped into the sloughs or back into the canal.
- Installation of pressure-relief wells to collect subsurface water and direct it into the parallel drainage ditch.

As indicated above and in Chapter 3, a geotechnical engineer would use site-specific geotechnical and hydrological information to design the canal, and the design would conform with the current standards and construction practices specified by USACE and DWR design standards. As described in Section 9.3.1, *Methods for Analysis*, such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*). For construction of the canal and any required seepage control measures, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects.* These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the canal design to minimize the potential excessive seepage. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury as a result of ground failure resulting from unlined canal seepage:

- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of potential excessive seepage and resulting soil instability.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the applicable design specifications and standards would ensure that the hazard of seepage from the canal would not cause an excessive increase in the water surface elevation in areas adjoining the canal resulting in ground failure. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures there would be no increased likelihood of loss of property, personal injury or death of individuals from ground failure caused by increased groundwater surface elevations. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

According to the available AP Earthquake Fault Zone Maps, only the Suisun Marsh ROA could be affected by rupture of an earthquake fault. The active Green Valley fault crosses the southwestern corner of the ROA. The active Cordelia fault extends approximately one mile into the northwestern corner of the ROA. Rupture of these faults could damage levees and berms constructed as part of the restoration, which could result in failure of the levees and flooding of otherwise protected areas.

Within the Delta, active or potentially active blind thrust faults were identified in the seismic study (California Department of Water Resources 2007a). The extreme southeastern corner of the Suisun Marsh ROA is underlain by the Montezuma Blind Thrust zone. Parts of the Cache Slough and Yolo Bypass ROAs are underlain by part of the North Midland blind thrust zone. The Cosumnes/ Mokelumne River and East Delta ROAs are underlain by the Thornton Arch zone. Although these blind thrusts are not expected to rupture to the ground surface during earthquake events, they may produce ground or near-ground shear zones, bulging, or both. In the seismic study (California Department of Water Resources 2007a), the Thornton Arch blind thrust was assigned a 20% probability of being active. The depth to the Thornton Arch blind fault is unknown. Based on limited geologic and seismic survey information, it appears that the potential of having any shear zones, bulging, or both at the depths of the habitat levees is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect of implementing the conservation measures in the ROAs could be substantial because rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and cause damage or failure of ROA facilities, including levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

Because there is limited information regarding the depths of the blind faults mentioned above, seismic surveys would be performed in the vicinity of the faults as part of final design. These surveys would be used to verify fault depths where levees and other features would be constructed. Collection of this depth information would be part of broader, design-level geotechnical studies prepared by a licensed engineer to support all aspects of site-specific project design. The studies would assess site-specific conditions at and near all the project facility locations, including the nature and engineering properties of all soil horizons and underlying geologic strata, and groundwater conditions. The engineer's information would be used to develop final engineering solutions to any hazardous condition, consistent with the code and standards requirements of federal, state and local oversight agencies. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that risks from a fault rupture are minimized as conservation levees are constructed and maintained. The hazard would be controlled to a safe level by following the proper design standards. The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of ground movement in the vicinity of the blind thrusts underlying the ROAs would not jeopardize the integrity of the levees and other features constructed in the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

Earthquake events may occur on the local and regional seismic sources at or near the ROAs. Because of its proximity to these faults, the Suisun Marsh ROA would be especially subject to ground shaking caused by the Concord-Green Valley fault. The Cache Slough ROA would be subject to shaking from the Northern Midland fault zone, which underlies the ROA. Although more distant from these sources, the other ROAs would be subject to shaking from the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust faults and the more proximate blind thrusts in the Delta.

Among all the ROAs, the Suisun Marsh ROA would be most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. The ground shaking could damage levees and other structures, and in an extreme event cause levees to fail such that protected areas flood.

NEPA Effects: All temporary facilities would be designed and built to meet the safety and collapse-prevention requirements for the above-anticipated seismic loads. Therefore, this effect is considered not adverse. No additional mitigation measures are required. All facilities would be designed and constructed in accordance with the requirements of the design measures described in Chapter 3, *Description of the Alternatives*. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize the potential of damage.

Design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the levees and other features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical engineer's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are implemented.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project features and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of seismic shaking would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property or personal injury in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

New structural features are proposed at the ROAs, such as levees as part of CM4, setback levees as part of CM5 and CM6, and experimental ramps and fish ladders at the Fremont Weir as part of CM2. Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees and other features constructed at the restoration areas. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), and increased lateral soil pressure. Failure of levees and other features could result in flooding of otherwise protected areas.

The ROAs vary with respect to their liquefaction hazard (Figure 9-6). The Suisun Marsh ROA generally has a moderate liquefaction hazard. The liquefaction damage potential among the other ROAs is generally low to medium.

NEPA Effects: This potential effect would be substantial because earthquake-induced liquefaction could damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

During final design, of conservation facilities site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content is less susceptible to liquefaction.

During final design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, the engineer would develop design parameters and construction methods to meet the design criteria established to ensure that design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods), and conforming with current seismic design codes and requirements, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic-related ground failure:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during implementation and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion: Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Implementation of CM2–CM7, would involve breaching, modification or removal of existing levees and construction of new levees and embankments. CM4 which provides for the restoration of up to 65,000 acres of tidal perennial aquatic, tidal mudflat, tidal freshwater emergent wetland, and tidal brackish emergent wetland natural communities within the ROAs involves the greatest amount of modifications to levees. Levee modifications, including levee breaching or lowering, may be performed to reintroduce tidal exchange, reconnect remnant sloughs, restore natural remnant meandering tidal channels, encourage development of dendritic channel networks, and improve floodwater conveyance.

Levee modifications could involve the removal of vegetation and excavation of levee materials. Excess earthen materials could be temporarily stockpiled, then re-spread on the surface of the new levee slopes where applicable or disposed of offsite. Any breaching or other modifications would be required to be designed and implemented to maintain the integrity of the levee system and to conform with flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies. Those agencies may include USACE, DWR, CVFPB, and other flood management agencies. For more detail on potential modifications to levees as a part of conservation measures, please refer to Chapter 3, *Description of Alternatives*.

New and existing levee slopes and stream/channel banks could fail and damage facilities as a result of seismic shaking and as a result of high soil-water content during heavy rainfall.

With the exception of levee slopes, natural stream banks, and part of the Suisun Marsh ROA, the topography of ROAs is nearly level to gently sloping. The areas that may be susceptible to slope failure are along existing Sacramento and San Joaquin River and Delta island levees and stream/channel banks, particularly those levees that consist of non-engineered fill and those streambanks that are steep and consist of low strength soil.

The structures associated with conservation measures would not be constructed in, nor would they be adjacent to, areas that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in flooding of otherwise protected areas.

As outlined in Chapter 3, *Description of Alternatives*, erosion protection measures and protection against related failure of adjacent levees would be taken where levee breaches were developed. Erosion protection could include geotextile fabrics, rock revetments, riprap, or other material selected during future evaluations for each location. Aggregate rock could be placed on the remaining levees to provide an access road to the breach location. Erosion protection measures would also be taken where levee lowering is done for the purposes of allowing seasonal or periodic inundation of lands during high flows or high tides to improve habitat or to reduce velocities and elevations of floodwaters. To reduce erosion potential on the new levee crest, a paved or gravel access road could be constructed with short (approximately 1 foot) retaining walls on each edge of the crest to reduce undercutting of the roadway by high tides. Levee modifications could also include excavation of watersides of the slopes to allow placement of slope protection, such as riprap or geotextile fabric, and to modify slopes to provide levee stability. Erosion and scour protection could be placed on the landside of the levee and continued for several feet onto the land area away from the levee toe. Neighboring levees could require modification to accommodate increased flows or to reduce effects of changes in water elevation or velocities along channels following inundation of tidal marshes. Hydraulic modeling would be used during subsequent analyses to determine the need for such measures.

New levees would be constructed to separate lands to be inundated for tidal marsh from non-inundated lands, including lands with substantial subsidence. Levees could be constructed as described for the new levees at intake locations. Any new levees would be required to be designed and implemented to conform with applicable flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies, which may include USACE, DWR, CVFPB, and local flood management agencies.

Additionally, during project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As required by design standards and building codes (see Appendix 3B, *Environmental Commitments*), foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, such as USACE's—*Design and Construction of Levees* and USACE's—*EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from landslides or other slope instability:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levee and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion**:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: The distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low tsunami wave height to reach the Suisun Marsh and the Delta. Conditions for a seiche to occur at the ROAs are not favorable. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.5 Alternative 2A—Dual Conveyance with Pipeline/Tunnel and Five Intakes (15,000 cfs; Operational Scenario B)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These locations would be where the intakes have a similar hazard of ground shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2A would, therefore, be the same as 1A. See the discussion of Impact GEO-1 under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2A. The impact would be less than significant. No additional mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. If Intakes 6 and 7, north of Vorden, are chosen, settlement of excavations could occur as a result of dewatering at Alternative 2A construction sites with shallow groundwater. Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. This can be anticipated at all intake locations and pumping plant sites adjacent to the Sacramento River. Similar dewatering may be necessary where intake and forebay pipelines cross waterways and major irrigation canals east of the Sacramento River and north of the proposed intermediate forebay. The conveyance pipeline built between Intake 7 and the intermediate forebay would cross six canals or ditches prior to joining with the conveyance pipeline for Intake 6. All of these crossings occur north of the facility grounds for Intake 7 and range in their distance from the intake site from 0.3 miles to one mile. The combined conveyance pipeline for Intakes 6 and 7 leading to the intermediate forebay would cross four canals or ditches. The northern two crossings would be 0.3 to 0.4 miles west of Lambert Road and the southern two would be 0.5 miles west and northwest (respectively) of Russell Road. This pipeline would also cross the Reclamation District 551 borrow canal.

NEPA Effects: These changes in locations would result in a similar hazard of settlement or collapse and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of ground settlement of tunnels and would not change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of slope failure at borrow and storage sites and would not change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from construction-related ground motions and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of fault rupture and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: There are no active faults capable of surface rupture that extend into the Alternative 2A alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 2A alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2A. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from seismic shaking and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from ground failure and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of landslides and other slope instability and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 2A would include the same physical/structural components as Alternative 1A, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of seiche or tsunami and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death from seiche or tsunami due to operation of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 2A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

CEQA Conclusion: Alternative 2A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2A. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 2A would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. The distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low tsunami wave height to reach the Suisun Marsh and the Delta. Conditions for a seiche to occur at the ROAs are not favorable. There would be no adverse effect.

***CEQA Conclusion*:** Based on professional judgment, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.6 Alternative 2B—Dual Conveyance with East Alignment and Five Intakes (15,000 cfs; Operational Scenario B)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would result in a similar hazard of ground shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2B. This impact is less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. If Intakes 6 and 7, north of Vorden, are chosen, settlement of excavations could occur as a result of dewatering at Alternative 2B construction sites with shallow groundwater. Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. This can be anticipated at all intake locations and pumping plant sites adjacent to the Sacramento River. Similar dewatering may be necessary where intake and forebay pipelines cross waterways and major irrigation canals east of the Sacramento River and north of the proposed intermediate forebay. The conveyance pipeline built between Intake 6 and the canal would cross Snodgrass Slough, an adjacent body of water, and seven irrigation canals or drainage ditches prior to joining with the canal. The crossings closest to the intake would occur approximately 0.25 miles to 0.5 miles southeast of Russell Road. Snodgrass Slough would be crossed approximately 0.5 miles north of Alfalfa Plant Road. Intersections with three canals or ditches would then be located west of Snodgrass Slough and east of the proposed canal. The conveyance pipeline built between Intake 7 and the canal would cross Snodgrass Slough, an adjacent body of water, and eleven irrigation canals or drainage ditches prior to joining with the canal. The five crossings closest to the intake would occur approximately 0.3 miles to 1.1 miles northeast of the facility grounds proposed for Intake 7. Three crossings would be located 0.1 to 0.2 miles south of Alfalfa Plant Road, in addition to the crossing with Snodgrass Slough and an associated waterway. Intersections with four canals or ditches would then be located west of Snodgrass Slough and east of the proposed canal.

NEPA Effects: These changes in locations would result in a similar hazard of settlement or collapse and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of ground settlement of tunnel siphons and would not change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2B. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of slope failure at borrow and storage sites and would not change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from construction-related ground motions and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of fault rupture and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect

CEQA Conclusion**:** There are no active faults capable of surface rupture that extend into the East alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the East alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from seismic shaking and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced strong ground shaking could damage the canals, pipelines, tunnel siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from ground failure and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage the canals, pipelines, tunnel siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of landslides and other slope instability and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of seiche or tsunami and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 2B would include the same physical/structural components as Alternative 1B, but could entail two different intake and intake pumping plant locations. These changes in locations would result in a similar hazard of ground shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

***CEQA Conclusion*:** Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2B. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:**

Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 2B would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.7 Alternative 2C—Dual Conveyance with West Alignment and Intakes W1–W5 (15,000 cfs; Operational Scenario B)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These alternative intakes would be located where there is a similar hazard of ground shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2C. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would result in a similar hazard of settlement or collapse and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of ground settlement of tunnels and culvert siphons and would not change the hazard of loss of property, personal injury, or death during construction. The effects of

Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of slope failure at borrow sites and storage sites and would not change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from construction-related ground motions and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. However, because DWR has committed to conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of fault rupture and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the West alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the West alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from seismic shaking and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage the canal, pipelines, tunnels, culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR‘s Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE‘s *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of structural failure from ground failure and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of landslides and other slope instability and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion**:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would have no bearing on the hazard of seiche or tsunami and would not change the hazard of loss of property, personal injury, or death during operation of the water conveyance features. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C from seiche or tsunami. The impact would be less than significant. No additional mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 2C would include the same physical/structural components as Alternative 1C, but could entail two different intake and intake pumping plant locations. These changes in locations would result in a similar hazard of ground shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 2C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion: Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 2C. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 2C as under 1A. See description and findings under Alternative 1A. There would be no adverse impact.

