Chapter 10
Geology and Seismicity

This chapter describes the environmental setting and study area for geology and seismicity; analyzes impacts that could result from construction, operation, and maintenance of the project; and provides mitigation measures to reduce the effects of potentially significant impacts. This chapter also analyzes the impacts that could result from implementation of compensatory mitigation required for the project and describes any additional mitigation necessary to reduce those impacts and analyzes the impacts that could result from other mitigation measures associated with other resource chapters in this Draft Environmental Impact Report (Draft EIR).

10.0 Summary Comparison of Alternatives

Table 10-0 provides a summary comparison of important impacts on geology and seismicity by alternative. The table presents the CEQA findings after all mitigation is applied. If applicable, the table also presents quantitative results after all mitigation is applied. Important potential impacts that were considered include any differences in the potential for surface fault rupture, level of earthquake shaking, liquefaction susceptibility, ground failure, tunnel flotation, and likelihood for a seiche to occur for a given alternative. Only Alternative 5 would not be subject to a potential earthquake-induced seiche. The potential hazard of a seiche for Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c would be addressed through detailed design, such that there would be a less-than-significant impact for all alternatives with respect to a seiche.

Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c vary from Alternative 5 with respect to the location of a given impact mechanism, but all the alternatives have similar impact mechanisms and magnitudes in common and therefore have the same impact conclusions.

Table ES-2 in the Executive Summary provides a summary of all impacts disclosed in this chapter.

Table 10-0. Comparison of Impacts on Geology and Seismicity by Alternative

	Alternative								
Chapter 10 – Geology and Seismicity	1	2a	2b	2c	3	4a	4b	4c	5
Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault or Based on Other Substantial Evidence of a Known Fault	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS
Impact GEO-2: Loss of Property, Personal Injury, or Death from Strong Earthquake-Induced Ground Shaking	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS
Impact GEO-3: Loss of Property, Personal Injury, or Death from Earthquake-Induced Ground Failure, including Liquefaction and Related Ground Effects	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS
Impact GEO-4: Loss of Property, Personal Injury, or Death from Ground Settlement, Slope Instability, or Other Ground Failure	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS
Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Project-Related Ground Motions	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS
Impact GEO-6: Loss of Property, Personal Injury, or Death from Seiche or Tsunami	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS	LTS

LTS = less than significant.

10.1 Environmental Setting

This section describes the environmental setting for the geology and seismicity study area. For the purposes of this chapter, the geology and seismicity study area refers to all areas that could involve excavation, filling, stockpiling, constructing, or otherwise disturbing the ground to design and construct the conveyance facilities and appurtenant features, such as tunnels, forebay, tunnel access shafts, levees, new and improved existing roads, power lines, reusable tunnel material (RTM) disposal and storage areas, and laydown/staging areas for all alternatives combined. The geology and seismicity study area also includes a 0.5-mile buffer beyond the footprints of these areas, with the exception of power transmission lines, metering areas, and park and ride sites, which have a 1/8-mile buffer. Additionally, the analysis also considers seismic sources located outside the study area that could cause seismic shaking within the study area.

This section describes the existing geologic and seismotectonic conditions and the associated potential geologic, seismic, and geotechnical hazards in the Sacramento–San Joaquin Delta (Delta) area (Figure 1-1 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), 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 activities under the project alternatives.

- Geologic setting focuses on the subsurface soils and the underlying bedrock units, including existing natural and man-made levees and channel deposits. Near-surface soils are fully discussed in Chapter 11, *Soils*, which describes surface erosion, subsidence processes, and other soil hazards. Mineral resources that could be affected by construction and operation of the project alternatives are fully discussed in Chapter 27, *Mineral Resources*.
- Seismotectonic setting describes seismic sources, historical seismic events, and the ground shaking potential during earthquakes.
- Geologic and seismic hazards, including ground shaking, fault displacement and 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.

The setting information for geology and seismicity, except where otherwise noted, is derived from the project's *Volume 1, Delta Conveyance Final Draft Engineering Project Report, Central and Eastern Options* (C-E EPR) and the *Volume 1, Delta Conveyance Final Draft Engineering Project Report, Bethany Reservoir Alternative* (Bethany EPR), both prepared by the Delta Conveyance Design and Construction Authority (DCA) (Delta Conveyance Design and Construction Authority 2022a, 2022b) at the direction of DWR.

10.1.1 Study Area

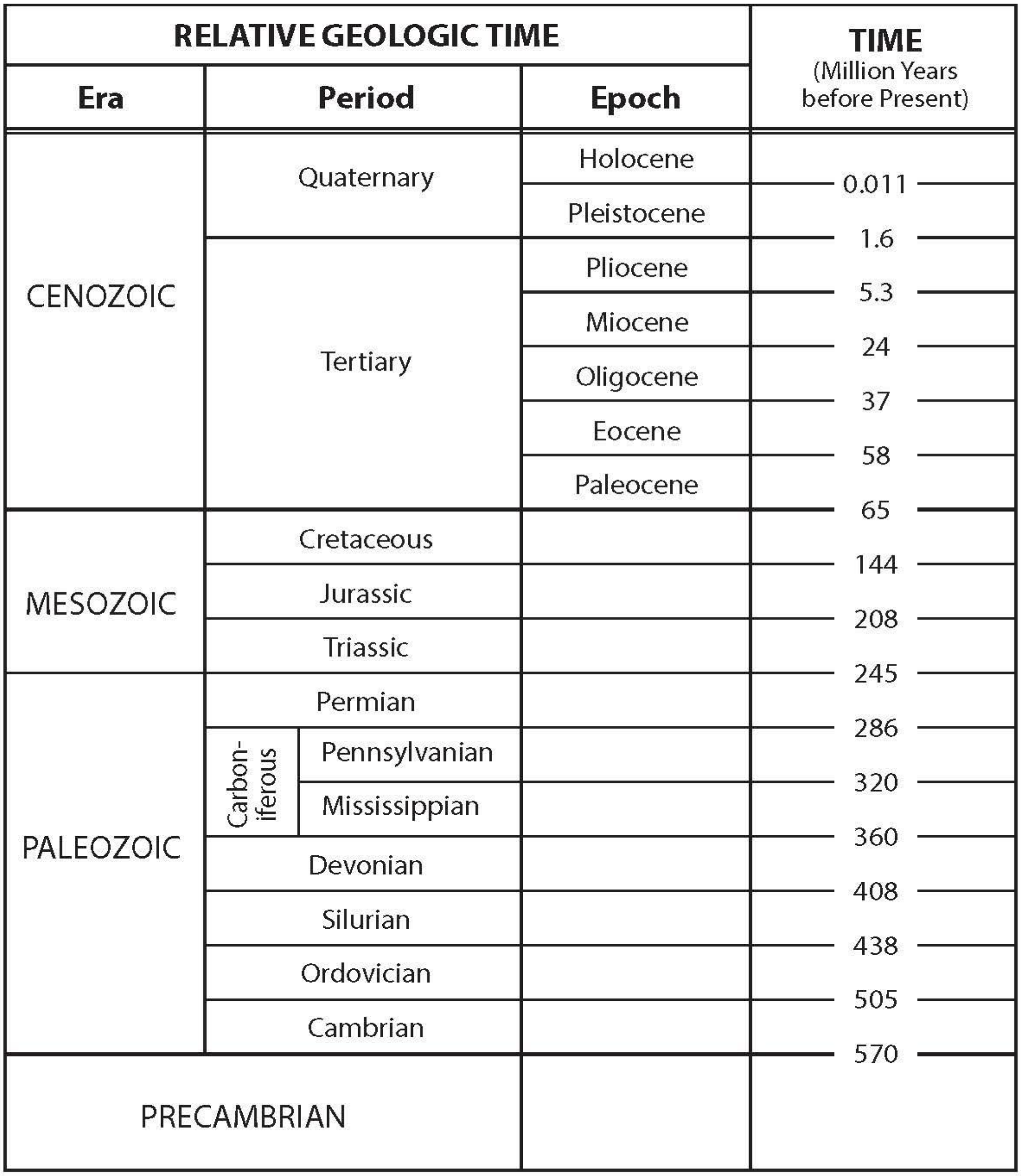
The study area exists in California's Central Valley, which is approximately 465 miles long and 40–60 miles wide. The valley is bounded by the Sierra Nevada on the east and the Coast Ranges on the west (Figure 10-1).

Paleogeographic reconstructions of this region indicate that Miocene (Figure 10-2) sedimentation was similar to a modern forearc 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.

In the mid-Pliocene epoch, a shift in plate tectonic movement triggered uplift of the Coast Ranges, which gradually closed the southern marine outlet to the basin. By the late Pliocene, subaerial 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 the 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 1991:164–176).

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 and the San Joaquin River Delta. The Sacramento River Delta comprises about 30% of the total Delta 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, natural levee-free freshwater tidal marsh dominated by tidal flows and peat and muck accretion (Deverel and Leighton 2010:18; California Department of Water Resources 2007a:3). Because the San Joaquin River Delta had less well-defined levees, sediments 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 they approach the natural levees and flood basins of the Sacramento River Delta (Whipple et al. 2012:81; Atwater and Belknap 1980:5).

Figure 10-1. Geomorphic Provinces of California



RELATIVE GEOLOGIC TIME				TIME (Million Years before Present)
Era	**Period**		**Epoch**	
CENOZOIC	Quaternary		Holocene	0.011
			Pleistocene	1.6
	Tertiary		Pliocene	5.3
			Miocene	24
			Oligocene	37
			Eocene	58
			Paleocene	65
MESOZOIC	Cretaceous			144
	Jurassic			208
	Triassic			245
PALEOZOIC	Permian			286
	Carbon-iferous	Pennsylvanian		320
		Mississippian		360
	Devonian			408
	Silurian			438
	Ordovician			505
	Cambrian			570
PRECAMBRIAN				

Source: Based on California Department of Conservation, California Geological Survey, Note 17, page 3, 2002.

Note: This geologic timescale is based on the time scale used by the California Geological Survey (CGS) (2002). The more recent U.S. Geological Survey geologic time scale (2010), which has revised age boundaries, is not used because it was published after the publication of the geologic maps used in this report.

Figure 10-2. Geologic Time Scale

10.1.1.1 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 (an assemblage of sandstone, shale, and conglomerate) rock of the Coast Ranges. 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.

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 the Tertiary Period. 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 (1975:265) 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 (Whipple et al. 2012:8). 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.

10.1.1.2 Local Geology

A geologic map of the study area is provided in Figure 10-3. It was necessary to use different sources to compile the geologic map and descriptions of the geologic map units (Tables 10-1 through 10-6) presented in this report. The map is primarily based on relatively detailed mapping derived from Atwater (1982) and covers most of the study area. The Atwater mapping, therefore, was the primary map used to compile Figure 10-3 since it provides the greatest detail and covers most of the study area. Geologic mapping of the southwestern edge of the study area not covered by Atwater is from the regional geologic map by Wagner et al. (1991:Sheet 1). Except where noted, the text descriptions of the geologic units provided in Tables 10-1 through 10-6 are from Atwater (1982). Where applicable, the geologic unit descriptions by Graymer et al. (2002:4–13) have been added to further round out and update the information provided in Tables 10-1 through 10-6. The work by Graymer et al. covers only a portion of the study area and contains much information already provided in Atwater (1982), but it does represent some of the more recent work done in the area. In general, the surficial geologic units of the study area include organic soils, alluvium, eolian deposits (i.e., dune sand), sedimentary bedrock, and hydraulic-dredge spoils, all of which are described in the sections below. The descriptions of the geologic units are organized by depositional environment and are generally described from youngest to oldest. As described in the Liquefaction and Ground Improvement Analysis (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022c:2), the logs of 147 historical cone penetration test (CPT) soundings and soil borings[1] advanced by DWR provide information on soil and bedrock characteristics extending to depths much greater than that depicted in the mapping by Atwater (1982), Graymer et al. (2002), and Wagner et al. (1991). The borehole logs provide a detailed depiction of the soil and bedrock composition at depth, with alternating layers of sediments and bedrock of various composition. In the boring logs, peat soils are shown to occur to a maximum depth of approximately 15 feet below the ground surface, and organic mineral soils (e.g., organic silt) are shown to occur to a maximum depth of approximately 30 feet below the ground surface. Both the peat and organic mineral soil types are well above what would be the main tunnel invert elevation (i.e., -143 feet to -

---

[1] Of the 147 CPT soundings and soil borings, 24 were used as a partial basis for preparation of the Liquefaction and Ground Improvement Analysis Technical Memorandum.

163 feet North American Vertical Datum of 1988 [NAVD88] for the tunnel from the intakes to the proposed new Southern Forebay Inlet Structure and -145 feet to -164 feet National Geodetic Vertical Datum [NGVD] for the tunnel between Twin Cities Complex and the Bethany Complex).

Hydraulic-Dredge Spoils (post-1900)

The hydraulic-dredge spoil deposits are the result of human activity, as described in Table 10-1 (Atwater 1982:9).

Table 10-1. Hydraulic-Dredge Spoils

Map Unit Symbol	Map Unit Name	Age	Description
Qds	Hydraulic-dredge spoils	Post-1900	Sand deposits that are locally laminated and contain minor amounts of silt, clay, and peat, which formed as a result of human activity. Deposited during work to widen, deepen, or straighten the Sacramento and San Joaquin Rivers.

Source: Atwater 1982:9.

Organic Soils

The tule marshes created by sea level rise covered most of the Delta and led to the formation of peat and muck, which are both forms of organic soils.[2] Prior to reclamation, the peat was as thick as 65 feet in the western Delta (Whipple et al. 2012:9). Organic and high organic matter mineral soils and sediments were labeled on geologic maps as peaty muds and were mapped by USGS (Graymer et al. 2002:5) as Holocene Delta mud deposits, as described in Table 10-2. Atwater (1982:9) mapped the Delta mud deposits as Peat and Mud of Delta Wetlands and Waterways (map symbol Qpm) (Figure 10-3).

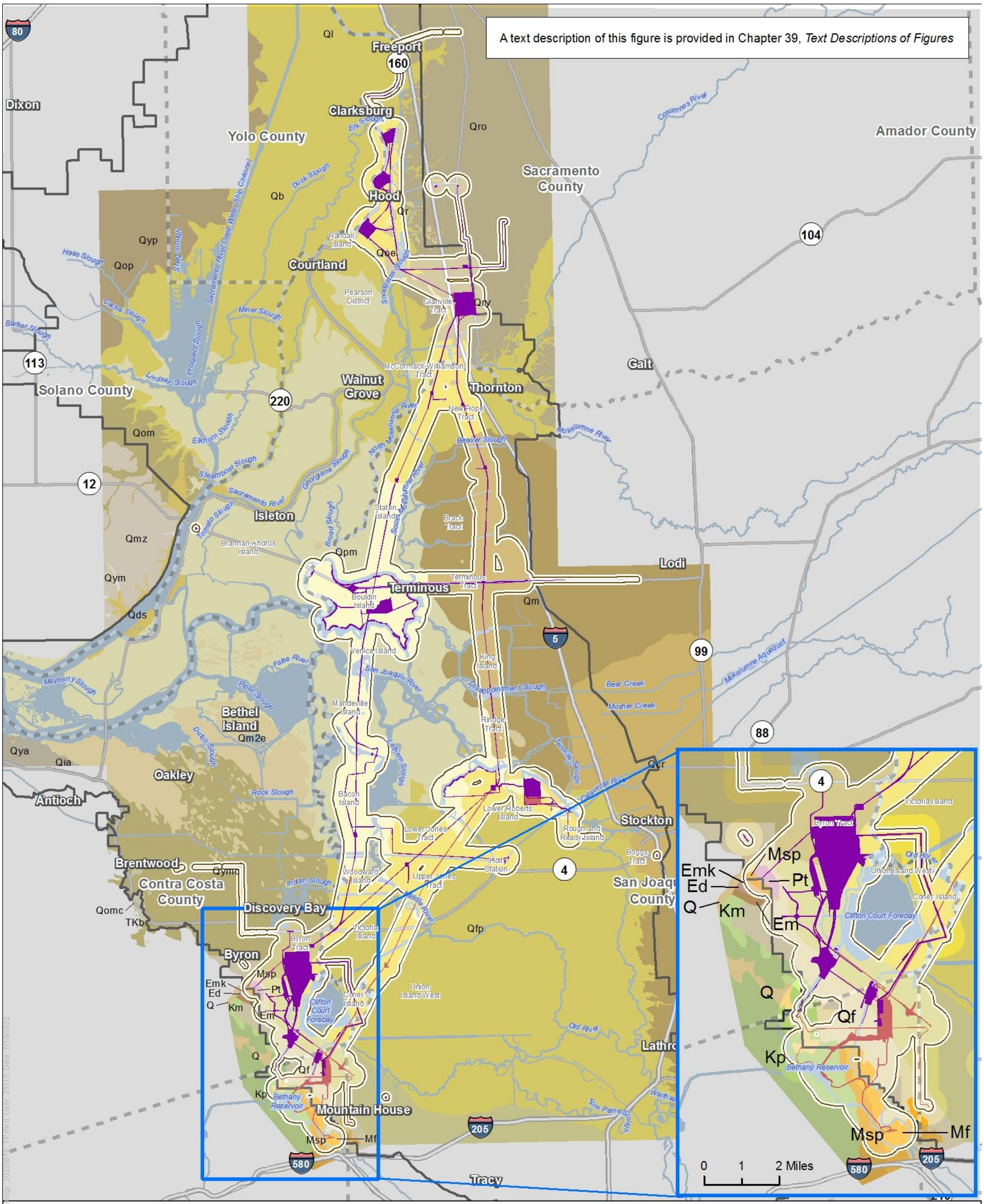
Table 10-2. Peat and Mud of Tidal Wetlands and Waterways

Map Unit Symbol	Map Unit Name	Age	Description
Qpm	Peat and mud of tidal wetlands and waterways	Holocene	Form soft, usually carbonaceous deposits that have a low bulk density. The unit was deposited as a result of sea level rise. According to Graymer et al. (2002:5), this mud and peat deposit has minor silt and sand deposited at or near sea level in the 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.

Sources: Atwater 1982:9; Graymer et al. 2002.

---

[2] See Chapter 11, Section 11.1.1.1, *NRCS Soil Associations*, and Figures 11-1 and 11-8 for a more detailed description of the organic soils in the study area.



Legend

▭ Study Area

▭ Legal Delta Extent

▭ County Boundary

Conveyance Construction Footprint

🟪 Central/Eastern Alternatives

🟥 Bethany Reservoir Alternative

N

0 3.5 7
Miles

Explanation

Detailed Geologic Map Units

Qds	Dredge soils—post 1900
Qpm	Peat and muck—Holocene

Alluvium of Supratidal Floodplains—Holocene

Qb, Qfp, Ql	Alluvial floodbasin deposits, Alluvial floodplain deposits, Natural levee deposits

Eolian Deposits—Pleistocene

Qoe	Older eolian deposits
Qmz	Montezuma Formation
Qe, Qm2e	Eolian deposits, undivided and upper member of Modesto Formation

Alluvial Fans from Glaciated Basins—Pleistocene

Qr, Qry, Qro	Riverbank Formation, younger and older
Qm	Modesto Formation

Alluvial Fans and Terraces from Unglaciated Drainage Basins—Holocene and Pleistocene

Qya, Qia, Qoa	Youngest, intermediate, and oldest alluvium of Antioch and vicinity
Qcr	Alluvium of Calaveras River
Qymc, Qom	Younger and older alluvium of Montezuma Hills and vicinity
Qomc	Older alluvium of Marsh Creek
Qyp, Qop	Younger and older alluvium of Putah Creek
Qch	Alluvium of creeks from the Corral Hollow Drainage to Brushy Creek

Regional Geologic Map Units

Q	Alluvium—Holocene
Qf	Alluvial fan deposits—Holocene and possibly Upper Pleistocene
Mf	Fanglomerate—Miocene
Msp	San Pablo Group—Miocene
Emk	Markley Sandstone—Eocene
Km	Moreno Formation—Cretaceous
Kp	Panoche Formation—Cretaceous
Pt	Tehama Formation—Pliocene

Notes Map unit colors appear lighter within the study area. Only geologic units present in the study area are included in the explanation. This map is primarily based on relatively detailed (scale 1:24,000) mapping derived from Atwater (1982), which covers most of the Delta. The geology of the remaining areas is based on regional geologic mapping (scale 1:250,000) from California Division of Mines and Geology (Wagner et al. 1991).

Figure 10-3. Geology of the Study Area

This page intentionally left blank

Alluvium

Alluvium is sediment deposited by a river or other running water and typically is composed of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. A river continually lifts and drops solid particles of rock and soil from its bed throughout its length. Where river flow is fast, more particles are suspended than are dropped out. Where the river flow is slow, more particles are dropped out than are suspended. Areas where more particles are dropped out develop into features 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 ability of a river to carry (suspend) sediment varies greatly with its flow volume and velocity. When a river floods over its banks, the water spreads out, loses its velocity, and deposits its load of suspended sediment. Based on density variations, fine-grained sediments are deposited further from the channel, whereas coarser sediments 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 near the banks 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 (Moore and Shlemon 2010:105).

The deposits in the Alluvium of Supratidal Floodplains mapped by Atwater (1982:8) formed in the portion of the tidal flat that lies above the mean high water level. The deposits include Holocene deposits of natural levees, flood basins, and channels of the Sacramento and San Joaquin Rivers, both active and abandoned. They are made up mainly of silty clay, micaceous silt, and micaceous sand and have a low organic matter content (Table 10-3).

Similar to the Alluvium of Supratidal Floodplains, the alluvium mapped by Wagner et al. (1991:Sheet 1) in the southern portion of the study area outside the area mapped by Atwater (1982), is made up of unconsolidated stream and basin deposits of Holocene age. In the study area, these occur in the drainages on the eastern edge of the Coast Ranges.

Table 10-3. Alluvium

Map Unit Symbol	Map Unit Name	Age	Description
Qfp	Alluvial flood plain deposits undivided	Holocene	A unit in Atwater's (1982:8) Alluvium of Supratidal Floodplains. A floodplain of the San Joaquin River that was historically covered with tidal-wetland peat, but has now been uncovered. Includes small bodies of peaty mud and abandoned channels with clay loam. Also includes local areas of overbank alluvium, which is likely of historic age.
Ql	Natural levee deposits	Holocene	A unit in Atwater's (1982:8) Alluvium of Supratidal Floodplains. Dark grayish brown to yellowish brown sand, silt, and silty clay. Occurs on broad natural levees and crevasse splays of the Sacramento River and in the immediate vicinity of historic and prehistoric nontidal channels. Probably formed the interface between rapidly flowing water and very slow moving water. Overlies peat and peaty mud in some localities and likely predates hydraulic mining. (Atwater 1982:8)

Map Unit Symbol	Map Unit Name	Age	Description
Qb	Flood basin deposits	Holocene	A unit in Atwater's (1982:8) Alluvium of Supratidal Floodplains. Firm to stiff silty clay, clayey silt, and silt, which often contain nodules of calcium carbonate and sometimes spherules of manganese and irons. This unit grades laterally into the peaty muds. (Atwater 1982:8)
Q	Alluvium	Holocene	Unconsolidated stream and basin deposits. (Wagner et al. 1991:Sheet 1)

Sources: Atwater 1982:8; Wagner et al. 1991: Sheet 1.

