Appendix X Geology and Soils Technical Appendix

This appendix documents the geology and soils technical analysis to support the impact analysis in the Environmental Impact Statement (EIS).

X.1 Introduction

This technical appendix describes the geology and soils resources in the study area, and potential changes that could occur as a result of implementing the action alternatives evaluated in this EIS. Implementation of the alternatives could affect geology and soils resources through potential changes in operations of the Central Valley Project (CVP) and State Water Project (SWP). The affected environment is described in Section X.2, *Affected Environment*, and evaluation of alternatives and potential impacts is discussed in Section X.3, *Evaluation of Alternatives*.

X.2 Affected Environment

This section describes the affected environment for the study area regarding the geological setting, regional seismic and soils characteristics, and subsidence potential that could be potentially affected by the implementation of the alternatives considered in this EIS. Changes in geology and soils characteristics caused by changes in CVP and SWP operations may occur in the Trinity River region; Central Valley, including affected subwatersheds in the lower reaches of the Sacramento River, Clear Creek, Feather River, American River, San Joaquin River, and Stanislaus River; Bay-Delta region; and CVP and SWP service areas. Geomorphic provinces in California are shown on Figure X.2-1, Geomorphic Provinces in California.

X.2.1 Trinity River Region

The Trinity River region includes the area in Trinity County along the Trinity River from Trinity Lake to the confluence with the Klamath River, and the areas in Humboldt and Del Norte Counties along the Klamath River from the confluence with the Trinity River.

X.2.1.1 *Geologic Setting*

The Trinity River region is located within the southwest area of the Klamath Mountains Geomorphic Province and the northwest area of the Coast Ranges Geomorphic Province, as defined by the U.S. Geological Survey (USGS) geomorphic provinces (CGS 2002). The Klamath Mountains Geomorphic Province covers approximately 12,000 square miles of northwestern California between the Coast Range on the west and the Cascade Range on the east and is considered to be a northern extension of the Sierra Nevada (CGS 2002; Reclamation 1997).

Figure X.2-1. Geomorphic Provinces in California

The Klamath Mountains trend mostly northward. The province is primarily formed by the eastern Klamath Mountain belt, central metamorphic belt, the western Paleozoic and Triassic belts, and the western Jurassic belt. Rocks in this province include Paleozoic meta-sedimentary and meta-volcanic rocks, Mesozoic igneous rocks, Ordovician to Jurassic-aged marine deposits in the Klamath belt; Paleozoic hornblend, mica schists, and ultramafic rocks in the central metamorphic belt; and slightly metamorphosed sedimentary and volcanic rocks in the western Jurassic, Paleozoic, and Triassic belts (Reclamation 1997).

The affected environment of the Trinity River watershed is located within the Klamath Mountain Geomorphic Province. Although the Trinity River watershed includes portions of both the Coast Ranges Province and the Klamath Mountains Province, the Trinity River channel is underlain by rocks of the Klamath Mountains Province (NCRWQCB and Reclamation 2009). The Klamath Mountains Province formations generally dip toward the east and are exposed along the river channel. Downstream of Lewiston Dam to Deadwood Creek, the area is underlain by the Eastern Klamath Terrane of the Klamath Mountains Province. The rocks in this area are primarily Copley Greenstone, metamorphosed volcanic sequence with intermediate and mafic volcanic rocks, and Bragdon formation, metamorphosed sedimentary formation with gneiss and amphibolite. Along the Trinity River between Lewiston Dam and Douglas City, outcrops of the Weaverville Formation occur. The Weaverville Formation, a series of nonmarine deposits, includes weakly consolidated mudstone, sandstone, and conglomerate of clays matrix and sparse beds of tuff. Downstream of Douglas City, the Trinity River is underlain by the Northfork and Hayfork Terranes. The Northfork Terrane near Douglas City includes silicious tuff, chert, mafic volcanic rock, phyllite, and limestone sandstone and pebble conglomerate with serpentine intrusions. As the Trinity River channel extends downstream toward the Klamath River, the geologic formation extends into the Hayfork Terrane that consists of metamorphic and meta-volcanic rock. Terraces of sand and gravel from glacial erosion along the Trinity River flanks near Lewiston Dam contribute sediment into the Trinity River.

The Trinity River flows into the Klamath River near Weitchpec. Downstream of the Weitchpec, the Klamath River flows to the Pacific Ocean through the Coast Ranges Geomorphic Province. The geology along the Klamath River in the Coast Ranges Geomorphic Province is characterized by the Eastern Belt of the Franciscan Complex and portions of the Central Belt of this complex. The Franciscan Complex consists of sandstone with some shale, chert, limestone, conglomerate, serpentine, and blueschist. The Eastern Belt is composed of schist and meta-sedimentary rocks with minor amounts of shale, chert, and conglomerate. The Central Belt is primarily composed of an argillite-matrix mélange with slabs of greenstone, serpentine, graywacke, chert, high-grade metamorphics, and limestone.

X.2.1.2 *Seismicity*

The areas along the Trinity River have been categorized as regions that are distant from known, active faults and generally would experience infrequent, low levels of shaking. However, infrequent earthquakes with stronger shaking could occur (CGS 2008). The closest areas to the Trinity River with known seismic, active areas capable of producing an earthquake with a magnitude of 8.5 or greater are the northern San Andreas Fault Zone and the Cascadia Subduction Zone, which are approximately 62 and 124 miles away, respectively (NCRWQCB and Reclamation 2009).

The areas along the lower Klamath River downstream of the confluence with the Trinity River have a slightly higher potential for greater ground shaking than areas along the Trinity River (CGS 2008). The lower Klamath River is closer than the Trinity River to the offshore Cascadia Subduction Zone, which runs offshore of Humboldt and Del Norte Counties and the states of Oregon and Washington. The Klamath River is approximately 30 to 40 miles from the Trinidad Fault, which extends from the area near

Trinidad northwest to the coast near Trinidad State Beach. The Trinidad Fault is potentially capable of generating an earthquake with a moment magnitude of 7.3 (Humboldt County 2012).

The San Andreas Fault, under the Pacific Ocean in a northwestern direction from the Humboldt and Del Norte Counties, is where the Pacific Plate moves toward the northwest relative to North America (Humboldt County 2012). The Cascadia Subduction Zone, located under the Pacific Ocean offshore from Cape Mendocino in southwest Humboldt County to Vancouver Island in British Columbia, has produced earthquakes with magnitudes greater than 8. The Cascadia Subduction Zone is where the Gorda Plate and the associated Juan de Fuca Plate descend under the North American Plate.

X.2.1.3 *Volcanic Potential*

Active centers of volcanic activity occur in the vicinity of Mount Shasta, near the northeastern edge of the Trinity River region. Mount Shasta is about 45 miles north of Shasta Lake. Over the past 10,000 years, Mount Shasta erupted about once every 800 years. During the past 4,500 years, Mount Shasta erupted about once every 600 years with the most recent eruption in 1786. Lava flows, dome, and mudflows occurred during the eruptions (Reclamation 2014).

X.2.1.4 *Soil Characteristics*

Soils in the southern region of the Klamath Mountain Geomorphic Province, where the Trinity River is located, are generally composed of gravelly loam with some alluvial areas with dredge tailings, river wash, and xerofluvents (NCRWQCB and Reclamation 2009).

Soils along the lower Klamath River are generally composed of gravelly clay loam and gravelly sandy loam with sand and gravels within the alluvial deposits (USDOI and CDFG 2012). Alluvial deposits (river gravels) and dredge tailings provide important spawning habitat for salmon and Steelhead.

X.2.1.5 *Subsidence*

Land subsidence is not a major occurrence in the Trinity River region.

X.2.2 Central Valley

The Central Valley contains the largest collective watershed in California, including six subwatersheds potentially affected by implementation of action alternatives: the Sacramento River, Clear Creek, Feather River, American River, Stanislaus River, and San Joaquin River watersheds. The Central Valley extends from above Shasta Lake in the north to the Tehachapi Mountains in the south, and includes the Sacramento Valley and San Joaquin Valley.

X.2.2.1 *Geologic Setting*

The Central Valley is located within the Great Valley Geomorphic Province, and is bounded by the Klamath Mountains, Cascade Range, Coast Ranges, and Sierra Nevada Geomorphic Provinces (CGS 2002).

The Great Valley Geomorphic Province is a vast elongated basin, approximately 430-miles-long, and 50-miles-wide, that extends from the northwest to the southeast, and bounded between the Sierra Nevada and Coast Ranges Geomorphic Provinces to the east and west, respectively. The faulted and folded sediments of the Coast Ranges extend eastward beneath most of the Central Valley. The igneous and metamorphic rocks of the Sierra Nevada extend westward beneath the eastern Central Valley (Reclamation 1997). The valley floor is an alluvial plain of sediments that have been deposited since the Jurassic age (CGS 2002). Below these deposits are Cretaceous Great Valley Sequence shales and sandstones and upper Jurassic bedrock of metamorphic and igneous rocks associated in the east with the Sierra Nevada and in the west with the Coast Ranges (DWR 2007). The trough of the Great Valley Geomorphic Province is asymmetrically filled with up to 6 vertical miles of Jurassic- to Holocene-age sediments. The trough is primarily made up of Tertiary and Quaternary continental rocks and deposits, which become separated by lacustrine, marsh, and floodplain deposits of varying thicknesses. Sediments deposited along the submarine fans within the Great Valley Geomorphic Province include mudstones, sandstones, and conglomerates from the Klamath Mountains and Sierra Nevada Geomorphic Provinces.

The valley floor in the Great Valley Geomorphic Province includes dissected uplands, low alluvial fans and plains, river floodplains and channels, and overflow lands and lake bottoms. The dissected uplands include consolidated and unconsolidated Tertiary and Quaternary continental deposits. The alluvial fans along the western boundary include poorly sorted fine sand, silt, and clay. The alluvial fans along the eastern boundary consist of well sorted gravel and sand along major tributaries, and poorly sorted materials along intermittent streams. River and floodplains primarily consist of coarse sands and fine silts. The lake bottoms primarily occur in the southern San Joaquin Valley and are composed of clay layers (Reclamation 1997).

The Sacramento Valley is in the northern portion of the Great Valley Geomorphic Province and is drained by the Sacramento River and its tributaries. Extending approximately 180-miles-long and 40- to 60-miles-wide, the Sacramento Valley lies between the Coast Ranges on the west and the Sierra Nevada on the east, and is bounded at the north end by the Cascade Geomorphic Province near Redding, and extends southeasterly to the Delta near Stockton. The surface of the Sacramento Valley consists of recent and Pleistocene-age alluvium deposited into the bottomlands by streams draining the surrounding highlands of the Klamath Mountain Geomorphic Province to the north and the Sierra Nevada and Coast Range geomorphic provinces to the east and west, respectively. These stream sediments consist of heterogeneous deposits of channel gravels, river bank sands, silt, and clay deposited on the broad floodplain that has become the Sacramento Valley (DeCourten 2008)

The San Joaquin Valley is in the southern half of the Great Valley Geomorphic Province and is drained by the San Joaquin River and its tributaries. The 250-mile-long and 50- to 60-mile-wide San Joaquin Valley lies between the Coast Ranges on the west and the Sierra Nevada on the east, and extends northwesterly to the Delta near Stockton. The continental deposits, which include the Mehrten, Kern River, Laguna, San Joaquin, Tulare, Tehama, Turlock, Riverbank, and Modesto Formations, form the San Joaquin Valley aquifer (Ferriz 2001; Reclamation and DWR 2011; Reclamation 2009).