CEQA Conclusion**:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 2C would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse impact.

CEQA Conclusion**:** Based on recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. There would be no increased likelihood of loss of property, personal injury or death in the ROAs from seiche or tsunami. The impact would be less than significant. No mitigation is required.

9.3.3.8 Alternative 3—Dual Conveyance with Pipeline/Tunnel and Intakes 1 and 2 (6,000 cfs; Operational Scenario A)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of structural failure from seismic shaking and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 3. This impact would be less than significant. No additional mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of settlement or collapse caused by dewatering and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of ground settlement hazard on the tunnel and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of slope failure at borrow and spoils storage sites and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of structural failure from construction-related ground motions and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would not present a difference in the hazard of an earthquake fault and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 3. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of structural failure from liquefaction but would not substantially change the hazard of loss of property or personal injury during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of landslides and other slope instability but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 3. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 3 would include the same physical/structural components as Alternative 1A, but would entail three less intakes and three less pumping plants. These differences would present a slightly lower hazard of a seiche or tsunami but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 3 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 3 from seiche or tsunami. The impact would be less than significant. No additional mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 3 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

CEQA Conclusion: Alternative 3 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 3 as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 3 as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 3 as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 3 as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 3 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the construction areas would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.9 Alternative 4—Dual Conveyance with Modified Pipeline/Tunnel and Intakes 2, 3, and 5 (9,000 cfs; Operational Scenario H)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

Earthquakes could be generated from local and regional seismic sources during construction of the Alternative 4 water conveyance facilities. Seismically induced ground shaking could cause injury of workers at the construction sites as a result of collapse of facilities.

The potential for experiencing earthquake ground shaking during construction in 2020 (during the project's near-term implementation stage) was estimated using the results of the seismic study (California Department of Water Resources 2007a). The seismic study also computed seismic ground shaking hazards at six locations in the Delta for 2005, 2050, 2100, and 2200. The results of these analyses show that the ground shakings in the Delta are not sensitive to the elapsed time since the last major earthquake (i.e., the projected shaking hazard results for 2005, 2050, 2100, and 2200 are similar).

Table 9-14 lists the expected PGA and 1.0-S_a values in 2020 at selected facility locations along the pipeline/tunnel alignment. These would also be applicable to the modified pipeline/tunnel alignment under Alternative 4. For the construction period, a ground motion return period of 72 years was assumed, corresponding to approximately 50% probability of being exceeded in 50 years. Values were estimated for a stiff soil site, as predicted by the seismic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No seismic study computational modeling was conducted for 2020, so the ground shaking that was computed for 2005 was used to represent the construction near-term period (i.e., 2020). Alternative 4 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted by the seismic study would increase if no major events take place on these faults through 2020. The effect could be substantial because seismically-induced ground shaking could cause loss of property or personal injury at the Alternative 4 construction sites (including intake locations, pipelines from intakes to the intermediate forebay, the tunnel, and the expanded Clifton Court Forebay) as a result of collapse of facilities. For example, facilities lying directly on or near active blind faults, such as the concrete batch plants and fuel stations near Twin Cities Road and Interstate 5 and at the expanded Clifton Court Forebay, as well as the expanded Forebay itself for Alternative 4 and may have an increased likelihood of loss of property or personal injury in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Figure M3-4 in the Mapbook Volume.

However, during construction, all active construction sites would be designed and managed to meet the safety and collapse-prevention requirements of the relevant state codes and standards listed earlier in this chapter and expanded upon in Appendix 3B, *Environmental Commitments*, for the above-anticipated seismic loads.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Engineering and Design – Earthquake Design and Evaluation of Concrete Hydraulic Structures, EM 1110-2-6053, 2007.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence). The safety requirements could include shoring, specified slope angles, excavation depth restrictions for workers, lighting and other similar controls. Conformance with these standards and codes are an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking that is estimated to occur and the resultant ground motion anticipated at Alternative 4 construction sites, including the intake locations, the tunnel, the pipelines and the forebays, could cause collapse or other failure of project facilities while under construction. For example, facilities lying directly on or near active blind faults, such as the concrete batch plants and fuel stations near Twin Cities Road and Interstate 5 and at the expanded Clifton Court Forebay, as well as the expanded Forebay itself for Alternative 4, may have an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

Settlement of excavations could occur as a result of dewatering at Alternative 4 construction sites with shallow groundwater. Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. This can be anticipated at all intake locations (Sites 2, 3, and 5) and pumping plant sites adjacent to the Sacramento River, where 70% of the dewatering for Alternative 4 would take place. All of the intake locations and adjacent pumping plants for Alternative 4 are located on alluvial floodbasin deposits, alluvial floodplain deposits and natural levee deposits. Similar dewatering may be necessary where intake and forebay pipelines cross waterways and major irrigation canals east of the Sacramento River and north of the proposed intermediate forebay. Unlike the pipeline/tunnel alternatives, the conveyance tunnels constructed between the three intakes and the intermediate forebay would not be anticipated to require dewatering prior to construction and would not have any associated impact.

Dewatering can stimulate settlement in excavation and tunneling sites. The settlement could cause the slopes of excavations to fail.

NEPA Effects: This potential effect could be substantial because settlement or collapse during dewatering could cause injury of workers at the construction sites as a result of collapse of excavations.

The hazard of settlement and subsequent collapse of excavations would be evaluated by assessing site-specific geotechnical and hydrological conditions at intake locations and adjacent pumping plants, as well as where intake and forebay pipelines cross waterways and major irrigation canals. A California-registered civil engineer or California-certified engineering geologist would recommend measures in a geotechnical report to address these hazards, such as seepage cutoff walls and barriers, shoring, grouting of the bottom of the excavation, and strengthening of nearby structures, existing utilities, or buried structures. As described in Section 9.3.1, *Methods for Analysis*, the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*. See Appendix 3B, *Environmental Commitments.*

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from settlement or collapse at the construction site caused by dewatering during construction:

- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Engineering and Design - Settlement Analysis, EM 1110-1-1904, 1990.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built in such a way that settlement is minimized. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement and failure of excavations. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to conform with appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

Two types of ground settlement could be induced during tunneling operations: large settlement and systematic settlement. Large settlement occurs primarily as a result of over-excavation by the tunneling shield. The over-excavation is caused by failure of the tunnel boring machine to control unexpected or adverse ground conditions (for example, running, raveling, squeezing, and flowing ground) or operator error. Large settlement can lead to the creation of voids and/or sinkholes above the tunnel. In extreme circumstances, this settlement can affect the ground surface, potentially causing loss of property or personal injury above the tunneling operation.

Systematic settlement usually results from ground movements that occur before tunnel supports can exit the shield and the tunnel to make full contact with the ground. Soil with higher silt and clay content tend to experience less settlement than sandy soil. Additional ground movements can occur with the deflection of the tunnel supports and over-excavation caused by steering/plowing of the tunnel boring machine at horizontal and vertical curves. A deeper tunnel induces less ground surface settlement because a greater volume of soil material is available above the tunnel to fill any systematic void space.

The geologic units in the area of the Alternative 4 modified pipeline/tunnel alignment are shown on Figure 9-3 and summarized in Table 9-26. The characteristics of each unit would affect the potential for settlement during tunneling operations. Segments 1 and 3, located in the Clarksburg area and the area west of Locke, respectively, contain higher amounts of sand than the other segments, so they pose a greater risk of settlement.

Table 9-26. Surficial Geology Underlying Alternative 4/ Modified Pipeline/Tunnel Alignment by Segments

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 and Segment 2	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qro	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well sort sand, gravel, silt and minor clay
	Qm2e	Eolian sand: well-sorted fine- to medium-grained sand
Segment 3	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay.
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 4	Qpm	Delta mud: mud and peat with minor silt or sand
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt.
Segment 5 and Segment 6	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 7	Qpm	Delta mud: mud and peat with minor silt or sand
	Qfp	Floodplain deposits: dense, sandy to silty clay
Segment 8	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.

Sources: Hansen et al. 2001 and Atwater 1982.

[a] The segments are shown on Figure 9-3.

Given the likely design depth of the tunnel, the potential for excessive systematic settlement expressed at the ground surface caused by tunnel installation is thought to be relatively low. Operator errors or highly unfavorable/unexpected ground conditions could result in larger settlement. Large ground settlements caused by tunnel construction are almost always the result of using inappropriate tunneling equipment (incompatible with the ground conditions), improperly operating the machine, or encountering sudden or unexpected changes in ground conditions.

NEPA Effects: The potential effect could be substantial because ground settlement could occur during the tunneling operation. During detailed project design, a site-specific subsurface geotechnical evaluation would be conducted along the modified pipeline/tunnel alignment to verify or refine the findings of the preliminary geotechnical investigation The tunneling equipment and drilling methods would be reevaluated and refined based on the results of the investigations, and field procedures for sudden changes in ground conditions would be implemented to minimize or avoid ground settlement. A California-registered civil engineer or California-certified engineering geologist would recommend measures to address these hazards, such as specifying the type of tunnel boring machine to be used in a given segment. The results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008).

As described in Section 9.3.1*, Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as USACE design measures. See Appendix 3B, *Environmental Commitments.*

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from ground settlement above the tunneling operation during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

As described in detail in Impacts GEO-1 and GEO-2, DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from settlement. DWR would also ensure that the design specifications are properly executed during construction. DWR has made this conformance and monitoring process an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*).

Generally, the applicable codes require that facilities be built so that they are designed for a landside slope stability and seepage/underseepage factors of safety greater than 1.0 (i.e., stable) and would therefore be less impacted in the event of ground settlement. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

Excavation of borrow material could result in failure of cut slopes and application of temporary spoils and RTM at storage sites could cause excessive settlement in the spoils, potentially causing injury of workers at the construction sites. Soil and sediment, especially those consisting of loose alluvium and soft peat or mud, would be particularly prone to failure and movement. Additionally, groundwater is expected to be within a few feet of the ground surface in these areas; this may make excavations more prone to failure.

While specific borrow sources have not yet been secured near the Alternative 4 alignment, several potential locations within the project area have been identified based on geologic data presented through the DRMS study. Borrow site locations identified outside the project area were based on reviews of published geologic maps, specifically the California Geological Survey Map No. 1A Sacramento Quadrangle (1981) and Map No. 5A San Francisco-San Jose Quandrangle (1991). Borrow areas for construction of intakes, sedimentation basins, pumping plants, forebays, and other supporting facilities would be sited near the locations of these structures (generally within 10 miles). Along the modified pipeline/tunnel alignment, selected areas would also be used for disposing of the byproduct (RTM) of tunneling operations. Table 9-27 describes the geology of these areas as mapped by Atwater (1982) (Figure 9-3).

Table 9-27. Geology Underlying Borrow and Reusable Tunnel Material Storage Areas—Alternative 4

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 Borrow and/or Spoil Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Onsite Borrow Areas	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel.
Segment 2 Reusable Tunnel Material Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qry	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well-sorted sand, gravel, silt, and minor clay
Segment 3 Reusable Tunnel Material Area	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qfp	Floodplain deposits: dense sandy to silty clay
Segment 4 Reusable Tunnel Material Area	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 7 Reusable Tunnel Material Area	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
	Qfp	Floodplain deposits: dense sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel

Source: Hansen et al. 2001; Atwater 1982.
[a] The segments are shown on Figure 9-3.

NEPA Effects: The potential effect could be substantial because excavation of borrow material and the resultant cutslopes and potential failure of spoils/RTM fill slopes could cause injury of workers at the construction sites.

Excavations in borrow areas would be designed to avoid excessive ground movements on adjacent areas and soil "boiling" (i.e., upwelling of groundwater) at the bottom of the excavation. Spoils would be placed in 12-inch lifts with proper compaction and stored no higher than 12 feet above preconstruction ground elevation with maximum side slopes of 5H:1V. During design, the potential for native ground settlement below the spoils would be evaluated by a geotechnical engineer using site-specific geotechnical and hydrological information. The use of shoring, seepage cutoff walls, and ground modifications to prevent slope instability, soil boiling, or excessive settlement would be considered in the design. As described in Section 9.3.1, *Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as the California Building Code and USACE's *Engineering and Design—Structural Design and Evaluation of Outlet Works*.

In addition to the risk of slope failure at borrow sites and spoils and RTM sites, there are also potential impacts on levee stability resulting from construction of Alternative 4 water conveyance facilities. The intakes would be sited along the existing Sacramento River levee system, requiring reconstruction of levees to provide continued flood management. At each intake pumping plant site, a new setback levee (ring levee) would be constructed. The space enclosed by the setback levee would be filled up to the elevation of the top of the setback levee, creating a building pad for the adjacent pumping plant.

As discussed in Chapter 3, *Description of the Alternatives*, the new levees would be designed to provide an adequate Sacramento River channel cross section and to provide the same level of flood protection as the existing levee and would be constructed to geometries that meet or exceed PL 84-99 standards. CALFED and DWR have adopted PL 84-99 as the preferred design standard for Delta levees. Transition levees would be constructed to connect the existing levees to the new setback levees. A typical new levee would have a broad-based, generally asymmetrical triangular cross section. The levee height considered wind and wave erosion. As measured from the adjacent ground surface on the landside vertically up to the elevation of the levee crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the levee (toe of levee to toe of levee) would range from approximately 180 to 360 feet. The minimum crest width of the levee would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. Cut-off walls would be constructed to avoid seepage, and the minimum slope of levee walls would be three units horizontal to one unit vertical. All levee reconstruction will conform with applicable state and federal flood management engineering and permitting requirements.

