Chapter 9
Geology and Seismicity

9.1 Affected Environment/Environmental Setting

9.1.1 Potential Environmental Effects Area

9.1.1.4 Geologic and Seismic Hazards

9.1.1.4.3 Liquefaction

Conditions Susceptible to Liquefaction

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

Liquefaction Hazard Mapping

No official Seismic Hazard Zone maps for liquefaction potential have been developed by CGS or the USGS for the soils of the entire ~~Delta~~Plan Area. Also, maps of liquefaction hazard (i.e., the susceptibility of the geologic or soil materials and ground water levels to liquefaction combined with shaking levels anticipated for a given earthquake scenario) have not been prepared for the entire Plan~~Delta a~~Area. However, the vulnerability of Delta and Suisun Marsh levees to failure caused by seismic shaking alone and by seismically-induced liquefaction was analyzed in two Delta Risk Management Strategy reports (California Department of Water Resources 2008a, b). These analyses recognized the following modes of seismically-induced levee failure: 1) water overtopping a levee as a result of levee crest slumping and settlement, 2) internal soil piping and erosion caused by earthquake-induced differential levee deformations, 3) sliding blocks and lateral spreading resulting in transverse cracking, and 4) exacerbation of existing seepage problems due to levee deformations and cracking.

The analyses grouped levees in the Delta and Suisun Marsh that are below the mean higher high water floodplain into 22 failure vulnerability classes based on results from standard penetration test blow count and cone penetration test blow count data, thickness of peat/organic soils underlying the levees, and the steepness of the waterside of the levee slope. The 22 vulnerability classes were then combined into three vulnerability groups: low, medium, and high, which are shown in Figure 9-6. The figure shows that many of the Delta levees are in the "high" vulnerability group and smaller proportions of Delta levee are in the "low" and "medium" vulnerability groups. All of the Suisun Marsh levees are in the "medium" vulnerability group.

~~a preliminary analysis of the risk of levee failure caused by liquefaction-induced seismic shaking was prepared for the CALFED Levee System Integrity Program (Torres et al. 2000). Torres et al. (2000) estimated the magnitude and recurrence intervals of peak ground accelerations throughout the Delta. Then, based on local knowledge and limited geotechnical information, they identified and mapped Damage Potential Zones (Figure 9-6). The Damage Potential Zones specifically are based on the "fragility" of existing levees as affected by seismically induced liquefaction considering levee characteristics, levee foundation soil characteristics, and seismic shaking factors. Consequently, the map should not be construed as a liquefaction hazard map. The map shows that the highest potential levee damage could occur in the central Delta and Sherman Island.~~

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

9.3 Environmental Consequences

9.3.3 Effects and Mitigation Approaches

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

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

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

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

Pile driving would be conducted at the intakes, where, based on boring logs, soil materials subject to liquefaction (e.g., saturated, poorly graded sand) are present. During project design, site-specific geotechnical and groundwater investigations would be conducted to build upon existing data (e.g., California Department of Water Resources 2010a, 2010b, 2011) to identify and characterize the vertical (depth) and horizontal (spatial) variability in soil bearing capacity and extent of liquefiable soil. Engineering soil parameters that could be used to assess the liquefaction potential, such as

(SPT) blow counts, (CPT) penetration tip pressure/resistance, and gradation of soil, would also be obtained. SPT blow counts and CPT tip pressure are used to estimate soil resistance to cyclic loadings by using empirical relationships that were developed based on occurrences of liquefaction (or lack of them) during past earthquakes. The resistance then can be compared to cyclic shear stress induced by the design earthquake (i.e., the earthquake that is expected to produce the strongest level of ground shaking at a site to which it is appropriate to design a structure to withstand). If soil resistance is less than induced stress, the potential of having liquefaction during the design earthquakes is high. It is also known that soil with high "fines" (i.e., silt- and clay-sized particles) content are less susceptible to liquefaction.

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

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

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

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

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

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

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

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

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

9.3.3.9 Alternative 4—Dual Conveyance with Modified Pipeline/Tunnel and Intakes 2, 3, and 5 (9,000 cfs; Operational Scenario H)

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

Earthquakes could be generated from local and regional seismic sources during construction of the Alternative 4 water conveyance facilities. Seismically induced ground shaking could cause injury of workers at the construction sites as a result of collapse of facilities.

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

Table 9-14 lists the expected PGA and 1.0-S_a values in 2020 at selected facility locations along the pipeline/tunnel alignment. These would also be applicable to the modified pipeline/tunnel alignment under Alternative 4. For the construction period, a ground motion return period of 72 years was assumed, corresponding to approximately 50% probability of being exceeded in 50 years. Values were estimated for a stiff soil site, as predicted by the seismic study (California Department of Water Resources 2007a), and for the anticipated soil conditions at the facility locations. No seismic study computational modeling was conducted for 2020, so the ground shaking that was computed for 2005 was used to represent the construction near-term period (i.e., 2020). Alternative 4 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and ~~two~~ five less pumping plants. These differences would present a slightly lower hazard of structural failure from seismic shaking but would not substantially change the hazard of loss of property, personal injury, or death during construction compared to Alternative 1A.