Dissected uplands, low alluvial fans and plains, river floodplains and channels, and overflow lands and lake bottoms are the several geomorphic land types within the San Joaquin Valley. Dissected uplands consist of slightly folded and faulted, consolidated and unconsolidated, Tertiary- and Quaternary-age continental deposits. The alluvial fans and plains, which cover most of the valley floor, consist of unconsolidated continental deposits that extend from the edges of the valley toward the valley floor. In general, alluvial sediments of the western and southern parts of the San Joaquin Valley tend to have lower permeability than deposits on the eastern side. River floodplains and channels lie along the major rivers and are well defined where rivers incise their alluvial fans. Typically, these deposits are coarse and sandy in the channels and finer and silty in the floodplains (Reclamation and DWR 2011).

Lake bottoms of overflow lands in the San Joaquin Valley include historic beds of Tulare Lake, Buena Vista Lake, and Kern Lake as well as other less defined areas in the valley trough. Near the valley trough, fluvial deposits of the east and west sides grade into fine-grained deposits. The largest lake deposits in the

Central Valley are found beneath the Tulare Lake bed, where up to 3,600 feet of lacustrine and marsh deposits form the Tulare Formation. This formation is composed of widespread clay layers, the most extensive being the Cocoran Clay member, which also is found in the western and southern portions of the San Joaquin Valley. The Cocoran Clay member is a confining layer that separates the upper semi-confined to unconfined aquifer from the lower confined aquifer (Reclamation 1997).

Watersheds within the Sacramento Valley that could be affected by CVP and SWP operations include the Sacramento River, Clear Creek, Feather River, and the lower American River watersheds. Watersheds within the San Joaquin Valley that could be affected by CVP and SWP operations include the San Joaquin River and Stanislaus River watersheds. Descriptions of the geological settings of the Sacramento Valley and San Joaquin Valley watersheds follow.

X.2.2.1.1 Sacramento River

The Sacramento River flows from Shasta Lake to the Delta. The area along the Sacramento River from Shasta Lake to downstream of Red Bluff is characterized by loosely consolidated deposits of Pliocene- and/or Pleistocene-age sandstone, shale, and gravel. Downstream of Red Bluff to the Delta, the river flows through Quaternary-age alluvium, lake, playa, and terrace deposits that are unconsolidated or poorly consolidated with outcrops of resistant, cemented alluvial units such as the Modesto and Riverbank formations (CALFED 2000).

The active river channel maintains roughly constant dimensions as it migrates across the floodplain within the limits of the meander belt which is constrained only by outcrops of resistant units or artificial bank protection. Sediment loads in the tributary streams and lower reaches of the Sacramento River include the effects of past and current land use practices on the tributary streams.

X.2.2.1.2 Clear Creek

Clear Creek is a tributary to the upper Sacramento River. The reach affected by the project is the lower portion of Clear Creek from Whiskeytown Dam to its point of discharge into the Sacramento River near the southwestern edge of the Redding city limits.

Formations of Tertiary and Quaternary age occupy most of the area of the Great Valley Geomorphic Province, including lower Clear Creek. Tertiary rocks in the lower Clear Creek area are included in the Tehama Formation of Pliocene age (Helley and Harwood 1985), consisting of sandstone and siltstone with lenses of conglomerate derived from the Coast Ranges and Klamath Mountains to the west and north. The Tehama Formation grades eastward into the Tuscan Formation, which consists of volcanic and volcanoclastic rocks erupted and transported from volcanic vents in the Cascades volcanic province to the east. The Nomlaki Tuff Member of the Tehama Formation is locally exposed in bluffs along Clear Creek and gulches incised into the terrace on the north side of Clear Creek. In the vicinity of lower Clear Creek it is typically a white or pale gray, massive, non-welded pumice lapilli tuff. Its stratigraphic position is at or near the base of the Tehama Formation. The flood plain of Clear Creek, including low terraces adjacent to the active stream channel, is underlain by alluvium of Holocene age. The bulk of this alluvial material is likely gravel and sand. As a result of restricted sediment supply in the current hydrologic regime, stream erosion has locally exposed the substrate beneath the gravel, described as a hard-pan clay layer composed of weathered Nomlaki Tuff, or in some cases relatively clay-rich weathered Tehama Formation (USGS 2008).

The placer deposits of lower Clear Creek have been mined intermittently by various methods since the 1850s (Clark 1970), with the result that all the alluvial gravel forming the flood plain of Clear Creek and most of the gravel capping adjacent terraces has been disturbed. In addition, aggregate mining in recent decades has removed gravel from the lower Clear Creek alluvial system from in-stream and off-stream mining pits (USGS 2008).

X.2.2.1.3 Feather River

Portions of the Feather River watershed analyzed in this EIS extend from Antelope Lake, Lake Davis, and Frenchman Lake upstream of Lake Oroville, through Lake Oroville and the Thermalito Reservoir complex, and along the Feather River to the confluence with the Sacramento River. The Yuba and Bear Rivers are the major tributaries to the Feather River downstream of Thermalito Dam.

The Feather River watershed upstream of Thermalito Dam is located in the Cascade Range Geomorphic Province and the metamorphic belt of the Sierra Nevada Geomorphic Province. The lower watershed downstream of Thermalito Dam is located in the Great Valley Geomorphic Province.

West of Lake Oroville, scattered sedimentary and volcanic deposits cover the older bedrock, including (from oldest to youngest) the marine Chico formation from the upper Cretaceous; the auriferous gravels and mostly nonmarine Ione Formation of the Eocene Epoch; the extrusive volcanic Lovejoy basalt of the late Oligocene to early Miocene; and volcanic flows and volcanoclastic rocks of the Tuscan Formation of the late Pliocene. Late Tertiary and Quaternary units in this area include alluvial terrace and fan deposits of the Plio-Pleistocene Laguna Formation, the Riverbank and Modesto Formations of the Pleistocene, riverbed sediments of the Holocene, and historical dredge and mine tailings from twentieth century mining activities (DWR 2007).

Alluvium deposits occur in active channels of the Feather, Bear, and Yuba Rivers and tributary streams. These deposits contain clay, silt, sand, gravel, cobbles, and boulders in various layers and mixtures. Historical upstream hydraulic mining substantially increased the sediment covering the lower Feather River riverbed with a thick deposit of fine clay-rich, light yellow-brown slickens (i.e., powdery matter from a quartz mill or residue from hydraulic mining). More recent floodplain deposits cover these slickens in the banks along most of the Feather River; cobbles and coarse gravel dredge tailings constitute most of the banks, slowing the bank erosion process between the cities of Oroville and Gridley. The river is wide and shallow, with low sinuosity and a sand bed between Honcut Creek and the mouth of the Feather River.

X.2.2.1.4 American River

The Folsom Lake area is located within the Sierra Nevada and the Great Valley Geomorphic Province at the confluence of the North and South Forks of the American River. The Folsom Lake region primarily consists of rolling hills and upland plateaus between major river canyons. Three major geologic divisions within the area are a north-northwest trending belt of metamorphic rocks, granitic plutons that have intruded and obliterated some of the metamorphic belt, and deposits of volcanic ash, debris flows, and alluvial fans that are relatively flat. These deposits overlie older rocks (Reclamation et al. 2006).

Igneous, metamorphic, and sedimentary rock types are present within the Folsom Lake area. Major rock divisions are ultramafic intrusive rocks, metamorphic rocks, granodiorite intrusive rocks, and volcanic mud flows and alluvial deposits. Ultramafic rocks are most common on Flagstaff Mountain (Hill) on the Folsom Reservoir Peninsula between the North Fork American River and South Fork American River. This rock division may contain trace amounts of serpentine minerals, chromite, minor nickel, talc, and naturally occurring asbestos (Reclamation et al. 2006).

Metamorphic rocks are found in a north-northwest trending band primarily on the eastern portions of the Folsom Lake area through most of the peninsula between the North Fork American River and South Fork American River (CGS 2010). The metamorphic rocks are mainly composed of Copperhill Volcanics (metamorphosed basaltic breccia, pillow lava, and ash) and ultramafic rocks, two formations that may contain trace amounts of naturally occurring asbestos (Reclamation et al. 2006).

Granodiorite intrusive rocks occur in the Rocklin Pluton on both sides of Folsom Lake extending to Lake Natoma and in the Penryn Pluton upstream of the Rocklin Pluton. Granodiorite intrusive rocks are composed of a coarse-grained crystalline matrix with slightly more iron and magnesium-bearing minerals and less quartz than granite. Of the granodiorite, the feldspar and hornblend are less resistant than the quartz crystals and easily weather. When weathering occurs, the remaining feldspars separate from the quartz, resulting in decomposed granite (Reclamation et al. 2006).

Volcanic mud flows and alluvial deposits are present downstream of Folsom Lake in the southwest corner of two major formations: Mehrten and Laguna. The Mehrten Formation contains volcanic conglomerate, sandstone, and siltstone, all derived from andesitic sources, and portions are gravels deposited by ancestral streams. The Laguna Formation, deposited predominately as debris flow on the Mehrten Formation, is a sequence of gravel, sand, and silt derived from granitic sources (Reclamation et al. 2006).

The area along the American River downstream of Folsom Lake and Nimbus Dam is located in the Great Valley Geomorphic Province. The area includes several geomorphic land types including dissected uplands and low foothills, low alluvial fans and plains, and river floodplains and channels. The dissected uplands consist of consolidated and unconsolidated continental Tertiary and Quaternary deposits that have been slightly folded and faulted (Reclamation 2005b).

The alluvial fans and plains consist of unconsolidated continental deposits that extend from the edges of the valleys toward the valley floor (Reclamation 2005b). The alluvial plains in the American River watershed include older Quaternary deposits (Sacramento County 2010). River flood plains and channel deposits lay along the American River as well as along smaller streams that flow into the Sacramento River south of the American River. Some floodplains are well defined, where rivers are incised into their alluvial fans. These deposits tend to be coarse and sandy in the channels and finer and silty in the floodplains (Reclamation 2005b; Sacramento County 2010).

X.2.2.2 *San Joaquin River and Stanislaus River*

X.2.2.2.1 San Joaquin River

The San Joaquin River watershed originates in the Sierra Nevada Geomorphic Province and the lower San Joaquin River extends into the Great Valley Geomorphic Province below Millerton Lake (Friant Dam). The area is underlain by Cenozoic sedimentary rocks which dip toward the southwest and overlies the Cretaceous sedimentary rocks of the Great Valley Sequence and older metamorphic basement rocks along the edges of the Sierra Nevada. Below Lake Millerton, the lower San Joaquin River flows through the agricultural region of the northern San Joaquin Valley to the Bay-Delta area at the confluence of the Sacramento River. The lower San Joaquin River is a low-gradient, single-channel, generally sand-bedded, meandering river. Most of the banks are natural, however, there are large sections that have revetted sloping banks covered with large rocks to reduce bank erosion and river migration (USGS 2017).