Depending on foundation material, foundation improvements would require excavation and replacement of soil below the new levee footprint and potential ground improvement. The levees would be armored with riprap—small to large angular boulders—on the waterside. Intakes would be constructed using a sheetpile cofferdam in the river to create a dewatered construction area that would encompass the intake site. The cofferdam would lie approximately 10–35 feet from the footprint of the intake and would be built from upstream to downstream, with the downstream end closed last. The distance between the face of the intake and the face of the cofferdam would be dependent on the foundation design and overall dimensions. The length of each temporary cofferdam would vary by intake location, but would range from 740 to 2,440 feet. Cofferdams would be supported by steel sheet piles and/or king piles (heavy H-section steel piles). Installation of these piles may require both impact and vibratory pile drivers. Some clearing and grubbing of levees would be required prior to installation of the sheet pile cofferdam, depending on site conditions. Additionally, if stone bank protection, riprap, or mature vegetation is present at intake construction site, it would be removed prior to sheet pile installation.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from failure of excavations and settlement. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from settlement/failure of cutslopes of borrow sites and failure of soil or RTM fill slopes during construction:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters. The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures (geotextile fabrics, rock revetments, riprap, or other material), seepage reduction measures, and overall mass. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4 at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures, seepage reduction measures, and overall mass. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

Pile driving and other heavy equipment operations would cause vibrations that could initiate liquefaction and associated ground movements in places where soil and groundwater conditions are present to allow liquefaction to occur. The consequences of liquefaction could be manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. These consequences could damage nearby structures and levees.

The lateral extent (or influenced distance) of damage potential caused by pile driving and heavy equipment operations depends on many factors, including soil conditions, the piling hammer used, frequency of piling, and the vibration tolerance of structures and levees.

Pile driving would be conducted at the intakes, where, based on boring logs, soil materials subject to liquefaction (e.g., saturated, poorly graded sand) are present. During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data (e.g., California Department of Water Resources 2010a, 2010b, 2011) to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil bearing capacity and extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as (SPT) blow counts, (CPT) penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake (i.e., the earthquake that is expected to produce the strongest level of ground shaking at a site to which it is appropriate to design a structure to withstand). If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high “fines” (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

NEPA Effects: The potential effect could be substantial because construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites.

During design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. The potential effects of construction vibrations on nearby structures, levees, and utilities would be evaluated using specific piling information (such as pile type, length, spacing, and pile-driving hammer to be used). In areas determined to have a potential for liquefaction, the California-registered civil engineer or California-certified engineering geologist would develop design strategies and construction methods to ensure that pile driving and heavy equipment operations do not damage facilities under construction and surrounding structures, and do not threaten the safety of workers at the site. As shown in Figure 9-6, the area south of the Sacramento River all the way across Woodward Island, which Alternative 4 crosses through, has medium to medium-high potential for levee liquefaction damage. Three barge unloading facilities are located in this medium to medium-high potential for levee liquefaction damage area. Design measures may include predrilling or jetting, using open-ended pipe piles to reduce the energy needed for pile penetration, using CIDH piles/piers that do not require driving, using pile jacking to press piles into the ground by means of a hydraulic system, or driving piles during the drier summer months. Field data collected during design also would be evaluated to determine the need for and extent of strengthening levees, embankments, and structures to reduce the effect of vibrations. These construction methods would conform with current seismic design codes and requirements, as described in Appendix 3B, *Environmental Commitments*. Such design standards include USACE‘s *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

DWR has made the environmental commitment (see Appendix 3B, *Environmental Commitments*) that the construction methods recommended by the geotechnical engineer are included in the design of project facilities and construction specifications to minimize the potential for construction-induced liquefaction. DWR also has committed to ensure that these methods are followed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from construction-related ground motions:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to construction method recommendations and other applicable specifications would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals due to construction-related ground motion and resulting potential liquefaction in the work area. Therefore, there would be no adverse effect.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

According to the available AP Fault Zone Maps, none of the Alternative 4 facilities would cross or be within any known active fault zones. However, numerous AP fault zones have been mapped west of the conveyance alignment (Figure 9-5). The closest AP fault zone would be the Greenville fault, located approximately 7.6 miles west of the conveyance facilities. Because none of the Alternative 4 constructed facilities would be within any of the fault zones (which include the area approximately 200 to 500 feet on each side of the mapped surface trace to account for potential branches of active faults), the potential that the facilities would be directly subject to fault offsets is negligible.

In the Delta, active or potentially active blind thrust faults were identified in the seismic study. Segments 3, and 4 of the Alternative 4 conveyance alignment (which is the same as the Modified

Pipeline/Tunnel Alignment in Figure 9-3) would cross the Thornton Arch fault zone. The western part of the proposed expanded Clifton Court Forebay is underlain by the West Tracy fault. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). If the West Tracy fault is potentially active, it could cause surface deformation in the western part of the existing Clifton Court Forebay. Because the western part of the expanded Clifton Court Forebay is also underlain by the hanging wall of the fault, this part of the forebay may also experience uplift and resultant surface deformation (Fugro Consultants 2011). In the seismic study (California Department of Water Resources 2007a), the Thornton Arch and West Tracy blind thrusts have been assigned 20% and 90% probabilities of being active, respectively. The depth to the Thornton Arch blind fault is unknown. The seismic study indicates that the West Tracy fault dies out as a discernible feature within approximately 3,000 to 6,000 feet bgs [in the upper 1- to 2-second depth two-way time, estimated to be approximately 3,000 to 6,000 feet using the general velocity function as published in the Association of Petroleum Geologists Pacific Section newsletter (Tolmachoff 1993)].

It appears that the potential of having any shear zones, bulging, or both at the depths of the modified pipeline/tunnel is low because the depth to the blind thrust faults is generally deep and there is no credible evidence to indicate that the faults could experience displacement within the depth of the modified pipeline/tunnel.

NEPA Effects: The effect would not be adverse because no active faults extend into the Alternative 4 alignment. Additionally, although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 4 alignment, they do not present a hazard of surface rupture based on available information, including the AP Earthquake Fault Zone Map showing faults capable of surface rupture (Figure 9-5).

However, because there is limited information regarding the depths of the Thornton Arch and West Tracy blind thrusts, seismic surveys would be performed on the blind thrust during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. The geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis,* such design codes, guidelines, and standards are considered environmental commitments by DWR (see also Appendix 3B, *Environmental Commitments*). For construction of the water conveyance facilities, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone and West Tracy, blind thrust would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 4 conveyance alignment or the proposed expanded Clifton Court Forebay and associated facilities adjacent to the existing Clifton Court Forebay. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the Alternative 4 modified pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 4 modified pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

Earthquake events may occur on the local and regional seismic sources during operation of the Alternative 4 water conveyance facilities. The ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities disrupting the water supply through the conveyance system. In an extreme event of strong seismic shaking, uncontrolled release of water from damaged pipelines, tunnels, intake facilities, pumping plants, and other facilities could cause flooding, disruption of water supplies to the south, and inundation of structures. These effects are discussed more fully in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*.

Table 9-17 lists the expected PGA and 1.0-S_a values in 2025 at selected facility locations along the pipeline/tunnel alignment. Alternative 4 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of seismic shaking but would not substantially change the hazard of loss of property or personal injury during construction compared to Alternative 1A.

For early long-term, earthquake ground motions with return periods of 144 years and 975 years were estimated from the results presented in the seismic study (California Department of Water Resources 2007a). The 144-year and 975-year ground motions correspond to the OBE (i.e., an earthquake that has a 50% probability of exceedance in a 100-year period (which is equivalent to a 144-year return period event) and the MDE (i.e., an earthquake that causes ground motions that have a 10% chance of being exceeded in 100 years) design ground motions, respectively. Values were estimated for a stiff soil site (as predicted in the seismic study), and for the anticipated soil conditions at the facility locations. No seismic study results exist for 2025, so the ground shaking estimated for the 2050 were used for Early Long-term (2025).

Table 9-17 shows that the proposed facilities would be subject to moderate-to-high earthquake ground shaking through 2025. All facilities would be designed and constructed in accordance with the requirements of the design guidelines and building codes described in Appendix 3B. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize damage potential.

NEPA Effects: This potential effect could be substantial because strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities and result in loss of property or personal injury. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the conveyance system could cause flooding and inundation of structures. Please refer to Chapter 6, *Surface Water* and Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flood effects.

The structure of the underground conveyance facility would decrease the likelihood of loss of property or personal injury of individuals from structural shaking of surface and subsurface facilities along the Alternative 4 conveyance alignment in the event of strong seismic shaking. The conveyance pipeline will be lined with precast concrete which will be installed continuously following the advancement of a pressurized tunnel boring machine. The lining consists of precast concrete segments inter-connected to maintain alignment and structural stability during construction. Reinforced concrete segments are precast to comply with strict quality control. High performance gasket maintains water tightness at the concrete joints, while allowing the joint to rotate and accommodate movements during intense ground shaking. PCTL has been used extensively in seismically active locations such as Japan, Puerto Rico, Taiwan, Turkey, Italy and Greece. The adoption of PCTL in the United States started about 20 years ago, including many installations in seismically active areas such as Los Angeles, San Diego, Portland and Seattle. PCTL provides better seismic performance than conventional tunnels for several reasons:

- higher quality control using precast concrete
- better ring-build precision with alignment connectors
- backfill grouting for continuous ground to tunnel support
- segment joints provide flexibility and accommodate deformation during earthquakes
- high performance gasket to maintain water tightness during and after seismic movement

Reviewing the last 20 years of PCTL seismic performance histories, it can be concluded that little or no damage to PCTL was observed for major earthquakes around the world. Case studies of the response of PCTL to large seismic events have shown that PCTL should not experience significant damage for ground acceleration less than 0.5g (Dean et al. 2006). The design PGA for a 975-year return period is 0.49g (California Department of Water Resources 2010i, Table 4-4). Based on this preliminary data, the Delta tunnels can be designed to withstand the anticipated seismic loads.

Design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the conveyance features to withstand the peak ground acceleration caused by fault movement in the region. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards are an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. DWR would also ensure that the design specifications are properly executed during construction. See Appendix 3B, *Environmental Commitments.*

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003.
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.

- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from structural shaking of surface and subsurface facilities along the Alternative 4 conveyance alignment in the event of strong seismic shaking. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR‘s Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE‘s *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

Earthquake-induced ground shaking could cause liquefaction, resulting in soil slumping or lateral spreading and subsequent damage to or breaching of water conveyance structures and facilities. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (soil movement), increased lateral soil pressure, and buoyancy within zones of liquefaction. Failure of tunnels, pipelines, levees, bridges, and other structures and facilities could result in loss, injury, and disrupt SWP and CVP water supply deliveries. The potential for impacts from flooding as a result of levee or dam failure is also discussed in Chapter 6, *Surface Water*.

The native soil underlying Alternative 4 facilities consist of various channel deposits and recent silty and sandy alluvium at shallow depths. The available data along the southern portion of the conveyance (from approximately Potato Slough to Clifton Court Forebay) show that the recent alluvium overlies peaty or organic soils, which in turn is underlain by layers of mostly sandy and silty soil (Real and Knudsen 2009). Soil borings advanced by DWR along the northern portion of the conveyance (from approximately Potato Slough to Intake 1) show the surface soil as being similar to the range reported for the southern portion, but locally containing strata of clayey silt and lean clay. Because the borings were made over water, peat was usually absent from the boring logs (California Department of Water Resources 2011).

The silty and sandy soil deposits underlying the peaty and organic soil over parts of the Delta are late-Pleistocene age dune sand, which are liquefiable during major earthquakes. The tops of these materials are exposed in some areas, but generally lie beneath the peaty soil at depths of about 10–40 feet bgs along the modified pipeline/tunnel alignment (Real and Knudsen 2009). Liquefaction hazard mapping by Real and Knudsen (2009), which covers only the southwestern part of the Plan Area, including the part of the alignment from near Isleton to the Palm Tract, indicates that the lateral ground deformation potential would range from <0.1 to 6.0 feet. Liquefaction-induced ground settlement during the 1906 San Francisco earthquake was also reported near Alternative 4 facilities at a bridge crossing over Middle River just north of Woodward Island (Youd and Hoose 1978). Local variations in thickness and lateral extent of liquefiable soil may exist, and they may have important influence on liquefaction-induced ground deformations.

Figure 9-6 shows that the Alternative 4 alignment has no substantial levee damage potential from liquefaction in its extreme northern part and low to medium-high levee damage potential throughout the remainder.

Because the tunnel invert would be at depths of 100–160 feet bgs, the potential effect on these facilities due to liquefaction is judged to be low. However, the surface and near-surface facilities that would be constructed at the access road, intake, pumping plant, and forebay areas would likely be founded on liquefiable soil.

NEPA Effects: The potential effect could be substantial because seismically induced ground shaking could cause liquefaction, and damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. Please refer to Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*, for a detailed discussion of potential flooding effects.