NEPA Effects: The seismic study employed time-dependent seismic source models for several major faults in the region. These models were characterized based on the elapsed times since the last major seismic events on the faults. Therefore, the exposure risks predicted by the seismic study would increase if no major events take place on these faults through 2020. The effect could be substantial because seismically-induced ground shaking could cause loss of property or personal injury at the Alternative 4 construction sites (including intake locations, pipelines from intakes to the intermediate forebay, the tunnels, the pumping plant, and the expanded Clifton Court Forebay) as a result of collapse of facilities. For example, facilities lying directly on or near active blind faults, such as the concrete batch plants and fuel stations near Twin Cities Road and Interstate 5 and at the expanded Clifton Court Forebay, as well as the expanded Forebay itself for Alternative 4 and may have an increased likelihood of loss of property or personal injury in the event of seismically-induced ground shaking. Although these blind thrusts are not expected to rupture to the ground surface under the forebays during earthquake events, they may produce ground or near-ground shear zones, bulging, or both (California Department of Water Resources 2007a). For a map of all permanent facilities and temporary work areas associated with this conveyance alignment, see Figure M3-4 in the Mapbook Volume.

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

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

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

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

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

Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce any potential risk such that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced ground shaking that is estimated to occur and the resultant ground motion anticipated at Alternative 4 construction sites, including the intake locations, the tunnels, the pipelines and the forebays, could cause collapse or other failure of project facilities while under construction. For example, facilities lying directly on or near active blind faults, such as the concrete batch plants and fuel stations near Twin Cities Road and Interstate 5 and at the expanded Clifton Court Forebay, as well as the expanded Forebay itself for Alternative 4, may have an increased likelihood of loss of property or personal injury at these sites in the event of seismically-induced ground shaking. However, DWR would conform ~~with~~ to Cal-OSHA and other state code requirements, such as shoring, bracing, lighting, excavation depth restrictions, required slope angles, and other measures, to protect worker safety. Conformance with these standards and codes is an environmental commitment of the project (see Appendix 3B, *Environmental Commitments*). Conformance with these health and safety requirements and the application of accepted, proven construction engineering practices would reduce this risk and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. This impact would be less than significant. No mitigation is required.

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

Settlement of excavations could occur as a result of dewatering at Alternative 4 construction sites with shallow groundwater. Soil excavation in areas with shallow or perched groundwater levels would require the pumping of groundwater from excavations to allow for construction of facilities. This can be anticipated at all intake locations (Sites 2, 3, and 5) and the pumping plant site~~s adjacent to the Sacramento River~~, where ~~70%~~much of the dewatering for Alternative 4 would take place. All of the intake locations and the~~adjacent~~ pumping plant~~s~~ for Alternative 4 are located on alluvial floodbasin deposits, alluvial floodplain deposits and natural levee deposits. Similar dewatering may be necessary where intake and forebay pipelines cross waterways and major irrigation canals east of the Sacramento River and north of the proposed intermediate forebay. Unlike the pipeline/tunnel alternatives, the conveyance tunnels constructed between the three intakes and the intermediate forebay would not be anticipated to require dewatering prior to construction and would not have any associated impact.

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

NEPA Effects: This potential effect could be substantial because settlement or collapse during dewatering could cause injury of workers at the construction sites as a result of collapse of excavations.

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from settlement or collapse caused by dewatering. Therefore, there would be no adverse effect.

CEQA Conclusion: Settlement or failure of excavations during construction could result in loss of property or personal injury. However, DWR would conform with Cal-OSHA and other state code requirements, such as using seepage cutoff walls, shoring, and other measures, to protect worker safety. DWR has made an environmental commitment to conform with appropriate codes and standards to minimize potential risks (Appendix 3B, *Environmental Commitments*). Additionally, DWR has made an environmental commitment~~would also ensure~~ that a geotechnical report be completed by a California-certified engineering geologist, that the report's geotechnical design recommendations be included in the design of project facilities, and that the report's design specifications are properly executed during construction to minimize the potential effects from settlement and failure of excavations. ~~design specifications are properly executed during construction.on.~~ Proper execution of these ~~DWR has made an~~ environmental commitments~~ to use the appropriate code and standard requirements~~ to minimize potential risks ~~(Appendix 3B, *Environmental Commitments*) and there~~ would result ~~be~~in no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

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

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

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

The geologic units in the area of the Alternative 4 modified pipeline/tunnel alignment are shown on Figure 9-3 and summarized in Table 9-26. The characteristics of each unit would affect the potential for settlement during tunneling operations. Segments 1 and 3, located in the Clarksburg area and the area west of Locke, respectively, contain higher amounts of sand than the other segments, so they pose a greater risk of settlement.

Table 9-26. Surficial Geology Underlying Alternative 4/~~-~~Modified Pipeline/Tunnel Alignment by Segments

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

Sources: Hansen et al. 2001 and Atwater 1982.

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

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

NEPA Effects: The potential effect could be substantial because ground settlement could occur during the tunneling operation. During detailed project design, a site-specific subsurface geotechnical evaluation would be conducted along the modified pipeline/tunnel alignment to verify or refine the findings of the preliminary geotechnical investigation. The tunneling equipment and drilling methods would be reevaluated and refined based on the results of the investigations, and field procedures for sudden changes in ground conditions would be implemented to minimize or avoid ground settlement. The primary exploration methods for these investigations include soil borings and CPTs (California Department of Water Resources 2014), which could potentially result in the settlement of dewatered sediments or liquefaction, respectively. However, these effects would be reduced with implementation of DWR's environmental commitments and Avoidance and Minimization Measures (Appendix 3B). A California-registered civil engineer or California-certified engineering geologist would recommend measures to address these hazards, such as specifying the type of tunnel boring machine to be used in a given segment. As required by DWR's environmental commitments ~~(Appendix 3B), T~~the results of the site-specific evaluation and the engineer's recommendations would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular *Guidelines for Evaluating and Mitigating Seismic Hazards in California* (California Geological Survey 2008).