X.2.2.2.2 Stanislaus River

The Stanislaus River watershed originates in the Sierra Nevada Geomorphic Province, including the area with New Melones Reservoir, and extends into the Great Valley Geomorphic Province. New Melones Reservoir is oriented along a northwest trend that is produced by the Foothill Metamorphic Belt in the Sierra Nevada Geomorphic Province (Reclamation 2010). The area is underlain by Cenozoic sedimentary rocks which dip toward the southwest and overlies the Cretaceous sedimentary rocks of the Great Valley Sequence and older metamorphic basement rocks along the edges of the Sierra Nevada. Tertiary sedimentary formations were deposited along the Stanislaus River from an area east of Knights Ferry to Oakdale (CGS 2010). The oldest Tertiary geologic unit, the Eocene Ione Formation, primarily consists of quartz, sandstone, and interbedded kaolinitic clays with a maximum thickness of about 200 feet near Knights Ferry. The Oligocene-Miocene Valley Springs Formation of rhyolitic ash, sandy clay, and gravel deposits overlay the Ione Formation. Andestic flows, lahars, and volcanic sediments of the Mehrten Formation were deposited by volcanism, especially from Table Mountain (CGS 2010; Reclamation 2010). Three major alluvial fan deposits occurred along the Stanislaus River after deposition of the Mehrten Formation, including the Turlock Lake Formation (between Orange Blossom Road and Oakdale) composed of fine sand and silt with some clay, sand, and gravel; Riverbank Formation (between Oakdale and Riverbank) composed of silt and clay; and Modesto Formation (between Riverbank and the confluence with the San Joaquin River) composed of sand, silt, clay, and gravel.

X.2.2.3 *Seismicity*

Most of the areas in the Central Valley have been categorized as regions that are distant from known, active faults and generally would experience infrequent, low levels of shaking. However, infrequent earthquakes with stronger shaking could occur (CGS 2008). Areas within and adjacent to the Bay-Delta region and along Interstate 5) in the San Joaquin Valley have a higher potential for stronger ground shaking due to their close proximity to the San Andreas Fault Zone.

The San Andreas Fault Zone is to the west of the Central Valley along a 150-mile northwest-trending fault zone (Reclamation 2005d). The fault zone extends from the Gulf of California to Point Reyes, where the fault extends under the Pacific Ocean (CGS 2006). The fault zone is the largest active fault in California (Reclamation 2005d).

In the Sacramento Valley, the major fault zones include the Battle Creek Fault to the east of the Sacramento River, Corning Fault that extends from Red Bluff to Artois parallel to the Corning Canal, Dunnigan Hills Fault located west of I-5 near Dunnigan, Cleveland Fault located near Oroville, and Great Valley Fault system along the west side of the Sacramento Valley (Reclamation 2005a).

In the San Joaquin Valley, the eastern foothills are characterized by strike-slip faults that occur because the rock underlying the valley sediment is slowly moving downward relative to the Sierra Nevada Block to the east. An example of this type of faulting is the Kings Canyon lineament, which crosses the valley north of Chowchilla and continues nearly to Death Valley in southeastern California (Reclamation and DWR 2011). Uplift and tilting of the Sierra Nevada block toward the west and tilting of the Coast Ranges block to the east appear to be causing gradual downward movement of the valley basement rock, in addition to subsidence caused by aquifer compaction and soil compaction discussed below. The San Joaquin Valley is bounded by the Stockton Fault of the Stockton Arch on the north and the Bakersfield Arch on the south. Most of the fault zones in the San Joaquin Valley do not appear to be active. However, numerous faults may not be known until future seismic events; an example of this fault discovery is the Nunez reverse fault, which was not known until the 1983 Coalinga earthquake. In areas adjacent to the San Joaquin Valley, the dominant active fault structure is the Great Valley blind thrust associated with the

San Andreas Fault. Other active faults occur along the western boundary of the San Joaquin Valley, including the Hayward, Concord-Green Valley, Coast Ranges-Sierra Block boundary thrusts, Mount Diablo, Greenville, Ortigalita, Rinconada, and Hosgri Faults (Reclamation 2005d).

X.2.2.4 *Volcanic Potential*

Active centers of volcanic activity occur in the vicinity of Mount Shasta and Lassen Peak in the northern Central Valley. Mount Shasta is about 45 miles north of Shasta Lake. Over the past 10,000 years, Mount Shasta erupted about once every 800 years. During the past 4,500 years, Mount Shasta erupted about once every 600 years with the last eruption in 1786. Lava flows, domes, and mudflows occurred during the eruptions (Reclamation 2014).

Lassen Peak, about 50 miles southeast of Shasta Lake, is a cluster of dacitic domes and vents that have formed during eruptions over the past 250,000 years. The last eruptions were relatively small and occurred between 1914 and 1917. The most recent large eruption occurred about 1,100 years ago. Large eruptions appear to occur about once every 10,000 years (USGS 2000a).

X.2.2.5 *Soil Characteristics*

The Central Valley includes the Sacramento Valley and San Joaquin Valley. The soil characteristics are similar in many aspects in the Sacramento and San Joaquin Valleys; therefore, the descriptions are combined in the following sections.

X.2.2.5.1 Sacramento Valley and San Joaquin Valley Soil Characteristics

The Sacramento Valley and San Joaquin Valley contain terrace land and upland soils along the foothills. Alluvial, Aeolian, clayey, and saline/alkaline soils exist in various locations along the valley floors (CALFED 2000; Reclamation 1997).

Foothills soils, located on well-drained, hilly-to-mountainous terrain along the east side of the Central Valley, form through in-place weathering of the underlying rock. Soils in the northern Sacramento Valley near Shasta Lake are different than soils along other foothills in the Sacramento and San Joaquin Valleys. The soils near Shasta Lake are related to the geologic formations of the Klamath Mountains, Cascade Ranges, and Sierra Nevada geomorphic provinces. These soils are formed from weathered metavolcanic and metasedimentary rocks and from intrusions of granitic rocks, serpentine, and basalt. These soils are generally shallow with numerous areas of gravels, cobbles, and stones; therefore, they do not have high water-holding capacity or support topsoil productivity for vegetation (Reclamation 2014). Soils derived from in-place weathering of granitic rock, referred to as decomposed granite, are coarse-grained, quartz-rich, and erodible.

Upland soils along other foothills in the Sacramento and San Joaquin Valleys are formed from the Sierra Nevada and Coast Ranges geomorphic provinces. Along the western boundary of the Central Valley, the soils primarily are formed from sedimentary rocks. Along the eastern boundary of the Central Valley, the soils primarily are formed from igneous and metamorphic rock. The soils include serpentine soils (which include magnesium, nickel, cobalt, chromium, iron, and asbestos); sedimentary sandstones; shales; conglomerates; and sandy loam, loam, and clay loam soils above bedrock (Reclamation 1997; Reclamation and DWR 2011; Reclamation 2014; DWR 2007). Erosion occurs in the upland soils around reservoirs and rivers especially downgradient of urban development where paving increases the peak flow, volume, and velocity of precipitation runoff (GCI 2003).

Along the western boundary of the Sacramento Valley and the southeastern boundary of the San Joaquin Valley, the terrace lands include brownish loam, silt loam, and/or clayey loam soils. The soils are generally loamy along the Sacramento Valley terraces, and more clayey along the San Joaquin Valley terraces. Along the eastern boundaries of Sacramento and San Joaquin valleys, the terraces are primarily red silica-iron cemented hardpan and clays, sometimes with calcium carbonate (also known as lime) (DWR 2007; Reclamation 1997; Reclamation 2005b; Reclamation 2013).

Surface soils of the Central Valley include alluvial and Aeolian soils. The alluvial soils include calcic brown and noncalcic brown alluvial soils on deep alluvial fans and floodplains. The calcic brown soil is primarily made of calcium carbonate and alkaline (also known as "calcareous" soils). The noncalcic brown soils do not contain calcium carbonate and are either slightly acidic or neutral in chemical properties. In the western San Joaquin Valley, light colored calcareous soils occur with less organic matter than the brown soils (Reclamation 1997).

Soils within the Yolo Bypass area, located in the southwestern portion of the Sacramento Valley, range from clays to silty clay loams and alluvial soils (CALFED 2001; CDFG 2008). The higher clay content soils occur in the western portion of the area north of I-80 and in the eastern portion of the area south of I-80. The silty clay loams and alluvial soils occur in the western portion of the Yolo Bypass area south of I-80, including soils within the Yolo Bypass Wildlife Area.

Basin soils occur in the San Joaquin Valley and portions of the Delta. These soils include organic soils, imperfectly drained soils, and saline alkali soils. The organic soils are typically dark, acidic, high in organic matter, and generally include peat. The organic soils occur in the Delta, as discussed below, and along the lower San Joaquin River adjacent to the Delta. The poorly drained soils contain dark clays and occur in areas with high groundwater in the San Joaquin Valley trough and as lake bed deposits (Reclamation and DWR 2011). One of the most substantial stratigraphic features of the San Joaquin Valley and a major aquitard is the Corcoran Clay, located in the western and central valley (Galloway and Riley 1999). The Corcoran Clay generally extends from Mendota Pool area through the center of the valley to the Tehachapi Mountains. The depth to the Corcoran Clay varies from 160 feet under the Tulare Lake bed to less than a foot near the western edge of the Central Valley. The Corcoran Clay is composed of numerous aquitards and coarser interbeds.

Selenium salts and other salts occur naturally in the western and central San Joaquin Valley soils that are derived from marine sedimentary rocks of the Coast Ranges. Salts are leached from the soils by applied pre-irrigation and irrigation water and collected by a series of drains. The drains also reduce high groundwater elevations in areas with shallow clay soils. Reclamation and other agencies are implementing programs to reduce salinity issues in the San Joaquin Valley that will convey and dispose of drainage water in a manner that would protect the surface water and groundwater resources (Reclamation and DWR 2011). As described in Appendix R, *Land Use and Agricultural Resources Technical Appendix*, areas in the western and southern San Joaquin Valley are affected by shallow, saline groundwater that accumulates because of irrigation; and the shallow groundwater is underlain by soils with poor drainage.

Soils in the eastern San Joaquin Valley come from the Sierra Nevada and contain low levels of salt and selenium. Most soils in the western and southern San Joaquin Valley are formed from Coast Range marine sediments, and contain higher concentrations of salts as well as selenium and molybdenum. Soluble selenium moves from soils into drainage water and groundwater, especially during agricultural operations to leach salts from the soils. As described in Appendix D, *Alternatives Development*, Reclamation and other agencies are implementing programs to reduce the discharge of selenium from the San Joaquin Valley into receiving waters (Reclamation 2005d; Reclamation and DWR 2011; Reclamation

2009). Additional information related to concerns with salinity and selenium in the San Joaquin Valley is presented in Appendix G, *Water Quality Technical Appendix*, and Appendix R.

Soil wind erosion is related to soil erodibility, wind speeds, soil moisture, surface roughness, and vegetative cover. Aeolian soils are more susceptible to wind erosion than alluvial soils. Nonirrigated soils that have been disturbed by cultivation or other activities throughout the Central Valley are more susceptible to wind erosion and subsequent blowing dust than soils with more soil moisture. Dust from eroding soils can create hazards due to soil composition (such as naturally occurring asbestos), allergic reactions to dust, adverse impacts to plants due to dust, and increased risk of Valley fever (Reclamation 2005d).

X.2.2.6 *Subsidence*

Land subsidence occurs for different reasons throughout the Central Valley as described in the following sections.