In the process of preparing final facility designs, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extents of liquefiable soil. Engineering soil parameters that could be used to further assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

During final design, site-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, a California-registered civil engineer or California-certified engineering geologist would develop design measures and construction methods to meet design criteria established by building codes and construction standards to ensure that the design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, and using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods). The results of the site-specific evaluation and California-registered civil engineer or California-certified engineering geologist's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design requirements is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from liquefaction and associated hazards. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from strong seismic shaking of water conveyance features during operations:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- USACE Engineering and Design – Time-History Dynamic Analysis of Concrete Hydraulic Structure, EM 1110-2-6051, 2003
- USACE Engineering and Design – Response Spectra and Seismic Analysis for Concrete Hydraulic Structures, EM 1110-2-6050, 1999.
- American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures, ASCE-7-05, 2005.
- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs. Additionally, any modification to a federal levee system would require USACE approval under 33 USC 408 (a 408 Permit) and would have to pass quality assurance review by the Major Subordinate Command prior to being forwarded to USACE headquarters for final approval by the Chief of Engineers.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of liquefaction and associated ground movements would not create an increased likelihood of loss of property, personal injury or death of individuals from structural failure resulting from seismic-related ground failure along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

Alternative 4 would involve excavation that creates new cut-and-fill slopes and construction of new embankments and levees. As a result of ground shaking and high soil-water content during heavy rainfall, existing and new slopes that are not properly engineered and natural stream banks could fail and cause damage to facilities. Levees can fail for several reasons: 1) high velocities of water flow can result in high rates of erosion and erode and overtop a levee; 2) the higher velocities of water flow can also lead to higher rates of erosion along the inner parts of levees and lead to undercutting and clumping of the levee into the river. Heavy rainfall or seepage into the levee from the river can increase fluid pressure in the levee and lead to slumping on the outer parts of the levee. If the slumps grow to the top of the levee, large sections of the levee may slump onto the floodplain and lower the elevation of the top of the levee, leading to overtopping; 3) increasing levels of water in the river will cause the water table in the levee to rise which will increase fluid pressure and may result in seepage and eventually lead to internal erosion called piping. Piping will erode the material under the levee, undermining it and causing its collapse and failure.

With the exception of levee slopes and natural stream banks, the topography along the Alternative 4 conveyance alignment is nearly level to very gently sloping. The areas that may be susceptible to slope failure are along existing levee slopes, and at intakes, pumping plants, forebay, and certain access road locations. Outside these areas, the land is nearly level and consequently has a negligible potential for slope failure. Based on review of topographic maps and a landslide map of Alameda County (Roberts et al. 1999), the conveyance facilities would not be constructed on, nor would it be adjacent to, slopes that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures built on these slopes could be damaged or fail entirely as a result of slope instability. As discussed in Impact SW-2 in Chapter 6, *Surface Water*, operation of the water conveyance features under Alternative 4 would not result in an increase in potential risk for flood management compared to existing conditions. Peak monthly flows under Alternative 4 in the locations considered were similar to or less than those that would occur under existing conditions. Since flows would not be substantially greater, the potential for increased rates of erosion or seepage are low. For additional discussion on the possible exposure of people or structures to impacts from flooding due to levee failure, please refer to Impact SW-6 in Chapter 6, *Surface Water*.

During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. The design criteria would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008). As discussed in Chapter 3, *Description of the Alternatives*, the foundation soil beneath slopes, embankments, or levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill also would be used to construct new slopes, embankments, and levees. Surface and internal drainage systems would be installed as necessary to reduce erosion and piping (internal erosion) potential.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Section 9.3.1, *Methods for Analysis*, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.* The design requirements would be presented in a detailed geotechnical report. Conformance with these design requirements is an environmental commitment by DWR to ensure that slope stability hazards would be avoided as the water conveyance features are operated. DWR would ensure that the geotechnical design recommendations are included in the design of cut and fill slopes, embankments, and levees to minimize the potential effects from slope failure. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic shaking or from high-pore water pressure:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not create an increased likelihood of loss of property, personal injury of individuals along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Therefore, the potential hazard of loss of property or personal injury as a result of a tsunami on the water conveyance facilities is low.

Similarly, with the exception of the expanded Clifton Court Forebay, the potential for a substantial seiche to take place in the Plan Area is considered low because seismic and water body geometry conditions for a seiche to occur near conveyance facilities are not favorable. Fugro Consultants, Inc. (2011) identified the potential for a seiche of an unspecified wave height to occur in the Clifton Court Forebay, caused by strong ground motions along the underlying West Tracy fault, assuming that this fault is potentially active. Since the fault also exists in the immediate vicinity of the expanded Clifton Court Forebay, a seiche could also occur in the expanded Clifton Court Forebay.

NEPA Effects: The effect of a tsunami generated in the Pacific Ocean would not be adverse because the distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low (i.e., less than 2 feet) tsunami wave height to reach the Delta (Contra Costa Transportation Agency 2009).

In most parts of the Plan Area, the effects of a seiche would not be adverse because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the expanded Clifton Court Forebay. The effect could be adverse because the waves generated by a seiche could overtop the expanded Clifton Court Forebay embankments, causing erosion of the embankments and subsequent flooding in the vicinity.

However, design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would determine the peak ground acceleration caused by movement of the West Tracy fault and the maximum probable seiche wave that could be generated by the ground shaking. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard, as well as the hazard of a seiche overtopping the expanded Clifton Court Forebay embankment, would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that the adverse effects of a seiche are controlled to an acceptable level while the forebay facility is operated.

DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and consequent seiche waves. DWR would also ensure that the design specifications are properly executed during construction.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury tsunami or seiche:

- U.S. Department of the Interior and USGS Climate Change and Water Resources Management: A Federal Perspective, Circular 1331.
- State of California Sea-Level Rise Task Force of the CO-CAT, Sea-Level Rise Interim Guidance Document, 2010
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes provide guidance on estimating the effects of climate change and sea level rise and associated effects when designing a project and ensuring that a project is able to respond to these effects.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to these and other applicable design specifications and standards would ensure that the embankment for the expanded portion of the Clifton Court Forebay would be designed and constructed to contain and withstand the anticipated maximum seiche wave height and would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the expanded Clifton Court Forebay (Fugro Consultants 2011). The effect would not be adverse because the expanded Clifton Court Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4 from seiche or tsunami. The impact would be less than significant. No additional mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 4 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

***CEQA Conclusion*:** Alternative 4 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

According to the available AP Earthquake Fault Zone Maps, only the Suisun Marsh ROA could be affected by rupture of an earthquake fault. The active Green Valley fault crosses the southwestern corner of the ROA. The active Cordelia fault extends approximately 1 mile into the northwestern corner of the ROA. Rupture of these faults could damage levees and berms constructed as part of the restoration, which could result in failure of the levees and flooding of otherwise protected areas.

Within the Delta, active or potentially active blind thrust faults were identified in the seismic study (California Department of Water Resources 2007a). The extreme southeastern corner of the Suisun Marsh is underlain by the Montezuma blind thrust zone. Parts of the Cache Slough and Yolo Bypass ROAs are underlain by part of the North Midland blind thrust zone. The Cosumnes/Mokelumne River and East Delta ROAs are underlain by the Thornton Arch zone. Although these blind thrusts are not expected to rupture to the ground surface during earthquake events, they may produce ground or near-ground shear zones, bulging, or both. In the seismic study (California Department of Water Resources 2007a), the Thornton Arch blind thrust was assigned a 20% probability of being active. The depth to the Thornton Arch blind fault is unknown. Based on limited geologic and seismic survey information, it appears that the potential of having any shear zones, bulging, or both at the sites of the habitat levees is low because the depth to the blind thrust faults is generally deep.

NEPA Effects: The effect of implementing the conservation measures in the ROAs could be substantial because rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and cause damage or failure of ROA facilities, including levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

Because there is limited information regarding the depths of the blind faults mentioned above, seismic surveys would be performed in the vicinity of the faults as part of final design. These surveys would be used to verify fault depths where levees and other features would be constructed. Collection of this depth information would be part of broader, design-level geotechnical studies prepared by a geotechnical engineer licensed in the state of California to support all aspects of site-specific project design. The studies would assess site-specific conditions at and near all the project facility locations, including the nature and engineering properties of all soil horizons and underlying geologic strata, and groundwater conditions. The geotechnical engineers' information would be used to develop final engineering solutions to any hazardous condition, consistent with the code and standards requirements of federal, state and local oversight agencies. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that risks from a fault rupture are minimized as conservation levees are constructed and maintained. The hazard would be controlled to a safe level by following the proper design standards.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of ground movement in the vicinity of the blind thrusts underlying the ROAs would not jeopardize the integrity of the levees and other features constructed in the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion**:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

Earthquake events may occur on the local and regional seismic sources at or near the ROAs. Because of its proximity to these faults, the Suisun Marsh ROA would be especially subject to ground shaking caused by the Concord-Green Valley fault. The Cache Slough ROA would be subject to shaking from the Northern Midland fault zone, which underlies the ROA. Although more distant from these sources, the other ROAs would be subject to shaking from the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, San Gregorio, Greenville, and Mt. Diablo Thrust faults and the more proximate blind thrusts in the Delta.

Among all the ROAs, the Suisun Marsh ROA would be most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31–0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11–0.26 g. The ground shaking could damage levees and other structures, and in an extreme event cause levees to fail such that protected areas flood.

NEPA Effects: All temporary facilities would be designed and built to meet the safety and collapse-prevention requirements for the above-anticipated seismic loads. Therefore, this effect is considered not adverse. No additional mitigation measures are required. All facilities would be designed and constructed in accordance with the requirements of the design measures described in Chapter 3, *Description of the Alternatives*. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize the potential of damage. Design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the levees and other features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical engineer's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are implemented.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of project features and construction specifications to minimize the potential effects from seismic events and the presence of adverse soil conditions. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from surface rupture resulting from a seismic event during operation:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR DSOD Guidelines for Use of the Consequence-Hazard Matrix and Selection of Ground Motion Parameters, 2002.
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995.
- USACE Design and Construction of Levees, EM 1110-2-1913, 2000.
- USACE (Corps, CESPK-ED-G), Geotechnical Levee Practice, SOP EDG-03, 2004.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that they incur minimal damage in the event of a foreseeable seismic event and that they remain functional following such an event and that the facility is able to perform without catastrophic failure in the event of a maximum design earthquake (the greatest earthquake reasonably expected to be generated by a specific source on the basis of seismological and geological evidence).

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

Conformance to these and other applicable design specifications and standards would ensure that the hazard of seismic shaking would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion**:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

New structural features are proposed at the ROAs, such as levees as part of CM4, setback levees as part of CM5 and CM6, and experimental ramps and fish ladders at the Fremont Weir as part of CM2. Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of these levees and other features constructed at the restoration areas. The consequences of liquefaction are manifested in terms of compaction or settlement, loss of bearing capacity, lateral spreading (horizontal soil movement), and increased lateral soil pressure. Failure of levees and other structures could result in flooding of otherwise protected areas in Suisun Marsh and behind new setback levees along the Sacramento and San Joaquin Rivers and in the South Delta ROA.

The ROAs vary with respect to their liquefaction hazard (Figure 9-6). The Suisun Marsh ROA generally has a moderate or high liquefaction hazard. The liquefaction damage potential among the other ROAs, as well as where setback levees would be constructed along the Old, Middle, and San Joaquin Rivers under CM5 and CM6, is generally low to medium.

NEPA Effects: The potential effect could be substantial because earthquake-induced liquefaction could damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

During final design of conservation facilities, site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as SPT blow counts, CPT penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquakes. If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content is less susceptible to liquefaction.

During final design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. In areas determined to have a potential for liquefaction, the engineer would develop design parameters and construction methods to meet the design criteria established to ensure that design earthquake does not cause damage to or failure of the facility. Such measures and methods include removing and replacing potentially liquefiable soil, strengthening foundations (for example, using post-tensioned slab, reinforced mats, and piles) to resist excessive total and differential settlements, using *in situ* ground improvement techniques (such as deep dynamic compaction, vibro-compaction, vibro-replacement, compaction grouting, and other similar methods), and conforming with current seismic design codes and requirements. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from seismic-related ground failure:

- USACE Engineering and Design - Design of Pile Foundations, EM 1110-2-2906, 1991
- USACE Engineering and Design – Stability Analysis of Concrete Structures, EM 1110-2-2100, 2005
- USACE Engineering and Design, Earthquake Design and Evaluation for Civil Works Projects, ER 1110-2-1806, 1995
- California Code of Regulations, Title 8, Sections 1509 and 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built so that if soil in the foundation or surrounding area are subject to liquefaction, the removal or densifaction of the liquefiable material should be considered, along with alternative foundation designs.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment, practicing crane and scaffold safety measures). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at construction sites.

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during implementation and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion: Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Implementation of CM2–CM7, would involve breaching, modification or removal of existing levees and construction of new levees and embankments. CM4 which provides for the restoration of up to 65,000 acres of tidal perennial aquatic, tidal mudflat, tidal freshwater emergent wetland, and tidal brackish emergent wetland natural communities within the ROAs involves the greatest amount of modifications to levees. Levee modifications, including levee breaching or lowering, may be performed to reintroduce tidal exchange, reconnect remnant sloughs, restore natural remnant meandering tidal channels, encourage development of dendritic channel networks, and improve floodwater conveyance.

Levee modifications could involve the removal of vegetation and excavation of levee materials. Excess earthen materials could be temporarily stockpiled, then re-spread on the surface of the new levee slopes where applicable or disposed of offsite. Any breaching or other modifications would be required to be designed and implemented to maintain the integrity of the levee system and to conform with flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies. Those agencies may include USACE, DWR, CVFPB, and other flood management agencies. For more detail on potential modifications to levees as a part of conservation measures, please refer to Chapter 3, *Description of Alternatives*.

New and existing levee slopes and stream/channel banks could fail and could damage facilities as a result of seismic shaking and as a result of high soil-water content during heavy rainfall.