As described in Section 9.3.1, *Methods for Analysis,* the measures would conform to applicable design and building codes, guidelines, and standards, such as USACE design measures. See Appendix 3B, *Environmental Commitments.*

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from ground settlement. Therefore, there would be no adverse effect.

CEQA Conclusion: Ground settlement above the tunneling operation could result in loss of property or personal injury during construction. However, DWR would conform with Cal-OSHA, USACE, and other design requirements to protect worker safety. DWR would also ensure that the design specifications are properly executed during construction. DWR would ensure that the geotechnical design recommendations are included in the design of project facilities and construction specifications and are properly executed during construction to minimize the potential effects from settlement. DWR has made this conformance and monitoring process an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*).~~DWR has made an environmental commitment to use the appropriate code and standard requirements to minimize potential risks (Appendix 3B, *Environmental Commitments*).~~ Hazards to workers and project structures would be controlled at safe levels and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

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

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

While specific borrow sources have not yet been secured near the Alternative 4 alignment, several potential locations within the project area have been identified based on geologic data presented through the DRMS study. Borrow site locations identified outside the project area were based on reviews of published geologic maps, specifically the California Geological Survey Map No. 1A Sacramento Quadrangle (1981) and Map No. 5A San Francisco-San Jose Qua~~n~~ddrangle (1991). Borrow areas for construction of intake facilities, ~~sedimentation basins, ~~pumping plant~~s~~, intermediate forebay~~s~~, and other supporting facilities would be sited near the locations of these structures (generally within 10 miles). Along the modified pipeline/tunnel alignment, selected areas would also be used for disposing of the byproduct (RTM) of tunneling operations. Table 9-27 describes the geology of these areas as mapped by Atwater (1982) (Figure 9-3).

Table 9-27. Geology Underlying Borrow and Reusable Tunnel Material Storage Areas—Alternative 4

Segment[a]	Geologic Unit	Geologic Unit Description
Segment 1 Borrow and/or Spoil Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
Onsite Borrow Areas	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
	Qfp	Floodplain deposits: dense, sandy to silty clay
	Qch	Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel~~.~~
Segment 2 Reusable Tunnel Material Area	Ql	Natural levee deposits: moderately to well-sorted sand, with some silt and clay
	Qb	Flood basin deposits: firm to stiff silty clay, clayey silt, and silt
	Qry	Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well-sorted sand, gravel, silt, and minor clay
Segment 3 Reusable Tunnel Material Area	~~Qb~~	~~Flood basin deposits: firm to stiff silty clay, clayey silt, and silt~~
	~~Qfp~~Qry	~~Floodplain deposits: dense sandy to silty clay~~Riverbank Formation: alluvial fans from glaciated basins that consist of moderately sorted to well-sorted sand, gravel, silt, and minor clay
Segment ~~4~~5 Reusable Tunnel Material Area	~~Qb~~	~~Flood basin deposits: firm to stiff silty clay, clayey silt, and silt~~
	~~Ql~~	~~Natural levee deposits: moderately to well-sorted sand, with some silt and clay~~
	Qpm	Delta mud: mud and peat with minor silt or sand
Segment 10~~7~~ Reusable Tunnel Material Area	Qymc	Alluvial fans and terraces from non-glaciated drainage basins: sand, silt and gravel
	~~Qfp~~	~~Floodplain deposits: dense sandy to silty clay~~
	~~Qch~~	~~Alluvial fans and terraces from non-glaciated drainage basins: clay, silt, sand, and gravel~~

Source: Hansen et al. 2001; Atwater 1982.

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

Some borrow areas and pre-cast tunnel segment plants would be in areas already proposed for disturbance and therefore are evaluated by this EIR/EIS; others would be at new locations outside the Plan Area. Areas outside of the Plan Area would likely occur at existing permitted facilities. Any ~~Such~~ new locations ~~that~~ would undergo additional technical and environmental review, including that for Geology and Seismicity impacts.

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

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

In addition to the risk of slope failure at borrow sites and spoils and RTM sites, there are also potential impacts on levee stability resulting from construction of Alternative 4 water conveyance facilities. The intake facilities would be sited along the existing Sacramento River levee system, requiring reconstruction of levees and construction of a perimeter levee/building pad to provide continued flood management. ~~At each intake pumping plant site, a new setback levee (ring levee) would be constructed. The space enclosed by the setback levee would be filled up to the elevation of the top of the setback levee, creating a building pad for the adjacent pumping plant.~~