X.2.2.6.1 Sacramento and San Joaquin Valley Subsidence

Land subsidence in the Sacramento and San Joaquin Valleys occurs primarily due to aquifer-system compaction as groundwater elevations decline as a result of groundwater overdraft (i.e., groundwater withdrawals at rates greater than groundwater recharge rates) typically used for irrigation. To a lesser degree, subsidence is also caused by weathering of some types of underlying bedrock, such as limestone; decomposition of organic matter; and natural compaction of soils (Reclamation 2014). Historic subsidence of the Sacramento Valley has been far less than that observed in the San Joaquin Valley. For example, the range of historic subsidence in the Sacramento Valley is generally less than 10 feet, whereas historical subsidence in the San Joaquin Valley has caused changes in land elevations ranging from as much as 28 feet (USGS 2019) to more than 30 feet (Reclamation and DWR 2011).

In the 1970s, land subsidence exceeded 1 foot near Zamora; however, additional subsidence has not been reported since 1973 (Reclamation 2014). Subsidence of 2 feet near Davis and 3 to 4 feet has been reported over the last several decades in the areas north of Woodland and east of Davis and Woodland (City of Davis 2007).

San Joaquin Valley subsidence primarily occurs when groundwater elevations decline due to pumping for irrigation water supply, which reduces water pressure in the soils and results in compressed clay lenses and subsided land elevations. Secondary factors that may influence the rate of subsidence in the San Joaquin Valley is the Sierran uplift, sediment loading and compressional down-warping or thrust loading from the Coast Ranges, and near surface compaction (Reclamation and DWR 2011). Some of the first reports of land subsidence in the San Joaquin Valley occurred in 1935 in the area near Delano (Galloway and Riley 1999). By the late 1960s, San Joaquin Valley subsidence had occurred over 5,212 square miles, or almost 50% of the San Joaquin Valley (Reclamation 2005d). The rate of subsidence decreased initially following implementation of CVP and SWP water supplies in the San Joaquin Valley during the 1970s and 1980s. Subsidence for the next 20 years appeared to continue at a rate of 0.008 to 0.016 inches/year (Reclamation and DWR 2011). However, the amount of water available for irrigation from the CVP and SWP has declined more than 20% to 30% since the early 1980s due to hydrologic, regulatory, and operational concerns, as described in Chapter 2, *Purpose and Need*. Due to the reduction in the availability of CVP and SWP water supplies, many water users have increased groundwater withdrawal. A recent study by the USGS of subsidence along the CVP Delta-Mendota Canal (USGS 2013a) reported that in areas where groundwater levels fluctuated consistently on a seasonal basis but were stable on a long-term basis, the land elevations also were relatively stable. Subsidence occurred in portions of the

San Joaquin Valley where groundwater elevations below the Corcoran clay and in the shallow groundwater declined on a long-term basis between 2003 and 2010. The highest subsidence rates occurred along the Delta Mendota Canal between Merced and Mendota with subsidence of 0.8 inches to 21 inches between 2003 and 2010 (USGS 2013a).

Shallow subsidence, or hydrocompaction, occurs when low density, relatively dry, fine-grained sediments soften and collapse upon wetting. Historically, hydrocompaction has been most common along the western margin of the San Joaquin Valley (Reclamation 2005c). In the southern San Joaquin Valley, extraction of oil also can result in compaction. Changes in elevation, both subsidence and uplift, occurred near Coalinga following the 1983 Coalinga earthquake with uplift up to 1.6 feet and subsidence of 2 inches.

X.2.3 Bay-Delta Region

The Bay-Delta region includes portions of Alameda, Santa Clara, San Benito, and Napa Counties that are within the CVP and SWP service areas. Portions of Napa County are within the SWP service area and use water diverted from Barker Slough in the Sacramento River watershed for portions of Solano and Napa Counties.

X.2.3.1 *Geologic Setting*

The Bay-Delta region is a northwest-trending structural basin, separating the primarily granitic rock of the Sierra Nevada from the primarily Franciscan Formation rock of the California Coast Ranges. The Bay-Delta region is a basin within the Great Valley Geomorphic Province that is filled with a 3- to 6-mile-thick layer of sediment deposited by streams originating in the Sierra Nevada, Coast Ranges, and South Cascade Range. Surficial geologic units throughout the Bay-Delta include peat and organic soils, alluvium, levee and channel deposits, dune sand deposits, older alluvium, and bedrock (USGS 1982).

The historical delta at the confluence of the Sacramento River and San Joaquin River is referred to as the Sacramento–San Joaquin Delta, or Delta. The Delta is a flat-lying river delta that evolved at the inland margin of the San Francisco Bay Estuary as two overlapping and coalescing geomorphic units: the Sacramento River Delta to the north and the San Joaquin River Delta to the south. During large river-flood events, silts and sands were deposited adjacent to the river channel, formed as a tidal marsh with few natural levees, and was dominated by tidal flows, allowing for landward accumulation of sediment behind the bedrock barrier at the Carquinez Strait. The sediment formed marshlands, which consisted of approximately 100 islands that were surrounded by hundreds of miles of channels. Generally, mineral soils formed near the channels during flood conditions and organic soils formed on marsh island interiors, as plant residues accumulated faster than they could decompose (Weir 1949).

In the past, because the San Joaquin River Delta had less defined levees than under current conditions, sediments were deposited more uniformly across the floodplain during high water, creating an extensive tule marsh with many small, branching tributary channels. Because of the differential amounts of inorganic sediment supply, the peat of the San Joaquin River Delta grades northward into peaty mud and mud toward the natural levees and flood basins of the Sacramento River Delta (Atwater and Belknap 1980).

The Delta has experienced several cycles of deposition, nondeposition, and erosion that have resulted in the thick accumulation of poorly consolidated to unconsolidated sediments overlying the Cretaceous and Tertiary formations since late Quaternary time. Shlemon and Begg (1975) calculated that the peat and organic soils in the Delta began to form about 11,000 years ago during an episode of sea-level rise. Tule marshes established on peat and organic soils in many portions of the Delta. Additional peat and other organic soils formed from repeated inundation and accumulation of sediment of the tules and other marsh vegetation.

X.2.3.1.1 Suisun Marsh

The Suisun Marsh area is located within the Coast Ranges Geomorphic Province. The Suisun Marsh is bounded by the steep Coast Ranges on the west and by the rolling Montezuma Hills on the east. The Montezuma Hills consist of uplifted Pleistocene sedimentary layers with active Holocene-age alluvium in stream drainages that divide the uplift. Low-lying flat areas of the marshland are covered by Holocene-age Bay Mud deposits. The topographically higher central portions of Grizzly Island in the marshlands north of the Suisun Bay are formed by the Potrero Hills. These hills primarily consist of folded and faulted Eocene marine sedimentary rocks and late Pleistocene alluvial fan deposits (Reclamation et al. 2010).

X.2.3.1.2 San Francisco Bay

The San Francisco Bay area is located primarily within the Coast Ranges Geomorphic Province. Eastern Contra Costa and Alameda Counties are located in the Great Valley Geomorphic Province. The Coast Ranges and Great Valley Geomorphic Provinces were described in Section X.2.2, *Central Valley*. San Francisco Bay is a structural trough formed as a gap in the Coast Range down-dropped, allowing the Sacramento, San Joaquin, Napa, Guadalupe, and Coyote Rivers to flow into the Pacific Ocean. When the polar ice caps melted 10,000 to 25,000 years ago, the ocean filled the inland valleys of the trough and formed San Francisco Bay, San Pablo Bay, and Suisun Bay (CALFED 2000). Initially, alluvial sands, silts, and clays filled the bays to form Bay Mud along the shoreline areas. More recently, sedimentation patterns have changed over the past 170 years due to development of upstream areas of the watersheds, including hydraulic mining and formation of levees and dams.

The San Francisco Bay is formed from the Salinian block located west of the San Andreas Fault, Mesozoic Franciscan Complex between the San Andreas and Hayward Faults, and the Great Valley Sequence to the east of Hayward Fault (WTA 2003). The Salinian block generally is composed of granitic plutonic rocks probably from the Sierra Nevada Batholith that was displaced because of movement along the San Andreas Fault. The Franciscan Complex includes deep marine sandstone and shale formed from oceanic crust with chert and limestone. The Great Valley Sequence in the area primarily includes marine sedimentary rocks.

X.2.3.2 *Seismicity*

Large earthquakes have occurred in the Bay-Delta region along the San Andreas, Hayward, Calaveras, Greenville, Antioch, Concord-Green Valley, Midway, Midland, and Black Butte Fault Zones over the past 10,000 years. The San Francisco earthquake of 1906 took place as the result of movement along the San Andreas Fault, and more recently the Loma Prieta earthquake of 1989 occurred in the Santa Cruz Mountains on a somewhat remote segment of the San Andreas Fault (USGS 2001). The San Andreas Fault remains active, as does the Hayward Fault, based on evidence of slippage along both (CALFED 2000).

The Delta and Suisun Marsh are near several major fault systems, including the San Andreas, Hayward-Rodgers Creek, Calaveras, Concord-Green Valley, and Greenville Faults (DWR et al. 2013). There are also many named and unnamed regional faults in the vicinity. The majority of seismic sources underlying the Delta and Suisun Marsh are “blind” thrusts that are not expected to rupture to the ground surface during an earthquake. The known blind thrusts in the Delta and Suisun Marsh area include the Midland, Montezuma Hills, Thornton Arch, Western Tracy, Midland, and Vernalis Faults. Blind thrust faults with discernible geomorphic expression/trace located at the surface occur near the southwestern boundary of the Delta are the Black Butte and Midway Faults. Two surface crustal fault zones (e.g., areas with localized deformation of geologic features near the surface) are located within the Suisun Marsh, including the Pittsburgh-Kirby Hills fault, which occurs along an alignment between Fairfield and Pittsburg, and Concord-Green Valley fault, which crosses the western portion of the Suisun Marsh. The Cordelia fault is a surface crustal fault zone that occurs near the western boundary of the Suisun Marsh. Since 1800, no earthquakes with a magnitude greater than 5.0 have been recorded in the Delta or Suisun Marsh.

X.2.3.3 *Soil Characteristics*

The Bay-Delta region soils include basin floor/basin rim, floodplain/valley land, terrace, foothill, and mountain soils (CALFED 2000). Basin floor/basin rim soils are organic-rich saline soils and poorly drained clays, clay loams, silty clay loams, and muck along the San Francisco Bay shoreline (SCS 1977, 1981; CALFED 2000). Well-drained sands and loamy sands and poorly drained silty loams, clay loams, and clays occur on gently sloping alluvial fans of the Bay-Delta that surround the floodplain and valley lands. Drained loams, silty loams, silty clay loams, and clay loams interbedded with sedimentary rock and some igneous rock occur in the foothills. Terrace loams are located along the southeastern edge of the Bay-Delta above the valley land.

X.2.3.3.1 Delta Soil Characteristics

Soils in the Delta region include organic and/or highly organic mineral soils, deltaic soils along the Sacramento and San Joaquin Rivers, basin rim soils, floodplain and stream terrace soils, valley alluvial and low terrace soils, and upland and high terrace soils (Reclamation 1997). Basin, deltaic, and organic soils occupy the lowest elevation ranges and are often protected by levees. In many areas of the western Delta, the soils contain substantial organic matter and are classified as peat or muck.