With the exception of levee slopes, natural stream banks, and part of the Suisun Marsh ROA, the topography of ROAs is nearly level to gently sloping. The areas that may be susceptible to slope failure are along existing Sacramento and San Joaquin River and Delta island levees and stream/channel banks, particularly those levees that consist of non-engineered fill and those streambanks that are steep and consist of low strength soil.

The structures associated with conservation measures would not be constructed in, nor would they be adjacent to, areas that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in loss, injury, and death as well as flooding of otherwise protected areas.

As outlined in Chapter 3, *Description of Alternatives*, erosion protection measures and protection against related failure of adjacent levees would be taken where levee breaches were developed. Erosion protection could include geotextile fabrics, rock revetments, riprap, or other material selected during future evaluations for each location. Aggregate rock could be placed on the remaining levees to provide an access road to the breach location. Erosion protection measures would also be taken where levee lowering is done for the purposes of allowing seasonal or periodic inundation of lands during high flows or high tides to improve habitat or to reduce velocities and elevations of floodwaters. To reduce erosion potential on the new levee crest, a paved or gravel access road could be constructed with short (approximately 1 foot) retaining walls on each edge of the crest to reduce undercutting of the roadway by high tides. Levee modifications could also include excavation of watersides of the slopes to allow placement of slope protection, such as riprap or geotextile fabric, and to modify slopes to provide levee stability. Erosion and scour protection could be placed on the landside of the levee and continued for several feet onto the land area away from the levee toe. Neighboring levees could require modification to accommodate increased flows or to reduce effects of changes in water elevation or velocities along channels following inundation of tidal marshes. Hydraulic modeling would be used during subsequent analyses to determine the need for such measures.

New levees would be constructed to separate lands to be inundated for tidal marsh from non-inundated lands, including lands with substantial subsidence. Levees could be constructed as described for the new levees at intake locations. Any new levees would be required to be designed and implemented to conform with applicable flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies, which may include USACE, DWR, CVFPB, and local flood management agencies.

Additionally, during project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As discussed in Chapter 3, *Description of the Alternatives*, foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, *Description of the Alternatives*, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

In particular, conformance with the following codes and standards would reduce the potential risk for increased likelihood of loss of property or personal injury from structural failure resulting from landslides or other slope instability:

- DWR Division of Engineering State Water Project – Seismic Loading Criteria Report, Sept 2012.
- DWR Division of Flood Management FloodSAFE Urban Levee Design Criteria, May 2012.
- USACE Slope Stability, EM 1110-2-1902, 2003.
- California Code of Regulations, Title 8, Section 3203, California Code of Regulations.

Generally, the applicable codes require that facilities be built to certain factors of safety in order to ensure that facilities perform as designed for the life of the structure despite various soil parameters.

The worker safety codes and standards specify protective measures that must be taken at construction sites to minimize the risk of injury or death from structural or earth failure (e.g., utilizing personal protective equipment). The relevant codes and standards represent performance standards that must be met by contractors and these measures are subject to monitoring by state and local agencies. Cal-OSHA requirements for an IIPP and the terms of the IIPP to protect worker safety are the principal measures that would be enforced at project sites during operations.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levees and other features at the ROAs and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: The distance from the ocean and attenuating effect of the San Francisco Bay would likely allow only a low tsunami wave height to reach the Suisun Marsh and the Delta. Conditions for a seiche to occur at the ROAs are not favorable. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur at the ROAs are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.10 Alternative 5—Dual Conveyance with Pipeline/Tunnel and Intake 1 (3,000 cfs; Operational Scenario C)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard of structural failure from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 5. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard of settlement or collapse caused by dewatering but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 5. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would not create a lower hazard of ground settlement on the tunnels and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A.

The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 5. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard of slope failure at borrow and spoils storage sites but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 5. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard of structural failure from construction-related ground motions but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 5. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard from an earthquake fault rupture but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. The impact would be less than significant.

CEQA Conclusion**:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 5. There would be no impact. Therefore, no mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. The impact would be less than significant.

CEQA Conclusion**:** Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 5. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard of structural failure from ground failure but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could result in flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 5. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would present a lower hazard from landslides and other slope instability but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 5. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 5 would include the same physical/structural components as Alternative 1A, except that it would entail four less intakes and four less pumping plants. These differences would not present a lower hazard of a seiche or tsunami and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of

Alternative 5 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 5 from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 5 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

CEQA Conclusion: Alternative 5 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 5 as under 1A, except that only up to 25,000 acres of tidal habitat would be restored. The effects of Alternative 5 relating to the hazard of loss of property, personal injury, or death from rupture of an earthquake fault would, therefore, be similar to that of Alternative 1A, but of a lower magnitude (fewer new levees and berms in restoration areas). See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 5 as under 1A, except that only up to 25,000 acres of tidal habitat would be restored. The effects of Alternative 5 relating to the hazard of loss of property, personal injury, or death from a structural failure from seismic shaking would, therefore, be similar to that of Alternative 1A, but of a lower magnitude (fewer new levees and berms in restoration areas). See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 5 as under 1A, except that only up to 25,000 acres of tidal habitat would be restored. The effects of Alternative 5 relating to the hazard of loss of property, personal injury, or death from ground failure would, therefore, be similar to that of Alternative 1A, but of a lower magnitude (because of fewer new levees and berms in restoration areas). See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 5 as under 1A, except that only up to 25,000 acres of tidal habitat would be restored. The effects of Alternative 5 relating to the hazard of loss of property, personal injury, or death from a landslide or other slope failure would, therefore, be similar to that of Alternative 1A, but of a lower magnitude. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 5 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Based recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.11 Alternative 6A—Isolated Conveyance with Pipeline/Tunnel and Intakes 1–5 (15,000 cfs; Operational Scenario D)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during construction compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*).

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6A. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from settlement or collapse caused by dewatering during construction compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground settlement of tunnels during construction compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6A. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from slope failure at borrow and spoils storage sites during construction compared to Alternative 1A.

The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from structural failure from construction-related motions compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from rupture of an earthquake fault compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative pipeline/tunnel, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6A. There would be no impact. Therefore, no mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed.

These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during operation compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system.

In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground failure compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.)

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from landslides and other slope instability compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6A. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 6A would include the same physical/structural components as Alternative 1A, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seiche or tsunami compared to Alternative 1A. The effects of Alternative 6A would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6A from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 6A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

***CEQA Conclusion*:** Alternative 6A would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6A as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 6A would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required. Similarly, the potential for a significant seiche to occur in the Plan Area is considered low because conditions for a seiche to occur near conveyance facilities are not favorable and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

9.3.3.12 Alternative 6B—Isolated Conveyance with East Alignment and Intakes 1–5 (15,000 cfs; Operational Scenario D)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during construction compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6B. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from settlement or collapse caused by dewatering during construction compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground settlement during construction of tunnel siphons, compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from slope failure at borrow and spoils storage sites during construction compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from structural failure from construction-related motions compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR has committed to conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from rupture of an earthquake fault compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the East alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the East alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of direct loss, injury or death due to operation of Alternative 6B. There would be no impact. Therefore, no mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during operation compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6B. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed.

These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground failure compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage the canals, pipelines, tunnel and culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from landslides and other slope instability compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seiche or tsunami compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6B from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 6B would include the same physical/structural components as Alternative 1B, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during operation compared to Alternative 1B. The effects of Alternative 6B would, therefore, be the same as 1B. See the description and findings under Alternative 1B. There would be no adverse effect.

CEQA Conclusion**:** Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6B. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix* *and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6B as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 6B would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Based on recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required. Similarly, the potential for a significant seiche to occur at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

9.3.3.13 Alternative 6C—Isolated Conveyance with West Alignment and Intakes W1–W5 (15,000 cfs; Operational Scenario D)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during construction compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction, resulting in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6C. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from settlement or collapse caused by dewatering during construction compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground settlement of tunnels and culvert siphons during construction compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*). Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from slope failure at borrow and spoils storage sites during construction compared to Alternative 1C.

The effects of Alternative 6A would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from structural failure from construction-related motions compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR has committed to conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from rupture of an earthquake fault compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the West alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the West alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed.

These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during operation compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage the canals, pipelines, tunnel, culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from ground failure compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from landslides and other slope instability compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seiche or tsunami compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming that the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 6C would include the same physical/structural components as Alternative 1C, but existing connections between the SWP and CVP south Delta export facilities would be severed. These differences would not have a bearing on the hazard of loss of property, personal injury, or death from seismic shaking during operation compared to Alternative 1C. The effects of Alternative 6C would, therefore, be the same as 1C. See the description and findings under Alternative 1C. There would be no adverse effect.

***CEQA Conclusion*:** Seepage from an unlined canal could raise the water table level along the canal, thereby increasing the hazard of liquefaction where the water table is not already close to the surface. The increased hazard of liquefaction could threaten the integrity of the canal in the event that liquefaction occurs. However, because DWR would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 6C. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR‘s Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE‘s *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE‘s *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures would be the same under Alternative 6C as under 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 6C would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. The impact would be less than significant. No mitigation is required. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.14 Alternative 7—Dual Conveyance with Pipeline/Tunnel, Intakes 2, 3, and 5, and Enhanced Aquatic Conservation (9,000 cfs; Operational Scenario E)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 7. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of settlement or collapse caused by dewatering but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of ground settlement hazard on the tunnel but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 7. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of slope failure at borrow and spoils storage sites but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from construction-related ground motions but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would not reduce the hazard structural damage from rupture of an earthquake fault and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 7. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from ground failure but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard from landslides and other slope instability but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 7. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 7 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard from a seiche or tsunami but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 7 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 7 from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 7 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

***CEQA Conclusion*:** Alternative 7 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 7 would be the same that as under Alternative 1A, except up to an additional 20 linear miles of channel margin habitat would be created and up to an additional 10,000 acres of seasonally inundated floodplain habitat would be restored. The potential effects of a structural failure from rupture of an earthquake fault would pertain only to the Suisun Marsh ROA, which is the only ROA in which AP faults are found. However, the same engineering design and construction requirements that apply to all the ROAs would ensure that levees and other structures would withstand the effect of a fault rupture. The effect of Alternative 7 would, therefore, be the similar to that of Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 7 would be the same that as under Alternative 1A, except that up to an additional 20 linear miles of channel margin habitat would be created and up to an additional 10,000 acres of seasonally inundated floodplain habitat would be restored. The potential effects of a structural failure from seismic shaking would also be of a greater magnitude than that of Alternative 1A. However, the same engineering design and construction requirements that apply to all the ROAs would ensure that levees and other structures would withstand the effects of seismic shaking. The effect of Alternative 7 would, therefore, be the similar to that of Alternative 1A but of a greater magnitude. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. This impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 7 would be the same that as under Alternative 1A, except that up to an additional 20 linear miles of channel margin habitat would be created and up to an additional 10,000 acres of seasonally inundated floodplain habitat would be restored. The potential effects of a structural failure from ground failure would also be of a greater magnitude than that of Alternative 1A. However, the same engineering design and construction requirements that apply to all the ROAs would ensure that levees and other structures would withstand the effects of liquefaction. The effect of Alternative 7 would, therefore, be the similar to that of Alternative 1A but of a greater magnitude. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Conservation measures under Alternative 7 would be the same that as under Alternative 1A, except that up to an additional 20 linear miles of channel margin habitat would be created and up to an additional 10,000 acres of seasonally inundated floodplain habitat would be restored. The potential effects of a landslide or other slope instability would also be of a greater magnitude than that of Alternative 1A. However, the same engineering design and construction requirements that apply to all the ROAs would ensure that levees and other structures would withstand the effects of landslides and other slope instability. The effect of Alternative 7 would, therefore, be the similar to that of Alternative 1A but of a greater magnitude. See description and findings under Alternative 1A.

NEPA Effects: The potential effect could be substantial because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in flooding of otherwise protected areas.

As outlined in Chapter 3, *Description of Alternatives*, erosion protection measures and protection against related failure of adjacent levees would be taken where levee breaches were developed. Erosion protection could include geotextile fabrics, rock revetments, riprap, or other material selected during future evaluations for each location. Aggregate rock could be placed on the remaining levees to provide an access road to the breach location. Erosion protection measures would also be taken where levee lowering is done for the purposes of allowing seasonal or periodic inundation of lands during high flows or high tides to improve habitat or to reduce velocities and elevations of floodwaters. To reduce erosion potential on the new levee crest, a paved or gravel access road could be constructed with short (approximately 1 foot) retaining walls on each edge of the crest to reduce undercutting of the roadway by high tides. Levee modifications could also include excavation of watersides of the slopes to allow placement of slope protection, such as riprap or geotextile fabric, and to modify slopes to provide levee stability. Erosion and scour protection could be placed on the landside of the levee and continued for several feet onto the land area away from the levee toe. Neighboring levees could require modification to accommodate increased flows or to reduce effects of changes in water elevation or velocities along channels following inundation of tidal marshes. Hydraulic modeling would be used during subsequent analyses to determine the need for such measures.

New levees would be constructed to separate lands to be inundated for tidal marsh from non-inundated lands, including lands with substantial subsidence. Levees could be constructed as described for the new levees at intake locations. Any new levees would be required to be designed and implemented to conform with applicable flood management standards and permitting processes. This would be coordinated with the appropriate flood management agencies, which may include USACE, DWR, CVFPB, and local flood management agencies.