As discussed in Chapter 3, *Description of the Alternatives*, the new perimeter levee~~s~~/building pad would be designed to provide an adequate Sacramento River channel cross section and to provide the same level of flood protection as the existing levee and would be constructed to geometries that ~~meet or~~ exceed PL 84-99 standards. ~~CALFED and DWR have adopted PL 84-99 as the preferred design standard for Delta levees. Transition levees would be constructed to connect the existing levees to the new setback levees. A typical new levee would have a broad-based, generally asymmetrical triangular cross section.~~ The design of the levee/building pad height would consider~~ed~~ potential wind and wave erosion. The ~~As measured from the adjacent ground surface on the landside vertically up to the~~ elevation of the levee/building pad crest~~,~~ would ~~range from approximately 20 to 45 feet to~~ provide adequate freeboard above anticipated water surface elevations. ~~The width of the levee (toe of levee to toe of levee) would range from approximately 180 to 360 feet. The minimum crest width of the levee would be 20 feet; however, in some places it would be larger to accommodate roadways and other features.~~ Depending on the foundation material at each intake facility, foundation improvements would entail excavation and replacement of soil below the new levee/building pad footprint and potential ground improvement. The levee/building pad height, as measured from the adjacent ground surface on the landside vertically up to the elevation of the berm crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the perimeter levee/berm (toe of berm to toe of berm) would range from approximately 180 to 360 feet. The minimum crest width of the berm would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. A c~~C~~ut-off wall~~s~~ would be constructed along the perimeter of the forebay part of the intake facility to avoid seepage, and the minimum slope of the levee walls/building pad would be three units horizontal to one unit vertical. All levee reconstruction/building pad construction w~~ill~~ould conform ~~with~~ to applicable state and federal flood management engineering and permitting requirements.

~~Depending on the foundation material at each intake facility, foundation improvements would requireentail excavation and replacement of soil below the new levee/building pad footprint and potential ground improvement. The levee/building pad height, as measured from the adjacent ground surface on the landside vertically up to the elevation of the berm crest, would range from approximately 20 to 45 feet to provide adequate freeboard above anticipated water surface elevations. The width of the perimeter levee/berm (toe of berm to toe of berm) would range from approximately 180 to 360 feet. The minimum crest width of the berm would be 20 feet; however, in some places it would be larger to accommodate roadways and other features. Cut-off walls would be~~

~~constructed to avoid seepage, and the minimum slope of levee walls would be three units horizontal to one unit vertical. All levee reconstruction will comply with applicable state and federal flood management engineering and permitting requirements.~~

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from slope failure at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures (geotextile fabrics, rock revetments, riprap, or other material), seepage reduction measures, and overall mass. Therefore, there would be no adverse effect.

CEQA Conclusion: Settlement/failure of cutslopes of borrow sites and failure of soil/RTM fill slopes could result in loss of property or personal injury during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable geotechnical design guidelines and standards, such as USACE design measures, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4 at borrow sites and spoils and RTM storage sites. The reconstruction of levees would improve levee stability over existing conditions due to improved side slopes, erosion countermeasures, seepage reduction measures, and overall mass. The impact would be less than significant. No mitigation is required.

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

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

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

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

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

During design, the facility-specific potential for liquefaction would be investigated by a geotechnical engineer. The investigations are an environmental commitment of the BDCP (Appendix 3B, *Environmental Commitments*). The potential effects of construction vibrations on nearby structures, levees, and utilities would be evaluated using specific piling information (such as pile type, length, spacing, and pile-driving hammer to be used). In areas determined to have a potential for liquefaction, the California-registered civil engineer or California-certified engineering geologist would develop design strategies and construction methods to ensure that pile driving and heavy equipment operations do not cause liquefaction which otherwise could damage facilities under construction and surrounding structures, and could~~do not~~ threaten the safety of workers at the site.

As shown in Figure 9-6, the ~~area south of the Sacramento River all the way across Woodward Island, which~~ Alternative 4 alignment extends through areas that generally have~~crosses through, has~~ a medium or high vulnerability for ~~medium to medium-high potential for~~ seismically-induced levee failure~~liquefaction damage~~, with a high risk of liquefaction at intakes 2 and 5 (California Department of Water Resources 2015). Figure 9-6 shows that four of ~~FourThree~~ the five barge unloading facilities would be ~~are~~ located ~~i~~on levees with a high vulnerability to seismically-induced failure; the fifth (the northernmost) has a low vulnerability~~this medium to medium-high potential for levee liquefaction damage area~~. Design measures to avoid pile-driving induced levee failure may include predrilling or jetting, using open-ended pipe piles to reduce the energy needed for pile penetration, using CIDH piles/piers that do not require driving, using pile jacking to press piles into the ground by means of a hydraulic system, or driving piles during the drier summer months. Field data collected during design also would be evaluated to determine the need for and extent of strengthening levees, embankments, and structures to reduce the effect of vibrations. These construction methods would conform with current seismic design codes and requirements, as described in Appendix 3B, *Environmental Commitments*. Such design standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute.

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

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

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

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

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

Conformance to construction method recommendations and other applicable specifications would ensure that construction of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals due to construction-related ground motion and resulting potential liquefaction in the work area. Therefore, there would be no adverse effect.

CEQA Conclusion: Construction-related ground motions could initiate liquefaction, which could cause failure of structures during construction. However, because DWR would conform with Cal-OSHA and other state code requirements and conform to applicable design guidelines and standards, such as USACE design measures, the hazard would be controlled to a level that would protect worker safety (see Appendix 3B, *Environmental Commitments*). Further, DWR has made an environmental commitment (see Appendix 3B, *Environmental Commitments*) that the construction methods recommended by the geotechnical engineer are included in the design of project facilities and construction specifications to minimize the potential for construction-induced liquefaction. DWR also has committed to ensure that these methods are followed during construction. Proper execution of these environmental commitments would result in ~~and there would be~~ no increased likelihood of loss of property, personal injury or death due to construction of Alternative 4. The impact would be less than significant. No mitigation is required.