Basin rim soils are found along the eastern edges (rims) of the Delta, and are generally moderately deep or deep mineral soils that are poorly drained to well-drained and have fine textures in surface horizons. Some areas contain soils with a hardpan layer in the subsurface (SCS 1992, 1993). Floodplain and stream terrace soils are mineral soils adjacent to the Sacramento and San Joaquin Rivers and other major tributaries. These soils are typically deep and stratified, with relatively poor drainage and fine textures. Valley fill, alluvial fan, and low terrace soils are typically very deep with variable texture and ability to transmit water, ranging from somewhat poorly drained silt loams and silty clay loams to well-drained fine sandy loams and silt loams. Upland and high terrace soils are generally well drained, ranging in texture from loams to clays and are primarily formed in material weathered from sandstone, shale, and siltstone, and can occur on dissected terraces or on mountainous uplands.

Soil erosion by rainfall or flowing water occurs when raindrops detach soil particles or when flowing water erodes and transports soil material. Sandy alluvial soils, silty lacustrine soil, and highly organic soil are erodible. Organic soil (peat) in the Delta is also susceptible to wind erosion (deflation). Clay soils are more resistant to erosion.

X.2.3.3.2 Suisun Marsh Soil Characteristics

Soil within the Suisun Bay include the Joice muck, Suisun peaty muck, and Tamba mucky clay, Reyes silty clay, and Valdez loam (SCS 1977; Reclamation et al. 2010). The Joice muck generally is poorly drained organic soils in saline water areas interspersed with fine-grain sediment. Suisun peaty muck is formed from dark colored organic soils and plant materials with high permeability. These soils are generally located in areas with shallow surface water and groundwater; therefore, surface water tends to accumulate on the surface. Tamba mucky clay also is poorly drained organic soil formed from alluvial soils and plant materials that overlays mucky clays. Reyes silty clays are poorly drained soils formed from alluvium. The upper layers of the silty clays are acidic and saline. The lower layers are alkaline that become acidic when exposed to air, especially under wetting-drying conditions in tidal areas. Valdez loam soils are poorly drained soils formed on alluvial fans.

Suisun Marsh soils have a low susceptibility to water and wind erosion (SCS 1977; Reclamation et al. 2010).

X.2.3.4 *Subsidence*

Subsidence in the Bay-Delta occurs primarily in the Santa Clara Valley of Santa Clara County. The Santa Clara Valley is underlain by a groundwater aquifer with layers of unconsolidated porous soils interspersed with clay lenses. Historically, when the groundwater aquifer was in overdraft, the water pressure in the soils declined, which resulted in compressed clay lenses and subsided land elevations. Between 1940 and 1970, soils near San Francisco Bay declined to elevations below sea level (USGS 1999). Under these conditions, saltwater intrusion and tidal flooding occurred in the tributary streams of Guadalupe River and Coyote Creek. As of 2000, the land elevation in downtown San Jose subsided 13 feet since 1915. In 1951, water deliveries from San Francisco Water Department were initiated (Ingebritsen and Jones 1999). In 1965, SWP deliveries were initiated in Santa Clara County. CVP water deliveries were initiated in 1987. The CVP and SWP water supplies are used to reduce groundwater withdrawals when groundwater elevations are low to allow natural recharge from local surface waters. The CVP and SWP water supplies also are used to directly recharge the groundwater through spreading basins in Santa Clara Valley.

X.2.3.4.1 Delta and Suisun Marsh Subsidence

Land subsidence on the islands in the central and western Delta and Suisun Marsh may be caused by the elimination of tidal inundation that formed the islands through sediment deposition and transport, and the oxidation and decay of plant materials that would compact to form soils. Following construction of levees, subsidence initially occurred through the mechanical settling of peat as the soil dried, and then the dried peat and other soils shrank (Reclamation et al. 2010; Drexler et al. 2009). Other contributing factors include agricultural burning of peat (a practice that has been discontinued), wind erosion, oxidation, and leaching of organic material. The rate of subsidence has declined from a maximum of 1.1 to 4.6 inches/year in the 1950s to less than 0.2 to 1.2 inches/year in the western Delta (Drexler et al. 2009; Rojstaczer et al. 1991). Many of the islands in the western and central Delta have subsided to elevations that are 10 to nearly 55 feet below sea level (USGS 2000b; Deverel and Leighton 2010).

Recently, the California Department of Water Resources (DWR) has implemented several projects to reverse subsidence. The 274-acre Mayberry Farms Duck Club Subsidence Reversal Project on Sherman Island includes creation of emergent wetlands ponds and channels through excavation of peat soils, improvement of water circulation, and waterfowl habitat. The facility was constructed in 2010 and is being monitored to determine the effectiveness of subsidence reversal, methyl mercury management, and carbon sequestration (Angell et al. 2013). Prior to that, DWR and USGS implemented wetlands restoration for about 15 acres on Twitchell Island in 1997 (DWR and USGS 2008) to encourage tule and cattail growth. After the growing season, the decomposed plant material accumulates and increases the land elevation. Since 1997, elevations have increased at a rate of 1.3 to 2.2 inches/year.

X.2.4 CVP and SWP Service Areas

The CVP and SWP service areas extend south to the general area of Diamond Valley. These services areas include the Central Coast and Southern California regions.

Portions of San Luis Obispo and Santa Barbara Counties on the Central Coast are served by the SWP. Portions of Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino Counties in Southern California are served by the SWP.

In Southern California, operations of the SWP affect the Coachella Valley in Riverside County. The Coachella Valley Water District receives water under a SWP entitlement contract; however, SWP water cannot be conveyed directly to the Coachella Valley due to lack of conveyance facilities. Therefore, Coachella Valley Water District receives water from the Colorado River through an exchange agreement with the Metropolitan Water District of Southern California, as described in Appendix C, *Facility Descriptions and Operations*. The Imperial Valley in Southern California receives irrigation water from the Colorado River through Reclamation canals, and does not use CVP or SWP water.

X.2.4.1 *Geologic Setting*

The Central Coast and Southern California regions are located in the geomorphic provinces of the Coast Ranges, Transverse Ranges, Peninsular Ranges, Colorado Desert, and Mojave Desert (CGS 2002).

Portions of San Luis Obispo and Santa Barbara Counties use SWP water supplies. These areas are located within the Coast Ranges and Transverse Ranges Geomorphic Provinces. The Coast Ranges Geomorphic Province was described in Section X.2.2, *Central Valley*. The Transverse Ranges Geomorphic Province consists of deeply folded and faulted sedimentary rocks (CGS 2002; SBCAG 2013). Bedrock along the stream channels, coastal terraces, and coastal lowlands is overlain by alluvial and terrace deposits; and, in some area, ancient sand dunes. The geomorphic province is being uplifted at the southern border along San Andreas Fault and compressed at the northern border along the Coast Ranges Geomorphic Province. Therefore, the geologic structure of the ridges and valleys are oriented along an east-west orientation, or in a *transverse* orientation, compared to the north-south orientation of the Coast Range.

Portions of Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino Counties use SWP water supplies. These areas are located within the geomorphic provinces of the Transverse Ranges, Peninsular Ranges, Mojave Desert, and Colorado Desert. The Transverse Ranges Geomorphic Province includes Ventura County and portions of Los Angeles, San Bernardino, and Riverside Counties. The Colorado Desert Geomorphic Province is also known as the Salton Trough, where the Pacific and North American plates are separating.

The Peninsular Ranges Geomorphic Province is composed of granitic rock with metamorphic rocks (CGS 2002; SCAG 2011; San Diego County 2011). The geologic structure is similar to the geology of the Sierra Nevada Geomorphic Province. The faulting of this geomorphic province has resulted in northwest trending valleys and ridges that extend into the Pacific Ocean to form the islands of Santa Catalina, Santa Barbara, San Clemente, and San Nicolas. The Peninsular Ranges Geomorphic Province includes Orange County and portions of southern Los Angeles County, western San Diego County, northwestern San Bernardino County, and northern Riverside County (including the northern portion of the Coachella Valley).

The Mojave Desert Geomorphic Province lies between the Garlock Fault along the southern boundary of the Sierra Nevada Geomorphic Province and the San Andreas Fault (CGS 2002; SCAG 2011; RCIP

2000). This geomorphic province includes extensive alluvial basins with nonmarine sediments from the surrounding mountains and foothills; many isolated ephemeral lakebeds (also known as playas) occur within this region with tributary streams from isolated mountain ranges. The Mojave Desert Geomorphic Province includes portions of Kern, Los Angeles, Riverside, and San Bernardino Counties.

The Colorado Desert Geomorphic Province, or Salton Trough, is characterized by a geographically depressed desert that extends northward from the Gulf of California (located at the mouth of the Colorado River) toward the Mojave Desert Geomorphic Province where the Pacific and North American plates are separating (CGS 2002; SCAG 2011; RCIP 2000; San Diego County 2011). Large portions of this geomorphic province were formed by the inundation of the ancient Lake Cahuilla and are filled with sediments several miles thick from the historical Colorado River overflows and erosion of the Peninsular Ranges uplands. The Salton Trough is separated from the Gulf of California by a large ridge of sediment. The Salton Sea is within the trough along an ancient playa. The Colorado Desert Geomorphic Province includes portions of Riverside County in the Coachella Valley, and portions of San Diego County and Imperial County that are located outside of the study area.

X.2.4.2 *Seismicity*

CVP and SWP service areas in the Central Coast and Southern California are characterized by active faults that are capable of producing major earthquakes with substantial ground displacement. The San Andreas Fault Zone extends from the Gulf of California in a northwest direction throughout the central coast and Southern California regions (CGS 2006).

Within portions of San Luis Obispo County that use SWP water supplies, the Nacimiento Fault also can result in major seismic events (CGS 2006; San Luis Obispo County 2010).

The northern portions of Santa Barbara County that use SWP water supplies include Lion’s Head Fault along the Pacific Ocean shoreline to the southwest of Santa Maria and along the northern boundary of Vandenberg Air Force Base (CGS 2006; SBCAG 2013). The Big Pine Fault may extend into the Vandenberg Air Force Base area. Areas near the mouth of the Santa Ynez River and Point Arguello could be affected by Lompoc Terrace Fault and Santa Ynez-Pacifico Fault Zone. The Santa Ynez Fault extends across this county and could affect communities near Santa Ynez. Along the southern coast of Santa Barbara County from Goleta to Carpinteria, the area includes many active faults, including More Ranch, Mission Ridge, Arroyo Parida, and Red Mountain Faults, and potentially active faults, including Goleta, Mesa-Rincon, and Carpinteria Faults.

Portions of Ventura County that use SWP water supplies are located in the southern portion of the county adjacent to Los Angeles County. Major faults in this area are: Oak Ridge Fault, which extends into the Oxnard Plain along the south side of the Santa Clara River Valley and may extend into San Fernando Valley in Los Angeles County; Bailey Fault, which extends from the Pacific Ocean to the Camarillo Fault; Simi-Santa Rosa, Camarillo, and Springville Faults in Simi and Tierra Rejada Valleys and near Camarillo; and Sycamore Canyon and Boney Mountain Faults, which extend from the Pacific Ocean toward Thousand Oaks (CGS 2006; Ventura County 2011).

Los Angeles County major fault zones are: Northridge Hills, San Gabriel, San Fernando, Verduga, Sierra Madre, Raymond, Hollywood, Santa Monica, and Malibu Coast Fault Zones; Elysian Park Fold and Thrust Belt in Los Angeles County; and Newport, Inglewood, Whittier, and Palos Verdes Fault Zones, which extend into Los Angeles and Orange Counties (CGS 2006; City of Los Angeles 2005). Recent major seismic events that have occurred in Southern California along faults in Los Angeles are the 1971 San Fernando, 1987 Whittier Narrows, 1991 Sierra Madre, and 1994 Northridge earthquakes.