Alluvial Fans

The deposits that make up the Alluvial Fans and Terraces from Unglaciated Drainage Basins units mapped by Atwater (1982:4) consist of clayey silt, silt, sandy silt, as well as some sand and gravel. Atwater defined these units based on watershed of origin and relative age (Table 10-4) (Atwater 1982:4). These units were deposited where streams emerged from upland areas and flowed onto more gently sloping valley floors or plains. They are mostly undissected by later erosion and in places may form only a thin veneer over Pleistocene and older deposits (Graymer et al. 2002:4).

In the southern portion of the study area west of the area mapped by Atwater, the alluvial fan deposits mapped by Wagner et al. (1991:Sheet 1) are made up of gravel, sand, silt, and clay of Holocene age. This unit is assumed to correlate with the Alluvium of Corral Hollow to Brushy Creek described by Atwater (1982:5) because of their colocation and descriptions. Although Wagner et al. (1991:Sheet 1) indicates the unit is Holocene in age, the more detailed mapping by Atwater indicates the unit may extend into the upper Pleistocene.

Table 10-4. Alluvial Fans and Terraces from Unglaciated Drainage Basins

Map Unit Symbol	Map Unit Name	Age	Description
Qymc	Younger Alluvium of Marsh Creek	Holocene – Upper Pleistocene	Forms alluvial fans in the southwestern portion of the study area. Consists of 5 to 15 feet of overbank silt that overlies channel sand and gravel. It locally contains shells of freshwater gastropods (the class of mollusks that contains snails, slugs, and whelks). The unit overlies and grades into the eolian deposits of the Modesto Formation (Atwater 1982:5).
Qch	Alluvium – Corral Hollow to Brushy Creek	Holocene – Upper Pleistocene	Alluvium deposited by the Corral Hollow drainage, Mountain House Creek, and Brushy Creek (Atwater 1982:5).
Qf	Alluvial fan deposits	Holocene	Alluvial gravel, sand, silt, and clay in the southwestern portion of the study area (Wagner et al. 1991:Sheet 1).
Qcr	Alluvium of Calaveras River	Holocene – Upper Pleistocene	Alluvium deposited by the Calaveras River, Bear Creek, and several other streams between the Mokelumne and Stanislaus Rivers (Atwater 1982:5).

Sources: Atwater 1982:5; Wagner et al. 1991:Sheet 1.

Eolian Deposits

Atwater used Eolian Deposits to classify windblown dune deposits of uncertain relative age. These units are largely related to the Modesto Formation. 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 Nevada were blown into dunes. Dune sand deposits are described in Table 10-5. (Atwater 1982:7, 8)

Table 10-5. Eolian Deposits

Map Unit Symbol	Map Unit Name	Age	Description
Qm2e	Eolian Deposits of Upper Modesto Formation	Upper Pleistocene	Forms a large dune field that fans out to the east and south of Antioch. A smaller field is also located between Hood and Walnut Grove and in isolated hills in the central Delta. In the southern part of the study area, it is widely overlain by the Marsh Creek alluvium and tidal-waterway deposits. According to Graymer et al. (2002:5), the dunes display as much as 100 feet of erosional relief and are being buried by basin deposits and delta mud.
Qoe?	Older Eolian Deposits	Upper Pleistocene?	This unit serves as a catchall for other Pleistocene windblown deposits.

Sources: Atwater 1982:7,8; Graymer et al. 2002:5.
Note: Question marks (?) are in the original source literature and denote uncertainty by the author of the literature in the determination of the age of the geologic unit.

Alluvial Fans from Glaciated Basins

The deposits that make up the Alluvial Fans from Glaciated Basins units are silt, sand, and minor gravel deposited by major rivers of the Sierra Nevada. These deposits record major episodes of glaciation during the Pleistocene in the Sierra Nevada (Atwater 1982:5) (Table 10-6).

This 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 1991:174; Cherven and Graham 1983:33).

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 consists of coarser gravel and sand capped by a very well-developed soil profile, containing a subsurface cemented hardpan (i.e., duripan). The timing of their deposition remains uncertain, but the Riverbank is probably Illinoian (roughly 300,000–130,000 years before present [B.P.]), while the Modesto is probably Late Wisconsin to early Holocene (roughly 21,000 to 10,000 years B.P.).

The Pleistocene Mokelumne River channels that deposited older alluvium show little relation to the present stream. The modern river channels meander in its floodplain and carry fine-grained sediment, whereas 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 1971:431).

Table 10-6. Alluvial Fans from Glaciated Basins

Map Unit Symbol	Map Unit Name	Age	Description
Qm	Modesto Formation	Pleistocene	Alluvial fans formed by deposition of the Mokelumne and Stanislaus Rivers. It overlies the Riverbank Formation and is overlain by tidal-wetland deposits. It generally ranges in thickness from 10 to 15 feet. The unit is made up of both fluvial (river lain) deposits and eolian (windblown) deposits.
Qr	Riverbank Formation undivided	Upper Pleistocene	Forms low rises that are surrounded by Holocene alluvium. The Holocene alluvium also forms a veneer over the unit.
Qry	Riverbank Formation–younger	Upper Pleistocene	The unit can be divided into an older unit and a younger unit in many places east of the Delta. The younger unit forms a slightly to moderately dissected surface and has a slightly lower surface than the older unit. It was deposited primarily by the Cosumnes and Mokelumne Rivers.
Qro	Riverbank Formation–older	Upper Pleistocene	The older unit forms moderately dissected surfaces. It was possibly deposited in large part by the American River.

Source: Atwater 1982:6.

Older Units at Southwestern Edge of Study Area

Several Tertiary and Cretaceous units occur in the foothills along the southwestern edge of the study area outside the area mapped by Atwater (1982). The older units occur where the valley floor transitions to the foothills.

The Tehama Formation is a poorly consolidated nonmarine sandstone, tuff, and conglomerate of Pliocene age. The unit also includes volcaniclastic rocks (Wagner et al. 1991:Sheet 1; Graymer et al. 2002:10). In the study area, it occurs as a narrow band along the western edge of the valley. The unit is derived from Coast Ranges and overlies Cretaceous rocks of the Great Valley Sequence (Helley and Harwood 1985:15–16).

The Miocene fanglomerate is a conglomerate, sandstone, and siltstone, which includes the Oro Loma and Carbona Formations. The unit occurs in a wide band along the base of the foothills in the southwestern portion of the study area (Wagner et al. 1991:Sheet 1). The Oro Loma Formation probably formed as a complex of alluvial fans along the central Diablo Range. These fans formed from material eroded from the Franciscan Formation. Similarly, the Carbona Formation was likely derived from the Franciscan Formation and also the Great Valley Sequence (Lettis 1982:29–39).

The San Pablo Group is a marine sandstone of similar age as the fanglomerate and found in association with that unit. The San Pablo Group is made up of sandstone, mudstone, siltstone, and shale with minor tuff that occurs in the low foothills in the southwestern portion of the study area. The group includes the Neroly Sandstone, Cierbo Sandstone, and Briones Sandstone (Wagner et al. 1991:Sheet 1).

The Markley Sandstone is a marine unit of Eocene age that is present in the low foothills on the western edge of the study area (Wagner et al. 1991:Sheet 1). It is a white to light-gray quartz-mica sandstone characterized by plates of white mica and carbonized plant debris.

The Moreno and Panoche Formations are both marine units of Cretaceous age on the westernmost edge of the study area in the low foothills. The Moreno Formation is an organic shale, siltstone, and sandstone, and the Panoche Formation is a sandstone and shale with siltstone and conglomerate lenses (Wagner et al. 1991:Sheet 1).

10.1.1.3 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 2.0 inches per year (U.S. Geological Survey 2015:1). 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 2008:19).

The Delta is in the eastern portion of the greater San Francisco Bay Area, one of the most seismically active areas in the United States. This eastern portion of the greater Bay region is near several major active fault systems, including the San Andreas, Hayward-Rodgers Creek, Calaveras, Concord–Green Valley, and Greenville Faults. Many named and unnamed regional faults also exist in the vicinity (U.S. Geological Survey 2021) (Figure 10-4). The U.S. Geological Survey estimated that there is a 72% probability of at least one earthquake of magnitude 6.7 or greater occurring in the San Francisco Bay region before 2043 (U.S. Geological Survey 2016:1). The majority of the seismic sources underlying the Delta are blind thrusts that are not expected to rupture at the ground surface during an earthquake. The known blind thrusts in the Delta and immediate vicinity include the Midland, Thornton Arch, West Tracy,[3] and Vernalis Faults. Blind thrust faults with a discernible geomorphic expression/trace at the surface near the southwestern boundary of the Delta are the Black Butte and Midway Faults (U.S. Geological Survey 2021). The Delta is vulnerable to seismic events as a result of these San Francisco Bay Area and western Delta faults.

Seismologists believe it is likely that the Delta will experience periodic moderate to large 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 Area would affect the Delta with minor-to-moderate ground shaking and could potentially induce damage in these areas. A magnitude 6.25 to 6.75 earthquake on the West Tracy Fault (Lettis Consultants International, Inc. 2021:3) would produce strong shaking in the Delta. Ground shaking is typically expressed in terms of peak ground acceleration (PGA) (i.e., the maximum acceleration by a soil particle at the ground surface during an earthquake).

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

Figure 10-5 provides a general overview of the relative intensity of ground motions for 1-second spectral acceleration (expressed as a fraction of gravity [g]) from future earthquakes with a 2%

---

[3] Ongoing and planned fault investigations for West Tracy Fault may identify surface or near-surface expressions of the fault.

exceedance probability in 50 years for the study area and vicinity.[4] The map incorporates anticipated amplification of ground motions by local soil conditions (California Geological Survey 2016:1).

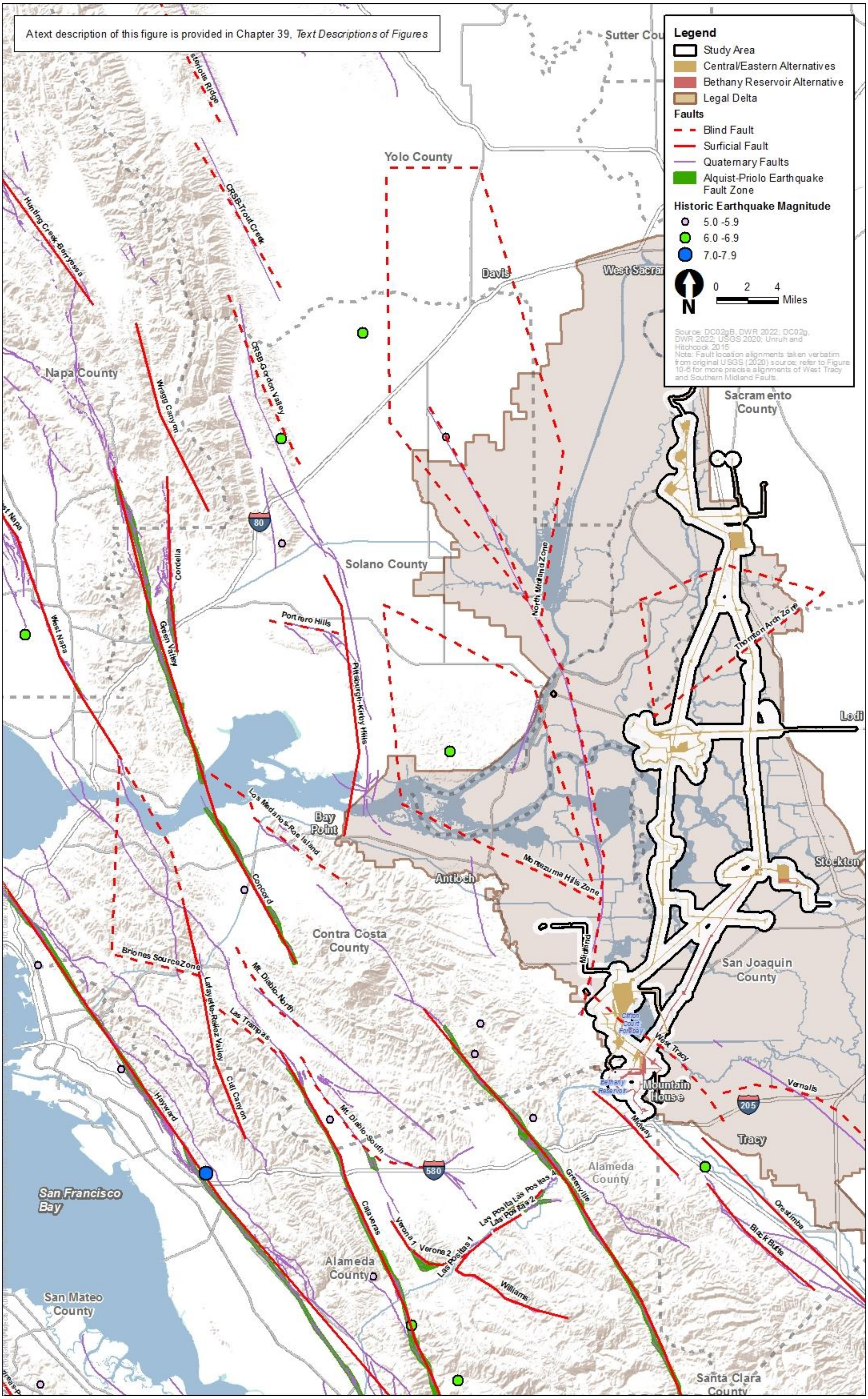
Past Earthquake Ground Motion Intensity and Damage

The San Francisco Bay Area has been subjected to damaging ground shaking during past earthquakes. Table 10-7 lists the largest earthquakes that have affected the greater San Francisco Bay Area since 1700 and the damage caused by these earthquakes (California Department of Conservation 2021).

As Figure 10-4 shows, several earthquakes with magnitude 5.0 or greater have occurred in the immediate San Francisco Bay Area since 1800, 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 moment magnitude 6.9 Loma Prieta earthquake and moment magnitude 6.0 South Napa earthquake that occurred in the Santa Cruz Mountains and southern Napa County, respectively. Magnitude 5.5 and 5.8 earthquakes on January 24, 1980, and January 26, 1980, respectively, were recorded near Livermore. These earthquakes were attributed to the Greenville Fault and the ground shaking may have caused levee slope rotational failures on Bacon Island and Empire Tract, although high water conditions were present at the time (California Department of Water Resources 1992:5-22–5-24). Since 1800, no earthquake with a magnitude greater than 5.0 has been recorded in the Delta, as shown in Figure 10-4.

---

[4] Figure 10-5 is intended to provide the reader with a broad overview of variations in the earthquake shaking hazard across the study area.

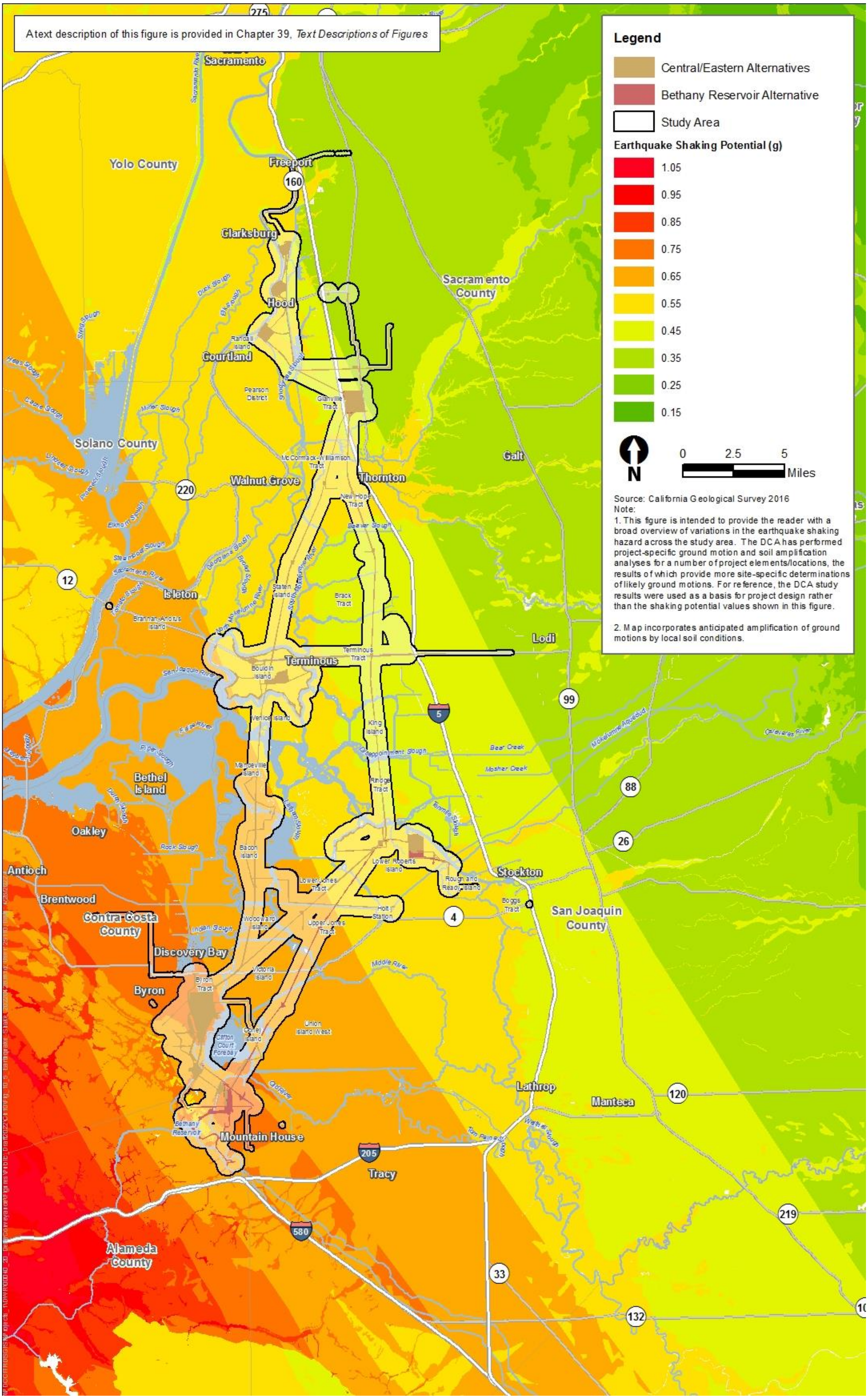


A text description of this figure is provided in Chapter 39, *Text Descriptions of Figures*

Source: DC02gB, DWR 2022; DC02g, DWR 2022; USGS 2020; Unruh and Hitchcock 2015

Note: Fault location alignments taken verbatim from original USGS (2020) source; refer to Figure 10-6 for more precise alignments of West Tracy and Southern Midland Faults.

Figure 10-4. Active Faults and Historical Seismicity of the Bay and Delta Region, 1800–2021



A text description of this figure is provided in Chapter 39, *Text Descriptions of Figures*

Source: California Geological Survey 2016

Note:

1. This figure is intended to provide the reader with a broad overview of variations in the earthquake shaking hazard across the study area. The DCA has performed project-specific ground motion and soil amplification analyses for a number of project elements/locations, the results of which provide more site-specific determinations of likely ground motions. For reference, the DCA study results were used as a basis for project design rather than the shaking potential values shown in this figure.

2. Map incorporates anticipated amplification of ground motions by local soil conditions.

Figure 10-5. Overview of Earthquake Shaking Potential based on California Geological Survey Data

Table 10-7. Largest Earthquakes Having Affected the Greater San Francisco Bay Area

Date	Magnitude	Name, Location, or Region Affected	Epicenter Latitude	Epicenter Longitude	Loss of Life and Property
2014, August 24	6.0	South Napa	38.22	-122.31	2 dead; total economic losses estimated at $443 million to $800 million
1989, October 17	6.9	Loma Prieta	37.04	-121.88	63 dead; 3,737 injured; $6 billion in property damage
1984, April 24	6.2	Morgan Hill	37.31	-121.68	$8 million in property damage
1911, July 1	6.6	Morgan Hill area	37.25	-121.75	–
1906, April 18	7.8	Great 1906 San Francisco Earthquake and Fire	37.70	-122.50	3,000 dead; $524 million in property damage (includes damage from fire)
1898, March 31	6.4	Mare Island	38.20	-122.50	$350,000 in property damage
1892, April 19	6.6	Vacaville	38.40	-122.00	1 dead; $225,000 in property damage
1868, October 21	7.0	Hayward Fault	37.70	-122.10	30 dead; $350,000 in property damage
1865, October 8	6.5	Santa Cruz Mountains	37.20	-121.90	$0.5 million in property damage
1838, June	Uncertain; 7.4 estimated	San Francisco to San Juan Bautista	37.30	-122.15	Damage to San Francisco and Santa Clara

Source: California Department of Conservation 2021.

Note: Data sorted chronologically (most recent first). Table shows earthquakes of magnitude greater than or equal to 6.0 or that caused loss of life or more than $200,000 in damage. Magnitude scale is unknown. Damage estimates not adjusted for inflation.

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 display evidence of rupture during the Holocene (i.e., 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 the California Geological Survey (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. Seismologists 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 seismology study by the California Department of Water Resources (2007b:7, 18) considered the following three categories of active and potentially active seismic sources that could produce ground motions in the study area.

- Crustal fault
- Seismic zone
- Subduction zone

The following characterization of these seismic sources, which are important to the Delta earthquake hazard potential, is based on the *Seismic Hazard Analyses and Development of Conceptual Seismic Design Ground Motions for the Delta Conveyance* (Lettis Consultants International, Inc. 2021) (hereafter referred to as Seismic Hazard Analyses study).

Crustal Faults

The approximate locations of the active and potentially active seismic sources in the greater San Francisco Bay Area are plotted in Figure 10-4.

Other major crustal faults in the greater San Francisco Bay Area (shown on Figure 10-4) that have the potential for generating substantial earthquake ground shaking in the Delta include the San Andreas, Hayward–Rodgers Creek, Calaveras, Concord–Green Valley, and Greenville Faults. The San Andreas, Hayward–Rodgers Creek, and Calaveras Faults are regional seismic sources that, although large distances away from the study area, can induce considerable ground shaking because of their potential for generating large-magnitude earthquakes.