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

According to the available AP Fault Zone Maps, none of the Alternative 4 facilities would cross or be within any known active fault zones. However, numerous AP fault zones have been mapped west of the conveyance alignment (Figure 9-5). The closest AP fault zone would be the Greenville fault, located approximately 7.6 miles west of the conveyance facilities. Because none of the Alternative 4 constructed facilities would be within any of the fault zones (which include the area approximately 200 to 500 feet on each side of the mapped surface trace to account for potential branches of active faults), the potential that the facilities would be directly subject to fault offsets is negligible.

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

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

NEPA Effects: The effect would not be adverse because no active faults extend into the Alternative 4 alignment. Additionally, although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 4 alignment, they do not present a hazard of surface rupture based on available information, including the AP Earthquake Fault Zone Map showing faults capable of surface rupture (Figure 9-5).

However, because there is limited information regarding the depths of the Thornton Arch and West Tracy blind thrusts, seismic surveys would be performed on the blind thrust during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. Consistent with the BDCP's environmental commitments (see Appendix 3B, *Environmental Commitments*), DWR would ensure that ~~T~~the geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards, would be included in the project design and construction specifications, and would be properly executed during construction. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

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

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone and West Tracy~~,~~ blind thrust. Therefore, such ground movements would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 4 conveyance alignment or the proposed expanded Clifton Court Forebay and associated facilities adjacent to the existing Clifton Court Forebay. Therefore, there would be no adverse effect.

CEQA Conclusion: There are no active faults capable of surface rupture that extend into the Alternative 4 modified pipeline/tunnel alignment. Although the Thornton Arch and West Tracy blind thrusts occur beneath the Alternative 4 modified pipeline/tunnel alignment, based on available information, they do not present a hazard of surface rupture and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. However, because there is limited information regarding the depths of the Thornton Arch and West Tracy blind thrusts, seismic surveys would be performed on the blind thrust during the design phase to determine the depths to the top of the faults. More broadly, design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would further assess site-specific conditions at and near all the project facility locations, including seismic activity, soil liquefaction, and other potential geologic and soil-related hazards. This information would be used to verify assumptions and conclusions included in the EIR/EIS. Consistent with the BDCP's environmental commitments (see Appendix 3B, *Environmental Commitments*), DWR would ensure that the geotechnical engineer's recommended measures to address adverse conditions would conform to applicable design codes, guidelines, and standards, would be included in the project design and construction specifications, and would be properly executed during construction. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements), and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

As described in Section 9.3.1, Methods for Analysis, such conformance with design codes, guidelines, and standards are environmental commitments by DWR (see Appendix 3B, *Environmental Commitments*). For construction of the water conveyance facilities, the codes and standards would include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters, DWR's Division of Flood Management FloodSAFE Urban Levee Design Criteria, and USACE's Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects. These codes and standards include minimum performance standards for structural design, given site-specific subsurface conditions. Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals in the event of ground movement in the vicinity of the Thornton Arch fault zone and West Tracy blind thrust. Therefore, such ground movements would not jeopardize the integrity of the surface and subsurface facilities along the Alternative 4 conveyance alignment or the proposed expanded Clifton Court Forebay and associated facilities adjacent to the existing Clifton Court Forebay. There would be no impact. No mitigation is required.

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

Earthquake events may occur on the local and regional seismic sources during operation of the Alternative 4 water conveyance facilities. The ground shaking could damage pipelines, tunnels, intake facilities, pumping plants, and other facilities disrupting the water supply through the conveyance system. In an extreme event of strong seismic shaking, uncontrolled release of water from damaged pipelines, tunnels, intake facilities, pumping plant~~s~~, and other facilities could cause flooding, disruption of water supplies to the south, and inundation of structures. These effects are discussed more fully in Appendix 3E, *Potential Seismicity and Climate Change Risks to SWP/CVP Water Supplies*.

Table 9-17 lists the expected PGA and 1.0-S_a values in 2025 at selected facility locations along the pipeline/tunnel alignment. Alternative 4 would include the same physical/structural components as Alternative 1A, but would entail two less intakes and ~~two~~ five less pumping plants. These differences would present a slightly lower hazard of seismic shaking but would not substantially change the hazard of loss of property or personal injury during construction compared to Alternative 1A.

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

Table 9-17 shows that the proposed facilities would be subject to moderate-to-high earthquake ground shaking through 2025. All facilities would be designed and constructed in accordance with the requirements of the design guidelines and building codes described in Appendix 3B. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize damage potential.