Riverside and San Bernardino Counties are characterized by the San Andreas Fault Zone that extends from the eastern boundaries of these counties and crosses to the western side of San Bernardino County (CGS 2006; RCIP 2000; SCAG 2011; DWR 2009). The San Jacinto Fault Zone also extends through the center of Riverside County and along the western side of San Bernardino County. The Elsinore Fault Zone extends along the western sides of both counties. In San Bernardino County, the Cucamonga Fault extends into Los Angeles County, where it intersects with the Sierra Madre and Raymond Faults. The Garlock and Lockhart Fault Zones extend into both San Bernardino and Kern Counties. San Bernardino County also includes several other major fault zones, including North Frontal and Helendale Faults.

Portions of San Diego County that use SWP water supplies include the Rose Canyon Fault Zone along the Pacific Ocean shoreline, extending into the city of San Diego (San Diego County 2011).

X.2.4.3 *Soil Characteristics*

In the Central Coast region, areas within San Luis Obispo and Santa Barbara Counties that use SWP water supplies are located within coastal valleys or along the Pacific Ocean shoreline. In San Luis Obispo County, Morro Bay, Pismo Beach, and Oceano along the coast have soils that range from sands and loamy sands in areas near the shoreline to shaley loams, clay loams, and clays in the terraces and foothills located along the eastern boundaries of these communities (SBCAG 2013; SCS 1984). In Santa Barbara County, the Santa Maria, Vandenberg Air Force Base, Santa Ynez, Goleta, Santa Barbara, and Carpinteria areas are in alluvial plains, along stream channels with alluvium deposits, along the shoreline, or along marine terrace deposits above the Pacific Ocean. The soils range from sands, sandy loams, loams, shaley loams, and clay loams in the alluvial soils and along the shoreline. The terrace deposits include silty clays, clay loams, and clays (SCS 1972; SCS 1981).

Southern California soils include gravelly loams and gravelly sands, sands, sandy loams and loamy sands, and silty loams along the Pacific Coast shorelines and on alluvial plains. The mountains and foothills of the region include silty loams, cobbly silty loam, gravelly loam, sandy clay loams, clay loams, silty clays, and clays (SCAG 2011; UCCE 2014; SCS 1978; SCS 1986; SCS 1973). The inland region in Riverside and San Bernardino Counties have sand, silty clays, cobbles, and boulders on the alluvial fans, valley floor, terraces, and mountains, and dry lake beds (CVWD 2011).

X.2.4.4 *Subsidence*

Subsidence in the Central Coast and Southern California regions occurs because of soil compaction following groundwater overdraft, oil and gas withdrawal, seismic activity, and hydroconsolidation of soils along alluvial fans (City of Los Angeles 2005). The USGS described areas with subsidence related to groundwater overdraft in the Central Coast and Southern California regions in San Luis Obispo, Santa Barbara, Los Angeles, Riverside, and Santa Bernardino Counties (USGS 1999; Ventura County 2011; City of Los Angeles 2005; RCIP 2000). Many of the areas with subsidence have alluvial unconsolidated sands and silty sands with lenses of silt and clayey silt.

A recent study by the USGS in the southern Coachella Valley portion of Riverside described land subsidence of about 0.5 feet between 1930 and 1996 (USGS 2013b). Groundwater elevations in this area had declined since the early 1920s until 1949, when water from the Colorado River was provided to the area. This area is served by Coachella Valley Water District; and as described in Appendix C surface water has not always been available to this area in recent years. The recent USGS study indicated that land subsidence of up to approximately 0.4 feet has occurred at some locations between 1996 and 2005, and possibly greater subsidence at other locations. A Coachella Valley Water District study indicated that up to 13 inches of subsidence have occurred in parts of the valley between 1996 and 2005 (CVWD 2011).

X.3 Evaluation of Alternatives

This section describes the technical background for the evaluation of environmental consequences associated with the action alternatives and the No Action Alternative.

X.3.1 Methods and Tools

Changes in CVP and SWP operations under the action alternatives compared to the No Action Alternative may result in changes to geology and soils resources. Changes in surface water deliveries may result in increased peak flow rates in rivers downstream of CVP and SWP reservoirs that could affect stream channel erosion. Changes in water deliveries and the extent of irrigated acreage has the potential for soil erosion on crop-idled lands over the long-term average condition and in dry and critically dry years. Changes in water delivery amounts may also result in increased use of groundwater resources to maintain cropping, which could affect land subsidence. Land subsidence is caused by the consolidation of certain subsurface soils when the pore pressure in those soils is reduced, usually caused by groundwater pumping that causes groundwater levels to fall below historical low levels. Changes in the water transfer program and restoration projects could also potentially affect soils.

Evaluation of changes in peak flow rates was taken from the surface water supply analysis conducted using the CalSim II model, as described in Appendix F, *Modeling*, to simulate the operational assumptions of each alternative that were described in Chapter 3, *Alternatives*. The CalSim II results were used to evaluate changes in peak flows under the action alternatives compared to the No Action Alternative with regards to potential effects of stream channel erosion. The No Action Alternative and action alternatives are analyzed under future conditions, so this model run also includes median climate change projections. Additionally, other resources include resource-specific models, such as groundwater and water quality modeling.

The analysis of land use changes, as described in Appendix R, was used to identify potential changes in irrigated acreage as a result in changes to water deliveries under the alternatives compared to the No Action Alternative, to evaluate potential effects on soil erosion. The groundwater analysis, as described in Appendix I, *Groundwater Technical Appendix*, was used to describe the characterize project effects upon land subsidence.

Water transfer programs have been historically developed on an annual basis. The demand for water transfers is dependent upon the availability of water supplies to meet water demands. Water transfers would occur within the normal operational elevations of the affected reservoirs and at flows less than peak flows in affected conveyance reaches, and as such, soil erosion would not be a concern for the reservoirs or transfer conveyance reaches, therefore, these changes are not analyzed further in this EIS.

X.3.2 No Action Alternative

Under the No Action Alternative, current CVP and SWP operations would continue. Flows and reservoir levels would remain as under current conditions. No additional habitat restoration or fish intervention actions are proposed, and thus no new construction is proposed.

X.3.3 Alternative 1

X.3.3.1 *Project-Level Effects*

Potential changes in soil erosion.

X.3.3.1.1 Trinity River Region

No changes in peak flows are expected in the Trinity River below Lewiston under Alternative 1 compared to the No Action Alternative, therefore, no changes in stream channel erosion are expected.

Regarding changes in irrigated acreage, as described in Appendix R, no agricultural lands in the Trinity River area are served by CVP and SWP water supplies under Alternative 1 compared to the No Action Alternative. As a result, the Trinity River region was not included in the Statewide Agricultural Production (SWAP) model used to evaluate effects of the project upon irrigated acreage. Therefore, no conversion of agricultural land or crop idling is anticipated. Soil erosion due to changes in irrigated acreage is not affected by CVP or SWP activity.

X.3.3.1.2 Sacramento Valley

No changes in peak flows are expected in the affected stream reaches for the Sacramento River, Clear Creek, Feather River, and American River under Alternative 1 compared to the No Action Alternative, therefore, stream channel erosion would not occur in these areas.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, typically January through March. Peak flows through the Yolo Bypass are expected to increase by 1% under Alternative 1 compared to the No Action Alternative, between the January peak of approximately 151,000 cubic feet per second (cfs) to the February peak of approximately 152,600 cfs. This minor increase in winter flood flows through the Yolo Bypass is negligible given the low channel gradient, large cross-sectional area for flow and low flow velocities at the margins of the bypass, and is not expected to result in a change in erosion.

As described in Appendix R, compared to the No Action Alternative in the Sacramento Valley, crop acreage would decrease by approximately 1,000 acres in both the average and dry conditions under Alternative 1. Although some conversion of agricultural land to nonagricultural uses could occur in the Sacramento Valley over time, the area affected is relatively small. Also, crops are modeled to shift from water-intensive crops to less water-intensive crops, which may reduce the total acreage subjected to crop idling. As suggested in Appendix R, Mitigation Measures AG-1 and AG-2 could reduce the effects of conversion of agricultural land to nonagricultural use. As a result, erosion due to crop idling is not expected to occur.

X.3.3.1.3 San Joaquin Valley

No changes in peak flows are expected in the affected stream reaches for the San Joaquin River and Stanislaus River under Alternative 1 compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area.

At Old and Middle Rivers within the San Joaquin River area of the Delta, flow rates on average will be less under Alternative 1, compared to the No Action Alternative. The relatively minor changes in flow will not result in notable changes to the rate of erosion. Regarding changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows on average would increase in this region under Alternative 1 compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

With regards to changes in irrigated acreage, as described in Appendix R, in both the average and dry conditions in the San Joaquin River region under Alternative 1 crop acreages are expected to increase, compared to the No Action Alternative. Therefore, soil erosion caused by agricultural land conversion or crop idling is not expected to occur.

X.3.3.1.4 <u>Bay-Delta Region</u>

No changes in peak flows are expected in the Bay-Delta region under Alternative 1 compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area.

No changes in peak flows are expected in the Suisun Marsh or the San Francisco Bay under Alternative 1; therefore, there is no expected change to erosion rates.

Alternative 1 includes some elements in the Summer-Fall Delta Smelt Habitat action that could vary year-to-year. The action could include operations of the SMSCG in some years or a fall action to maintain the X2 position at 80 km in some above normal and wet years. Both of these actions would require water and affect CVP and SWP operations, but the frequency of these actions is not specifically defined. The modeling of Alternative 1 in in this appendix does not include these actions. Generally, the potential impacts and benefits of Alternative 1 could range between what is described in Chapter 5, *Environmental Consequences*, and the No Action Alternative, which includes a Fall X2 action.

X.3.3.1.5 <u>CVP and SWP Service Areas</u>

There are no affected stream reaches in the CVP and SWP service areas, therefore, erosion as a result in changes to flow is not a concern in these areas.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows would increase in this region under Alternative 1 compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

Potential changes in rate of land subsidence due to increased use of groundwater.

X.3.3.1.6 <u>Trinity River Region</u>

As described in Appendix I, the area along the Trinity River is not known to be susceptible to subsidence and groundwater pumping is not expected to increase in this region, therefore, changes in land subsidence is not a concern in this area.

X.3.3.1.7 <u>Sacramento Valley</u>

As described in Appendix I, groundwater levels are generally not expected to decrease in the Sacramento Valley (containing the watersheds of the Sacramento River, Clear Creek, Feather River, and American River) under Alternative 1 compared to the No Action Alternative, therefore, it is unlikely that additional land subsidence would occur.

X.3.3.1.8 <u>San Joaquin Valley</u>

As described in Appendix I, groundwater levels are generally not expected to decrease in the San Joaquin Valley (containing the watersheds of the San Joaquin River and Stanislaus River) under Alternative 1 compared to the No Action Alternative. Therefore, it is unlikely that additional land subsidence would occur.

X.3.3.2 *Program-Level Effects*

A single potential effect was identified for program-level effects for Alternative 1.

Potential temporary change in soil mobilization.