The Seismic Hazard Analyses study (Lettis Consultants International, Inc. 2021:2) was based on a time-independent source model of active and potentially active seismic sources in a version of the source model that was updated from the Delta Risk Management Strategy (DRMS) seismology study (California Department of Water Resources 2007b). In a time-independent model, the likelihood of having an earthquake at a specific future time does not depend on the elapsed time since the last earthquake. The seismic source model used in support of the Seismic Hazard Analyses study includes the fault sources used for the DRMS study. As appropriate, the geometry of some of the fault sources, and other parameters such as seismogenic crustal thickness and slip rate, were modified from the DRMS model to incorporate new data and interpretations, some of which are included in the Uniform California Earthquake Rupture Forecast, Version 3. Significant local fault sources are summarized below.

The maximum earthquake moment magnitude, closest distance to the study area, long-term geologic slip rate, and faulting style assigned to these major active faults are presented in Table 10-8. 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 10-8. Characteristics of Major Seismic Sources in San Francisco Bay Area, UCERF3

Fault (closest to farthest)	Distance from Study Area [a] (miles)	Maximum Earthquake (moment magnitude)	Faulting Style
Calaveras	36.2	6.9	Strike-slip
Hayward–Rodgers Creek	44.5	7.3	Strike-slip

Fault (closest to farthest)	Distance from Study Area [a] (miles)	Maximum Earthquake (moment magnitude)	Faulting Style
San Andreas–North	65.0	8.1	Strike-slip
San Andreas–South	61.3	7.9	Strike-slip

Source: Field et al. 2015:527.

Note: Faults shown are those for which time-dependent model data are available in the third Uniform California Earthquake Rupture Forecast (UCERF3).

[a] Distance shown is nearest section of a fault trace to the mid-point of the study area (includes both conveyance facilities and compensatory mitigation areas).

The seismic sources underlying the Delta are mostly blind thrusts. Thrust faults are a type of crustal fault. 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,[5] and Vernalis Faults. The Black Butte and Midway Faults are thrust faults, with a discernible geomorphic expression/trace at the surface.

The following discussion of faults and seismic sources in the Delta region is generally based on the Seismic Hazard Analyses study (Lettis Consultants International, Inc. 2021) and *Seismic Hazard Analyses of Metropolitan Water District Emergency Freshwater Pathway* (Wong et al. 2021).

Table 10-9 summarizes the probabilities of activity, maximum earthquake magnitudes, and long-term geologic slip rates assigned to the major seismic sources in the Delta as described in Wong et al. (2021:7–15).

Table 10-9. Seismic Sources in the Study Area Vicinity

Seismic Source (closest to farthest)	Probability of Activity	Slip Rate (mm/year)	Earthquake Magnitude (M)	Rupture Scenario
Montezuma Hills	0.5	0.02–0.2	6.0–6.5	Floating earthquake
Thornton Arch (zone) (buried)	0.2	0.05–0.15	6.0–6.5	Floating earthquake
Midland (northern and southern) (buried)	0.9	0.02–0.2	6.8–7.4	Unsegmented and floating earthquake
West Tracy (buried)	0.9	0.2 to 0.6	6.25 to 6.75	Floating earthquake
Greenville	1.0	0.2–0.6	6.6–7.2	Unsegmented
Mt. Diablo	1.0	0.2–0.6	6.1–6.9	Unsegmented and segmented
Pittsburgh-Kirby Hills	1.0	0.3–0.7	6.0–7.1	Unsegmented

Source: Wong et al. 2021:8, 9.

mm/yr = millimeters per year.

West Tracy Fault. The West Tracy Fault is a northwest-striking, southwest-dipping blind reverse or reverse-oblique fault along the southwestern margin of the Delta that was originally identified during exploration for natural gas. The trace of the fault passes beneath the southwestern part of Clifton Court Forebay (Figures 10-4 and 10-6).

---

[5] Among the studies described in the Future Field Investigations Technical Memorandum are fault trenching and geophysical surveys directed to determining whether the West Tracy Fault is not a blind thrust fault and is instead capable of surface rupture. See a more detailed discussion of this issue below.

The West Tracy Fault near the Southern Complex may have experienced movement within the past 35,000 years and therefore is potentially active. As defined by the California Geological Survey under the Alquist–Priolo Earthquake Fault Zoning Act,[6] *potentially active* faults are those that display evidence of displacement during the Quaternary and late Quaternary (i.e., approximately 1.6 million to 11,000 years before present).

It is currently unknown whether the West Tracy Fault is capable of rupturing to the ground surface to the south of the Southern Forebay area in a large earthquake (Delta Conveyance Design and Construction Authority 2022a:2), but based on the results of the probabilistic fault displacement hazard analysis described in the West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022d:9), the principal fault displacement hazard at the proposed tunnel is low to very low. The width of the permanent deformation of soils in the shallow subsurface, caused by a surface rupture on the West Tracy Fault during a large earthquake, is uncertain. Broad folding and tilting, where differential vertical displacement may be distributed over hundreds of feet, may result if the West Tracy Fault locally is blind, in which the top of the fault is hundreds to thousands of feet deep. If the West Tracy Fault extends to the shallow subsurface (i.e., to within 100 feet to tens of feet below ground), the width of deformation in the shallow subsurface may be about 30 feet or less. The preliminary probabilistic fault displacement analysis determined that fault displacements would be about 1 inch and 9.8 feet, corresponding to mean return periods of approximately 3,100 years and 130,000 years, respectively (Delta Conveyance Design and Construction Authority 2022a:799).

Geologic investigations and research conducted since the DRMS study (California Department of Water Resources 2007b) have developed additional data in support of late Quaternary activity of the West Tracy Fault and have revised the average late Quaternary average separation rate to about 0.3 ± 0.1 millimeters per year (mm/yr) (Unruh and Hitchcock 2014:24). The Seismic Hazard Analyses study adopted a range of fault slip rate values between 0.2 to 0.6 mm/yr (weighted average 0.4 mm/yr) to encompass uncertainty in the timing of ground deformation and the potential for a component of strike-slip displacement on the fault. Analysis of light detection and ranging (LiDAR) and other remote sensing data suggest that the fault may branch into two splays northwest of Clifton Court Forebay (Wong et al. 2021:7); the revised fault trace for the analysis includes two options for the northern termination of the fault to model this geometry. The range of modeled earthquake magnitudes was also revised to magnitude 6.25 to 6.75 to reflect current interpretations of the fault dip and crustal thickness in this region.

Midland Fault. The Midland Fault is an approximately north-to-northwest-striking, blind reverse or reverse-oblique fault that borders the western margin of the central Delta region and dips west and southwest beneath the Montezuma Hills north of the Sacramento River at the latitude of Rio Vista. The southern end of the fault is located near Byron in the southwestern Delta. Although some studies show the Midland Fault extending over 63 miles north into the southwestern Sacramento Valley, experts in the oil and gas industry interpret the northern termination of the fault to be at about the latitude of the northern Montezuma Hills. Based on subsurface mapping of the Midland Fault for oil and gas exploration, the southern 17-mile reach of the fault is characterized as a single fault trace or a narrow, discrete fault zone. At about the latitude of the southern Montezuma Hills, the fault is interpreted to branch into multiple splays. In the vicinity of Lindsay Slough, the main trace of the fault steps or bends sharply to the west and assumes a more northwesterly strike. The northern Midland fault has been interpreted to break up into a series of right-stepping *en echelon*

---

[6] California Pub. Resources Code as Division 2, Chapter 7.5.

splays. Based on these south-to-north variations in the subsurface geometry, the DRMS study modeled the southern 17 miles of the Midland Fault as a discrete fault source (i.e., as the "Southern Midland fault"). The less-well-documented, right-stepping northern splays of the Midland Fault were captured in an areal source zone (i.e., the "Northern Midland fault zone"), which was extended north to the latitude of Davis and Winters to capture buried faults associated with numerous gas fields between the Delta and the southwestern Sacramento Valley. The DRMS model assumed similar activity rates for the Southern Midland Fault and structures in the Northern Midland areal zone and assigned a range of weighted slip rates from 0.1 to 1.0 mm/yr to both sources (with a weighted average 0.5 mm/yr).

Montezuma Hills Source Zone. The DRMS study defined an areal source zone west of the Midland Fault to encompass the possibility that potentially seismogenic blind faults are present and responsible for uplift and northeast tilting of the surface of the Montezuma Hills during the Quaternary. Given the uncertainty about the origin of the hills, the DRMS source model assigned a P(a) 0.5 to the possibility that presently unknown seismogenic faults, independent of the Midland Fault, are present beneath the Montezuma Hills. The DRMS model adopted a range of slip rates from 0.05 to 0.5 mm/yr (weighted average 0.27 mm/yr) for the Montezuma Hills source zone, with the assumption that the activity rate of faults beneath the hills is likely to be similar to that of the Midland Fault. For the Seismic Hazard Analyses (Lettis Consultants International, Inc. 2021:6), the range of slip rates for the Montezuma Hills source zone was revised downward to be the same as the revised rates for the Midland Fault (0.02 to 0.2 mm/yr; weighted average 0.08 mm/yr). The DRMS model assumed that the preferred orientations of potentially seismogenic faults beneath the Montezuma Hills strike approximately north–south, subparallel to the southern part of the Midland Fault. Exploration for oil and gas has documented that the Montezuma Hills are underlain by a system of early Tertiary west-northwest-east-southeast-striking normal faults. Consequently, the *Seismic Hazard Analyses* study revised the preferred orientation of potential fault sources beneath the hills to be subparallel to the buried structural fabric.

Thornton Arch Source Zone. The DRMS study defined an areal zone (the Thornton Arch source zone) in the northeastern part of the Delta to encompass the possibility that a buried structure associated with the Thornton and West Thornton gas fields may be a potential seismic source. The motivation for assuming that an active fault may be present is the observation that the Mokelumne River does not continue along a straight course across the Delta from the point where it exits the western Sierran foothills, but rather it appears to be deflected to the north in an anomalous loop north and west of Thornton, approximately around the gas fields. The DRMS study assigned a low probability of activity (i.e., 0.2) to the Thornton Arch areal source, and it adopted a range of maximum magnitudes with a weighted mean of magnitude 6.25. No new information bearing on the seismic potential of the Thornton Arch zone has been published since the DRMS and the *Seismic Hazard Analyses* study (Lettis Consultants International, Inc. 2021) did not update or reevaluate this seismic source.

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 2007b:15). 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 seismology study (California

Department of Water Resources 2007b:16, 17) characterized the Black Butte and Midway Faults as a single structure.

Background Seismic Sources

The *Seismic Hazard Analyses* study (Lettis Consultants International, Inc. 2021) also evaluated the hazard of background seismicity in the Delta region. Background (floating or random) earthquakes are not associated with known or mapped faults. In most of the western United States, the maximum magnitude of earthquakes not associated with known faults usually ranges from magnitude 6 to 6.5. Repeated earthquake events larger than these magnitudes generally produce recognizable fault-or-fold-related features at the Earth's surface (e.g., the October 31, 2007, magnitude 5.4 Alum Rock earthquakes, both of which occurred east of San Jose and resulted in no discernable surface rupture).

Background earthquakes occur on crustal faults that exhibit no surficial expression (buried faults) or are unmapped due to inadequate studies. In the Seismic Hazard Analyses study, the hazard from background earthquakes was modeled through two seismic source zones: the Coast Ranges Zone and the Central Valley Zone. The two seismic source zones are delineated based on similar seismotectonic characteristics such as style(s) of faulting, seismogenic thickness, estimated maximum earthquake magnitude (for earthquakes not occurring on the fault sources within that seismic source zone), and historical and instrumental seismicity rate. The earthquake shaking hazard at the conveyance facilities was evaluated for each seismic source zone, described in Section 10.1.1.4, *Geologic and Seismic Hazards*, under *Earthquake Ground Shaking*.

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 great distance from the Delta, 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 great distances from the energy source. Long-period ground motions are important for assessments of linear structures, such as tunnels and levee deformations.

10.1.1.4 Geologic and Seismic Hazards

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

Fault Ruptures

Fault Trace and Rupture Zones

The Alquist–Priolo Earthquake Fault Zoning Act, passed in 1972, required the establishment of earthquake fault zones (known as *Special 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 (California Geological Survey 2018a:30–35), which is described in Section 10.2, *Relevant Laws, Regulations, and Programs*. Strict regulations for development in these fault zones are enforced to reduce the potential for damage resulting from fault rupture. Special Publication 42 does not show any Alquist–Priolo Fault Zones delineated in the study area.

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, other than possibly the West Tracy Fault. Blind thrust fault ruptures generally terminate before they reach the surface. They may produce ground manifestations (i.e., below ground shear zone or ground surface bulging) during fault displacement; however, in most cases, no clear ruptures.

Those faults that could cause subsurface ground deformation, 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. As shown in Table 10-10, based on the results of a deterministic fault displacement hazard analysis as presented in the *West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft*) (Delta Conveyance Design and Construction Authority 2022d:8), the West Tracy Fault is estimated to have displacement of 2.3 to 6.0 feet during an earthquake on the fault.

Table 10-10. Estimated Fault Offsets for West Tracy Fault

Maximum Credible Earthquake (Mw)	Fault Displacement Model Used and Associated Weighting			50th Percentile	84th Percentile
	WC94 All	WC94 SS	HEA13	Feet	Feet
6.7	0.5	0.2	0.3	2.3	6.0

Source: West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) (Delta Conveyance Design and Construction Authority 2022d:8).
HEA13 = model developed by Hecker et al.; Mw = moment magnitude; WC94 = model developed by Wells and Coppersmith.

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 2007b:10).

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. CGS and USGS show the West Tracy Fault as not active. However, Fugro Consultants (2011:13) 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 existing Clifton Court Forebay and the proposed Southern Forebay.

As described in Seismic Hazard Analyses and Development of Conceptual Seismic Design Ground Motions for the Delta Conveyance (Lettis Consultants International, Inc. 2021:5), although the West Tracy and Midland Faults both are part of the Coast Range Sierra Boundary zone and the northern end of the West Tracy Fault is nearly coincident with the southern end of the Midland Fault, the two faults have distinctly different strikes and possibly different slip rates, which suggests there may be significant behavioral differences between the two faults that suggest that they would not rupture at the same time (i.e., a combined rupture).

There is very little data regarding the timing, magnitude, and frequency of earthquakes on the West Tracy and Midland Faults that would provide a clear assessment of the likelihood of a combined rupture; however, the likelihood of a combined rupture appears to be low given the different geometries of the faults and their likely different slip rates. Additional data on the magnitude and timing of events on both the West Tracy and Midland Faults are required to rigorously evaluate the combined rupture hypothesis (Lettis Consultants International, Inc. 2021:5). Such data would be acquired as part of the field investigations described in the *Potential Future Field Investigations—Central and Eastern Corridor Options (Final Draft)* (Delta Conveyance Design and Construction Authority 2022e) and in the West Tracy Fault Preliminary Displacement Hazard Analysis Technical Memorandum (Delta Conveyance Design and Construction Authority 2022d).

Earthquake Ground Shaking

The potential for earthquake ground shaking at 12 conveyance facility sites along the two alignments at the top of the soil below any existing peat, muck, and basin deposits was evaluated in the Seismic Hazard Analyses (Lettis Consultants International, Inc. 2021:1). The analyzed sites were Intake B, Intake C, Twin Cities, New Hope, Canal Ranch, Bouldin Island, King Island, Lower Roberts Island, Bacon Island, Southern Forebay North, Southern Forebay South, and Jones Connection.[7] For the Bethany Reservoir alignment, the potential for earthquake ground shaking was evaluated for the Union Island Tunnel Maintenance Shaft, the Bethany Reservoir Pumping Plant, and the Bethany Reservoir Discharge Structure in the Liquefaction and Ground Improvement Analysis for Bethany Reservoir Alternative Technical Memorandum (Final Draft) (Delta Conveyance Design and Construction Authority 2022f:2, 3). The analyses used recent geotechnical boring information. Presented data for each site include seismic hazard curves at different ground accelerations; acceleration distribution for each seismic source; magnitude and distance contributions for different earthquake return intervals; mean uniform hazard spectra at different earthquake return periods; and maximum design earthquake response. In general, the analyses found the shaking hazards reflected proximity to major active faults in the San Francisco Bay Area and along the western edge of the Delta. Consequently, the shaking hazard is lowest in the north and increases to the south and increases from the east to the west.

The analyses performed both Probabilistic Seismic Hazard Analyses (PSHA) and Deterministic Seismic Hazard Analyses. With the PSHA analysis, seismic hazard is expressed in terms of the probabilities of exceeding peak and spectral accelerations and is computed by combining the following three probability distributions for all seismic sources: (1) probability distribution of earthquake magnitude in time (earthquake recurrence), (2) probability distribution of distance from

---

[7] Intake A was not evaluated in the Seismic Hazard Analyses study (Lettis Consultants International, Inc. 2021).

the earthquake rupture area to the site given magnitude (geometry), and (3) probability distribution of peak and spectral accelerations given magnitude and distance (attenuation). Hazard curves are computed at 21 spectral periods between 0.01 (PGA) and 10 seconds.

With the Deterministic Seismic Hazard Analyses, the deterministic median, 69th, 84th, and 95th percentile acceleration response spectra were calculated for the significant faults at all 12 sites and a comparison of the spectra was made at five return periods (144, 200, 475, 975, and 2,475 years) of interest. The results of the analyses are discussed in the next section.

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 10-11 summarizes the primary controlling seismic source at the 12 modeled sites described in *Development of Conceptual Seismic Design Ground Motions for the Delta Conveyance* (Lettis Consultants International, Inc. 2021:1). The analysis for PGA source and 1.0-second spectral acceleration at ground motion return periods of 144 and 2,475 years shows multiple contributions (i.e., multiple controlling sources) for seismic shaking, especially for PGA at 144 years.

Table 10-11. Seismic Source Contributions at PGA and 1.0 Second Spectral Acceleration for 144-Year and 2,475-Year Return Periods

Location	Seismic Source Contribution (PGA)	Seismic Source Contribution (1.0 Second Spectral Acceleration)
144-Year Return Period		
Intake B	15% CRSB North 11% Central Valley Background Seismicity 11% Berryessa-Green Valley 10% Hayward 10% San Andreas	21% San Andreas 13% Hayward 10% Berryessa-Green Valley
Intake C	14% CRSB North 11% Berryessa-Green Valley 10% Central Valley Background Seismicity 10% Hayward 10% San Andreas	20% San Andreas 13% Hayward 10% Berryessa-Green Valley
Twin Cities Complex	11% Central Valley Background Seismicity 10% CRSB North 10% Hayward 10% San Andreas	21% San Andreas 13% Hayward
Bouldin Island	16% Mt. Diablo 10% Hayward	18% San Andreas 13% Hayward 11% Mt. Diablo

Location	Seismic Source Contribution (PGA)	Seismic Source Contribution (1.0 Second Spectral Acceleration)
Southern Forebay North	25% Mt. Diablo 12% Greenville 11% Calaveras	19% Mt. Diablo 13% Calaveras 12% San Andreas 11% Hayward 10% Greenville 10% Midway-Black Butte
Southern Forebay South	25% Mt. Diablo 13% Greenville 11% Calaveras	19% Mt. Diablo 13% Calaveras 11% San Andreas 11% Greenville 10% Hayward
2,475-Year Return Period		
Intake B	34% Central Valley Background Seismicity 15% CRSB North	24% San Andreas 11% Hayward 10% CRSB North
Intake C	32% Central Valley Background Seismicity 13% CRSB North 12% Pittsburg-Kirby Hills	24% San Andreas 11% Hayward
Twin Cities Complex	34% Central Valley Background Seismicity	25% San Andreas 11% Hayward
Bouldin Island	18% Mt. Diablo 17% Central Valley Background Seismicity 15% West Tracy-Midland	18% San Andreas 14% Mt. Diablo 11% West Tracy-Midland 10% Hayward
Southern Forebay North	38% Mt. Diablo 19% West Tracy-Midland 11% Greenville 10% Midway-Black Butte	32% Mt. Diablo 17% West Tracy-Midland 13% Greenville
Southern Forebay South	36% Mt. Diablo 20% West Tracy-Midland 13% Midway-Black Butte 12% Greenville	32% Mt. Diablo 18% West Tracy-Midland 14% Greenville 13% Midway-Black Butte

Source: Lettis Consultants International, Inc. 2021:Table 3.
Note: Intake A was not evaluated in the Seismic Hazard Analyses Report and Development Conceptual Seismic Design Ground Motions for the Delta Conveyance (Lettis Consultants International, Inc. 2021).
CRSB = Coast Range-Sierran Block zone (encompasses the West Tracy and Midland Faults); PGA = peak ground acceleration.

Site Soil Amplifications

Thick deposits of peaty and soft soil tend to de-amplify short-period earthquake ground motions and amplify long-period ground motions. The earthquake ground motions (expressed in fractions of g (i.e., the standard acceleration due to Earth's gravity) developed for the Delta 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.

Table 10-12 (based on the *Conceptual Design Phase Seismic Site Response Analysis (Final Draft)* (Delta Conveyance Design and Construction Authority 2022g:28) presents the ranges of PGA values at 16 conveyance facility sites. The range of input PGAs shown in the table reflects the ground motions calculated on the stiffer alluvium underlying the Delta at each conveyance facility site. The range of calculated ground-surface PGAs refers to the PGA values calculated at the ground surface above the peaty and soft soils. The ratio between the ground surface PGA and the corresponding stiffer soil PGA (or input PGA) is defined as the *site amplification factor*. The table shows that the strongest shaking potential is on the Byron Tract (PGA 0.59–0.67 g), and the weakest shaking potential is at Intake B (PGA 0.19–0.24 g).

Table 10-12. Input and Calculated Ground Surface PGAs at Each Facility

	Peak Ground Accelerations (g)	
Facility	Range of Input PGAs	Range of Calculated Ground Surface PGAs
Bacon Island	0.63–0.86	0.29–0.35
Banks Connection	0.52–0.65	0.25–0.33
Bethany Reservoir Pumping Plant	0.37–0.49	0.29–0.33
Bouldin Island	0.53–0.64	0.30–0.34
Byron Tract	0.69–0.93	0.59–0.67
Canal Ranch Tract	0.28–0.36	0.31–0.35
Discharge Structure[a]	N/A	N/A
Intake B	0.26–0.40	0.19–0.24
Intake C	0.32–0.40	0.27–0.37
King Island	0.34–0.49	0.25–0.36
Lower Roberts Island	0.36–0.57	0.2–0.24
New Hope Tract	0.32–0.51	0.23–0.33
Southern Forebay–North	0.55–0.67	0.53–0.58
Southern Forebay–South	0.79–1.11	0.32–0.42
Twin Cities Road	0.25–0.44	0.28–0.41
Union Island	0.69–0.92	0.24–0.32

Source: Conceptual Design Phase Seismic Site Response Analysis (Draft) (Delta Conveyance Design and Construction Authority 2022g:28).
Note: Intake A was not evaluated in the Conceptual Design Phase Seismic Site Response Analysis (Delta Conveyance Design and Construction Authority 2022g:28).
g = acceleration due to gravity (32.2 square feet per second).
[a] Bethany Reservoir Discharge Structure was not analyzed because the facility overlies rock; no liquefaction is anticipated.