Additionally, during project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As discussed in Chapter 3, foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, such as USACE*'s Design and Construction of Levees* and USACE*'s EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levee and other features thereby creating an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. Therefore, there would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 7 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Based recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.15 Alternative 8—Dual Conveyance with Pipeline/Tunnel, Intakes 2, 3, and 5, and Increased Delta Outflow (9,000 cfs; Operational Scenario F)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 8. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of settlement or collapse caused by dewatering but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of ground settlement on the tunnel but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 8. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of slope failure at borrow and spoils storage sites but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from construction-related ground motions but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would not create a change in the hazard of structural damage from rupture of an earthquake fault and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 8. There would be no impact. Therefore, no mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR‘s Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE‘s *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard of structural failure from ground failure but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system.

In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard from landslides and other slope instability but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as

USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 8. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Alternative 8 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and two less pumping plants. These differences would present a slightly lower hazard from a seiche or tsunami but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 8 would, therefore, be the same as 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the Clifton Court Forebay and the Byron Tract Forebay (Fugro Consultants 2011). The impact would not be significant because the Byron Tract Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height. There would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 8 from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 8 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

***CEQA Conclusion*:** Alternative 8 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 8 would be the same as those under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 8 would be the same as those under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures. Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 8 would be the same as those under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas.

However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 8 would be the same as those under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 8 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.16 Alternative 9—Through Delta/Separate Corridors (15,000 cfs; Operational Scenario G)

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking of Water Conveyance Features during Construction

Construction of water conveyance facilities under Alternative 9 would involve two screened intakes the Delta Cross Channel and Georgiana Slough near Locke and Walnut Grove, culvert siphons, canals, pumping plants, borrow areas, enlargement of a channel, operable barriers, and other facilities. The locations of some of the Alternative 9 facilities would be different than those of any of the other alternatives. The operable barriers along Delta channels and the two pumping plants on Old River and Middle River would be in locations not discussed for other alternatives (see Figure 3-16).

Table 9-28 lists the expected PGA and 1.0-S_a values in 2020 at selected facility locations. As with other alternatives, ground motions with a return period of 72 years and calculated for 2005 are used to represent the construction period (2020) motions.

Table 9-28. Expected Earthquake Ground Motions at Locations of Selected Major Facilities during Construction (2020)—Alternative 9

	72-year Return Period Ground Motions			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Fish Screen Area[c]	0.11	0.14	0.13	0.21
Corridor Location near Venice Island[d]	0.20	0.26	0.22	0.35
Clifton Court Forebay / Byron Tract Forebay	0.18	0.23	0.20	0.32

g = gravity
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.3 and 1.6 were applied to PGA and 1.0-sec S_a values, respectively (adjustments from a stiff soil site to a soft soil site).
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island site were used.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted by the seismic study would increase if no major events take place on these faults through 2020. The effect could be substantial because seismically-induced ground shaking could cause loss of property or personal injury at the Alternative 9 construction sites (including intake locations, canals, and operable barriers) as a result of collapse of facilities. For example, facilities lying directly on or near active blind faults, such as the concrete batch plant and fuel station north of Locke, both intakes, the operable barriers on the Mokelumne River near Lost Slough and on Snodgrass Slough near the Mokelumne River, extension of Meadows Slough to the Sacramento River, and operable barrier on Meadows Slough, the boat lock and channel at the diversion structure at Georgiana Slough, the operable barrier at Threemile Slough, the operable barrier at Fisherman's Cut at False River for Alternative 9, which may result in an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Mapbook Figure M3-5.

The overall hazard of loss of property, personal injury, or death from structural failure caused by seismic shaking during construction would be less than that of Alternative 1A due to the fact that fewer facilities would be constructed. The same engineering design and construction requirements that apply to all the project facilities would reduce the risk of structural failure from seismic shaking. The effects of Alternative 9 would be of a similar nature but greatly reduced compared to those of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking could cause collapse or other failure of project facilities while under construction. However, DWR would conform with Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 9. This impact would be less than significant. No mitigation is required.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Settlement or Collapse Caused by Dewatering during Construction of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. The operable barriers along Delta channels and the two pumping plants on Old River and Middle River would be in locations not discussed for other alternatives (see Figure 3-16). At the primary two such locations, operable barriers would be constructed. The same engineering design and construction requirements that apply to all the project facilities would prevent settlement or collapse during dewatering and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 9. The impact would be less than significant. No mitigation is required.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Ground Settlement during Construction of Water Conveyance Features

Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, fish screens, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. The operable barriers along Delta channels and the two pumping plants on Old River and Middle River would be in locations not discussed for other alternatives (Figure 3-16). At the primary two such locations, operable barriers would be constructed.

Table 9-29 summarizes the geology of the Alternative 9 facilities as mapped by Atwater (1982) (Figure 9-3).

NEPA Effects: The overall hazard of loss of property or personal injury from ground settlement of culvert siphons during construction would be less than that of Alternative 1A. Additionally, the same engineering design and construction requirements that apply to all the project facilities would prevent ground settlement and would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to those under Alternative 1A. See the discussion of Impact GEO-3. See the description and findings under Alternative 1A. There would be no adverse effect.

Table 9-29. Geology of Key Facilities—Alternative 9

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 and Segment 2 Fish Screens	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay
Segment 1, Segment 2, Segment 4, and Segment 5 Operable Barriers	Ql	Natural levee deposits: moderately- to well-sorted sand, with some silt and clay
Segment 3 Operable Barriers	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Ql	Natural Levee deposits: moderately to well-sorted sand with some silt and clay
Segment 6 Operable Barriers	Qds	Dredge soil, post 1900
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 7 Operable Barriers	Qpm	Delta mud: mud and peat with minor silt or sand
	Qfp	Floodplain deposits: dense sandy to silty clay
Segment 9 and Segment 16 Canal	Qfp	Floodplain deposits: dense sandy to silty clay
Segment 16 Bridges	Qfp	Floodplain deposits: dense sandy to silty clay

Source: Hansen et al. 2001 and Atwater 1982.

[a] The reaches are defined in Chapter 3 and shown on Figure 9-3.

***CEQA Conclusion*:** Ground settlement above the tunneling operation for the culvert siphons could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 9. Hazards to workers and project structures would be controlled at safe levels and the impact would be less than significant. No mitigation is required.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Slope Failure during Construction of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. The operable barriers along Delta channels and the two pumping plants on Old River and Middle River would be in locations not discussed for other alternatives (see Figure 3-16). At the primary two such locations, operable barriers would be constructed. The overall hazard of loss of property or personal injury from slope failure at borrow and spoils sites during construction would be less than that of Alternative 1A. Additionally, the same engineering design and construction requirements that apply to all the project facilities would prevent slope failure would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 9. The impact would be less than significant. No mitigation is required.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Construction-Related Ground Motions during Construction of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. At the primary two such locations, operable barriers would be constructed. The overall hazard of loss of property or personal injury from structural failure from ground motions during construction would be overall slightly greater than that of Alternative 1A because of the greater amount pile driving that would be required. Additionally, the same engineering design and construction requirements that apply to all the project facilities would prevent structural failure from construction-related ground motions and would not substantially change the hazard of loss of property, personal injury, or death during construction. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction, which could result in injury of workers at the construction sites. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*) and there would be no increased likelihood of loss of property, personal injury or death due to the construction of Alternative 9. The impact would be less than significant. No mitigation is required.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault during Operation of Water Conveyance Features

Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives.

According to the available AP Earthquake Fault Zone Maps, none of the Alternative 9 constructed conveyance facilities would cross or be on any known active fault zones. Numerous AP fault zones have been mapped west of the conveyance alignment. The closest AP fault zone would be the Greenville fault, approximately 10.0 miles southwest of the constructed conveyance facilities. Because of their distances from the AP fault zones, the potential that the facilities would be directly subject to fault offsets is negligible.

In the Delta, active or potentially active blind thrust faults were identified in the seismic study. The operable barrier on Threemile Slough would be in the Montezuma Hills fault zone, and the extreme southwestern corner of the Byron Tract Forebay (to the northwest of the Clifton Court Forebay) may be underlain by the West Tracy fault (Figure 9-5). Although these blind thrusts are not expected to rupture to the ground surface under the forebay during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). Assuming that the West Tracy fault is potentially active, it could cause surface deformation in the western part of the Clifton Court Forebay (Fugro Consultants 2011) and the Byron Tract Forebay. In the seismic study (California Department of Water Resources 2007a), the Montezuma Hills and West Tracy blind thrusts have been assigned 50% and 90% probabilities of being active, respectively. The depth to the Montezuma Hills faults is unknown. The seismic study indicates that the West Tracy fault dies out as a discernible feature within approximately 3,000 to 6,000 feet bgs (in the upper 1 to 2 second depth two-way time, estimated to be approximately 3,000 to 6,000 feet using the general velocity function as published in the Association of Petroleum Geologists Pacific Section newsletter [Tolmachoff 1993]).

It appears that the potential of having any shear zones, bulging, or both at the depths of the facilities is low because the depth to the blind thrust faults is generally deep. However, because of there is limited information regarding depth for these faults, a geotechnical evaluation and seismic surveys would be performed at these two blind thrust locations during the design phase to determine the depths to the top of faults. The geotechnical work would provide the basis for design recommendations as would be done at the other project facilities. As with the other facilities, the facility design would conform to USACE design standards.

NEPA Effects: The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** There are no active faults capable of surface rupture that extend into the pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 9. There would be no impact. No mitigation is required.

Impact GEO-7: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking during Operation of Water Conveyance Features

Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. At the primary two such locations, operable barriers would be constructed.

Similar to the earthquake ground shaking hazard during construction, earthquake occurrences on the local and regional seismic sources for 2025 would subject the Alternative 9 facilities to ground shaking.

Table 9-30 lists the expected PGA and 1.0-S_a values for 2025 at selected facility locations. Earthquake ground shakings for the OBE (144-year return period) and MDE (975-year return period) were estimated for the stiff soil site, as predicted in the seismic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No seismic study results exist for 2025, so the ground shakings estimated for 2050 were used for 2025. The table shows that the proposed facilities would be subject to moderate-to-high earthquake ground shakings for 2025.

Table 9-30. Expected Earthquake Ground Motions at Locations of Selected Major Facilities in the Early Long-Term (2025)—Alternative 9

	144-year Return Period Ground Motions (OBE)			
	Peak Ground Acceleration (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[b]	Stiff Soil[a]	Local Soil[b]
Intake and Fish Screen Area[c]	0.14	0.15	0.19	0.30
Corridor Location near Venice Island[d]	0.30	0.33	0.31	0.50
Clifton Court Forebay / Byron Tract Forebay	0.28	0.31	0.30	0.48
	975-year Return Period Ground Motions (MDE)			
	PGA (g)		1.0-sec S_a (g)	
Major Facilities	Stiff Soil[a]	Local Soil[e]	Stiff Soil[a]	Local Soil[e]
Intake and Fish Screen Area[c]	0.24	0.24	0.33	0.53
Corridor Location near Venice Island[d]	0.50	0.50	0.60	0.96
Clifton Court Forebay / Byron Tract Forebay	0.50	0.50	0.61	0.98

g = gravity
MDE = maximum design earthquake
OBE = operating basis earthquake
PGA = Peak Ground Acceleration
S_a = second spectral acceleration
[a] Stiff soil site, with a V_{s100ft} value of 1,000 ft/s.
[b] Site-adjusted factors of 1.1 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.
[c] The results of California Department of Water Resources 2007a for the Sacramento site were used.
[d] The results of California Department of Water Resources 2007a for the Sherman Island site were used.
[e] Site-adjusted factors of 1.0 and 1.60 were applied to PGA and 1.0-sec S_a values, respectively.

NEPA Effects: The Alternative 9 facilities would be subject to the same engineering design and construction requirements that apply to all the project facilities, which would prevent structural failure from seismic shaking and not substantially change the hazard of loss of property, personal injury, or death compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion**:** Seismically induced strong ground shaking could damage culvert siphons, intake facilities, pumping plants, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 9. The impact would be less than significant. No mitigation is required.

Impact GEO-8: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) during Operation of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. (Some of the facilities would primarily involve in-water work and would have no bearing on geology and seismicity.) The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. At the primary two such locations, operable barriers would be constructed. The Alternative 9 facilities would be subject to the same engineering design and construction requirements that apply to all the project facilities, which would prevent structural failure from liquefaction and not substantially change the hazard of loss of property, personal injury, or death compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Seismically induced ground shaking could cause liquefaction. Liquefaction could damage culvert siphons, intake facilities, pumping plants, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 9. The impact would be less than significant. No mitigation is required.

Impact GEO-9: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability during Operation of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. (Some of the facilities would primarily involve in-water work and would have no bearing on geology and seismicity.) The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. At the primary two such locations, operable barriers would be constructed. The Alternative 9 facilities are subject to a similar hazard of slope instability as Alternative 1A and would not substantially change the hazard of loss of property, personal injury, or death compared to Alternative 1A. The effects of Alternative 9 would, therefore, be similar to that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability. However, through the final design process, measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 9. The hazard would be controlled to a safe level. The impact would be less than significant. No mitigation is required.

Impact GEO-10: Loss of Property, Personal Injury, or Death from Seiche or Tsunami during Operation of Water Conveyance Features

NEPA Effects: Construction of water conveyance facilities under Alternative 9 would involve an array of intakes, pumping plants, pipelines, culvert siphons, canals, borrow areas, enlargement of a channel, and other facilities. (Some of the facilities would primarily involve in-water work and would have no bearing on geology and seismicity.) The locations of some of the Alternative 9 facilities would be different than that of any of the other alternatives. At the primary two such locations, operable barriers would be constructed. The Alternative 9 facilities are subject to a similar hazard of a seiche or tsunami as Alternative 1A and would not substantially change the hazard of loss of property, personal injury, or death from a seiche or tsunami compared to Alternative 1A, with the exception of the Byron Tract Forebay, which would not be a component of this alternative. The effects of Alternative 9 would, therefore, be similar to or less than that of Alternative 1A. See the description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. There would be no increased likelihood of loss of property, personal injury or death due to the operation of Alternative 9 from seiche or tsunami. The impact would be less than significant. No mitigation is required.