Restoration of seasonal floodplains and tidally influenced wetlands could potentially affect soils resources at the restoration locations. The following program-level projects were identified that may result in temporary soil alteration or disturbance:

- Upper Sacramento River Spawning and Rearing Habitat Restoration
- American River Spawning and Rearing Habitat Restoration
- Stanislaus River Spawning and Rearing Habitat Restoration
- Lower San Joaquin River Habitat Program
- Tidal Habitat Restoration (8,000 acres)

Although soils may be affected during construction, all necessary permits required for construction would be obtained to minimize any short-term adverse effects, whereas the long-term effects of restoration are expected to be stabilizing and beneficial to soils. Therefore, these changes are not analyzed further in this EIS.

X.3.4 Alternative 2

X.3.4.1 *Project-Level Effects*

Potential changes in soil erosion.

X.3.4.1.1 Trinity River Region

No changes in peak flows are expected in the Trinity River below Lewiston Dam under Alternative 2 compared to the No Action Alternative; therefore, stream channel erosion will not be a concern in this area.

Regarding changes in irrigated acreage, as described in Appendix R, no agricultural lands in the Trinity River area are served by CVP and SWP water supplies under Alternative 2 compared to the No Action Alternative. As a result, the Trinity River region was not included in the SWAP model used to evaluate effects of the project upon irrigated acreage. Therefore, no conversion of agricultural land or crop idling is anticipated. Soil erosion due to changes in irrigated acreage is not affected by CVP or SWP activity.

X.3.4.1.2 Sacramento Valley

No changes in peak flows are expected in the affected stream reaches for the Sacramento River, Clear Creek, Feather River, and American River under Alternative 2 compared to the No Action Alternative; therefore, stream channel erosion would not occur in these areas.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, typically January through March. Peak flows through the Yolo Bypass are expected to increase by 1% under Alternative 2 compared to the No Action Alternative, between the January peak of approximately 151,000 cfs to the February peak of approximately 152,600 cfs. This minor increase in winter flood flows through the Yolo Bypass is negligible given the low channel gradient, large cross-sectional area for flow and low flow velocities at the margins of the bypass, and is unlikely to result in a potential impact.

As described in Appendix R, compared to the No Action Alternative in the Sacramento Valley area, crop acreage would decrease by approximately 100 acres in the average condition and increases by 250 acres in the dry condition under Alternative 2. Although some conversion of agricultural land to nonagricultural uses could occur in the Sacramento River region over time, the area affected is relatively small. Also, crops are modeled to shift from water-intensive crops to less water-intensive crops, which may reduce the total acreage subjected to crop idling. As suggested in Appendix R, Mitigation Measures AG-1 and AG-2 could reduce the effects of conversion of agricultural land to nonagricultural use. As a result, erosion due to crop idling is not expected to result in any notable impact or change.

X.3.4.1.3 San Joaquin Valley

No changes in peak flows are expected in the affected stream reaches for the San Joaquin River and Stanislaus River under Alternative 2 compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area.

At Old and Middle Rivers within the San Joaquin River system, flow rates on average will be less under Alternative 2, compared to the No Action Alternative. The relatively minor changes in flow will not result in notable changes to the rate of erosion.

With regards to changes in irrigated acreage, as described in Appendix R, in both the average and dry conditions in the San Joaquin River region under Alternative 2 crop acreages are expected to increase, compared to the No Action Alternative. Therefore, soil erosion caused by agricultural land conversion or crop idling would not occur.

X.3.4.1.4 Bay-Delta Region

No changes in peak flows are expected in the Bay-Delta under Alternative 2, compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area. No changes in peak flows are expected in the Suisun Marsh or the San Francisco Bay under Alternative 2; therefore, there is no expected change to erosion rates.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows on average would increase in this region under Alternative 2 compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

X.3.4.1.5 CVP and SWP Service Areas

There are no affected stream reaches associated with the Central Coast or Southern California regions, therefore, erosion as a result in changes to flow is not a concern in this area.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows would increase in this region under Alternative 2 compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

Potential changes to land subsidence

X.3.4.1.6 Trinity River Region

As described in Appendix I, the area along the Trinity River is not known to be susceptible to subsidence and groundwater pumping is not expected to increase in this region, therefore, subsidence is not be a concern in this area.

X.3.4.1.7 Sacramento Valley

As described in Appendix I, groundwater levels are generally not expected to decrease in the Sacramento Valley (containing the watersheds of the Sacramento River, Clear Creek, Feather River, and American River) under Alternative 2 compared to the No Action Alternative, therefore, it is unlikely that additional land subsidence would occur.

X.3.4.1.8 San Joaquin Valley

As described in Appendix I, groundwater levels are generally not expected to decrease in the San Joaquin Valley (containing the watersheds of the San Joaquin River and Stanislaus River) under Alternative 2 compared to the No Action Alternative. Therefore, it is unlikely that additional land subsidence would occur.

X.3.4.2 *Program-Level Effects*

Program-related potential effects to geology and soil resources were not identified for Alternative 2.

X.3.5 Alternative 3

X.3.5.1 *Project-Level Effects*

Potential change in soil erosion

X.3.5.1.1 Trinity River Region

No changes in peak flows are expected in the Trinity River below Lewiston Dam under Alternative 3 compared to the No Action Alternative; therefore, stream channel erosion is not a potential impact as a result of implementing Alternative 3.

Regarding changes in irrigated acreage, as described in Appendix R, no agricultural lands in the Trinity River area are served by CVP and SWP water supplies under Alternative 3 compared to the No Action Alternative. As a result, the Trinity River region was not included in the SWAP model used to evaluate effects of the project upon irrigated acreage. Therefore, no conversion of agricultural land or crop idling is anticipated. Soil erosion due to changes in irrigated acreage is not affected by CVP or SWP activity.

X.3.5.1.2 Sacramento Valley

No changes in peak flows are expected in the affected stream reaches for the Sacramento River, Clear Creek, Feather River, and American River under Alternative 3, compared to the No Action Alternative; therefore, stream channel erosion would not occur in these areas.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, typically January through March. Peak flows through the Yolo Bypass are expected to increase by 1% under Alternative 3, compared to the No Action Alternative, between the January peak of approximately 151,000 cfs to the February peak of approximately 152,600 cfs. This minor increase in winter flood flows through the Yolo Bypass are negligible given the low channel gradient, large cross-sectional area for flow and low flow velocities at the margins of the bypass, and is unlikely to result in a potential impact.

As described in Appendix R, compared to the No Action Alternative in the Sacramento Valley area, crop acreage would decrease by approximately 200 acres in the average condition and by 3 acres in the dry condition under Alternative 3. Although some conversion of agricultural land to nonagricultural uses could occur in the Sacramento River region over time, the area affected is relatively small. Also, crops are modeled to shift from water-intensive crops to less water-intensive crops, which may reduce the total acreage subjected to crop idling. As suggested in Appendix R, Mitigation Measures AG-1 and AG-2 could reduce the effects of conversion of agricultural land to nonagricultural use. As a result, erosion due to crop idling is not expected to notably change.

X.3.5.1.3 San Joaquin Valley

No changes in peak flows are expected in the affected stream reaches for the San Joaquin River and Stanislaus River under Alternative 3, compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area.

At Old and Middle Rivers within the San Joaquin River system, flow rates on average will be less under Alternative 3 compared to the No Action Alternative; however, peak flows during January under Alternative 3 will be increased from approximately 30,000 cfs under the No Action Alternative to almost 42,000 cfs, an increase in peak flow of almost 40% during that month.

With regards to changes in irrigated acreage, as described in Appendix R, in both the average and dry conditions in the San Joaquin River region under Alternative 3, crop acreages are expected to increase, compared to the No Action Alternative. Therefore, soil erosion caused by agricultural land conversion or crop idling would not occur.

X.3.5.1.4 Bay-Delta Region

As mentioned above, a minor increase in flow under Alternative 3 is expected through the Delta during January; however, this increase is well below peak flows during winter flood events through the Bay-Delta, therefore, erosion is not a substantial concern in this area. The increase in flow in January would be far less than flood flows during major winter storm events, and given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of Suisun Marsh, this increase in peak flow under Alternative 3 will not result in notable erosion in this area.

Under Alternative 3, an increase in peak flows of approximately 4% is expected during the month of January, compared to the No Action Alternative. This minor increase in flow in January would be far less than flood flows during major winter storm events, and given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of the Delta, this minor increase in peak flow under Alternative 3 is not likely to result in a potential impact.

As discussed in Appendix H, *Water Supply Technical Appendix,* hydrological conditions in the Delta and Suisun Marsh are substantially affected by structures that route water through the Delta toward the major Delta water diversions in the south Delta, including the CVP Jones Pumping Plant, the SWP Banks Pumping Plant, the Delta-Mendota Canal/California Aqueduct Intertie, the CVP Contra Costa Canal Pumping Plant at Rock Slough, and the Contra Costa Water District (CCWD) intakes on Old and Middle Rivers. As a result, the Old and Middle Rivers area is located in a highly disturbed area, and the effects of

1 month of increased peak flows during the winter under Alternative 3 is not a substantial concern with respect to erosion.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows on average would increase in this region under Alternative 3, compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

X.3.5.1.5 CVP and SWP Service Areas

There are no affected stream reaches associated with the Central Coast or Southern California regions, therefore, erosion as a result of changes to flow is not a concern in this area.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows would increase in this region under Alternative, compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

Potential changes in rate of land subsidence due to increased use of groundwater.

X.3.5.1.6 Trinity River Region

As described in Appendix I, the area along the Trinity River is not known to be susceptible to subsidence and groundwater pumping is not expected to increase in this region, therefore, subsidence is not be a concern in this area.

X.3.5.1.7 Sacramento Valley

As described in Appendix I, groundwater levels are generally not expected to decrease in the Sacramento Valley (containing the watersheds of the Sacramento River, Clear Creek, Feather River, and American River) under Alternative 3 compared to the No Action Alternative, therefore, it is unlikely that additional land subsidence would occur.

X.3.5.1.8 San Joaquin Valley

As described in Appendix I, groundwater levels are generally not expected to decrease in the San Joaquin Valley (containing the watersheds of the San Joaquin River and Stanislaus River) under Alternative 3 compared to the No Action Alternative. Therefore, it is unlikely that additional land subsidence would occur.

X.3.5.2 *Program-Level Effects*

A single potential effect was identified for program-level effects for Alternative 3.

Potential temporary change in soil mobilization

Restoration of seasonal floodplains and tidally influenced wetlands could potentially affect soils resources at the restoration locations. The following program-level projects were identified that may result in temporary soil alteration or disturbance:

- Upper Sacramento River Spawning and Rearing Habitat Restoration

- American River Spawning and Rearing Habitat Restoration
- Stanislaus River Spawning and Rearing Habitat Restoration
- Lower San Joaquin River Habitat Program
- Tidal Habitat Restoration (8,000 acres)
- Additional Delta Habitat Restoration (25,000 acres)

Although soils may be affected during construction, all necessary permits required for construction would be obtained to minimize any short-term adverse effects, whereas the long-term effects of restoration are expected to be stabilizing and beneficial to soils. Therefore, these changes are not analyzed further in this EIS.

X.3.6 Alternative 4

X.3.6.1 *Project-Level Effects*

Potential changes in soil erosion

X.3.6.1.1 Trinity River Region

Notable changes in peak flows are not expected in the Trinity River below Lewiston under Alternative 4 compared to the No Action Alternative, therefore, no changes in stream channel erosion are expected.