Liquefaction

Liquefaction is a process whereby strong ground shaking causes loose and saturated soil to lose strength and to behave as a viscous fluid. This process can cause partial or total loss of soil's shear strength and temporary loss of soil-bearing capacity, resulting in excessive ground deformations, foundation instability, embankment failures, and damage to structures and levees. Many factors could influence the severity of these consequences, including site topography, subsurface soil heterogeneity, horizontal and vertical extents of potentially liquefiable soils, and effects of foundations.

Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials; depth to groundwater; rate of drainage; slope gradient; proximity to free faces; and intensity and duration of ground shaking. Ground failures can take the form of lateral spreading, excessive differential or total compaction or settlement, and slope failure.

Liquefaction can also increase the potential for buoyancy to buried structures, such as buried pipes, tunnels, and other structures, causing them to float toward the ground surface.

The Delta is 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, the soil of the levee embankment and the soil of the levee 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 possible liquefaction during the 1906 San Francisco earthquake was reported in two locations within and in the vicinity of the study area. Youd and Hoose (1978:122) reported settlements of several inches at the Southern Pacific Bridge Crossing over the San Joaquin River in Stockton and settlement of 3 feet at a bridge crossing over Middle River, approximately 10 miles west of Stockton. The specific mechanism for the settlements (e.g., liquefaction, consolidation) were not identified.

Holzer (1998:B1) reports that the greatest distance from the epicenter of the more recent 1989 Loma Prieta earthquake was 76 miles, in the Bolinas Lagoon tidal flats. The southern end of the Delta is 52 miles from the epicenter, but Holzer (1998) does not mention liquefaction occurring in the Delta.

Liquefaction Susceptibility and Potential Mapping

Part of the study area falls within an area that the California Geological Survey (2021a) has evaluated for a type of Seismic Hazard Zone referred to as *Earthquake Zones of Required Investigation*. The general approach and recommended methods of the required investigations are presented in the CGS Special Publication 117A—Guidelines for Evaluating and Mitigating Seismic Hazards in California (California Geological Survey 2008:35–42), including requirements for screening investigations for liquefaction potential and quantitative evaluation of liquefaction resistance. The identification of a Seismic Hazard Zone for liquefaction is intended to prompt more detailed, site-specific geotechnical investigations, as required by the Seismic Hazards Mapping Act (Section 10.2, *Relevant Laws, Regulations, and Programs*). As such, these maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements or the amount of damage to facilities that may result from liquefaction.

Areas identified as Liquefaction Zones in the mapping of Earthquake Zones of Required Investigation by the California Geological Survey (2018b:13, 14; 2018c:13, 14; 2021c:25, 26) have been mapped for those parts of the study area west of Old River and south of the San Joaquin River corresponding to parts of the USGS 7.5’ Woodward Island quadrangle, the area surrounding the

Clifton Court Forebay on the Clifton Court Forebay USGS 7.5’ quadrangle, and the Bouldin Island 7.5’ quadrangle, where Alternative 1, 2a, 2b, 2c, 3, 4a, 4b, 4c, and 5 facilities would be located.[8] The mapped areas (Figure 10-6) (which included the Rail Depot area, RTM area and associated facilities, and the Byron Tract Working Shaft) extend from approximately Isleton to the north and southerly to the northern part of the proposed Southern Complex. The mapping shows that the area surrounding Clifton Court Forebay is subject to liquefaction hazard, with a pseudo-peak ground acceleration (g) of 0.23 to 0.32 with a 10% probability in 50 years (California Geological Survey 2021c:11-13, plate 2.2). The mapping shows that the Byron Tract Working Shaft site is subject to liquefaction hazard, with a pseudo-peak ground acceleration (g) of 0.26 to 0.27g with a 10% probability in 50 years (California Geological Survey 2018c:11-13, plate 3.2). The Rail Depot area and RTM area and associated facilities are subject to liquefaction hazard, with a pseudo-peak ground acceleration of 0.26 to 0.28g.

The remaining parts of the study area have not been evaluated for liquefaction hazard zonation by the California Geological Survey (2018b:13, 14; 2018c:13, 14; 2021c:plate 1.1).

The Association of Bay Area Governments (ABAG) (2021) Metropolitan Transportation Commission (MTC)/ABAG Hazard Viewer Map shows liquefaction susceptibility for the part of the USGS 7.5’ Clifton Court Forebay quadrangle (i.e., the quadrangle immediately south of the Woodward Island quadrangle) that is within Contra Costa and Alameda Counties. Within the study area, the ABAG mapping covers the entire perimeter of the Clifton Court Forebay (including the Southern Complex) as well as the Bethany Complex area (Figure 10-6). The susceptibility rating scale is from very low to very high. With respect to Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c, the mapping shows a high rating in the area of the Southern Complex launch shaft and Southern Forebay and a low rating in the remainder of the Southern Complex. With respect to Alternative 5, the mapping shows very high liquefaction susceptibility to the east and southeast sides of Clifton Court Forebay, intersecting the Bethany Reservoir alignment tunnel. South of Clifton Court Forebay, the Bethany Reservoir alignment tunnel and the Bethany Complex are in an area of moderate and low liquefaction susceptibility.

For Delta Conveyance Project-specific analyses, the Liquefaction and Ground Improvement Analysis Technical Memorandum in *Volume 1, Delta Conveyance Final Draft Engineering Project Report, Central and Eastern Options* (Delta Conveyance Design and Construction Authority 2022c) describes the results of a conceptual-level evaluation of the liquefaction potential of the foundation soils at the following locations.

- Three potential intake sites
- Southern Forebay Inlet Structure and South Delta Pumping Plant
- Southern Forebay Outlet Structure
- South Delta Outlet and Control Structure
- Tunnel shaft sites along the central and eastern alignments

The evaluation determined that all the evaluated sites are subject to liquefaction, with the exception of the facilities near Twin Cities Road and the South Delta Outlet and Control Structure.

---

[8] Within the study area, areas north of the San Joaquin River and east of Old River have not been evaluated by the California Geological Survey for liquefaction hazard.

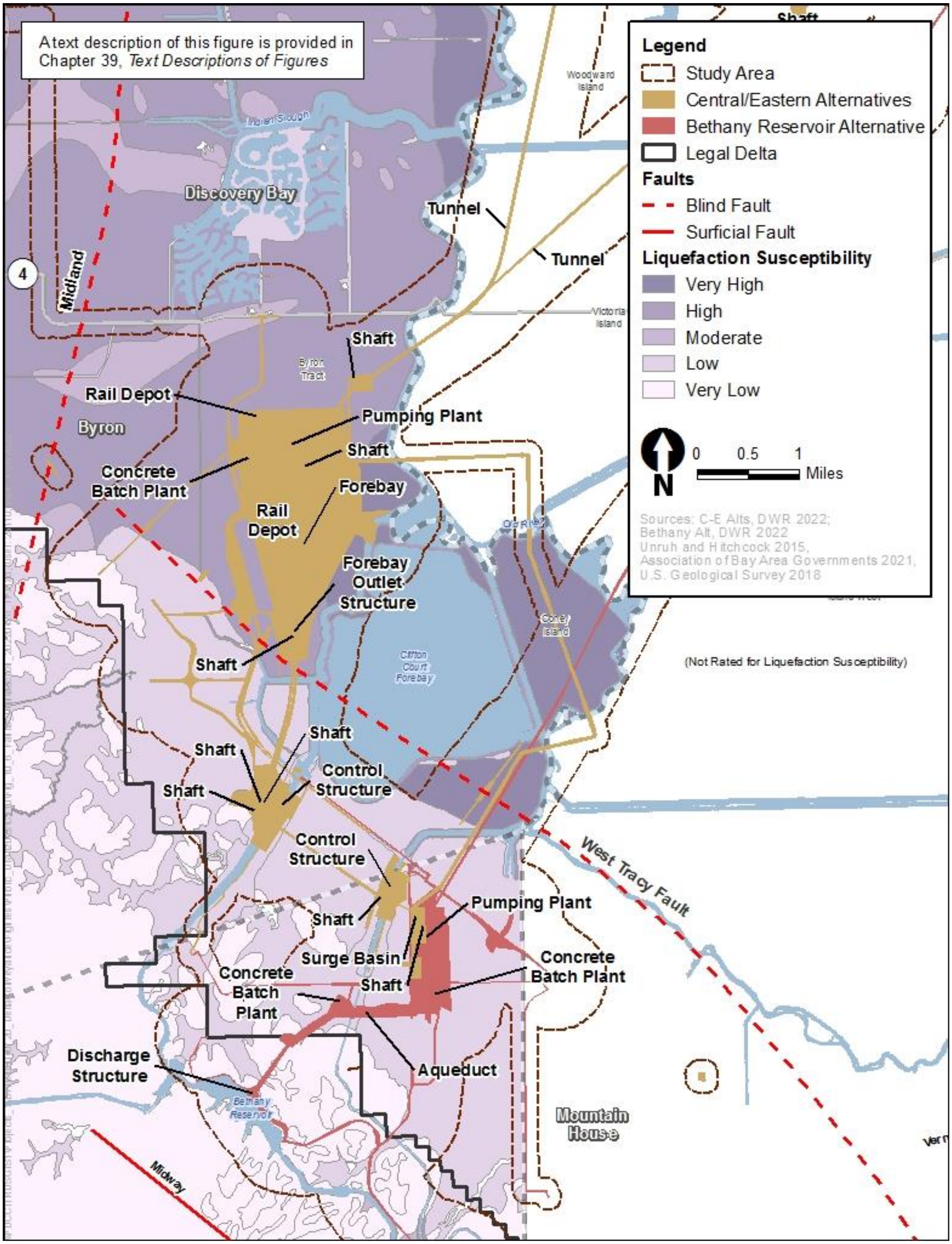


Figure 10-6. Faults and Liquefaction Susceptibility in Vicinity of Southern Complex and Bethany Complex

The Liquefaction and Ground Improvement Analysis for Bethany Reservoir Alternative Technical Memorandum (Delta Conveyance Design and Construction Authority 2022f) describes the results of a conceptual-level evaluation of the liquefaction potential of the foundation soils at the following locations that are in addition to the three intakes and tunnel shaft sites described above for the central and eastern alignments.

- Union Island Tunnel Maintenance Shaft
- Bethany Reservoir Pumping Plant and Surge Basin
- Bethany Reservoir Discharge Structure

The evaluation determined that a significant liquefaction potential exists at the Union Island tunnel maintenance shaft site. However, at the Bethany Reservoir Pumping Plant and Surge Basin, the evaluation determined that the soil characteristics are clayey and that the Bethany Reservoir Discharge Structure is underlain by soft rock, such that there is no significant liquefaction potential at these sites.

Conditions Associated with Landslides/Slope Instability

A landslide (more broadly referred to as mass movements and slope failures) is a mass of rock, soil, or debris that has been displaced downslope by sliding, flowing, or falling. Landslides may also occur as a result of liquefaction, which reduces soil shear strength to a low residual value, causing the soil to move. 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 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.

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 in the Study Area

Existing landslides have been mapped for all of Alameda County (Roberts et al. 1999). Within the study area, the map shows one relatively small landslide (i.e., less than one acre) located approximately 2,800 feet southeast of the Bethany Reservoir.

Historical Occurrences of Levee Failure in the Study Area

During the last century through 2015, more than 160 levee failures or breaches have been reported in the Delta islands and tracts (California Department of Water Resources 2015:1).

Areas Susceptible to Landslides and Debris Flows in the Study Area

Because the topography of the Delta has little relief, the potential for mass failure of natural slopes, including landslides and debris flows in nearly all the study area is considered very low. However, certain streambanks may be subject to undercutting and resultant failure, although there are no known maps of channel banks that are prone to failure.

The MTC/ABAG Hazard Viewer Map (Association of Bay Area Governments 2021), which covers only the Alameda and Contra Costa Counties parts of the study area, rates the areas to the east and west of the Bethany Reservoir within the study area as being subject to "few landslides."

Areas Susceptible to Levee Failure in the Study Area

Levee damage or mass failure can occur as a result of hydrologic and hydraulic conditions and from seismic loading. Site-specific conditions that can contribute to a levee's vulnerability for failure when subjected to seismic loading include poor/weak embankment or foundation soils, insufficient levee geometry (i.e., height, width, and slope inclination), and damaging animal activity or vegetation growth. Liquefaction of levee materials and levee foundation soils is also known to cause levee failure in the Delta.

There are no known maps of levees in the study area that are particularly subject to failure from mass movement alone. Studies of levees in the Delta tend to be directed to evaluating the overall vulnerability of a levee to failure as a result of levee geometry, soil foundation conditions, floodwater levels and wave runup, sea level rise, and seismic loading, which could contribute to mass failure of a levee. Relative levee vulnerability in the Delta was evaluated in the Levee Vulnerability Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022h). The assessment assigned Delta levees at approximately 5,000 cross-sections according to one of four relative vulnerability ratings (high, medium, low, and very low). Approximately ¼ of the cross-sections received a high vulnerability rating and half of the cross-sections received scores were Low or very low vulnerability. Levees with a High rating most frequently are mapped in the central parts of the eastern and central alignments. Levees with the very low rating most frequently are mapped in the northern and southern parts of the eastern and central alignments.

Despite extensive geological and geotechnical explorations and multiple analyses by seismic experts, there remains uncertainty regarding the effects of potential seismic events on Delta levee integrity.

Earthquake hazards to Delta levees in particular were reviewed in a workshop organized by the Delta Independent Science Board in July 2016. Earthquake hazards in the Delta were described in terms of ground motions from Bay Area earthquakes, infrequent earthquake recurrence on faults beneath the Delta, and levee fills prone to earthquake-induced liquefaction. Large uncertainties are associated with all of these seismic contributions to the hazard of levee failure. Those uncertainties, according to presentations in the workshop, include whether the Delta ground motions previously computed for Bay Area earthquakes were overestimated (Delta Independent Science Board 2016:3). According to the Delta Independent Science Board, Bay Area faults pose an overall greater risk to Delta levee failure in the Delta than faults located beneath the Delta itself (Delta Independent

Science Board 2016:3) because earthquakes in the Bay Area occur more frequently than Delta earthquakes. However, faults beneath the Delta are capable of producing stronger ground shaking because they are located in the Delta itself. The degree to which a Bay Area earthquake affects the Delta, however, depends on attenuation (i.e., how abruptly the ground motions diminish as the seismic waves advance eastward from the Bay Area into the Delta).

Earthquake-Induced Landslide Potential Maps

California Geological Survey Seismic Hazard Zones for earthquake-induced landslides are delineated using criteria adopted by the California State Mining and Geology Board. Under these criteria, these zones are defined as areas that meet one or both of the following conditions.

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas, as well as any landslide that is known to have been triggered by historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure (California Geological Survey 2021c:31).

The only official Seismic Hazard Zone mapping for earthquake-induced landslide hazard potential in the study area is an area corresponding to the northwestern part of the Clifton Court Forebay USGS 7.5’ quadrangle (California Geological Survey 2021c), and only the Contra Costa County part of the quadrangle was evaluated for earthquake-induced landslide hazard potential. Within the study area, the resultant mapping (California Geological Survey 2021a) shows small areas located on the side slopes of areas mapped as artificial fill around both sides of the California Aqueduct/Banks Pumping Plant Inlet channel (Figure 10-6), as having the potential for an earthquake-induced landslide.

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 a 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 of levees and other aboveground 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, tunnels, 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 structures.

Tsunami and Seiche

Tsunamis, which typically consist of multiple waves that rush ashore, range in size from micro-tsunamis detectable only by sensitive instruments to waves tens of feet high. They may be triggered by earthquakes, volcanic eruptions, submarine landslides, and by onshore landslides. The California Governor's Office of Emergency Services (2021) MyHazards website[9] shows that there is no potential hazard of a tsunami in the study area nor in the Delta in general. The website shows that the tsunami inundation hazard area nearest to the study area is on the north shore of the Sacramento River, extending approximately 1 mile upstream (i.e., east) of the Benicia Bridge. The inundation area extends 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 Delta are mostly attenuated in the San Francisco Bay. Any tsunami effects significantly to the east of the Benicia Bridge are presumed to be further attenuated in 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 (Ritter and Dupre 1972:Plate 1).

Based on available data, the Safety Element of the 2005–2020 Contra Costa County General Plan reports that there is a systematic diminishment of wave height from the Golden Gate to about half that height on the shoreline near Richmond. The wave height would be negligible upon reaching the Carquinez Strait (County of Contra Costa 2005:10-30).

Based on the above information, the effects of a tsunami in the study area 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

---

[9] Available at: myhazards.caloes.ca.gov.

occurring miles away can produce seiches in local bodies of water that could overtop and damage levees and dams and cause water to inundate surroundings. In 1868, an earthquake along the Hayward Fault in the Bay Area generated a seiche along the Sacramento River (AECOM 2013:3.7).

With the exception of the Clifton Court Forebay, the hazard of a seiche occurring in the study area is expected to be low because of the lack of existing deep, narrow, and enclosed waterbodies and distance from seismic sources capable of generating strong ground motions.

As a point of reference, Fugro Consultants (2011:14) 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.

10.2 Applicable Laws, Regulations, and Programs

The applicable laws, regulations, and programs considered in the assessment of project impacts on geology and seismicity are indicated in this section, in Section 10.3.1, *Methods for Analysis*, or the impact analysis, as appropriate. Applicable laws, regulations and programs associated with state and federal agencies that have a review or potential approval responsibility have also been considered in the development of CEQA impact thresholds or are otherwise considered in the assessment of environmental impacts. A listing of some of the agencies and their respective potential review and approval responsibilities, in addition to those under CEQA, is provided in Chapter 1, *Introduction*, Table 1-1. A listing of some of the federal agencies and their respective potential review, approval, and other responsibilities, in addition to those under NEPA, is provided in Chapter 1, Table 1-2. DWR would follow the applicable standards, guidelines, and codes (or the most current applicable version at the time of implementation), which establish minimum design criteria and construction requirements for project facilities, levees, pipelines, excavations and shoring, pumping stations, grading, and foundations, bridges, access roads, structures, and other facilities, where applicable, in the design of project facilities and would include each as minimum standards in the construction specifications. The following list provides examples of the standards, guidelines, and code requirements that are legally mandated.

- **Liquefaction and Landslide Hazard Maps (Seismic Hazards Mapping Act):** The act (Pub. Resources Code §§ 2690–2699.6) directs the California Geological Survey to identify and map areas prone to earthquake-induced liquefaction, landslides, and amplified ground shaking, and requires site-specific geotechnical investigations for seismic hazard and mitigation measure identification prior to permitting most developments designed for human occupancy. Seismic hazard guidance and maps prepared by the California Geological Survey under this act are used in the seismic hazard analyses presented in this chapter.

- **Alquist–Priolo Earthquake Fault Zones:** Pub. Resources Code Section 2621 *et seq*. directs the California Geological Survey to identify and map known active faults to prevent building construction for human occupancy on a fault surface trace. The Alquist–Priolo Earthquake Fault Zone establishes a 200- to 500-foot zone on each side of the mapped fault trace to account for potential branches of active faults. California Geological Survey Special Publication 42 shows mapped faults capable of surface fault rupture. Maps and data prepared by the California Geological Survey that identify active faults are used in the seismic hazard analyses presented in this chapter.

- **Regulatory Design Codes and Standards for Project Structures:** Numerous state, federal and professional association design codes and standards regulate and guide structure construction. These codes and structures establish minimum design and construction requirements including for concrete and steel structures, levees, tunnels, pipelines, canals, buildings, bridges, and pumping stations. Project-specific design criteria and guidelines will be developed as part of future design activities either to meet or exceed the requirements of the design standards. DWR would also follow any other applicable standards, guidelines, and code requirements that are promulgated during the detailed design and construction phases and during operation of the water conveyance facilities. Additionally, during construction, the California Occupational Safety and Health Act of 1973, as administered by California Occupational Safety and Health Administration (Cal/OSHA), would be followed as a minimum standard to protect workers. The requirements established by these design codes and standards are considered in the analysis of impacts in this chapter.

10.3 Environmental Impacts

This section describes the direct and cumulative environmental impacts associated with geology and seismicity that would result from project construction and operations and maintenance. It describes the methods used to determine the impacts of the project and lists the thresholds they used to conclude whether an impact would be significant. Measures to mitigate (i.e., avoid, minimize, rectify, reduce, eliminate, or compensate for) significant impacts are provided. Indirect impacts are discussed in Chapter 31, *Growth Inducement*.

10.3.1 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 risk to loss of life or loss of property or other associated risks. Other than seismic sources that exist outside the study area, lands outside of the study area are not considered because there are no structures or other facilities being proposed there and because project alternative operations within the water user service areas would not increase geologic or seismic hazards in those areas. There would be no Delta Conveyance Project structures in areas upstream of the intakes and Delta in general, nor would there be any changes as a result of the project in those areas. Both quantitative and qualitative methods were used to evaluate these effects, depending on the type and availability of data.

10.3.1.1 Process and Methods of Review for Geology and Seismicity

The DCA has developed geologic and geotechnical information for all of the conveyance facility alternatives. This information has been developed under the supervision of professional engineers and documented in the technical memoranda DCA prepared for the project. These documents show project and alternative feasibility by identifying site geotechnical conditions and associated site constraints. The methods used by the DCA to prepare the technical memoranda are specific to the objectives of a given memorandum, but typically preparation of each memorandum involved review of existing literature and data, analyses of new mapping and data (some of which was generated by the DCA), statement of design parameters, development of conceptual design and construction measures, and recommendations for future studies and design work.

The geology and seismicity analyses conducted to prepare this chapter were based on critical review and use of the engineering project reports (EPR) narrative reports and those associated technical memoranda that are relevant to geologic and seismic conditions and hazards. Information in the EPR narratives and technical memoranda and other existing reports and data were used to determine whether significant risks might occur from constructing and operating the project. The impact analysis for geology and seismicity was performed primarily using information on geologic substrate, topography, and potential fault rupture and earthquake hazards, largely derived from the EPR narrative reports and technical memoranda, as listed below.

- *Volume 1: Delta Conveyance Final Draft Engineering Project Report—Central and Eastern Options*
- *Volume 1: Delta Conveyance Draft Engineering Project Report—Bethany Reservoir Alternative*
- *Potential Future Field Investigations—Central and Eastern Corridor Options (Final Draft)*
- *Potential Future Field Investigations—Bethany Reservoir Alternative (Final Draft)*
- Conceptual Design Phase Seismic Site Response Analysis (Final Draft) Technical Memorandum, Version 1
- *Conceptual-Level Seismic Design and Geohazard Evaluation Criteria (Final Draft)*
- Liquefaction and Ground Improvement Analysis for Bethany Reservoir Alternative (Final Draft) Technical Memorandum
- Liquefaction and Ground Improvement Analysis (Final Draft) Technical Memorandum
- West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) Technical Memorandum, Central and Eastern Options
- Supplementary Tunnel Information Technical Memorandum for the Bethany Reservoir Alternative
- Dewatering Estimates for Intake Facilities and Southern Forebay Emergency Spillway (Final Draft) Technical Memorandum

Other study results and applicable maps and information published by various regulatory agencies, researchers and consultants were also used in the analysis (e.g., California Geological Survey 2021a, 2021b; California Governor's Office of Emergency Services 2021; Knudsen et al. 2000; Unruh and Hitchcock 2014; U.S. Geological Survey 2016; Working Group on Northern California Earthquake Potential 2012; Wong et al. 2021).