Impact GEO-11: Ground Failure Caused by Increased Groundwater Surface Elevations from Unlined Canal Seepage as a Result of Operating the Water Conveyance Facilities

NEPA Effects: Alternative 9 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

CEQA Conclusion: Alternative 9 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

Impact GEO-12: Loss of Property, Personal Injury, or Death Resulting from Structural Failure Caused by Rupture of a Known Earthquake Fault at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 9 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, through the final design process for conservation measures in the ROAs, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-13: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Strong Seismic Shaking at Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 9 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Ground shaking could damage levees, berms, and other structures, Among all the ROAs, the Suisun Marsh ROA would be the most subject to ground shaking because of its proximity to active faults. The Suisun Marsh ROA is subject to a PGA of approximately 0.31 to 0.35 g for 200-year return interval, while the PGA for the other ROAs ranges from approximately 0.11 to 0.26 g. Damage to these features could result in their failure, causing flooding of otherwise protected areas. However, as described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, design codes, guidelines, and standards, including the California Building Code and resource agency and professional engineering specifications, such as DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria* and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects* would be used for final design of conservation features. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that strong seismic shaking risks are minimized as the conservation measures are operated and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-14: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Seismic-Related Ground Failure (Including Liquefaction) Beneath Restoration Opportunity Areas

NEPA Effects: Conservation measures under Alternative 9 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

CEQA Conclusion: Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-15: Loss of Property, Personal Injury, or Death from Landslides and Other Slope Instability at Restoration Opportunity Areas

Conservation measures under Alternative 9 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A.

NEPA Effects: The effect would be adverse because levee slopes and embankments may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Failure of these features could result in flooding of otherwise protected areas. During project design, a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. As discussed in Chapter 3, foundation soil beneath embankments and levees could be improved to increase its strength and to reduce settlement and deformation. Foundation soil improvement could involve excavation and replacement with engineered fill; preloading; ground modifications using jet-grouting, compaction grouting, chemical grouting, shallow soil mixing, deep soil mixing, vibro-compaction, or vibro-replacement; or other methods. Engineered fill could also be used to construct new embankments and levees.

Site-specific geotechnical and hydrological information would be used, and the design would conform with the current standards and construction practices, as described in Chapter 3, such as USACE's *Design and Construction of Levees* and USACE's *EM 1110-2-1902, Slope Stability.*

The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not jeopardize the integrity of levee and other features at the ROAs. There would be no adverse effect.

***CEQA Conclusion*:** Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, because the BDCP proponents would conform with applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

Impact GEO-16: Loss of Property, Personal Injury, or Death from Seiche or Tsunami at Restoration Opportunity Areas as a Result of Implementing the Conservation Actions

NEPA Effects: Conservation measures under Alternative 9 would be similar to that as under Alternative 1A. See description and findings under Alternative 1A. There would be no adverse effect.

***CEQA Conclusion*:** Based on recorded tsunami heights at the Golden Gate, the height of a tsunami wave reaching the ROAs would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in the Plan Area that would cause loss of property, personal injury, or death at the ROAs is considered low because conditions for a seiche to occur near conveyance facilities are not favorable. The impact would be less than significant. No mitigation is required.

9.3.3.17 Cumulative Analysis

The cumulative effects analysis for geology and seismicity considers the effects of BDCP implementation in combination with other past, present, and reasonably foreseeable projects or programs. The analysis focuses on projects and programs within the Plan Area, in particular those that could create a cumulatively significant geologic or seismic risk to people or structures, including the risk of loss of property, personal injury, or death. The principal programs and projects considered in the analysis are listed in Table 9-31. This list has been drawn from a more substantial compilation of past, present, and reasonably foreseeable programs and projects included in Appendix 3D, *Defining Existing Conditions, the No Action/No Project Alternative, and Cumulative Impact Conditions*.

Table 9-31. Cumulative Effects on Geology and Seismicity from Plans, Policies, and Programs

Agency	Program/Project	Status	Description of Program/Project	Effects on Geology and Seismicity
USACE	Delta Dredged Sediment Long-Term Management Strategy	Ongoing	Maintaining and improving channel function, levee rehabilitation, and ecosystem restoration.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
Semitropic Water Storage District	Delta Wetlands	Final EIR released in August 2011	Transforming four low-lying islands in the Central Delta within San Joaquin and Contra Costa counties into two Reservoir Islands and two Habitat Islands by fortifying the surrounding levee systems and installing new pumps, siphons, and state-of-the-art fish screens.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
West Sacramento Area Flood Control Agency and USACE	West Sacramento Levee Improvements Program	Final EIR/EIS certified on March 10, 2011	Improvements to levees protecting West Sacramento to meet local and federal flood protection criteria.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.

Agency	Program/Project	Status	Description of Program/Project	Effects on Geology and Seismicity
DWR	Levee Repair-Levee Evaluation Program	Ongoing	Repair of state and federal project levees. To date, nearly 300 levee repair sites have been identified, with more than 100 of the most critical sites having already been completed with AB 142 funds. Repairs to others are either in progress or scheduled to be completed in the near future, and still more repair sites are in the process of being identified, planned, and prioritized.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
DWR	Delta Levees Flood Protection Program	Ongoing	Levee rehabilitation projects in the Delta.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
DWR, DFW, USACE	CALFED Levee System Integrity Program	Planning phase	Levee maintenance and improvement in the Delta.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
DWR	Central Valley Flood Management Planning Program	Planning phase	Among other management actions, involves levee raising and construction of new levees for flood control purposes.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
SAFCA, Central Valley Flood Protection Board, USACE	Flood Management Program	Ongoing	South Sacramento Streams Project component consists of levee, floodwall, and channel improvements.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
USBR, DWR	2-Gates Fish Protection Demonstration Project	Delayed	Temporary gates would be placed across Old River and Connection Slough in the central Delta and operated from December to March for fish protection purposes.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.

Agency	Program/Project	Status	Description of Program/Project	Effects on Geology and Seismicity
USBR, DWR	Franks Tract Project	Delayed	State and federal agencies would evaluate and implement, if appropriate and authorized, a strategy to significantly reduce salinity levels in the south Delta and at the CCWD and SWP/CVP export facilities and improve water supply reliability by reconfiguring levees and/or Delta circulation patterns around Franks Tract while accommodating recreational interests	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.
DWR, USBR and CCWD	Los Vaqueros Expansion Investigation	Final EIR certified by CCWD in March 2010	The existing Los Vaqueros Reservoir would be expanded up to a total of 275 thousand acre-feet to take full advantage of the existing state of the art fish screens currently in use in the Delta. New Delta intakes, pumps, and pipelines would be required to fill the additional reservoir capacity, and water deliveries would be made from the expanded reservoir to Bay Area beneficiaries through new conveyance facilities.	No direct effect on increased risks at BDCP construction locations from earthquakes, groundshaking, liquefaction, slope instability, seiche or tsunami.

No Action Alternative

The cumulative effect of the No Action Alternative is anticipated to result in the current hazard resulting from earthquake-induced ground shaking from regional and local faults persisting. It is also anticipated that the current hazard of earthquake-induced liquefaction triggered by regional and local faults would persist. Slope instability associated with non-engineered levees would continue to present a risk of levee failure and subsequent flooding of Delta islands, with a concomitant influx of seawater into the Delta, thereby adversely affecting water quality and water supply. Ongoing and reasonably foreseeable future projects in parts of the Delta are expected to upgrade the levees to a "flood-safe" condition under the 100-year return flood elevation. However, these projects would provide very little levee foundation strengthening and improvements directed at improving the stability of the levees to better withstand ground shaking, liquefaction, and slope instability.

The Delta and vicinity is within a highly active seismic area, with a generally high potential for major future earthquake events along nearby and/or regional faults, and with the probability for such events increasing over time. Based on the location, extent and non-engineered nature of many existing levee structures in the Delta area, the potential for significant damage to, or failure of, these structures during a major local seismic event is generally moderate to high. In the instance of a large seismic event, levees constructed on liquefiable foundations are expected to experience large deformations (in excess of 10 feet) under a moderate to large earthquake in the region. There would potentially be loss, injury or death resulting from ground rupture, ground shaking and liquefaction, (See Appendix 3E, *Potential Seismic and Climate Change Risks to SWP/CVP Water Supplies* for more detailed discussion). While similar risks would occur under implementation of the action alternatives, these risks may be reduced by BDCP-related levee improvements along with those projects identified for the purposes of flood protection in Table 9-31.

BDCP Alternatives

NEPA Effects: Implementation of the BDCP and other local and regional projects as presented in Table 9-31, could contribute to regional impacts and hazards associated with geology and seismicity. The geologic and seismic hazards that would exist and the potential adverse effects that could occur to structures and persons in association with construction and operation of all BDCP alternatives would be restricted to the locations of the construction and the operational activities of these alternatives. Depending on which alternative is chosen, the location of these impacts would vary slightly. These impacts include the potential for loss, injury or death as a result of strong seismic shaking, settlement or collapse caused by dewatering, ground settlement, slope failure (including decreased levee stability from construction and operation activities), seismic-related ground failure (including liquefaction), ground shaking, fault rupture, seiche or tsunami. All of the impacts are mitigated by incorporating standard construction and structural measures into project design and construction. No impacts related to construction or operation of any of the BDCP alternatives or from implementation of the conservation measures were identified for this resource area. These cumulative impacts would result from construction activities and development of additional structures that may be subject to geologic, seismic, or slope failure and could be reduced by implementing measures similar to those described for BDCP. However, these projects would not increase the risks to structures and people at the specific locations affected by BDCP alternatives. Therefore, the risks of loss of property, personal injury, or death associated with the alternatives would not combine with the geologic and seismic risks from other projects or programs to create a cumulatively adverse effect at any one locality in the Plan Area. There would be no cumulative adverse effect.

CEQA Conclusion: The geologic and seismic hazards that would exist and the potential adverse effects that could occur in association with construction and operation of all project alternatives would be restricted to the locations of the construction and the operational activities of these alternatives. Other past, present and probable future projects and programs in the Plan Area that are identified in Table 9-31 would not increase the risks of loss, injury or death at the specific locations affected by project alternatives. Therefore, the risks of loss, injury or death associated with the project alternatives would not combine with the geologic and seismic risks from other projects or programs to create a substantial cumulative effect at any one locality in the Plan Area. This cumulative impact is considered less than significant. No mitigation is required.

9.4 References Cited

Association of Bay Area Governments. 2011. *Liquefaction Maps and Information*. Earthquake and Hazards Program. Available: <http://quake.abag.ca.gov/liquefaction/>. Accessed: October 20, 2011.

Atkinson, G. M., and D. M. Boore. 2003. Empirical Ground-Motion Relations for Subduction-Zone Earthquakes and their Application to Cascadia and Other Regions. *Bulletin of the Seismological Society of America* 93(4):1703–1729.

Atwater, B. F. 1982. *Geologic Maps of the Sacramento–San Joaquin Delta, California: U.S. Geological Survey*. (Miscellaneous Field Studies Map MF-1401, scale 1:24,000). Reston, VA.

Atwater, B. F., and D. F. Belknap. 1980. Tidal–Wetland Deposits of the Sacramento–San Joaquin Delta, California. In: M. E. Field, A. H. Bouma, I. P. Colburn, R. G. Douglas, and J. C. Ingle (eds.). *Quaternary Depositional Environments of the Pacific Coast*: *[papers] Pacific Coast Paleogeography, Symposium 4, April 9, 1980*. Los Angeles, CA: Pacific Section, Society of Economic Paleontologists and Mineralogists.

Boore, D. M., and G. M. Atkinson. 2007. *Boore-Atkinson NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters*. PEER 2007/01, Pacific Earthquake Engineering Research Center Report.

Brocher, T. M. 2005. A Regional View of Urban Sedimentary Basins in Northern California Based on Oil Industry Compressional-Wave Velocity and Density Logs. *Bulletin of the Seismological Society of America* 95:2093–2114.

Bryant, W. A., and E. W. Hart. 2007. *Fault-Rupture Hazard Zones in California Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Maps* (Interim Revision). Special Publication 42. California Department of Conservation, California Geological Survey. Sacramento, CA.

CALFED Bay-Delta Program. 2000. *Levee System Integrity Program Plan, Final Programmatic EIS/EIR Technical Appendix*. July.

California Department of Conservation. 2000. *Seismic Hazard Zone Report 044 for the San Jose East 7.5-minute Quadrangle, Santa Clara County, California.* Open-File Report 2000-010. Division of Mines and Geology. Available: <http://gmw.consrv.ca.gov/shmp/download/evalrpt/sjose_eval.pdf>. Accessed: April 25, 2012.

———. 2009. *Tsunami Inundation Map for Emergency Planning, Benicia Quadrangle*. July. Sacramento, CA. Available: <http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Solano/Documents/Tsunami_Inundation_Benicia_Quad_Solano.pdf>. Accessed: October 21, 2011.

California Department of Water Resources. 1992. *Seismic Stability Evaluation of the Sacramento–San Joaquin Delta Levees, Volume 1, Phase I Report: Preliminary Evaluations and Review of Previous Studies*. August.

———. 2007a. *Technical Memorandum: Delta Risk Management Strategy (DRMS) Phase 1 (Topical Area: Seismology, Final)*. Prepared by URS Corporation / Jack R. Benjamin and Associates, Inc.

———. 2007b. *Draft Summary Report: Delta Risk Management Strategy (DRMS) Phase 1 (Risk Analysis, Draft)*. Prepared by URS Corporation / Jack R. Benjamin and Associates, Inc.