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

The structure of the underground conveyance facility would decrease the likelihood of loss of property or personal injury of individuals from structural shaking of surface and subsurface facilities along the Alternative 4 conveyance alignment in the event of strong seismic shaking. The conveyance pipeline will be lined with precast concrete which will be installed continuously following the advancement of a pressurized tunnel boring machine. The lining consists of precast concrete segments inter-connected to maintain alignment and structural stability during construction. Reinforced concrete segments are precast to comply with strict quality control. High performance gasket maintains water tightness at the concrete joints, while allowing the joint to rotate and accommodate movements during intense ground shaking. PCTL has been used extensively in seismically active locations such as Japan, Puerto Rico, Taiwan, Turkey, Italy and Greece. The adoption of PCTL in the United States started about 20 years ago, including many installations in seismically active areas such as Los Angeles, San Diego, Portland and Seattle. PCTL provides better seismic performance than conventional tunnels for several reasons:

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

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

In accordance with the DWR's environmental commitments (see Appendix 3B, *Environmental Commitments*), ~~D~~design-level geotechnical studies would be conducted by a licensed civil engineer who practices in geotechnical engineering. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the conveyance features to withstand the peak ground acceleration caused by fault movement in the region. The California-registered civil engineer or California-certified engineering geologist's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards are an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated.

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that operation of Alternative 4 would not create an increased likelihood of loss of property, personal injury or death of individuals from structural shaking of surface and subsurface facilities along the Alternative 4 conveyance alignment in the event of strong seismic shaking. Therefore, there would be no adverse effect.

CEQA Conclusion: Seismically induced strong ground shaking could damage pipelines, tunnels, intake facilities, pumping plant~~s~~, and other facilities. The damage could disrupt the water supply through the conveyance system. In an extreme event, an uncontrolled release of water from the damaged conveyance system could cause flooding and inundation of structures. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, which would be supported by geotechnical investigations required by DWR's environmental commitments (see Appendix 3B, *Environmental Commitments*), measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters,* DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure that ground shaking risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

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

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

The native soil underlying Alternative 4 facilities consist of various channel deposits and recent silty and sandy alluvium at shallow depths. The available data along the southern portion of the conveyance (from approximately Potato Slough to Clifton Court Forebay) show that the recent alluvium overlies peaty or organic soils, which in turn is underlain by layers of mostly sandy and silty soil (Real and Knudsen 2009). Soil borings advanced by DWR along the northern portion of the conveyance (from approximately Potato Slough to Intake 1) show the surface soil as being similar to the range reported for the southern portion, but locally containing strata of clayey silt and lean clay. Because the borings were made over water, peat was usually absent from the boring logs (California Department of Water Resources 2011).

The silty and sandy soil deposits underlying the peaty and organic soil over parts of the Delta are late-Pleistocene age dune sand, which are liquefiable during major earthquakes. The tops of these materials are exposed in some areas, but generally lie beneath the peaty soil at depths of about 10–

40 feet bgs along the modified pipeline/tunnel alignment (Real and Knudsen 2009). Liquefaction hazard mapping by Real and Knudsen (2009), which covers only the southwestern part of the Plan Area, including the part of the alignment from near Isleton to the Palm Tract, indicates that the lateral ground deformation potential would range from <0.1 to 6.0 feet. Liquefaction-induced ground settlement during the 1906 San Francisco earthquake was also reported near Alternative 4 facilities at a bridge crossing over Middle River just north of Woodward Island (Youd and Hoose 1978). Local variations in thickness and lateral extent of liquefiable soil may exist, and they may have important influence on liquefaction-induced ground deformations.

Figure 9-6 shows that the northern part of the Alternative 4 alignment is outside the area (i.e., outside the mean higher high water floodplain) within which levees were evaluated by DWR (California Department of Water Resources 2008b) for their vulnerability to seismically-induced levee failure. The remainder of the alignment, extending south from approximately Courtland, extends through areas in which the levees generally have a high or medium vulnerability to seismically-induced failure~~has no substantial levee damage potential from liquefaction in its extreme northern part and low to medium-high levee damage potential throughout the remainder~~.

Because the tunnel invert would be at depths of 100–160 feet bgs, the potential effect on these facilities due to liquefaction is judged to be low. However, ~~the~~ certain surface and near-surface facilities, such as the pumping plant and Clifton Court forebay expansion area,~~ that~~ would be constructed in areas with medium or high vulnerability to failure from seismic shaking, as inferred from the levee seismic vulnerability map (Figure 9-6)~~at the access road, intake, pumping plant, and forebay areas would likely be founded on liquefiable soil~~.

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

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

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

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that the hazard of liquefaction and associated ground movements would not create an increased likelihood of loss of property, personal injury or death of individuals from structural failure resulting from seismic-related ground failure along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion: Seismically induced ground shaking could cause liquefaction. Liquefaction could damage pipelines, tunnels, intake facilities, pumping plant~~s~~, and other facilities, and thereby disrupt the water supply through the conveyance system. In an extreme event, flooding and inundation of structures could result from an uncontrolled release of water from the damaged conveyance system. (Please refer to Chapter 6, *Surface Water*, for a detailed discussion of potential flood impacts.) However, through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by DWR to ensure that liquefaction risks are minimized as the water conveyance features are operated. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

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

Alternative 4 would involve excavation that creates new cut-and-fill slopes and construction of new embankments and levees. As a result of ground shaking and high soil-water content during heavy rainfall, existing and new slopes that are not properly engineered and natural stream banks could fail and cause damage to facilities. Levees can fail for several reasons: 1) high velocities of water flow can result in high rates of erosion and erode and overtop a levee; 2) the higher velocities of water flow can also lead to higher rates of erosion along the inner parts of levees and lead to undercutting and clumping of the levee into the river. Heavy rainfall or seepage into the levee from the river can increase fluid pressure in the levee and lead to slumping on the outer parts of the levee. If the slumps grow to the top of the levee, large sections of the levee may slump onto the floodplain and lower the elevation of the top of the levee, leading to overtopping; 3) increasing levels of water in the river will cause the water table in the levee to rise which will increase fluid pressure and may result in seepage and eventually lead to internal erosion called piping. Piping will erode the material under the levee, undermining it and causing its collapse and failure.