The emphasis of the impact analysis was on identifying where the existing data suggest that geologic or seismic conditions pose a potentially serious threat to loss of life and loss of property, including the structural integrity of the conveyance facilities and related improvements. The analysis determines whether these conditions and associated risk can be reduced to a less-than-significant level by conformance with existing codes and standards and the application of accepted, proven construction engineering practices.

The methods used in this chapter to evaluate some of the geologic and seismic hazards are similar for both construction and operations and maintenance impacts; those impacts that are unique to one or the other are discussed under their respective sections.

10.3.1.2 Evaluation of Construction Activities

Geologic and seismic hazards were evaluated by analyzing the presence or creation of conditions that could jeopardize project worker safety and nearby properties. Specifically, potential impacts would occur if construction resulted in one of the following conditions.

- Unstable soil in tunnel bores, excavations, cut slopes, fill slopes, or areas of native soil material that is naturally subject to instability (e.g., landslide, debris flow).
- The presence of soil and groundwater conditions within the conveyance facility footprints and the conveyance alternatives and their construction conditions that could be subject to construction-induced liquefaction, such as that generated from impact pile driving and heavy construction vehicle vibrations.

In general, geologic methods and sequences were identified and were used to evaluate potential construction impacts related to geology and seismicity at the project level.

Tunnel-Bore Ground Settlement

The hazard of ground settlement above the tunnel during boring was assessed based on a review of relevant discussions in the EPR narrative reports for the central and eastern alignments and the Bethany Reservoir alignment and the Supplementary Tunnel Information Technical Memorandum in the EPR for the Bethany Reservoir alignment (Delta Conveyance Design and Construction Authority 2022i).

Excavation Failure

The likelihood that excavations such as shafts could collapse during construction was assessed based on a qualitative review of geotechnical boring logs and the discussions in the EPR narrative reports for the central and eastern alignments and the Bethany Reservoir alignment and the ground improvement technical memoranda for the central and eastern alignments and the Bethany Reservoir alignment.

Slope Instability

The potential for failure of new cut or fill slopes under construction was evaluated qualitatively based on slope inclination, slope height, and soil characteristics.

Soil Instability from Construction Vibrations

The potential for soil and levee instability (e.g., settlement) caused by ground vibrations generated by geotechnical investigations, pile driving, heavy equipment operations, and tunnel boring was evaluated based on the type, duration, and amplitude of the vibrations; soil characteristics; and distance of the potential failure areas from project workers.

Construction-related Liquefaction

The potential for construction activities such as impact pile driving, use of heavy equipment and heavy vehicle traffic, and geotechnical investigations to trigger liquefaction was evaluated based on the types of construction activities that could trigger ground motions, the soil characteristics, and the depth to groundwater.

10.3.1.3 Evaluation of Operations and Maintenance

To evaluate geologic and seismic impacts during operations and maintenance at a project level, geologic substrate/soil characteristics, fault rupture, liquefaction, and other hazards present within the conveyance facility footprints (both surface and at depth) were identified. Earthquake-induced seismic shaking hazards generated from both within the study area and in the greater San Francisco Bay Area, as well as the potential for operation of the proposed facilities to increase risks associated with geologic hazards, were identified based on quantitative information.

Fault Rupture

Two (or three) types of (surface) fault rupture (sudden, offset and slow-offset) were identified as having the potential to occur in the study area and vicinity. Additionally, there are blind thrust faults known to occur within the study area and vicinity; however, these are not anticipated to result in near-surface ground rupture.

The methodology for assessing the potential for fault rupture was based primarily on the available Alquist–Priolo Fault Zone maps. Additional information provided in the West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022d) and unpublished information pertaining to the West Tracy Fault was also used. Areas within the footprints of each alternative located within the Alquist–Priolo Fault Zones or having the potential of experiencing fault ruptures during future earthquakes were identified. Regarding potential rupture of the West Tracy Fault, the probabilistic and deterministic fault offsets during earthquakes were determined using the West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022d:8, 9).

The long-term offset attributable to fault creep was also estimated using fault slip rate and time frame considered.

Earthquake Ground Shaking

The potential exposure to ground shaking during future earthquakes and the effects on facilities within all project alternative footprints were evaluated using acceleration response spectral value at period of zero seconds, which is also widely used to characterize the level of ground motion. The DRMS Phase 1 Technical Memorandum for seismology (California Department of Water Resources 2007b), the DRMS *Risk Analysis Report* (California Department of Water Resources 2008), the Seismic Hazard Analyses and Development of Conceptual Seismic Design Ground Motions for the Delta Conveyance (Lettis Consultants International, Inc. 2021) served as the primary sources for the analysis.

Liquefaction and Lateral Spreading

The assessment of the hazard of liquefaction and differential settlement to occur at the conveyance facility locations was based on California Geological Survey Seismic Hazard Zone reports for liquefaction susceptibility for the Southern Complex vicinity and the results of the EPR Liquefaction and Ground Improvement technical memoranda for the central and eastern alignments and the Bethany Reservoir alignment(Alternative 5) (Delta Conveyance Design and Construction Authority 2022c, 2022f). The seismic vulnerability (including liquefaction potential) of existing levees in the Delta was based on two DRMS reports (California Department of Water Resources 2007a, 2007b).

The assessment of the hazard of lateral spreading triggered by liquefaction was based on the liquefaction hazard determined above and on a review of the presence of any open-face topographic features in the vicinity of each conveyance facility.

Buoyancy of Below-Ground Structures

The evaluation of the potential for below-ground or buried structures to become buoyant (i.e., become subject to "flotation") and possibly fail was based on a review of the Conceptual Tunnel Lining Evaluation Technical Memorandum (Final Draft) (Delta Conveyance Design and Construction Authority 2022j:10, 11) for the central and eastern alignments and the Bethany Reservoir alignment.

Slope Instability

The potential for failure of new cut or fill slopes was assessed based on slope inclination, slope height, and soil characteristics, and approaches to constructing these slopes was assessed qualitatively based on the Soil Balance (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022k) and Post-Construction Land Reclamation Technical Memorandum for the central and eastern alignments (Delta Conveyance Design and Construction Authority 2022l:5, 8) and the *Soil Balance and Reusable Tunnel Material Supplement—Bethany Reservoir Alternative (Final Draft) (*Delta Conveyance Design and Construction Authority 2022m:6) and *Post-Construction Land Reclamation Supplement—Bethany Reservoir Alternative* (Delta Conveyance Design and Construction Authority 2022n:5–9).

Seiche and Tsunami

The evaluation of the hazard for the impact of tsunami was based on review of online geographic information system data for tsunami-related wave runup in the Sacramento and San Joaquin Rivers.

The evaluation for the impact of a seiche was based on review of expected earthquake-induced ground motions, presence of any landslide-prone areas adjacent to the conveyance facilities, and the height of the freeboard incorporated into the design of facilities that would impound water.

10.3.2 Thresholds of Significance

This impacts analysis assumes that a project alternative would have a significant impact under CEQA if implementation would result in one of the following conditions.

- Directly or indirectly cause potentially substantial impacts, including the risk of loss, injury, or death involving:
  - Rupture of a known earthquake fault, as delineated on the most recent Alquist–Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault. Refer to Division of Mines and Geology Special Publication 42.
  - Strong seismic ground shaking.
  - Landslides.

- Be located on a geologic unit or soil that is unstable or that would become unstable as a result of the project and potentially result in on- or off-site landslide, lateral spreading, settlement, liquefaction, or collapse.
- Be subject to inundation by seiche or tsunami.

10.3.2.1 Evaluation of Mitigation Impacts

CEQA also requires an evaluation of potential impacts caused by the implementation of mitigation measures. Following the CEQA conclusion for each impact, the chapter analyzes potential impacts associated with implementing both the Compensatory Mitigation Plan and the other mitigation measures required to address with potential impacts caused by the project. Mitigation impacts are considered in combination with project impacts in determining the overall significance of the project. Additional information regarding the analysis of mitigation measure impacts is provided in Chapter 4, *Framework for the Environmental Analysis*.

10.3.3 Impacts and Mitigation Approaches

10.3.3.1 No Project Alternative

As described in Chapter 3, *Description of the Proposed Project and Alternatives*, CEQA Guidelines Section 15126.6 directs that an EIR evaluate a specific alternative of "no project" along with its impact. The No Project Alternative in this Draft EIR represents the circumstances under which the project (or project alternative) does not proceed and considers predictable actions, such as projects, plans, and programs, that would be predicted to occur in the foreseeable future if the Delta Conveyance Project is not constructed and operated. This description of the environmental conditions under the No Project Alternative first considers how geology and seismicity could change over time and then discusses how other predictable actions could affect geology and seismicity.

Future Geology and Seismicity Conditions

For geology and seismicity, most future conditions are not anticipated to substantially change compared to existing conditions because climate change, sea level rise, and other variables are not expected to affect the incidence of fault rupture and incidence or strength of earthquake ground shaking if the project (or project alternative) does not proceed. However, sea level rise could cause an indirect impact on the potential for liquefaction and its secondary effects by raising the water table underlying Delta islands. Sea level rise could also make Delta levees more vulnerable to liquefaction of their foundations and to mass failure of their waterside slopes as a result of increased soil pore water pressure at a higher elevation of the levee. Levee failure caused by liquefaction of levee foundations and mass failure of levee slopes could cause inundation of Delta islands.

In the event of large-scale, seismically induced levee failures, DWR, in cooperation with the Metropolitan Water District and other federal and state agencies, would develop an Emergency Freshwater Pathway. The purpose of the freshwater pathway is to move fresh water from north to south through the Delta to the existing pumping facilities of the State Water Project and Central Valley Project (Wong et al. 2021).

Predictable Actions by Others

A list and description of actions included as part of the No Project Alternative are provided in Appendix 3C, *Defining Existing Conditions, No Project Alternative, and Cumulative Impact Conditions*. As described in Chapter 4, *Framework for the Environmental Analysis,* the No Project Alternative analyses focus on identifying the additional water-supply-related actions public water agencies may opt to follow if the Delta Conveyance Project does not occur.

Public water agencies participating in the Delta Conveyance Project have been grouped into four geographic regions. The water agencies within each geographic region would likely pursue a similar suite of water supply projects under the No Project Alternative (Appendix 3C). Construction of water supply reliability projects would result in various construction types that would each be designed to address the site-specific geologic conditions, as well as the impacts that the geologic environment would have on the facility.

Desalination projects would most likely be pursued in the northern and southern coastal regions. The southern coastal regions would likely require larger and more desalination projects than the northern coastal region to replace the water yield that otherwise would have been received through Delta Conveyance. These projects would be sited near the coast. Groundwater recovery (brackish water desalination) would involve similar facilities, but could occur across the northern inland, southern coastal, southern inland regions and in both coastal and inland areas, such as the San Joaquin Valley. Facility location and design would address avoidance of Alquist–Priolo Fault Zones, unstable ground (e.g., liquefaction, lateral spreading, slope failure), the potential for tsunami or seiche, and withstanding anticipated seismic shaking. Design parameters would vary according to underlying geologic materials such as competent bedrock or less competent and loose sedimentary (e.g., alluvial) deposits.

The northern and southern coastal regions are also most likely to explore constructing groundwater management projects. The southern coastal region would require more projects than the northern coastal region under the No Project Alternative. Groundwater management projects would occur in association with an underlying aquifer, but could occur in a variety of locations. Since these projects require an underlying aquifer, they would generally be in areas with deep sedimentary (e.g., alluvial) deposits. Construction activities for each project could require excavation for the construction of the recharge basins, conveyance canals, and pipelines and drilling for the construction of recovery wells (with completion intervals between approximately 200 and 900 feet below ground surface). Construction activities would include site clearing; excavation and backfill; and construction of basins, pipelines, and pump stations. Earthwork activities associated with the construction of recharge basins would involve earthmoving, excavation, and grading. Pipelines would likely be constructed using typical open trench construction methods. In some cases where siphons would be installed, jack and bore methods could be used to tunnel under and avoid disruption of surface features. Buildings required for these projects would generally be small, e.g., housing pumps or electrical equipment.

Water recycling projects could be pursued in all four regions. The northern inland region would require the fewest number of wastewater treatment/water reclamation plants, followed by the northern coastal region, followed by the southern coastal region. The southern inland region would require the greatest number of water recycling projects to replace the anticipated water yield that it would receive through Delta Conveyance. These projects would be located near water treatment facilities and could entail large buildings and potentially expanded outdoor treatment ponds.

Building size and associated infrastructure for water recycling projects would vary depending on the type of project (e.g., for landscape irrigation, groundwater recharge, dust control, industrial processes), but could require earth moving activities, grading, excavation, and trenching. Design and construction of all project components would address site geologic and seismic conditions. In the southern inland region where a greater number of projects would be needed as a substitute for Delta Conveyance, the potential for an impact would also be increased, although appropriate design and construction measures would minimize potential impacts.

Water efficiency projects could be pursued in all four regions and involve a wide variety of project types, such as flow measurement or automation in a local water delivery system, lining of canals, use of buried perforated pipes to water fields, and additional detection and repair of commercial and residential leaking pipes. These projects could occur anywhere in the regions and most would involve only small buildings to house equipment or electrical facilities. Little ground disturbance or would occur in previously disturbed areas.

As detailed above, all project types across all regions would involve relatively typical construction techniques and would be required to conform to seismic standards other requirements which take into consideration the geologic conditions of the sites in which these facilities may be located. These requirements would be commensurate with the type of water supply action being implemented. As an example, desalination plants or large-scale water recycling projects would be required to meet seismic standards and a wide range of building code requirements, whereas water conservation actions such as retrofits would have little or no need to comply with seismic or other standards.

10.3.3.2 Impacts of the Project Alternatives on Geology and Seismicity

Impact GEO-1: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Rupture of a Known Earthquake Fault or Based on Other Substantial Evidence of a Known Fault

All Project Alternatives

<u>Project Construction</u>

Project construction activities would not increase the potential for loss of property, personal injury, or death from structural failure resulting from rupture of a known earthquake fault under any of the alternatives. A surface rupture of the West Tracy Fault (if field investigations determine surface rupture to be a hazard) during construction of certain Southern Complex or Bethany Complex water conveyance facilities would not pose a threat to workers at the construction sites as the suspected fault alignment does not cross any proposed aboveground structures. However, workers could be at risk from the effects of ground deformation along the West Tracy Fault alignment even in the absence of surface rupture.

The field investigations would include geotechnical investigations, including excavation of five 1,000-foot-long test trenches along the projected alignment of the West Tracy Fault between Byron and the Clifton Court Forebay, which cover the alignments for Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, 4c, and 5. Because of the depth of the fault, neither the trench excavations nor the other geotechnical investigations are likely to increase the potential for fault rupture. Similarly, the chances of personnel conducting the West Tracy Fault trench study, geotechnical borings and geophysical surveys being present at the time that fault rupture (if this is indeed a possibility) occurs are remote.

Operations and Maintenance

Strict regulations apply to faults for development in Alquist–Priolo Earthquake Fault Zones (California Geological Survey 2008). There are no faults in or near the project area designated as an Alquist–Priolo Earthquake Fault Zone (California Geological Survey 2021a).

However, the C-E EPR and other sources (Delta Conveyance Design and Construction Authority 2022d:9; Unruh and Hitchcock 2014:14) report that the West Tracy Fault may have the potential for surface rupture along the western portion of its alignment. The West Tracy Fault near the Southern Complex may have experienced movement within the past 35,000 years and, therefore, is potentially active. It is currently unknown whether the West Tracy Fault is capable of rupturing to the ground surface to the south of the proposed Southern Forebay area in a large earthquake, but the principal fault displacement hazard at the proposed dual southern tunnels (Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c) is low to very low. Based on available information, the width of the permanent deformation of soils in the shallow subsurface that a rupture on the West Tracy Fault may cause during a large earthquake is uncertain (Delta Conveyance Design and Construction Authority 2022d:8, 9). Broad folding and tilting, where differential vertical displacement may be distributed over hundreds of feet, may result if the West Tracy Fault is locally blind (i.e., the top of the fault is hundreds to thousands of feet below the ground surface). If the West Tracy Fault extends to the shallow subsurface (to within a hundred feet to tens of feet below ground), the width of deformation in the shallow subsurface may be about 30 feet or less. Additionally, work by DCA determined that there could be significant fault offset over a short distance, essentially confirming a narrow width of predicted rupture (Delta Conveyance Design and Construction Authority 2022d:10). The precise location of the West Tracy Fault is poorly understood. Unruh and Hitchcock (2014:44) have mapped the fault beneath the southwestern part of the Clifton Court Forebay and approximately 1,800 feet south of what would be the southern tip of the Southern Forebay (Figure 10-6). For central and eastern alignments, the fault alignment would intersect the dual southern tunnels between the Southern Forebay Outlet Structure double launch shaft and the South Delta Outlet and Control Structure. For the Bethany Reservoir alignment, the fault alignment would intersect the tunnel segment between the Union Island maintenance shaft and the surge basin reception shaft/Bethany Reservoir Pumping Plant.

To further investigate the geometry and location of the West Tracy Fault between the town of Byron and the area southeast of the Clifton Court Forebay, during the design phase, five test trenches (up to approximately 1,000 feet long and 20 feet deep) would be excavated along a line running from the southeast of Byron to the southeast of Clifton Court Forebay, along the suspected alignment of the fault. Additionally, two arrays of surface geophysical surveys (1,000 feet long and 3 feet wide), conducted as part of the field investigations, would be completed and up to 15 CPTs and six soil borings would be completed to a depth of 150 feet. Selected soil samples from the test borings would be subjected to age-dating laboratory testing. The Conceptual-Level Seismic Design and Geohazard Evaluation Criteria (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022o) describes guidelines for assessing the permanent ground displacement (PGD) hazard from fault rupture from a major seismic event at the conveyance facilities. A PGD from fault rupture or from fault-related geologic folding without fault rupture could be a significant hazard for critical infrastructure that intersects or is adjacent to active faults. The following key parameters would be considered as part of the engineering evaluation and design for PGDs due to fault rupture.

- The fault location and the level of uncertainty for the determination.

- An estimate of the expected co-seismic rupture and the level of uncertainty for the determination.
- The style of faulting, such as direction of displacement and horizontal and vertical components of fault slip.
- The distribution of fault displacement, such as folding, knife-edge dislocation, or distributed shear across a zone.

Unlike oil and gas well drilling and hydraulic fracturing (also referred to fracking), which has been known to stimulate seismic activity, geotechnical exploration drilling does not introduce very high - pressure fluids into the ground. During geotechnical drilling, the downhole drilling fluid pressures are limited to those required to balance the soil and water pressures at depths less than 200 feet, typically less than 150 pounds per square inch. In contrast, downhole drilling fluid pressures used to stimulate oil and gas production often exceed 9,000 pounds per square inch. Consequently, the likelihood of the geotechnical investigations to trigger an earthquake on the West Tracy Fault or other faults in the region is low.

The final design of the conveyance facilities, which would be based on the results of the geological and geotechnical investigations described above and the results of the fault rupture displacement hazard assessment, would meet USACE, DWR, American Society of Civil Engineers, and other industry standards to prevent failure of the conveyance facilities as a result of fault rupture or fault-related geologic folding.

CEQA Conclusion—All Project Alternatives

Although both the central and eastern alignments pass through the Thornton Arch, based on available information, it does not present a hazard of surface rupture because it is a blind thrust fault (California Department of Water Resources 2007b:8, 12), and there would be no increased likelihood of loss of property, personal injury, or death associated with the Thornton Arch. The impact would be less than significant for a possible surface rupture of the Thornton Arch; therefore, no mitigation is required.

A rupture of the West Tracy Fault (if field investigations determine surface rupture to be a hazard) during construction of certain Southern Complex or Bethany Complex water conveyance facilities would not pose a threat to workers at the construction sites, as the suspected fault alignment does not cross any proposed aboveground structures. However, workers in the tunnel boring machine (TBM) could be at risk from a rupture on the fault, but the risk of such a rupture occurring during construction is low. The impact would be less than significant for a possible surface rupture of the West Tracy Fault. No mitigation is required.

Other than the West Tracy Fault, there are no known active faults capable of surface rupture in the project area. The field investigations would include trench explorations and geophysical surveys along the possible surface trace of the West Tracy Fault. The investigations may determine that fault is capable of rupture. Additionally, as described in the West Tracy Fault Preliminary Displacement Hazard Analysis (Final Draft) (Delta Conveyance Design and Construction Authority 2022d:2), possible ground deformation (e.g., uplift) from fault movement along the fault could occur without rupture in the vicinity of the Southern Complex or Bethany Complex (Figure 10-6). Depending on the precise alignment of the fault relative to the conveyance facilities, surface rupture and ground deformation could damage the southern tip of the Southern Forebay and Bethany Reservoir alignment aqueduct pipelines, and in extreme cases, the damage to the facilities could disrupt the water supply through the conveyance system or could cause an uncontrolled release of water from tunnels, the Southern Complex, or the Bethany Complex facilities, resulting in uncontrolled flooding. However, DWR would conduct field investigations prior to construction to determine the potential for fault rupture, slip rate of fault displacement, and PGA generated by movement on the West Tracy Faults. The results of the investigations would be used to inform the detailed design of the conveyance facilities. The detailed design would be consistent with applicable design standards and building codes, which require that all facilities and active construction sites be designed and managed to meet Cal/OSHA and safety-and-collapse-prevention requirements for the anticipated seismic loads, such as by implementing shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety.

Because the geotechnical investigations would not introduce high pressure fluids into the ground (which are associated with causing seismic activity), the likelihood of the investigations to trigger an earthquake on the West Tracy Fault or other faults in the region is low. The impact would be less than significant. No mitigation is required.

Additionally, based on the field investigations and the PGD, a California-licensed geotechnical engineer or engineering geologist would ensure that the final design conforms to applicable design specifications and standards. When applied to project design, the standards set by USACE, DWR, American Society of Civil Engineers, and other entities have been proven to enable facilities to withstand fault rupture or fault displacement such that the Delta Conveyance Project facilities would be able to withstand the design ground movements or deformations. Accordingly, operation of the facilities would not increase the likelihood of loss of property, personal injury, or death of individuals in the event of fault rupture or ground deformation at the Southern Complex or Bethany Complex. The impact would be less than significant. No mitigation is required.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction or operations and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation; therefore, this discussion is included here.