———. 2009a. *Conceptual Engineering Report—Isolated Conveyance Facility—East Option*. November 18. Revision 1. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2009b. *Conceptual Engineering Report—Isolated Conveyance Facility—West Option*. November 25. Revision 0. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010a. *Conceptual Engineering Report—Isolated Conveyance Facility—All Tunnel Option*. March 10. Revision 0. Design Document 500-05-05-100-03. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010b. *Conceptual Engineering Report—Isolated Conveyance Facility—Pipeline/Tunnel Option (formerly All Tunnel Option)—Addendum*. October 22. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010c. *Conceptual Engineering Report—Isolated Conveyance Facility—East Option—Addendum*. October 25. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010d. *Conceptual Engineering Report—Isolated Conveyance Facility—West Option—Addendum*. October 25. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010e. *Option Description Report—Separate Corridors Option, Volume 1—Report*. June. Revision 0. Document 600-05-05-100-001. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010f. *The State Water Project Delivery Reliability Report 2009*. August. Available: <http://baydeltaoffice.water.ca.gov/swpreliability/Reliability2010final101210.pdf>. Accessed: September 6, 2010.

———. 2010g. *Draft Phase I Geotechnical Investigation—Geotechnical Data Report—Isolated Conveyance Facility West*. July 12. Revision 0. Document 002-31-05-183-001. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010h. *Draft Phase I Geotechnical Investigation—Geotechnical Data Report—Isolated Conveyance Facility East*. July 12. Revision 0. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2010i. *Draft Report of the Analysis and Optimization of the Pipeline/Tunnel Option*. November 23. Document 005-05-05-100-004. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

———. 2011. *Draft Phase II Geotechnical Investigation—Geotechnical Data Report—Pipeline/Tunnel Option.* August 22. Revision 1.1. Delta Habitat Conservation and Conveyance Program. Sacramento, CA.

California Department of Water Resources and California Department of Fish and Game. 2008. *Risk and Options to Reduce Risks to Fishery and Water Supply Uses of the Sacramento/San Joaquin Delta*. A Report Pursuant to Requirements of Assembly Bill 1200, Laird.

California Division of Oil and Gas. 1982. *Oil and Gas Fields, Northern California: Volume 3 of Publication TR10*. State of California.

California Geological Survey. 2008. *Guidelines for Evaluating and Mitigating Seismic Hazards in California*. Special Publication 117A. Sacramento, CA.

Campbell, K. W., and Y. Bozorgnia. 2007. *Campbell-Bozorgnia NGA Ground Motion Relations for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters*. PEER 2007/02. Pacific Earthquake Engineering Research Center.

Cao, T., W. A. Bryant, B. Rowshandel, D. Branum, and C. J. Wills. 2003. *Revised 2002 California Probabilistic Seismic Hazard Maps, June*. California Geological Survey.

Cherven, V. B., and S. A. Graham (eds.). 1983. *Geology and Sedimentology of the Southwestern Sacramento Basin and East Bay Hills*. Field Trip Guidebook, Pacific Section (Society of Economic

Paleontologists and Mineralogists). Los Angeles, CA: Pacific Section, Society of Economic Paleontologists and Mineralogists.

Chiou, B. S-J., and R. R. Youngs. 2006. *Chiou and Youngs PEER NGA Empirical Ground Motion Model for the Average Horizontal Component of Peak Acceleration and Pseudo-Spectral Acceleration for Spectral Periods of 0.01 to 10 Seconds*. Interim Report for U.S. Geological Survey Review. Revised July 10, 2006.

City and County of San Francisco. 2011. *Emergency Response Plan—Tsunami Response Annex*. March. An element of the CCSF Emergency Management Program. San Francisco, CA.

Contra Costa County. 2009. *Draft Environmental Impact Report, Contra Costa Pipeline Project.* May. State Clearinghouse No. 20070662007. Department of Conservation and Development.

Contra Costa Transportation Agency. 2009. *Draft Environmental Impact Report, 2009 Countywide Comprehensive Transportation Plan*. February 18. State Clearinghouse No. 2008052073.

County of Sacramento. 1993. *Safety Element: Background to the 1993 General Plan as Amended*. Planning and Community Development Department. Sacramento, CA. Available: < http://www.per.saccounty.net/PlansandProjectsIn-Progress/Documents/ General%20Plan%202030/Safety%20Element%20Background.pdf >. Accessed: June 21, 2013.

Dean A., D. J. Young, and G. J. E. Kramer. 2006. *The Use and Performance of Precast Concrete Tunnel Linings in Seismic Areas*. September. International Association of Engineering Geology (IAEG) Congress.

DeCourten, F. 2008. *Geology of Northern California*. Available: <http://cengage.com/custom/regional_geology/data/DeCourten_0495763829_LowRes_ New.pdf>. Accessed: September 21, 2012.

Fugro Consultants. 2011. *Reprocessing and Interpretation of Seismic Reflection Data, Clifton Court Forebay*. Letter to Mark Pagenkopp, California Department of Water Resources. July 22. Walnut Creek, CA.

Graymer, R. W., D. L. Jones, and E. E. Brabb. 2002. *Geologic Map and Map Database of Northeastern San Francisco Bay Region, California, Most of Solano Country, and Parts of Napa, Marin, Contra Costa, San Joaquin, Sacramento, Yolo, and Sonoma Counties*. U.S. Geological Survey Miscellaneous Field Studies Map MF-2403. U.S. Geological Survey. Menlo Park, CA.

Hansen, D. T., G. J. West, P. Welch, and B. Simpson. 2001. *Geomorphology_Delta*. U.S. Bureau of Reclamation, Mid-Pacific Region GIS. Available: <http://atlas.ca.gov/catalog/>. Accessed: April 9. 2012.

Helley, E. J., and J. A. Barker. 1979. *Preliminary Geologic Map of Cenozoic Deposits of the Guinda, Dunningan, Woodland, and Lake Berryessa Quadrangles, California*. U.S. Geological Survey Open-File Report OF-79-1606, 4 sheets, scale 1:62,500. Available: <http://ngmdb.usgs.gov/Prodesc/proddesc_11190.htm>. Accessed: April 25, 2012.

Hendy, I. L., and J. P. Kennett. 2000. Stable Isotope Stratigraphy and Paleoceanography of the Last 170 K. Y.: ODP Site 1014, Tanner Basin, California. In: M. Lyle, I. Koizumi, C. Richter, and T. C. Moore, Jr. (eds.). *Proceedings of the Ocean Drilling Program*, *Scientific Results* 167:129–140. College Station, TX.

Imbrie, J., J. D. Hays, D. G. Martinson, A. McIntyre, A. C. Mix, J. J. Morley, N. G. Pisias, W. L. Prell, and N. J. Shackleton. 1984. The Orbital Theory of Pleistocene Climate: Support from a Revised Chronology of the Marine δ^{18}O Record. In Berger et al. (eds.). *Milankovitch and Climate (Part 1): NATO ASI Series C, Math and Physical Science* 126:269–305.

Lettis, W. R., and J. R. Unruh. 1991. Quaternary Geology of the Great Valley, California. In R. B. Morrison (ed.), *Quaternary Non-Glacial Geology of the Western United States: Decade of North American Geology*. Volume K-2, Geological Society of America. Pages 164–176.

Marchand, D. E. 1977. The Cenozoic History of the San Joaquin Valley and the Adjacent Sierra Nevada as Inferred from the Geology and Soils of the Eastern San Joaquin Valley. In Singer, M. J. (ed.), *Soil Development, Geomorphology, and Cenozoic History of the Northeastern San Joaquin Valley and Adjacent Areas, California*. Guidebook for Joint Field Session, Soil Science Society of America and Geologic Society of America. University of California Press.

Martinson, D. G., N. G. Pisias, J. D. Hays, J. Imbrie, T. C. Moore, and N. J. Shackleton. 1987. Age Dating and the Orbital Theory of the Ice Ages—Development of a High-Resolution-0 to 300,000-Year Chronostratigraphy. *Quaternary Research* 27(1): 1–29.

Miller, A. W., R. S. Miller, H. C. Cohen, and R. F. Schultze. 1975. *Suisun Marsh Study, Solano County, California*. U.S. Department of Agriculture Soil Conservation Service.

Norris, R. M., and R. W. Webb. 1990. *Geology of California.* Second Edition. New York: John Wiley & Sons, Inc.

Petersen, M. D., A. D. Frankel, S. C. Harmsen, C. S. Mueller, K. M. Haller, R. L. Wheeler, R. L. Wesson, Y. Zeng, O. S. Boyd, D. M. Perkins, N. Luco, E. H. Field, C. J. Wills, and K. S. Rukstales. 2008. *Documentation for the 2008 Update of the United States National Seismic Hazard Maps*. U.S. Geological Survey Open-File Report 2008-1128.

Real, C. R., and K. L. Knudsen. 2009. *Application of New Liquefaction Hazard Mapping Technique to the Sacramento-San Joaquin Delta Area*. Final Technical Report. December 23. Collaborative Research with URS Corporation, California Geological Survey.

Roberts, S., M. Roberts, and E. Brennan. 1999. *Landslides in Alameda County, California*. A digital database extracted from preliminary photointerpretation maps of surficial deposits by T. H. Nilsen. In: U.S. Geological Survey Open File Report 75-277. Open-File Report 99-504. U.S. Geological Survey.

San Joaquin County. 1992. *Countywide General Plan 2010. Volume I, Chapter V. Public Health and Safety.* Amended 2005, 2010. Community Development Department, Stockton, CA. Available: <http://www.sjgov.org/commdev/cgi-bin/cdyn.exe?grp=planning&htm=generalplan>. Accessed: June 21, 2013.

Shlemon, R. J. 1971. The Quaternary Deltaic and Channel System in the Central Great Valley, California. *Annals of the Association of American Geographers* 61:427–440.

Shlemon, R. J., and E. L. Begg. 1975. *Late Quaternary Evolution of the Sacramento–San Joaquin Delta, California. In R. P. Suggate and M. M. Cresswell (eds.), Quaternary Studies 13:259–266. Wellington, New Zealand: The Royal Society of New Zealand*.

Solano County. 2008. *Solano County General Plan*. December. Fairfield, CA. Available: <http://www.co.solano.ca.us/depts/rm/planning/general_plan.asp>. Accessed: February 11, 12, and 13, 2009; January 17, 2012.

Tolmachoff, W. 1993. *Linear Velocity Functions and the Effect of Mentors in the Oil Industry*. Association of Petroleum Geologists Pacific Section. Newsletter No. 2, Pacific Section, American Association of Petroleum Geologists. Pages 4–5.

Torres, R. A., N. A. Abrahamson, F. N. Brovold, G. Cosino, M. W. Driller, L. F. Harder, N. D. Marachi, C. N. Neudeck, L. M. O'Leary, M. Ramsbotham, and R. B. Seed. 2000. *Seismic Vulnerability of the Sacramento-San Joaquin Delta Levees*. CALFED Bay-Delta Program, Levees and Channels Technical Team, Seismic Vulnerability Sub-Team. April.

U.S. Geological Survey. 2009. *United States National Seismic Hazard Maps*. Available: <http://earthquake.usgs.gov/research/hazmaps>. Accessed: March 13, 2009.

Wagner, D. L. and E. J. Bortugno. 1982. *Geologic Map of the Santa Rosa Quadrangle.* California Geological Survey, Regional Geologic Map No. 2A, 1:250,000 scale. Last revised: Unknown. Available:<http://www.conservation.ca.gov/cgs/information/geologic_mapping/Pages/googlemaps.aspx>. Accessed: March 21, 2012.

Wagner, D. L., E. J. Bortugno, and R. D. McJunkin. 1991. *Geologic Map of the San Francisco—San Jose Quadrangle.* California Geological Survey, Regional Geologic Map No. 5A, 1:250,000 scale. Last revised: Unknown. Available:<http://www.conservation.ca.gov/cgs/information/geologic_mapping/Pages/googlemaps.aspx>. Accessed: March 21, 2012.

Wagner, D. L., C. W. Jennings, T. L. Bedrossian, and E. J. Bortugno. 1981. *Geologic Map of the Sacramento Quadrangle.* California Geological Survey, Regional Geologic Map No. 1A, 1:250,000 scale. Last revised: Unknown. Available:<http://www.conservation.ca.gov/cgs/information/geologic_mapping/Pages/googlemaps.aspx>. Accessed: March 21, 2012.

Wells, D. L., and K. J. Coppersmith. 1994. New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. *Bulletin of the Seismological Society of America* 84(4):974–1002.

Working Group on California Earthquake Probabilities. 2003. *Earthquake Probabilities in the San Francisco Bay Region b: 2002–2031*. U.S. Geological Survey Open-File Report 03-214.

Working Group on Northern California Earthquake Potential. 1996. *Database of Potential Sources for Earthquakes Larger than Magnitude 6 in Northern California*. USGS Open-File Report 96-705.

Wong, I. and M. Dober. 2007. *Screening/Scoping Level Probabilistic Seismic Hazard Analysis for Buckhorn Dam, California*. Unpublished Report. Prepared for Bureau of Reclamation. Prepared by URS Corporation.

Youd, T. L. and S. N. Hoose. 1978. *Historic Ground Failures in Northern California Triggered by Earthquakes*. U.S. Geological Survey Professional Paper 993. U.S. Government Printing Office. Washington, DC.

Youngs, R. R., S-J. Chiou, W. A. Silva, and J. R. Humphrey. 1997. Strong Ground Motion Attenuation Relationships for Subduction Zone Earthquakes. Seismological Society of America. *Seismological Research Letters* 68:58–73.