With the exception of levee slopes and natural stream banks, the topography along the Alternative 4 conveyance alignment is nearly level to very gently sloping. The areas that may be susceptible to slope failure are along existing levee slopes, and at intakes, pumping plant~~s~~, forebay, and certain access road locations. Outside these areas, the land is nearly level and consequently has a negligible potential for slope failure. Based on review of topographic maps and a landslide map of Alameda County (Roberts et al. 1999), the conveyance facilities would not be constructed on, nor would it be adjacent to, slopes that are subject to mudflows/debris flows from natural slopes.

NEPA Effects: The potential effect could be substantial because levee slopes and stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures built on these slopes could be damaged or fail entirely as a result of slope instability. As discussed in Impact SW-2 in Chapter 6, Surface Water, operation of the water conveyance features under Alternative 4 would not result in an increase in potential risk for flood management compared to existing conditions. Peak monthly flows under Alternative 4 in the locations considered were similar to or less than those that would occur under existing conditions. Since flows would not be substantially greater, the potential for increased rates of erosion or seepage are low. For additional discussion on the possible exposure of people or structures to impacts from flooding due to levee failure, please refer to Impact SW-6 in Chapter 6, *Surface Water*.

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

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

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

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

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

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

Conformance to the above and other applicable design specifications and standards would ensure that the hazard of slope instability would not create an increased likelihood of loss of property, personal injury of individuals along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

***CEQA Conclusion*:** Unstable levee slopes and natural stream banks may fail, either from high pore-water pressure caused by high rainfall and weak soil, or from seismic shaking. Structures constructed on these slopes could be damaged or fail entirely as a result of slope instability.

However, during~~through~~ the final project ~~design process~~design process, as required by DWR's environmental commitments (see Appendix 3B, *Environmental Commitments*), a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions during facility operations. The design criteria would be documented in a detailed geotechnical report prepared in accordance with state guidelines, in particular Guidelines for Evaluating and Mitigating Seismic Hazards in California (California Geological Survey 2008).

DWR would also ensure that measures to address this hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the California Building Code and resource agency and professional engineering specifications, such as USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these codes and standards is an environmental commitment by DWR to ensure cut and fill slopes and embankments will be stable as the water conveyance features are operated and there would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4. The impact would be less than significant. No mitigation is required.

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

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

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

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

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

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

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

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

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

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

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

Conformance to these and other applicable design specifications and standards would ensure that the embankment for the expanded portion of the Clifton Court Forebay would be designed and constructed to contain and withstand the anticipated maximum seiche wave height and would not create an increased likelihood of loss of property, personal injury or death of individuals along the Alternative 4 conveyance alignment during operation of the water conveyance features. Therefore, the effect would not be adverse.

CEQA Conclusion: Based on recorded tsunami wave heights at the Golden Gate (Contra Costa Transportation Agency 2009) and in the interior of the San Francisco Bay and on tsunami inundation maps prepared by the California Department of Conservation (2009), the height of a tsunami wave reaching the Suisun Marsh and the Delta would be small because of the distance from the ocean and attenuating effect of the San Francisco Bay. Similarly, the potential for a significant seiche to occur in most parts of the Plan Area is considered low because the seismic hazard and the geometry of the water bodies (i.e., wide and shallow) near conveyance facilities are not favorable for a seiche to occur. However, assuming the West Tracy fault is potentially active, a potential exists for a seiche to occur in the expanded Clifton Court Forebay (Fugro Consultants 2011).

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

The effect would not be adverse because the expanded Clifton Court Forebay embankment would be designed and constructed according to applicable design codes, guidelines, and standards to contain and withstand the anticipated maximum seiche wave height, as required by DWR's environmental commitments (see Appendix 3B, *Environmental Commitments*). There would be no increased likelihood of loss of property, personal injury or death due to operation of Alternative 4 from seiche or tsunami. The impact would be less than significant. No additional mitigation is required.

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

NEPA Effects: Alternative 4 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no effect caused by canal seepage. There would be no adverse effect.

***CEQA Conclusion*:** Alternative 4 would not involve construction of unlined canals; therefore, there would be no increase in groundwater surface elevations and consequently no impact caused by canal seepage. The impact would be less than significant. No mitigation is required.

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

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

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

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

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

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

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

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

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

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

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

CEQA Conclusion: Rupture of the Cordelia and Green Valley faults could occur at the Suisun Marsh ROA and damage ROA facilities, such as levees and berms. Damage to these features could result in their failure, causing flooding of otherwise protected areas.

However, through the final design process for conservation measures in the ROAs and because ~~,~~there is limited information regarding the depths of the blind faults mentioned above, seismic surveys would be performed in the vicinity of the faults as part of final designs. These surveys would be used to verify fault depths where levees and other features would be constructed. Collection of this depth information would be part of broader, design-level geotechnical studies conducted by a geotechnical engineer licensed in the state of California to support all aspects of site-specific project design. The studies would assess site-specific conditions at and near all the project facility locations, including the nature and engineering properties of all soils and underlying geologic strata, and groundwater conditions. The geotechnical engineer's information would be used to develop final engineering solutions and project designs to any hazardous condition, consistent with DWR's environmental commitments (see Appendix 3B, *Environmental Commitments*).