Compensatory mitigation, as described in Appendix 3F would be implemented on Bouldin Island and the Interstate (I-)5 ponds, where there are no known or suspected earthquake faults capable of rupture in the mitigation areas, nor are the mitigation areas within the Thornton Arch zone, such that the hazard of loss of property, personal injury, or death from structural failure caused by fault rupture is low. Therefore, the project alternatives combined with compensatory mitigation implemented at Bouldin Island and the I-5 ponds would not change the overall impact conclusion of less than significant.

As described in Appendix 3F, compensatory mitigation would also involve construction of setback levees at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc. However, it is unknown at this time if any of the levees would cross any known earthquake faults because the West Tracy Fault is the only fault that has the potential for surface rupture in the Delta, and because its trace appears to not cross any tidal channels, it is unlikely that any of the levees at the undetermined tidal wetland or channel margin restoration sites would be subject to fault rupture. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

The other mitigation measures would not involve activities that could trigger an earthquake on the West Tracy Fault or other faults in the region, and there would be no increased likelihood of loss of property, personal injury, or death associated with surface fault rupture. In addition, it is unlikely that any of the other mitigation measures would involve construction of structures or pipelines that would cross the West Tracy Fault or other faults in the region; nor would they be within the Thornton Arch zone. Therefore, the hazard of loss of property, personal injury, or death from structural failure caused by fault rupture as a result of implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, remains low. The overall impact of implementing the compensatory mitigation and other mitigation measures, combined with the project alternatives, would not change the impact conclusion of less than significant.

Impact GEO-2: Loss of Property, Personal Injury, or Death from Strong Earthquake-Induced Ground Shaking

All Project Alternatives

Project Construction

Project construction activities would not increase the potential for earthquake shaking to occur in the project area. However, earthquakes could be generated from local seismic sources during construction of the water conveyance facilities (Table 10-11) and pose threats to workers, particularly those working in shafts and tunnels, behind vulnerable levees and cofferdams, and in similar situations. For example, workers could be at risk from flooding caused by seismically induced levee failure on Bouldin Island, Lower Roberts Island, and other islands. Ground shaking could cause injury or death of workers at the construction sites as a result of facilities collapse, especially those conveyance facilities located closer to regional and local active faults, such as the facilities that make up the Southern Complex or Bethany Complex and the southern tunnel segments and tunnel shafts. (See related Impact FP-2 in Chapter 7, *Flood Protection*, for additional discussion of worker safety as affected by flooding as a result of failure of levees and other facilities during construction.)

The field investigations would include geotechnical investigations where the investigators would be in areas subject to ground shaking. However, because the investigators would not be working in structures, the likelihood of an injury caused by strong earthquake event occurring while the investigations are being conducted is low, and the investigation activities would not trigger an earthquake, the investigations are unlikely to cause a loss of property, personal injury, or death from strong earthquake-induced ground shaking.

Operations and Maintenance

Earthquakes may occur along Delta-area and regional faults during operation and maintenance of the water conveyance facilities. Unless properly engineered, ground shaking in the project area could damage the intakes, tunnels, and tunnel shafts, Southern Complex or Bethany Complex facilities, and other facilities, disrupting the water supply through the conveyance system. During an extreme event of seismic shaking, the uncontrolled release of water from the damaged tunnels, Southern Forebay, and other facilities could cause flooding, disruption of water supplies to the south, and inundation of structures, potentially resulting in loss of property, personal injury, or death.

CEQA Conclusion—All Project Alternatives

Seismically induced ground shaking that may occur could cause damage, collapse, or other failure of project facilities while under construction and during operations and maintenance. The damage to the facilities could disrupt the water supply through the conveyance system or could cause an uncontrolled release of water from the damaged tunnels, Southern Complex, or Bethany Complex facilities, resulting in flooding or collapse of facilities like bridges. The ground shaking could also cause loss of property, personal injury, or death as a result of damage or failure of the conveyance facilities, both during construction and operations and maintenance. Prior to construction, DWR would conduct additional field investigations, which include geotechnical studies, to inform the detailed design of the conveyance facilities. The detailed design would be consistent with applicable design standards and building codes, which require that all facilities and active construction sites be designed and managed to meet Cal/OSHA and safety-and-collapse-prevention requirements for the anticipated seismic loads, such as by implementing shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to avoid potential release of water from the facilities and flood the surrounding area and to protect worker safety. The project's seismic guidelines discuss a minimum level of ground shaking (currently set at ground shaking with a 200-year return period or a 5% chance of being exceeded in 10 years) that would be used to assess the safety of temporary works during construction (Delta Conveyance Design and Construction Authority 2022g:4–6). Additionally, the facilities have been designed with safety precautions/system redundancy in the event of an extreme case where facilities are damaged. The detailed design would also conform to other standards and codes by applying accepted, proven construction engineering practices to reduce any potential risk such that construction of the facilities would not create an increased likelihood of loss of property, personal injury, or death of individuals as a result of seismic shaking. Because the project would conform to relevant design standards and building codes and would apply proven engineering practices, the impact would be less than significant.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction or operations and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation; therefore, this discussion is included here.

Compensatory mitigation may involve construction of new setback levees on Bouldin Island. Moderate earthquake-induced ground shaking could damage the levees, and strong earthquakes could cause the levees to fail, resulting in an uncontrolled release of water and potentially flooding, loss of property, personal injury, or death. However, the project alternatives would be engineered consistent with applicable design standards and building codes. Therefore, the project alternatives combined with compensatory mitigation implemented at Bouldin Island, and the I-5 ponds would not change the overall impact conclusion of less than significant with mitigation.

As described in Appendix 3F, compensatory mitigation would also involve construction of setback levees at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc. Moderate earthquake-induced ground shaking could damage the levees, and strong earthquakes could cause the levees to fail, resulting in an uncontrolled release of water and potentially flooding, loss of property, personal injury, or death. However, since the setback levees would be engineered in the same manner as those on Bouldin Island and consistent with applicable design standards and building codes, the hazard of ground shaking on the stability of the levees would be reduced to an acceptable level. The impact would not change the impact conclusion of less than significant after implementation of the Compensatory Mitigation Plan. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

The other mitigation measures could involve construction of structures that would be affected by seismically induced ground shaking. However, these structures and any visual or noise barriers (which could include chain link fencing, a wood or concrete barrier, or other similar barrier a minimum of 6 feet tall) would be constructed to be consistent with applicable design standards and building codes such that there would be no increased likelihood of loss of property, personal injury, or death associated with strong ground shaking. Therefore, the hazard of loss of property, personal injury, or death from structural failure caused by strong ground shaking as a result of implementing compensatory mitigation and other mitigation measures, combined with project alternatives, remains low. The overall impact of implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, would not change the impact conclusion of less than significant.

Impact GEO-3: Loss of Property, Personal Injury, or Death from Earthquake-Induced Ground Failure, including Liquefaction and Related Ground Effects

All Project Alternatives

Project Construction

Project construction activities would not increase the potential for loss of property, personal injury, or death from structural failure resulting from earthquake-induced ground failure, including liquefaction under any of the alternatives, because the ground vibrations generated by the activities would not create sufficient ground motions to trigger liquefaction.

However, an earthquake of sufficient magnitude and duration of shaking along local or regional faults could result in ground failure, including liquefaction during construction, and could cause injury or death of workers as a result of collapse of the conveyance facilities. Refer to the discussion below, under *Operations and Maintenance*, for detail on the specific facility construction sites where a hazard for liquefaction could occur.

Given the infrequency of strong ground shaking in the project area, the likelihood that earthquake-induced liquefaction would occur at the time the personnel are conducting field investigations is low. Further, the personnel would not be in any structures during the investigations; therefore, they would not be subject to liquefaction-induced structural hazards and damage should a strong earthquake occur.

Operations and Maintenance

The Liquefaction and Ground Improvement Analysis Technical Memorandum for the central and eastern alignments (Delta Conveyance Design and Construction Authority 2022c) describes the results of a conceptual-level evaluation of the liquefaction potential of the foundation soils for all the facility sites. The evaluation determined that the three intakes and the Southern Forebay Inlet Structure and tunnel launch shaft sites are subject to liquefaction.

The available data acquired to date in support of the project design indicate the main tunnel would be bored through consolidated soil materials, which would have a low potential for liquefaction. However, because the data are limited, it is possible that the liquefaction potential may be determined to be greater as more data become available in the future.

The aqueduct pipelines as part of Alternative 5 would be constructed at a depth in which groundwater is likely to be encountered. However, the substrate underlying the pipelines consists of clayey soil and is not liquefiable. Therefore, there is no hazard for liquefaction to occur in the material surrounding the aqueduct pipelines.

The Liquefaction and Ground Improvement Analysis for Bethany Reservoir Alternative Technical Memorandum (Delta Conveyance Design and Construction Authority 2022f) describes the results of a conceptual-level liquefaction potential evaluation for the Union Island tunnel maintenance shaft, the Bethany Reservoir Pumping Plant and Surge Basin, and the Bethany Reservoir Discharge Structure. The evaluation determined that a significant liquefaction potential exists at the Union Island tunnel maintenance shaft site. The evaluation determined that the soil characteristics are clayey at the Bethany Reservoir Pumping Plant and Surge Basin and Bethany Reservoir Discharge Structure, such that there is no significant liquefaction potential at these sites. Similar to the potential effect during project construction, an earthquake of sufficient magnitude along local or regional faults could result in ground failure, including liquefaction during operations and maintenance, and could damage the affected conveyance facilities.

CEQA Conclusion—All Project Alternatives

During construction, seismically induced ground shaking could cause liquefaction and related ground effects at certain conveyance facilities. The ground effects could cause temporary structural features (e.g., scaffolding) to collapse and could cause injury or death of the workers. However, adherence to standard Cal-OSHA health and safety regulations would ensure the safety of the construction workers during an earthquake event. The impact would be less than significant.

Seismically induced liquefaction could occur at the locations where the field investigations are being conducted. However, in most cases since the investigators would not be working in or around structures, the impact would be less than significant.

The safety of investigators working in fault trenches for the West Tracy Fault investigation could be jeopardized in the event of liquefaction for those trenches that are located in a liquefaction hazard zone. However, adherence to standard Cal-OSHA health and safety regulations require shoring of trenches deeper than 5 feet and emergency trench egress measures would ensure the safety of the workers during an earthquake event. The impact would be less than significant.

During operation and maintenance, seismically induced ground shaking could cause liquefaction and related ground effects at certain conveyance facilities. The consequences of liquefaction could be manifested by soil compaction or settlement, loss of soil-bearing capacity, lateral spreading, increased lateral soil pressure, and buoyancy within the zones of liquefaction. Failure of the tunnels, certain tunnel shafts, intakes, facilities at the Southern Complex or Bethany Complex facilities including the aqueduct pipelines, bridges, and other structures and facilities could result in injury or loss of life and uncontrolled releases of water, flooding, and disruption of water supply deliveries through the conveyance system. Prior to construction, DWR would conduct the field investigations, which include advancing soil borings and conducting standard penetration tests to characterize subsurface conditions and installing groundwater test wells to determine the depth to groundwater at various facility locations. Combined with historic boring logs and studies done in support of the liquefaction and ground improvement analyses conducted for central and eastern alignments and the Bethany Reservoir alignment, the results of these investigations would be used to inform the detailed design of the conveyance facilities. The design, which would include measures for ground improvement such as deep mechanical mixing to form a soil-cement grid at those facility locations determined to be subject to liquefaction, would be consistent with applicable design standards and building codes. Seismic design criteria of all project facilities are in general conformance with those recommended in the Conceptual-Level Seismic Design and Geohazard Evaluation Criteria (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022o), by DWR for the State Water Project in the Seismic Loading Criteria Report (California Department of Water Resources 2012a) with some modifications to incorporate specific requirements of agencies including DWR's Division of Safety of Dams, USACE, California Department of Transportation, and other agencies. The detailed design would also conform to other standards and codes by applying accepted, proven construction engineering practices to reduce the risk that the facilities could fail or that there would be an increased hazard of loss of property, personal injury, or death of individuals as a result of liquefaction and related ground effects. The impact would be less than significant.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction or operations and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation, and therefore, this discussion is included here.

The Compensatory Mitigation Plan outlined in Appendix 3F may involve degradation (i.e., lowering) of existing levees and construction of new setback levees adjoining and connected to the existing levees along the northern perimeter of Bouldin Island. If the mitigation area has a potential for liquefaction, liquefaction-induced ground failure below the foundation of the new setback levees could damage the levees or cause a breach of the levees, resulting in an uncontrolled release of water and potentially flooding and loss of property.

The potential for liquefaction at the Bouldin Island compensatory mitigation area has not been formally evaluated. However, the Delta island immediately southwest of Bouldin Island (i.e., the Webb Tract) has been determined to be in a liquefaction zone by the California Geological Survey (2021b). Given that Bouldin Island and the Webb Tract are underlain by the same geologic unit (Pleistocene eolian deposits) (Figure 10-3), are underlain by similar surface soils (generally the organic Rindge series), and have a shallow water table, it is possible that the Bouldin Island compensatory mitigation area may be subject to liquefaction.

The potential for liquefaction at the I-5 ponds compensatory mitigation area has not been formally evaluated. However, the mitigation proposed at this mitigation area would involve only excavation and minor recontouring with no construction of levees or other similar earthworks or structures. Consequently, the mitigation construction activities would not increase the potential for liquefaction to occur and would not have any features that could be affected by liquefaction to the point that there would be no loss of property, personal injury, or death from earthquake-induced ground failure.

CMP project design would require that the new setback levee be designed and constructed according to applicable design standards and building codes. The detailed design would also conform to other standards and codes by applying accepted, proven construction engineering practices to reduce the risk that the facilities could fail or that there would be an increased hazard of loss of property, personal injury, or death of individuals as a result of liquefaction and related ground effects. Therefore, the project alternatives combined with compensatory mitigation implemented at Bouldin Island and the I-5 ponds would not change the overall impact conclusion of less than significant.

As described in Appendix 3F, compensatory mitigation would also involve construction of setback levees at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc. Earthquake-induced ground shaking could cause liquefaction of the levee foundations, potentially causing the levees to fail and result in an uncontrolled release of water and potentially flooding, loss of property, personal injury, or death. However, the project alternatives would be engineered consistent with applicable design standards and building codes. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

The other mitigation measures could involve construction of structures that would be affected by liquefaction to the point that there could be a loss of property, personal injury, or death from earthquake-induced ground failure, such as liquefaction. The hazard of loss of property, personal injury, or death from structural failure caused by earthquake-induced ground failure as a result of implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, remains low. However, any visual or noise barriers (which could include chain link fencing, a wood or concrete barrier, or other similar barrier a minimum of 6 feet high) would be constructed to be consistent with applicable design standards and building codes such that the overall impact after implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, would not change the impact conclusion of less than significant.

Impact GEO-4: Loss of Property, Personal Injury, or Death from Ground Settlement, Slope Instability, or Other Ground Failure

This impact discussion addresses the hazards of ground settlement associated with tunnel boring during and after boring; ground settlement caused by construction of project facilities at the surface; failure of cut slopes, fill slopes, embankments, stockpile slopes, and excavations (including those resulting from construction dewatering); and landsliding on natural slopes.

All Project Alternatives

Project Construction

For all project alternatives, field investigations prior to the start of construction would involve a variety of ground-disturbing activities. With the exception of the trenching that would be conducted to enable the West Tracy Fault investigation, none of these activities are likely to cause an increase in the hazard settlement or slope failure. The trenching would involve excavation of five 1,000-foot-long, 20-foot-deep test trenches along the suspected alignment of the West Tracy Fault. Additionally, at all conveyance facility sites, test trenches (approximately 30 feet long and 10 feet deep) would be excavated to characterize the near-surface soils. Where unstable soils are present, the trench walls could fail or collapse, threatening worker safety. DWR would conform to Cal/OSHA and other state code requirements, such as by implementing shoring, bracing, excavation depth restrictions, and required slope angles to protect worker safety. Shoring of trenches deeper than a 5-foot depth and emergency trench egress measures would ensure the safety of the workers during the investigation. The trenches would be immediately backfilled following observations of the soil conditions encountered in the trench. The impact would be less than significant.

Tunneling-Induced Ground Settlement. Both the central and eastern tunnel alignments would cross under levees, railroads, highways, and the East Bay Municipal Utility District Mokelumne Aqueducts. The top of the tunnel structure would cross under these surface features at depths of approximately 100 feet under the ground surface and in some areas approximately 80 feet under the ground surface (e.g., Bouldin Island for central alignment and near the Southern Forebay Outlet Structure). The tunnel and shafts would be excavated in saturated soft ground conditions. At the tunnel depth, the soils are expected to consist of clays, silts, silty and clayey sands, and clean sands, which are below the depth of the near-surface peat layers.

As tunnel boring proceeds, settlement of the soil above the tunnel could potentially occur as a result of uncontrollable ground loss. In extreme circumstances, the settlement effects could translate to the ground surface. Tunneling at a greater depth below ground level induces less ground surface settlement because a greater volume of soil material is available above the tunnel to fill any void space.

During tunnel boring, the main tunnels would be lined with precast, 18-inch-thick concrete segmental liners. This liner thickness is based on a tunnel inside diameter of 36 feet and experience with other tunnel projects having similar ground conditions. The voids between the liners and excavated soil would be continuously pressure-grouted simultaneous with the installation of new liner segments. The tunnel liner would provide support against static and dynamic external and internal pressures. External pressures would include TBM construction forces, earth weight, groundwater pressure, and earthquake loads.

The main tunnel would be constructed within the Alluvial Fans from Glaciated Basins geologic unit (Figure 10-3), not the Alluvium unit. The older Alluvial Fans from Glaciated Basins (Modesto and Riverbank formations) unit is older and partially cemented compared to the younger and less consolidated Alluvium unit. Therefore, the Alluvial Fans unit is much harder and stiffer than the recent, looser sediment that forms the Alluvium unit, which is more prone to settlement.

The Tunneling Effects Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022q:5, 11–18) describes the results of a preliminary analysis of tunneling-induced ground settlement. Based on the data previously collected within the potential main tunnel alignments and the anticipated depth of the tunnels for the California WaterFix project conceptual engineering report, it is expected the soil deposits around the tunnel would consist of clays, silts, silty and clayey sands, and clean sands. The tunnel alignment would not cross beneath nearby communities. For example, at a location along State Route 4 near Discovery Bay, which is the closest community to the alignment, the maximum ground settlement was computed to be 0.22 inch. This amount of settlement is not likely to result in any effects on Discovery Bay. The central alignment tunnel would pass under the Mokelumne Aqueducts. At that point, the aqueducts are located aboveground and rest on pipe saddles that are supported on piles. Two of the aqueduct piles at this location have a minimum tip elevation of approximately -50 feet NGVD. The third aqueduct is underground at this location as it approaches the Old River crossing. At the approximate central alignment tunnel crossing location, the invert of the third aqueduct is approximately at elevation -30 feet NGVD. The central alignment tunnel excavation crown (i.e., the top of the tunnel) near this point would be approximately at elevation -120 feet NGVD. This would result in approximately 70 feet of soil cover between the tunnel springline (i.e., the widest point of the tunnel, and generally, the mid-point of the tunnel diameter) and the bottom of the Mokelumne Aqueduct piles. The Tunneling Effects Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022q:12) determined that the maximum settlement beneath the tip (i.e., bottom) of the Mokelumne Aqueduct piles where the central alignment tunnel would pass under the Mokelumne Aqueducts would range from 0.18 to 0.43 inch, depending on the radius of the tunnel that is bored. Such settlement is not likely to result in substantial changes to the aqueducts.

At the point where the eastern alignment tunnel would cross under the Mokelumne Aqueducts, all three aqueducts are above the ground surface and sit on pipe saddles that are supported on piles. The piles at this location have a tip elevation of approximately -60 feet NGVD. The tunnel excavation crown at this location would be approximately at elevation -120 feet NGVD. This would result in approximately 60 feet of soil cover between the pile tips and the tunnel springline. The Tunneling Effects Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022q:15) determined that the maximum surface settlement where the eastern alignment tunnel would pass under the Mokelumne Aqueducts would range from 0.20 to 0.48 inch depending on the radius of the tunnel that is bored. Such settlement is not likely to result in substantial changes to the aqueducts.

Surface Structure-Related Ground Settlement. For all project alternatives, some of the project facilities would be constructed in areas where the surface soils and substrates are subject to settlement when the load, such as an embankment, levee, RTM stockpile, shaft pad, and bridge abutments, is applied to them.

Damage to certain conveyance facilities, such as pumping plants, control structures, and forebay embankments, caused by ground settlement under the facilities and consequent damage to or failure of the facility, could occur. Facility damage or failure could cause a release of water to the surrounding area, resulting in flooding, thereby endangering people and property in the vicinity.

Based on site-specific geotechnical investigations, feasible ground improvement measures would be designed for each facility site in which the soils are subject to excessive settlement, depending on the nature of the facility. Embankment foundation improvements would be implemented where needed (i.e., cutoff walls for seepage, or ground improvement for embankment stability). The ground improvement measures for a given facility may include various combinations of removal of peat soils, installation of vertical wick drains, and preloading of soils to promote soil consolidation prior to construction, installation of seepage cutoff walls, and in situ soil treatments for improving foundation strength, such as deep mechanical mixing or jet grouting approaches.

For the Southern Forebay, shaft pad fills, ring levees, and the intakes, design considerations to avoid excessive settlement would include flood management, soil stability and seismic considerations, embankment and foundation stability, and seepage cutoff wall placement. Embankment foundation improvements would be implemented where needed (i.e., cutoff walls for seepage, or ground improvement for embankment stability) because of potentially poorly consolidated or weak foundation soils. A 15-foot-wide access road and groundwater monitoring network would be installed along the perimeter of the outboard toe of the embankment (exterior slope). Ground improvement would be implemented under portions of the embankment to minimize risk of excessive settlement. Ground improvement would include excavation and replacement of at least 6 feet of the upper Southern Forebay embankment foundation and would be performed for the entire embankment perimeter. The excavation and replacement, and ground improvement if required, would create a consistent embankment foundation and remove variations in foundation soil characteristics. Deeper excavation and replacement could be performed, if practical, to remove unsuitable foundation materials, such as peat and highly organic mineral soils.

In addition to excavation and replacement of the upper foundation soils, three additional methods of ground improvement would be used at the Southern Forebay for improving foundation strength, including a deep mechanical mixing cutoff wall, surcharging, and wick drains.

Slope Failure. Slope failures, as discussed here, includes failure of cut slopes, fill slopes, embankments, stockpile slopes, and excavations.

Permanent embankments, such as those to construct the Southern Forebay, would be graded to stable slopes ranging from 3:1 (horizontal/vertical) to 6:1 (horizontal/vertical), depending on soil conditions.

Excavations into native soils for borrow material at the intakes and at the Southern Forebay could result in failure of the cut slopes, potentially causing injury of workers at the construction sites. Soil and sediment, especially those consisting of loose alluvium and soft peat or mud, particularly would be prone to failure and movement. Additionally, groundwater is expected to be within a few feet of the ground surface in some of these areas, which may make excavations more prone to failure.

Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. Based on the Dewatering Estimates for Intake Facilities and Southern Forebay Emergency Spillway (Final Draft) Technical Memorandum (Delta Conveyance Design and Construction Authority 2022r:1) and the EPR narrative reports for the central and eastern alignments and Bethany Reservoir alignment (Delta Conveyance Design and Construction Authority 2022a:12, 100, 102; 2022b:37, 66), dewatering is primarily anticipated to be conducted at the intakes, sedimentation basins, Bethany Reservoir Discharge Structure, and the Southern Forebay emergency spillway, with more site-specific dewatering conducted at the planned bridge replacements and at miscellaneous site improvement locations, such as for installation of underground utilities. Dewatering can stimulate soil settlement in excavations and could cause the slopes or sidewalls of the excavations to fail. However, dewatering typically would be performed in conjunction with subsurface isolation measures, such as cutoff walls and sheet piles that would be designed to withstand the external loads once the water is removed through dewatering. This also would reduce the amount of dewatering required to lower the groundwater table in the construction area and would decrease the local effects of dewatering outside of the cutoff walls.

Because of high groundwater levels, the tunnel shafts would be constructed in saturated soil conditions. Water at the bottom of the tunnel shafts would be pumped after a 5-foot-thick slurry wall and a 3-foot-thick shaft secondary lining are installed, which would resist external earth, seismic and hydrostatic pressures. The tunnel shaft would then be excavated, followed by placement of an approximate 30-foot-thick concrete base slab. Following installation of the concrete plug at the base of the tunnel shaft, the shaft would be dewatered. The interior shaft concrete lining would then be placed from the top of the base slab. The tunnel liner and the 30-foot-thick concrete base slab would resist uplift pressures from groundwater and separate the tunnel from the surrounding groundwater. This approach to constructing the shafts would avoid failure of the walls of the shaft.

New and repaired levees would have 2:1 (horizontal to vertical) or shallower interior (land side) slopes and have 3:1 (horizontal to vertical) or shallower exterior (water side) slopes.

Operations and Maintenance

The hazard of systematic settlement during operations and maintenance is similar to that described above under *Project Construction*.

The hazard of fill slope, embankment, and stockpile slopes during operations and maintenance would be similar to that as described above, under *Project Construction*.

With respect to tunnel flotation**,** the possibility of main tunnel flotation (buoyancy) exists when tunnels are constructed in areas with high groundwater (i.e., where a tunnel is bored at a depth where groundwater is present). Flotation could cause the tunnel to weaken and fail, causing release of water from the tunnel and erosion of the sediments surrounding the failure location (refer to Section 7.3.1.1, *Process and Method of Review for Impeding or Redirecting Localized Flood Flow,* in Chapter 7, *Flood Protection,* for additional discussion). The highest groundwater table along the alignment would be approximately 10 feet below ground surface. The buoyancy of the tunnel depends on the weight of water for the volume displaced and is resisted by the weight of the precast segmental lining and the weight of the ground above the tunnel. The flotation analysis described in the Conceptual Tunnel Lining Evaluation Technical Memorandum (Final Draft) (Delta Conveyance Design and Construction Authority 2022j:10, 11) was conducted using a conservative approach, in which the tunnel was assumed to be empty and not in use. A minimum ground cover of 98 feet over the tunnel was assumed; however, as constructed, the thickness of the ground cover would range from approximately 98 to 119 feet along the entire tunnel alignment. The analysis as conducted using project design capacity scenarios of 3,000 cubic feet per second (cfs). 4,500 cfs, 6,000 cfs, and 7,500 cfs and for all scenarios determined that there would be adequate forces from the ground cover above the tunnel to withstand flotation pressure, such that flotation would not occur.

With respect to landsliding of natural slopes, only one existing landslide has been mapped in the study area (Roberts et al. 1999:1). The area, less than 1 acre, is approximately 2,800 feet southeast of the Bethany Reservoir. The slide is in the area covered by the MTC/ABAG Hazard Viewer Map (Association of Bay Area Governments 2021), which covers only the Alameda and Contra Costa County parts of the project area. It rates the areas east and west of the Bethany Reservoir within the project area as being subject to “few landslides.” Consequently, because of the overwhelmingly shallow slopes in the project area and low hazard for landslides, the potential for construction activities to create a condition that could initiate a landslide on a natural or constructed slope during operations and maintenance is low.

CEQA Conclusion—All Project Alternatives

Ground settlement, slope instability, and other ground failure impacts during operation and maintenance would be similar to those that could occur during construction. Therefore, construction and operation and maintenance impacts are combined in the discussion below.

Many of the project construction sites would be located near existing levees, and both the central and eastern tunnel alignments would cross under levees, railroads, highways, and the East Bay Municipal Utility District Mokelumne Aqueducts. The top of the tunnel structure would cross under these surface features at depths of approximately 100 feet below under the ground surface, with some areas (e.g., Bouldin Island for central alignment and near the Southern Forebay Outlet Structure) approximately 80 feet below the ground surface. The nearest tunnel alignment (i.e., central alignment) to homes in Discovery Bay would be approximately 4,000 feet from the nearest home.

Ground settlement above the tunnel could result in loss of property or personal injury during construction. In extreme circumstances, large settlement above the tunnel, caused by voids and/or sinkholes above the tunnel during boring, could translate to the ground surface, potentially causing loss of property or personal injury above the tunnel construction area. Collapse of the tunnel during boring could also translate to the ground surface and result in a greater depth of ground surface settlement than large settlement. However, as described above, based on the results of the Tunneling Effects Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022q:14, 15) the amount of surface settlement above the main tunnel where it would pass near Discovery Bay and pass under the Mokelumne Aqueducts is expected be negligible to less than ½ inch and therefore the impact would be less than significant.

Excavation of borrow material could result in failure of oversteepened cut slopes, potentially causing injury of workers at the construction sites.

Soil excavations in areas with shallow or perched groundwater levels, such as the intake structure, sedimentation basins and drying lagoons at the intake facilities; Bethany Aqueduct tunnel shaft; Bethany Reservoir Discharge Structure; Southern Forebay emergency spillway and certain structures are the pumping plants would require construction dewatering. Dewatering could stimulate soil settlement in the excavations and could cause the slopes or sidewalls of the excavations to fail, endangering workers in the excavations themselves and workers at ground level near the edge of the excavation. The potential impact from ground settlement during tunnel construction; from excavation at borrow sites, cut slopes, and spoils and RTM storage sites; and from dewatering of excavations could be significant. Complying with applicable design standards and building codes would avoid a loss of property, personal injury, or death from slope instability or other ground failures, during both construction and operation and maintenance. A California-registered civil engineer or California-certified engineering geologist would recommend measures to address the hazards of slope instability and ground failure, such as specifying the type of TBM to be used in a given tunnel segment. The results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report, which would contain site-specific evaluations of the settlement hazard associated with the site-specific soil conditions overlying the tunnel throughout the alignment. During tunnel construction, DWR would evaluate and refine the tunneling equipment and drilling methods to account for sudden changes in ground conditions; these actions would be implemented to minimize or avoid settlement over the tunnel to minimize the likelihood of loss of property or personal injury from ground settlement above the tunnel during and after construction.

The new and repaired levees also would be constructed according to relevant design standards and specifications, and DWR would conform to Cal/OSHA, USACE, and other design requirements to protect worker safety at borrow sites, cut slopes and other excavations, and fill slopes and embankments (e.g., levees), both during construction and operation and maintenance.

As described in the Potential Future Field Investigations Technical Memorandum for the central and eastern alignments (Delta Conveyance Design and Construction Authority 2022e:24), equipment for monitoring movement and settlement during levee repairs and new levee construction would be installed during construction. Specifically, inclinometers and extensometers would be installed in vertical borings along levees at the intakes, Bouldin Island, Lower Roberts Island, and Byron Tract and along levees near bridge improvements along Hood-Franklin Road over Snodgrass Slough, State Route 12 over Little Potato Slough, the access road to Mandeville Island over Connection Slough, the access road to Lower Roberts Island over Burns Cut and Turner Cut; and the bridge across the California Aqueduct near Byron Highway. Inclinometers and extensometers are also planned at the Southern Complex and along the tunnel alignment and at tunnel shafts. The average installation depth is estimated to be 150 feet. Inclinometers are planned to be installed on 1,000-foot centers along areas of levee improvements. Additionally, tilt meters, settlement plates, and survey monuments would be installed at all construction sites and approximately every mile along the tunnel alignment. Periodic monitoring of this instrumentation would be conducted by security and on-site personnel.

As described in the Potential Future Field Investigations Technical Memorandum for the Bethany Reservoir alignment (Delta Conveyance Design and Construction Authority 2022p:24), inclinometers and extensometers would be installed in vertical borings along levees at the intakes, King Island, Lower Roberts Island, Upper Jones Tract, Victoria Island, Union Island, and Coney Island and along levees near bridge improvements along Hood-Franklin Road over Snodgrass Slough and the access road to Lower Roberts Island over Burns Cut and Turner Cut. Inclinometers and extensometers would also be installed at the Bethany Complex. The average installation depth is estimated to be 150 feet. Inclinometers are planned at 1,000-foot centers along areas of levee improvements. Additionally, tilt meters, settlement plates, and survey monuments would be installed at all construction sites and approximately every mile along the tunnel alignment. Periodic monitoring of this instrumentation would be conducted by security and on-site personnel.

The detailed design would also conform to other standards and codes by applying accepted, proven construction engineering practices to reduce the risk that the facilities could fail or that there would be an increased hazard of loss of property, personal injury, or death of individuals as a result of slope instability and ground failure. Consequently, the likelihood of a failure of a levee slope, whether as a result of earthquake ground shaking or other type of failure mechanism (e.g., construction of an oversteepened slope, excess loading of a foundation), is judged to be low because slope designs would conform to applicable design standards. The impact would be less than significant.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction, operations, and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation, and therefore, this discussion is included here.

As described in Appendix 3F, compensatory mitigation may involve construction of up to 5 miles of setback levees adjacent and connected to existing levees along the northern perimeter of Bouldin Island. Unless properly engineered, the levees could be subject to mass failure as a result of high soil pore water pressure, causing inundation of the area behind the levee. However, levee designs would need to conform to standards and codes by applying accepted, proven construction engineering practices to reduce the risk of loss of property, personal injury, or death of individuals as a result of slope instability. Design and construction of the levees would adhere to relevant design standards and specifications such that they would be constructed with slopes and would not be subject to mass failure. Therefore, the project alternatives combined with compensatory mitigation implemented at Bouldin Island and the I-5 ponds would not change the overall impact conclusion of less than significant with mitigation.

As described in Appendix 3F, compensatory mitigation would also involve construction of setback levees at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc. Unless properly engineered, the levees could be subject to mass failure as a result of high soil pore water pressure, causing inundation of the area behind the levee. However, levee designs would need to conform to standards and codes by applying accepted, proven construction engineering practices to reduce the risk of loss of property, personal injury, or death of individuals as a result of slope instability. Design and construction of the levees would adhere to relevant design standards and specifications such that they would be constructed with slopes and would not be subject to mass failure. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

The other mitigation measures could involve construction of structures or infrastructure that could be affected by ground settlement, slope instability, or other ground failure, such that there could be no increased likelihood of loss of property, personal injury, or death associated with these types of ground failures. However, any visual or noise barriers (which could include chain link fencing, a wood or concrete barrier, or other similar barrier a minimum of 6 feet high) would be constructed to be consistent with applicable design standards and building codes such that they would not be subject to mass failure. Therefore, the hazard of loss of property, personal injury, or death from structural failure caused by ground failure as a result of implementing compensatory mitigation and other mitigation measures, combined with project alternatives, remains low. The overall impact after implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, would remain less than significant.

Impact GEO-5: Loss of Property, Personal Injury, or Death from Structural Failure Resulting from Project-Related Ground Motions

All Project Alternatives

Project Construction

Pile Driving Effects. Impact pile driving during construction could cause vibrations that may 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 (i.e., horizontal soil movement), increased lateral soil pressure, and buoyancy within the zones of liquefaction. These consequences could cause personal injury or death and could damage nearby structures and levees. The lateral extent (i.e., influenced distance) of potential ground effects caused by pile driving depends on soil characteristics, groundwater conditions, the piling hammer used, frequency of pile driving, and the vibration tolerance of structures and levees.

The ground vibrations from impact pile driving during construction could also cause soil compaction and resultant ground settlement/failure, even in the absence of liquefaction. These effects on soil movements and ground elevation could cause personal injury or death and could damage nearby structures and levees.

Impact pile driving would be conducted only at the intakes and the modified bridges. At the intakes, sheet-pile walls are expected to be installed using both the vibratory approach (which would tend not to cause seismic motions) and impact driving. Because of the characteristics of the soils at these sites, it is anticipated that up to the last 10 feet of the sheet-pile installation would require impact driving. Because liquefaction caused by impact pile driving is rare and very localized, and because most of the piles would be installed using non-impact driving techniques, it is unlikely that pile driving-induced liquefaction would occur or cause any distress at ground surface related to pile driving-induced liquefaction.

If liquefaction due to pile driving is encountered, it is typically extremely restricted to a zone immediately surrounding the pile and can actually facilitate the pile driving, reducing the number of required pile strikes to advance to the pile tip depth. Increased soil pore water pressures due to pile driving dissipate quickly in liquefaction-prone soils, allowing a gain in soil strength and an increased resistance to future liquefaction. Evaluation of pile-driving-induced liquefaction would be completed at sites where seismic liquefaction potential was identified during final design activities and would be rechecked prior to construction using the characteristics of the specific hammer to be used by the contractor.

Heavy Equipment Effects. In addition to impact pile-driving activities, construction of the water conveyance facilities would involve use of heavy equipment (e.g., bulldozers, motor scrapers) and heavy trucks to load and transport RTM and topsoil to stockpiles and use locations. Gravel, aggregate base material, concrete, and asphalt would be imported to some construction sites from outside the project area.

Some construction sites and access roads where heavy equipment and trucks would be used have subsurface soil layers with potential for liquefaction. Although the heavy equipment and trucks could generate vibrations in levees, the severity of the vibrations would not be capable of initiating sufficient ground motion to cause soil liquefaction. However, the vibrations could cause soil compaction and resultant settlement in the absence of liquefaction. These effects on the soil and ground elevation could cause personal injury or death and could damage nearby structures and levees.

Some existing public roads would be used as haul routes for the construction of conveyance facilities. Use of the state highway system as haul routes would be used, where feasible, because these roadways are rated for truck traffic and would generally provide the most direct and easily maneuverable routes for large loads. Construction traffic may need to access levee roads at various points along state highways, as shown in Figure 10-7, as well as on access roads and levee access roads shown in Figure 10-8.

Except at the intakes, levee modifications, and bridges, all construction would be set back by at least 300 feet from existing levees to reduce the potential to affect the levees. Construction traffic would be prohibited from using levee roads except along State Routes 4 and 12 during construction and State Route 160 to repave the road areas moved during construction of the intakes. Field investigation results would be used to further analyze soil stability responses and develop appropriate construction methods to protect existing levees, utilities, structures, and adjacent lands.

Tunneling Effects. The Tunneling Effects Assessment Technical Memorandum (Delta Conveyance Design and Construction Authority 2022q:20, 21) describes the results of a preliminary analysis of TBM vibrations that can be expected to occur along the main tunnel alignments. The analysis of potential TBM vibrations was based on attenuation curves developed for a variety of types of construction equipment. Based on the current tunnel depth profiles, a minimum ground cover of 110 feet can be expected along the main tunnel alignment for the central and eastern alternatives. Based on this minimum ground cover, a peak particle velocity of 0.003 inch per second can be expected. Assuming that humans can detect vibrations equal to or greater than 0.01 inch per second, it appears unlikely there would be noticeable vibrations generated along the main tunnel alignment.

The technical memorandum states vibrations generated by TBM excavation are typically extremely low and rarely cause damage to surface structures.

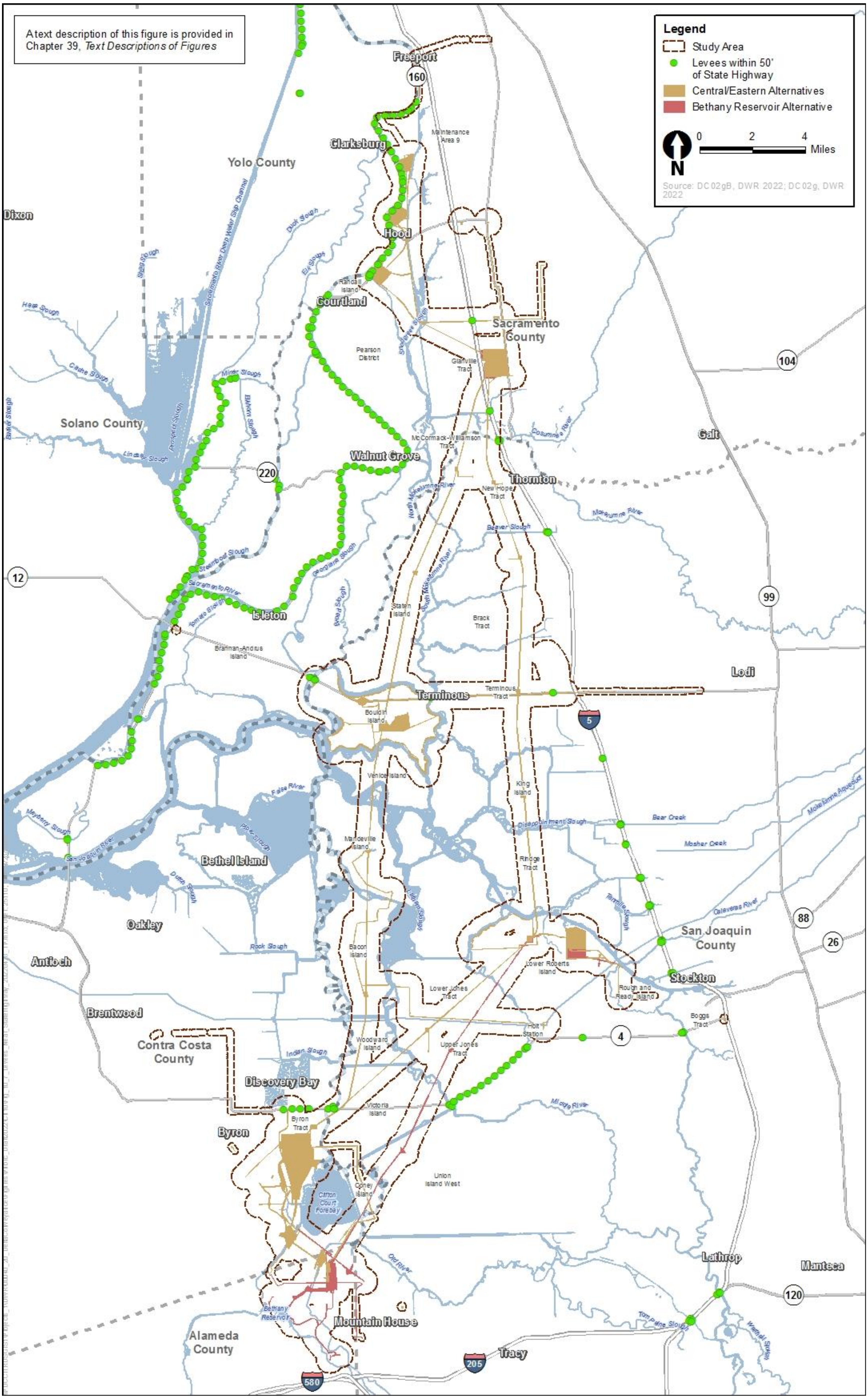
During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil-bearing capacity and extent of liquefiable soil. During final design, the facility-specific potential for construction-induced 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 (e.g., pile type, length, spacing, 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 minimize the potential for liquefaction caused by pile driving, heavy equipment operations, and heavy truck traffic, thereby protecting the safety of workers at the site and avoiding property damage.

Field investigations would involve conducting geotechnical investigations at the intakes, tunnel shafts, Southern Complex facilities, or Bethany Complex facilities, and along the tunnel alignment. The investigations would involve one or more of the following methods at a given facility site: fault trenching, soil borings, CPTs, groundwater well-installation testing and monitoring, geophysical surveys, utility potholing and test pile driving. The soil borings would be drilled to create a 4-inch to 8-inch-diameter hole from which soil samples would be recovered. The CPTs would involve hydraulically pressing a 1-inch to 2-inch-diameter cone-tipped rod into the ground. The groundwater test wells would involve installing a 12-inch-diameter steel casing within a 24-inch-diameter borehole to conduct pump tests. The groundwater monitoring wells are likely to entail installing a 4-inch-diameter groundwater monitoring well within the soil bore holes. A test pile driving program would be conducted only at the intakes. Based on DWR’s 30 years of well drilling and deep-soil investigations in the Delta, none of the investigations are likely to cause a ground vibration sufficiently strong to initiate liquefaction or ground settlement.

Operations and Maintenance

Impact pile driving would be conducted only during construction; therefore, there would be no hazard of pile driving-induced liquefaction or ground settlement during operations and maintenance.

Heavy equipment use at RTM stockpiles and heavy truck traffic on access roads and state highways could continue at times during operations and maintenance. The RTM stockpiles and access roads are in areas that may be subject to vibration-induced liquefaction. However, the strength of the vibrations caused by heavy equipment at construction sites and on haul routes would not be sufficient to initiate liquefaction and associated ground failures.