Additionally, measures to address the fault rupture hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include the Division of Safety of Dams *Guidelines for Use of the Consequence Hazard Matrix and Selection of Ground Motion Parameters*, DWR's Division of Flood Management *FloodSAFE Urban Levee Design Criteria*, and USACE's *Engineering and Design—Earthquake Design and Evaluation for Civil Works Projects*. Conformance with these design codes, guidelines, and standards is an environmental commitment by the BDCP proponents to ensure that fault rupture risks are minimized as the conservation measures are implemented. The hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

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

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

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

NEPA Effects: All temporary facilities would be designed and built to meet the safety and collapse-prevention requirements for the above-anticipated seismic loads. Therefore, this effect is considered not adverse. No additional mitigation measures are required. All facilities would be designed and constructed in accordance with the requirements of the design measures described in Chapter 3, *Description of the Alternatives*. Site-specific geotechnical information would be used to further assess the effects of local soil on the OBE and MDE ground shaking and to develop design criteria that minimize the potential of damage. Design-level geotechnical studies would be prepared by a geotechnical engineer licensed in the state of California during project design. The studies would assess site-specific conditions at and near all the project facility locations and provide the basis for designing the levees and other features to withstand the peak ground acceleration caused by fault movement in the region. The geotechnical engineer's recommended measures to address this hazard would conform to applicable design codes, guidelines, and standards. Potential design strategies or conditions could include avoidance (deliberately positioning structures and lifelines to avoid crossing identified shear rupture zones), geotechnical engineering (using the inherent capability of unconsolidated geomaterials to "locally absorb" and distribute distinct bedrock fault movements) and structural engineering (engineering the facility to undergo some limited amount of ground deformation without collapse or significant damage).

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

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

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

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

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

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

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

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

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

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

The ROAs vary with respect to their liquefaction hazard (Figure 9-6). All of the levees in t~~T~~he Suisun Marsh ROA ~~generally~~ haves~~s~~ a ~~moderate or high~~medium vulnerability to failure from seismic shaking and resultant liquefaction~~ hazard~~. The liquefaction ~~damage potential~~vulnerability among the other ROAs in which seismically-induced levee failure vulnerability has been assessed (Figure 9-6) (i.e., in parts or all the Cache Slough Complex and South Delta ROAs) is medium or high~~, as well as where setback levees would be constructed along the Old, Middle, and San Joaquin Rivers under CM5 and CM6, is generally low to medium~~.

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

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

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

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

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

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

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

As required by the environmental commitments (see Appendix 3B, *Environmental Commitments*), the BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during implementation and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. This effect would not be adverse.

CEQA Conclusion: Earthquake-induced ground shaking could cause liquefaction, resulting in damage to or failure of levees, berms, and other features constructed at the restoration areas. Failure of levees and other structures could result in flooding of otherwise protected areas. As required by the environmental commitments (see Appendix 3B, *Environmental Commitments*), site-specific geotechnical and groundwater investigations would be conducted to identify and characterize the vertical (depth) and horizontal (spatial) extent of liquefiable soil. The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of levees and construction specifications to minimize the potential effects from liquefaction and associated hazard. The BDCP proponents would also ensure that the design specifications are properly executed during implementation and would not create an increased likelihood of loss of property, personal injury or death of individuals in the ROAs. Further,~~However,~~ through the final design process, measures to address the liquefaction hazard would be required to conform to applicable design codes, guidelines, and standards. As described in Section 9.3.1, *Methods for Analysis*, and in Appendix 3B, *Environmental Commitments*, such design codes, guidelines, and standards include USACE's *Engineering and Design—Stability Analysis of Concrete Structures* and *Soil Liquefaction during Earthquakes,* by the Earthquake Engineering Research Institute. Conformance with these design standards is an environmental commitment by the BDCP proponents to ensure that liquefaction risks are minimized as the water conservation features are implemented and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. No mitigation is required.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

CEQA Conclusion: Unstable new and existing levee and embankment slopes could fail as a result of seismic shaking and as a result of high soil-water content during heavy rainfall and cause flooding of otherwise protected areas. However, during project design and as required by the BDCP proponents' environmental commitments (see Appendix 3B, *Environmental Commitments*), a geotechnical engineer would develop slope stability design criteria (such as minimum slope safety factors and allowable slope deformation and settlement) for the various anticipated loading conditions. The BDCP proponents would ensure that the geotechnical design recommendations are included in the design of embankments and levees to minimize the potential effects from slope failure. The BDCP proponents would also ensure that the design specifications are properly executed during implementation.

Additionally, ~~because~~ as required by the BDCP proponents' environmental commitments (see Appendix 3B, *Environmental Commitments*), site-specific geotechnical and hydrological information would be used to~~would~~ ensure conformance with applicable design guidelines and standards, such as USACE design measures.~~,~~ Through implementation of these environmental commitments, the hazard would be controlled to a safe level and there would be no increased likelihood of loss of property, personal injury or death in the ROAs. The impact would be less than significant. Therefore, no mitigation is required.

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

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

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

9.4 References Cited

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