A text description of this figure is provided in Chapter 39, *Text Descriptions of Figures*

Figure 10-7. Levees Near State Highways

This page intentionally left blank

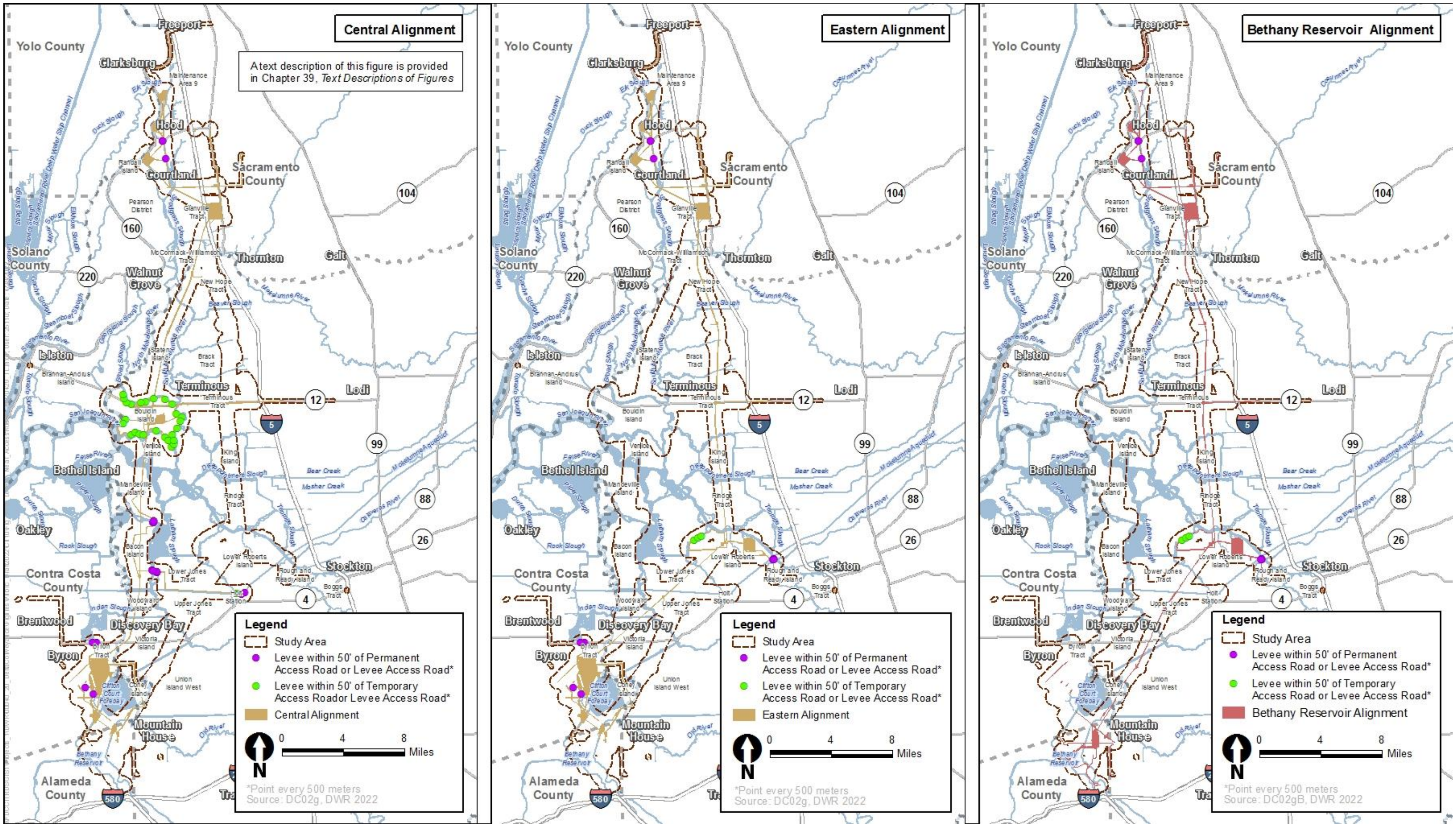


Figure 10-8. Levees Near Access Roads and Levee Access Roads

CEQA Conclusion—All Project Alternatives

Construction-related ground motions from impact pile driving could initiate liquefaction, which could cause failure of temporary works and structures during construction and result in injury of workers at the construction sites. However, impact pile driving at the intakes would be conducted approximately 200 or more feet from active levees, and nearby levees would be constructed by the project with ground improvement measures before pile driving. Such conditions would minimize potential impact pile driving-induced liquefaction or ground settlement effects on levees. Additionally, heavy equipment and truck traffic could result in soil compaction and resultant ground settlement without liquefaction occurring, which could cause failure of temporary works and structures during construction and result in injury of workers at the construction sites.

With very few exceptions, the conceptual project design avoids the use of existing levees as haul routes. Where levees are used for haul routes, potential effects on levees that could occur during the construction may include rutting, settlement, and slope movement. Heavy equipment could also cause ground vibrations during operations and maintenance. However, the strength of the vibrations caused by heavy equipment at construction sites and on haul routes would not be capable of initiating liquefaction. Conformance with applicable design standards and building codes would avoid a loss of property, personal injury, or death from project-related ground motions during both construction and operations and maintenance. The impact would be less than significant.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction, operations, and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation, and therefore, this discussion is included here.

Implementation of the compensatory mitigation on Bouldin Island and the I-5 ponds site would involve use of heavy grading equipment and possibly heavy truck traffic at the mitigation areas and possibly along nearby access roads. Similar to the conveyance facilities, the heavy equipment and truck traffic could be in areas that may be subject to liquefaction. Although the heavy equipment and trucks could generate vibrations in levees, the strength of the vibrations is not expected to be sufficient to initiate liquefaction and ground settlement. As with the project, compensatory mitigation would conform with applicable design standards and building codes. The project and compensatory mitigation would conform with applicable design standards, which would avoid a loss of property, personal injury, or death from project-related ground motions.

As described in Appendix 3F, compensatory mitigation would also involve construction of setback levees at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc. Unless properly engineered, the levees could be subject to similar ground vibrations and effects as described for the Bouldin Island and I-5 ponds sites. However, levee designs would need to conform to standards and codes by applying accepted, proven construction engineering practices to reduce the risk of loss of property, personal injury, or death of individuals as a result of slope instability. Design and construction of the levees would adhere to relevant design standards and specifications such that they would be constructed with slopes and would not be subject to vibration-induced liquefaction and ground settlement. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

Some of the other mitigation measures would involve the use of heavy equipment such as graders, excavators, dozers, and haul trucks that would have the potential to result in ground motions underlying existing structures. Similar to the conveyance facilities, the heavy equipment and truck traffic could be in areas that may be subject to liquefaction. Although the heavy equipment and trucks could generate vibrations, the strength of the vibrations is not expected to be sufficient to initiate liquefaction and ground settlement under existing structures. Therefore, the hazard of loss of property, personal injury, or death caused by project-related ground motions as a result of constructing the project alternatives and implementing the compensatory mitigation and the other mitigation measures, remains low. Therefore, the impact of loss of property, personal injury, or death from structural failure caused by ground failure as a result of vehicle and equipment vibrations during implementation of the compensatory mitigation and other mitigation measures, combined with project alternatives, would remain less than significant.

Impact GEO-6: Loss of Property, Personal Injury, or Death from Seiche or Tsunami

Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c

Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c, described in Chapter 3, *Description of the Alternatives*, have similar impact levels and are discussed together.

Project Construction

Project construction activities would not increase the potential for a seiche or tsunami to occur at the conveyance facilities under Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c. A seiche during construction of the Southern Forebay would be unlikely to occur since the forebay would not be filled until near project completion and following major construction activities. Once filled, the conceptual design of the Southern Forebay includes 10.5 feet of total freeboard between the Maximum Normal Operating Water Level and the perimeter embankment crest, which greatly reduces the potential for embankment overtopping. The potential for an earthquake-induced seiche to occur in the Southern Forebay would also be addressed through site-specific fault studies of fault offset to be completed as part of the field investigations. The freeboard requirements would be confirmed or modified following completion of additional site-specific geotechnical and seismic studies that would evaluate the potential for seiche and the resulting wave height and associated freeboard criteria to avoid overtopping.

Construction activities at the Southern Forebay generally would be several hundred feet from the Clifton Court Forebay embankments, which greatly reduces the potential for project construction activities to initiate a seiche in Clifton Court Forebay. The effects of project construction activities would be confirmed during design following completion of site-specific geotechnical studies.

The field investigations would involve conducting geotechnical investigations at the intakes, tunnel shafts, Southern Complex facilities, and along the tunnel alignment. The investigations would involve one or more of the following methods at a given facility site: fault trenching, soil borings, CPTs, groundwater well-installation testing and monitoring, geophysical surveys, utility potholing and test pile driving at the intakes. The soil borings would be accomplished by advancing an approximate 4-inch to 8-inch-diameter sampler using a drill bit; impact driving of the sampler would be used only if the drill bit does not penetrate smoothly though the soil column. The CPTs would involve hydraulically pushing a 1-inch to 2-inch-diameter cone-tipped rod into the ground. The groundwater test wells would involve installing 12-inch-diameter steel casing within a 24-inch-diameter borehole to conduct pump tests. The groundwater monitoring wells are likely to entail installing a 4-inch-diameter groundwater monitoring well within the soil bore holes.

The conceptual design of the Southern Forebay includes 10.5 feet of total freeboard between the Maximum Normal Operating Water Level and the perimeter embankment crest, which greatly reduces the potential for embankment overtopping. Although there are no known reports that well drilling on any of the Delta islands has triggered a seiche, the freeboard requirements for the Southern Forebay would be confirmed following completion of additional site-specific geotechnical and seismic studies to evaluate the potential for seiche and the resulting wave height.

The field investigations would not increase the hazard of a tsunami to occur in the area because the locations of the investigations are beyond the reach of tsunami waves.

Operations and Maintenance

Apart from the Southern Forebay, the potential for a substantial earthquake-induced seiche to occur at the conveyance facilities that could cause loss of property or personal injury is considered low because the seismic hazard and the geometry (e.g., width and depth) of the waterbodies (e.g., sedimentation basins, sediment drying lagoons, drying lagoon outlet structures) are not favorable for a seiche to occur.

However, Fugro Consultants (2011:14) identified the potential for 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. Because the Southern Forebay effectively would be a similar distance from the West Tracy Fault as the Clifton Court Forebay,[10] there is a potential for a seiche to occur in the Southern Forebay, assuming that the geometry of the Southern Forebay is conducive to the occurrence of a seiche. It is conceivable that a seiche could also occur in the Southern Forebay from seismic shaking generated along a more distant fault, such as a fault in the San Francisco Bay Area. If a seiche occurred in the Southern Forebay and the embankment was not properly designed, multiple seiche waves could overtop the embankment, erode it, and cause localized flooding.

The conceptual design of the Southern Forebay includes 10.5 feet of total freeboard between the Maximum Normal Operating Water Level and the perimeter embankment crest, which greatly reduces the potential for embankment overtopping. The potential for an earthquake-induced seiche to occur in the Southern Forebay would also be addressed through site-specific studies ground shaking in the vicinity. The freeboard requirements would be confirmed following completion of additional site-specific geotechnical and seismic studies evaluating the potential for seiche and the resulting wave height.

Seiches can also occur as a result of a movement of an underwater landslide within a waterbody or one generated upslope and entering a waterbody. The likelihood of a landslide-induced seiche occurring at the Southern Forebay is judged to be low because the forebay would have a level

---

[10] The West Tracy Fault crosses the southwestern part of the Clifton Court Forebay and would intersect the southern tip of the Southern Forebay.

bottom, the forebay embankments would have a stable 4:1 (horizontal/vertical) slope, and there would be no landslide-prone areas near the perimeter of the forebay.

At the other conveyance facilities consisting of some form of waterbody (e.g., sedimentation basins, sediment drying lagoons, drying lagoon outlet structures), the potential for a seiche to occur is judged to be low, either because the earthquake- or landslide-induced hazard is low, because the geometry of the waterbody (i.e., wide and shallow) is not favorable for a seiche to occur, or because of a combination of the two factors.

Based on the California Governor's Office of Emergency Services (2021) MyHazards website, the tsunami inundation hazard area nearest to the project area is on the north shore of the Sacramento River, extending approximately to 1 mile upstream (i.e., east) of the Benicia Bridge. 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. The low height of a tsunami wave in the vicinity of the Benicia Bridge, combined with the attenuating effect of the Suisun Bay and the northwestern part of the Delta, indicates that the potential hazard of loss of property or personal injury as a result of a tsunami on the water conveyance facilities is low.

For the Southern Forebay, the field investigations and design-level studies conducted by a California-licensed civil engineer or certified engineering geologist would consider the PGA caused by movement of the West Tracy Fault and regional faults along with the geometry of the forebay in determining the maximum probable seiche wave height that could be generated by ground shaking. The civil engineer or certified engineering geologist would recommend any design measures, such as increasing the freeboard to address any seiche hazard and conform to applicable design codes, guidelines, and standards, as described in Appendix 3B, *Environmental Commitments and Best Management Practices*. 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.

- DWR Division of Flood Management *FloodSAFE Urban Levee Design Criteria* (California Department of Water Resources 2012b)
- USACE Engineering Report 1110-2-1806, *Earthquake Design and Evaluation for Civil Works Projects* (U.S. Army Corps of Engineers 2016)

DWR would require that the geotechnical design recommendations be included in the design of project facilities and construction specifications to minimize the potential effects from any seismic events and consequent seiche waves. DWR would also require that the design specifications be properly executed during construction. Conformance with these codes and standards is an environmental commitment by DWR to require that any potential significant impacts of a seiche are reduced to an acceptable level while the forebay facility is operated.

The worker safety codes and standards specify protective measures that must be taken at workplaces 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 employers and these measures are subject to monitoring by state and local agencies. Cal/OSHA requires implementation of a workplace Injury and Illness Prevention Program, the terms of which would be used as the principal measures enforced at the facility sites to protect worker safety during operations and maintenance.

Conformance to these and other applicable design specifications and standards would require that the Southern 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 at the forebay during operation and maintenance of the water conveyance features.

Alternative 5

Project Construction

Project construction activities would not increase the potential for a seiche or tsunami to occur at the conveyance facilities under Alternative 5 because the ground vibrations generated by the activities would not be sufficient to generate seiche waves. Further, the construction activities would not increase the project area's exposure to a tsunami.

Field investigations would not increase the hazard of a seiche or tsunami to occur in the project area under Alternative 5 for the same reasons as described for Alternatives 1–4c.

Operations and Maintenance

The low likelihood for a seiche or tsunami to occur under Alternative 5 would be similar to that of Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c, except that Alternative 5 does not involve construction of a Southern Forebay. (The Bethany Reservoir surge basin is deemed to be too small [i.e., 815 by 815 feet] for a significant seiche wave to form during seismic ground shaking. Additionally, the surge basin would contain water only during an infrequent surge event from the pumping plant.) Therefore, Alternative 5 does not have any apparent potential for a seiche to occur at any of its facilities.

CEQA Conclusion—All Project Alternatives

As described above, the hazard of a substantial tsunami affecting the project area appears to be minor because of its distance from the Pacific Ocean and the attenuating effect of San Francisco and Suisun Bays.

None of the conveyance facilities proposed under Alternative 5 would be measurably affected by a seiche.

The Southern Complex components of Alternatives 1, 2a, 2b, 2c, 3, 4a, 4b, and 4c would be located near the Clifton Court Forebay, which may be subject to a seiche because of its proximity to sources of seismic shaking, including possibly the West Tracy Fault (Fugro Consultants 2011:14). A seiche in the Clifton Court Forebay could therefore affect the Southern Complex facilities as a result of water overtopping the Clifton Court Forebay embankment. Additionally, the Southern Forebay may be subject to a seiche because of its proximity to the same sources of seismic shaking. DCA has already designed the Southern Forebay to have sufficient freeboard to prevent wave-driven waves from overtopping the forebay embankment. During detailed design, DWR would assess whether there is a hazard of a seiche occurring in the forebay and would follow engineering requirements to require that the design allows for any coincident seiche wave height and wave-driven waves. This would ensure that the coincident waves do not exceed the embankment freeboard and overtop the embankment. A California-licensed geotechnical engineer would recommend any design measures to conform to applicable design codes, guidelines, and standards which would require that any seiche occurring in the Southern Forebay does not overtop the forebay embankment or otherwise risk the loss of property or personal injury from a seiche. The impact would be less than significant.

Mitigation Impacts

Compensatory Mitigation

Although the Compensatory Mitigation Plan described in Appendix 3F, *Compensatory Mitigation Plan for Special-Status Species and Aquatic Resources*, does not act as mitigation for impacts on this resource from project construction, operations, and maintenance, its implementation could result in impacts on this resource. CEQA requires analysis of the impacts of mitigation; therefore, this discussion is included here.

The compensatory mitigation would involve excavating areas to create open water channels and ponds. Because of their small size and geometry, these newly created channels are not likely to experience a seiche. Although the geometry of the I-5 ponds may be conducive to a seiche, they would be distant from sources of strong seismic shaking; therefore, they are unlikely to experience a significant seiche. Any seiche that would occur in the compensatory mitigation channels or ponds likely would not cause a loss of property, personal injury, or death. The compensatory mitigation would not increase the hazard of a tsunami to occur in the area and would be located beyond the influence of a tsunami. Therefore, the project alternatives combined with compensatory mitigation implemented at Bouldin Island and the I-5 ponds site would not change the overall impact conclusion of less than significant with mitigation.

As described in Appendix 3F, compensatory mitigation would also involve excavation and other earthwork at undetermined tidal wetland or channel margin restoration sites within the North Delta Arc, although none of the restored open water components of the mitigation are expected to be sufficiently large or have geometry conducive to the formation of seiche waves. Additionally, the undetermined tidal wetland or channel margin restoration sites would not be located in an area subject to a tsunami. Therefore, the project alternatives combined with compensatory mitigation would not change the overall impact conclusion of less than significant.

Other Mitigation Measures

None of the other mitigation measures would involve construction of waterbodies, and the mitigation measures would not increase the hazard of a seiche or tsunami to occur in the project area. The project area is located beyond the influence of a tsunami. Therefore, the hazard of loss of property, personal injury, or death project-related caused by a seiche or tsunami as a result of implementing the other mitigation measures, combined with project alternatives, remains low. The overall impact after implementing the compensatory mitigation and the other mitigation measures, combined with project alternatives, would not change the conclusion of less than significant.

10.3.4 Cumulative Analysis

The geographic scope of the analysis for geology and seismicity is the project area as defined in Chapter 1, *Introduction* (Figure 1-4). This geographic limit encompasses the footprints of all construction and conservation-related ground-disturbing activity associated with the project.

The geographic scope of the geology and seismicity cumulative analysis is centered on large-scale ground-disturbing projects in the Delta region. The analysis focuses on large projects and programs within the project area and the broader Delta region that involve substantial excavation, filling, or construction (e.g., levees). The principal programs and projects considered in the analysis are listed in Table 10-13. A full list of projects and greater detail about each project shown in the table is provided in Appendix 3C, *Defining Existing Conditions, No Project Alternative, and Cumulative Impact Conditions.*

Table 10-13. Cumulative Impacts on Geology and Seismicity from Plans, Policies, and Programs

Program/Project	Agency	Status	Description of Program/Project	Impacts on Geology and Seismicity
Delta Dredged Sediment Long-Term Management Strategy/Pinole Shoal Management Study	USACE	Ongoing	Maintaining and improving channel function, levee rehabilitation, and ecosystem restoration	No direct impact on increased risks at Delta Conveyance Project construction locations from earthquakes, ground shaking, liquefaction, slope instability, seiche, or tsunami.
Delta Dredged Sediment Long-Term Management Strategy	USACE	Ongoing	Maintaining and improving channel function, levee rehabilitation, and ecosystem restoration	No direct impact on increased risks at Delta Conveyance Project construction locations from earthquakes, ground shaking, liquefaction, slope instability, seiche, or tsunami.
2019 NMFS and USFWS BiOps	DWR	Ongoing	Restore 8,000 acres of tidal marsh	No direct impact on increased risks at Delta Conveyance Project construction locations from earthquakes, ground shaking, liquefaction, slope instability, seiche, or tsunami.
Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (EcoRestore project)	DWR	Planning phase	Construction of approximately 2.9 miles of new setback levee to restore and enhance approximately 3,164 acres of upland, tidal, and floodplain habitat	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Prospect Island Tidal Habitat Restoration Project (EcoRestore project)	DWR	Ongoing	Convert 1,253 acres of freshwater tidal marshes and associated aquatic habitat	No direct impact on increased risks at Delta Conveyance Project construction locations from earthquakes, ground shaking, liquefaction, slope instability, seiche, or tsunami.
Dutch Slough Tidal Marsh Restoration Project (EcoRestore project)	DWR	Planning phase	Wetland and upland habitat restoration in area used for agriculture	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Alameda Watershed HCP	Alameda County	Planning phase	Habitat restoration and implementation of best management and maintenance practices for conservation sites	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.

Program/Project	Agency	Status	Description of Program/Project	Impacts on Geology and Seismicity
Restoring Ecosystem Integrity in the Northwest Delta	CDFW	Completed	Management and restoration of up to 1,300 acres of perennial grassland/vernal pool complex in Solano County Island Corridor	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
CALFED Levee System Integrity Program	DWR, CDFW, USACE	Planning phase	Reuse of dredge material. Levee maintenance and levee improvement	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Delta Flood Protection Fund	DWR	Ongoing	Maintenance and rehabilitation of non-project levees in the Delta	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Mayberry Farms Subsidence Reversal and Carbon Sequestration Project	DWR	Completed (ongoing maintenance)	Wetland restoration and enhancement to reverse subsidence	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Sherman Island Setback Levee-Mayberry Slough	DWR	Completed	Construction of four sections of setback levees to increase levee stability	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Sherman Island – Whale’s Belly Wetlands	DWR	Ongoing	Wetland restoration and enhancement and levee construction to reverse subsidence provide 30,000 acres of habitat	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Twitchell Island - San Joaquin River Setback Levee	DWR	Planning phase	Levee stabilization and habitat restoration	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.

Program/Project	Agency	Status	Description of Program/Project	Impacts on Geology and Seismicity
Central Valley Joint Venture Program	Central Valley Joint Venture	Ongoing	Restoration of 19,170 acres of seasonal wetland, enhancement of 2,118 acres of seasonal wetland annually, restoration of 1,208 acres of semi-permanent wetland	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.
Lower Putah Creek Realignment	CDFW	Planning phase	Restoration of 300–700 acres of tidal freshwater wetlands and creation of 5 miles of a new fish channel	No direct impact on increased risks at Delta Conveyance Project construction locations from fault rupture, earthquake ground shaking, liquefaction, slope instability, seiche, or tsunami.

BiOps = Biological Opinions; CDFW = California Department of Fish and Wildlife; DWR = California Department of Water Resources; EIR = Environmental Impact Report; EIS = environmental impact statement; USACE= U.S. Army Corps of Engineers.

10.3.4.1 Cumulative Impacts of the No Project Alternative

The ongoing projects and programs under the No Project Alternative in addition to the cumulative projects would require ground disturbance, construction of facilities, and habitat restoration activities. These activities could result in construction or operational activities in areas with geologic and seismic hazard concerns such as fault rupture, earthquake ground shaking, and liquefaction. However, these types of projects are required to be designed to meet geotechnical design standards. Thus, impacts of ongoing projects and programs within and outside of the Delta under the No Project Alternative related to geologic and seismic hazards are not anticipated to result in loss, injury, or death from geologic hazards.

10.3.4.2 Cumulative Impacts of the Project Alternatives

This cumulative impact analysis considers projects that could be constrained or affected by geologic and seismic hazards and, where relevant, in the same time frame as the project alternatives, resulting in a cumulative impact. Other than rise in sea level, which could increase groundwater levels such that there could be a modest increase in liquefaction hazard, the geologic and seismic environment is not expected to change as a result of past, present, and reasonably foreseeable future projects because projects in and near the study area would not change the underlying geologic conditions or seismic hazards and are required to be designed to meet geotechnical design standards. The project alternatives contribution would not be cumulatively considerable, and this cumulative impact is less than significant.