Regarding changes in irrigated acreage, as described in Appendix R, no agricultural lands in the Trinity River area are served by CVP and SWP water supplies under Alternative 4 compared to the No Action Alternative. As a result, the Trinity River region was not included in the SWAP model used to evaluate effects of the project upon irrigated acreage. Therefore, no conversion of agricultural land or crop idling is anticipated. Soil erosion due to changes in irrigated acreage is not affected by CVP or SWP activity.

X.3.6.1.2 Sacramento Valley

Project-level action alternatives would change operations of the CVP and SWP, as described in Appendix F. The changes to CVP and SWP operations would change river flows and reservoir levels. Increases in peak flows are expected in the affected stream reaches for the Sacramento River, Clear Creek, Feather River, and American River under Alternative 4 compared to the No Action Alternative. The increases will maintain higher flows generally in the February through June period, where it is common for seasonal discharge to increase naturally. Average annual deliveries to all contract delivery types with the exception of CVP Refuge Level 2 deliveries and deliveries to the SWP Feather River Service Area would decrease. These reductions in average annual deliveries would be less than 5% and are considered similar to conditions under the No Action Alternative. Minor fluctuations of up to 5% due to model assumptions and approaches and changes 5% or less are considered “similar” to conditions under the No Action Alternative. While the generally higher releases and reduced deliveries from these rivers are notably increased, the overall peak discharge is well-within normally occurring flow and will not likely result in mobilizing sediment or increasing erosion.

As described in Appendix R, compared to the No Action Alternative in the Sacramento Valley, crop acreage would decrease by approximately 2,427 acres during dry conditions and remain relatively similar to the No Action Alternative during under normal conditions under Alternative 4. Some conversion of agricultural land to nonagricultural uses could occur in the Sacramento Valley over time. Also, crops are modeled to shift from water-intensive crops to less water-intensive crops, which may reduce the total acreage subjected to crop idling. As suggested in Appendix R, Mitigation Measures AG-1 and AG-2 could reduce the effects of conversion of agricultural land to nonagricultural use. As a result, erosion due to crop idling may increase and could be offset to a degree by conversion or mitigation; however, the sizable amount of decreased acreage may still result in increased erosion.

X.3.6.1.3 San Joaquin Valley

No changes in peak flows are expected in the affected stream reaches for the San Joaquin River and Stanislaus River under Alternative 4 compared to the No Action Alternative; therefore, stream channel erosion would not occur in this area.

With regards to changes in irrigated acreage, as described in Appendix R, in both the dry (12,333 ac reduction) and average (5,578 ac reduction) conditions in the San Joaquin River region notable reductions would occur under Alternative 4, compared to the No Action Alternative. Therefore, soil erosion caused by agricultural land conversion or crop idling may occur. As suggested in Appendix R, Mitigation Measures AG-1 and AG-2 could reduce the effects of conversion of agricultural land to nonagricultural use.

At Old and Middle Rivers within the San Joaquin River area of the Delta, flow rates on average will be somewhat similar under Alternative 4, compared to the No Action Alternative. The trend between Alternative 4 and the No Action Alternative is relatively similar with mild differences varying from increases and reduction over the year. The most notable differences occur from mid-February through early Aprils when greater flow is present under Alternative 4. Nonetheless, the differences are not sufficient to result in a notable change to the rate of erosion. Regarding changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP, but flows do periodically increase in this region under Alternative 4 compared to the No Action Alternative. Regardless, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

X.3.6.1.4 Bay-Delta Region

The Bay-Delta region will experienced increased outflow from February through May when compared to the No Action Alternative. Differences are highest in March, were average increased outflow can approach a 5,000 cfs or 10 percent increase. While the increase in flow is not insubstantial, the Delta is a broad and complex area that regularly sees varied flow and stage. It is unlikely that significant increases in erosion would occur.

Similarly, the increased outflow may result in higher flow through the Suisun Marsh or the San Francisco Bay under Alternative 4, but is not anticipated to increase erosion.

X.3.6.1.5 CVP and SWP Service Areas

There are no affected stream reaches in the CVP and SWP service areas, therefore, erosion as a result in changes to flow is not a concern in these areas.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows would increase in this region under Alternative 4 compared to the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

Potential changes in rate of land subsidence due to increased use of groundwater

X.3.6.1.6 Trinity River Region

As described in Appendix I, the area along the Trinity River is not known to be susceptible to subsidence and groundwater pumping is not expected to increase in this region, therefore, changes in land subsidence is not a concern in this area.

X.3.6.1.7 Sacramento Valley

As described in Appendix I, compared with the No Action Alternative, Alternative 4 is expected to result in surface water supply to the Sacramento Valley increasing and decreasing, depending on the year. An increase in supply, especially when made to meet agricultural demands, will result in a decrease in the need for groundwater pumping to meet demands. A decrease in supply may result in an increase in groundwater pumping. Most of the change is not expected to occur in the Sacramento Valley. Modeled simulation show that the change in groundwater-surface water interaction is 0.7 percent (reduced flow from groundwater to surface water) in Alternative 4 compared with the No Action Alternative. Subsidence as a result of groundwater pumping is not expected.

X.3.6.1.8 San Joaquin Valley

As described in Appendix I, compared with the No Action Alternative, Alternative 4 is expected to result in surface water supply to the San Joaquin Valley increasing and decreasing, depending on the year. An increase in supply, especially when made to meet agricultural demands, will result in a decrease in the need for groundwater pumping to meet demands. A decrease in supply may result in an increase in groundwater pumping. Most of the change in pumping is expected to be in the San Joaquin Valley. Modeled simulation show that the change in groundwater-surface water interaction is 0.7 percent (reduced flow from groundwater to surface water) in Alternative 4 compared with the No Action Alternative. Subsidence as a result of groundwater pumping is not expected.

X.3.6.2 *Program-Level Effects*

Program-related potential effects to geology and soil resources were not identified for Alternative 4.

X.3.7 Summary of Impacts

Table X.3-1, Impact Summary, includes a summary of impacts, the magnitude and direction of those impacts, and potential mitigation measures for consideration.

Table X.3-1. Impact Summary

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
Potential changes in soil erosion (Project-Level)	No Action	No Impact	–
	Alternative 1	No Impact	–
	Alternative 2	No Impact	–

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
	Alternative 3	Increased January Delta flow is a minor change overall, but may result in up to 40% increases in specific areas. Overall change is expected to result in negligible differences.	–
	Alternative 4	Increase in releases from Sacramento Valley tributaries will occur, but well within the standard bounds of operational peak flows. Delta outflow will also increase, but overall differences are expected to result in negligible differences in the potential for increased erosion from outflow. Reduction in crop acreage may lead to increased erosion. Construction and restoration on agricultural land could result in conversion.	MM AG-1 and MM AG-2
Potential changes in rate of land subsidence due to increased use of groundwater (Project-Level)	No Action	No Impact	–
	Alternative 1	No Impact	–
	Alternative 2	No Impact	–
	Alternative 3	Increased January Delta flow is a minor change overall, but may result in up to 40% increases in specific areas. Overall change is expected to result in negligible differences.	–
	Alternative 4	A mix of increases and decreases in groundwater pumping may occur. Differences compared to the No Action Alternative for the Sacramento and San Joaquin valleys are unlikely to lead to subsidence.	–
Potential temporary change in soil mobilization (Program-Level)	No Action	No Impact	–
	Alternative 1	Short-term effects addressed through project-specific permitting requirements. Long-term effects expected to be beneficial.	–
	Alternative 2	No Impact	–
	Alternative 3	Short-term effects addressed through project-specific permitting requirements. Long-term effects expected to be beneficial.	–
	Alternative 4	No Impact	–

X.3.8 Cumulative Effects

As described in Appendix Y, *Cumulative Methodology*, the cumulative effects analysis considers projects, programs, and policies that are not speculative and that are based upon known or reasonably foreseeable long-range plans, regulations, operating agreements, or other information that establishes them as reasonably foreseeable.

Potential change in water supply leading to subsidence or erosion

Climate change and sea-level rise, development under the general plans, FERC relicensing projects, and some future projects to improve water quality and/or habitat are anticipated to reduce carryover storage in reservoirs and create changes in stream flow patterns. These changes could reduce the availability of water to meet current demands as well as future demands for water in the summer and fall months. Reduced CVP and SWP water deliveries could also reduce the amount of irrigated acreage, thereby potentially increasing the incidence of crop idling and associated soil erosion, and/or increasing the demand for groundwater to maintain cropping patterns, which may affect land subsidence. Climate change may also increase the frequency and magnitude of storm events that occur with a greater fraction of rainfall compared to snowfall, thereby resulting in increased runoff and peak flood flows and decreased snowpack and snowmelt, which could increase stream channel erosion during the winter and decrease water supply in the summer and fall months for irrigation. Future water supply projects are anticipated to both improve water supply reliability due to reduced surface water supplies and to accommodate planned growth in the general plans.

Implementation of No Action Alternative and reasonably foreseeable actions would result in changes in stream flows and related changes in groundwater use patterns, and reduced CVP and SWP water supplies. If CVP and SWP water supply reliability decreases, demand for alternative water supplies could increase reliance on groundwater, resulting in potential land subsidence effects.

Alternative 1 would not result in notable change to water deliveries. In the case of cumulative projects anticipated to potentially generate temporary reductions in water deliveries, the Alternative 1 improvement to water supply deliveries for many water users would help to reduce the severity of any potential cumulative effect, which would maintain irrigated crops and reduce erosion and likely subsidence from less groundwater pumping. For those users who would not see improvements in water supply deliveries under this alternative, the potential changes in water supply deliveries under this alternative would not contribute to any cumulative water supply impacts because of Alternative 1's similarity to the No Action Alternative. Large amounts of restoration would occur under Alternative 1. These, in combination with restoration actions proposed under the cumulative projects, would result in temporary effect mitigated through permitting and likely result in long-term benefits.

Notable change to water deliveries would also not occur under Alternative 2. In the case of cumulative projects anticipated to potentially generate temporary reductions in water deliveries, the Alternative 2 improvement to water supply deliveries for many water users would help to reduce the severity of any potential cumulative effect, which would maintain irrigated crops and reduce erosion and likely subsidence from less groundwater pumping. For those users who would not see improvements in water supply deliveries under this alternative, the potential changes in water supply deliveries would not contribute to any cumulative water supply impacts because of Alternative 1's similarity to the No Action Alternative. Restoration actions are not proposed under Alternative 2.

Under Alternative 3, there may be changes in irrigated agriculture only through reduced flows to the Sacramento Valley region. Increased flows would be observed in the Delta during specific time periods (i.e., January). While some revision to flow quantity and delivery would occur, the differences to those flows would not result in substantial or notable change leading to contribution of cumulative impacts. Large amounts of restoration would occur under Alternative 3. This restoration, in combination with restoration actions under the cumulative projects, would result in temporary effects mitigated through permitting and would likely result in long-term benefits.

Alternative 4 would result in increased releases largely from Sacramento Valley tributaries and result in lowered deliveries for San Joaquin River and Delta water users. Total Delta deliveries would reduce overall, but the general trend of deliveries is similar to the No Action Alternative. The reductions will result in some shortages of water deliveries and increased groundwater usage. Reductions in crops will follow the reduced water deliveries and may result in increased erosion. Conversion of agricultural land and increased storage long-term may alleviate some of the potential impact.

X.4 References

Angell, B., R. Fisher, and R. Whipple. 2013. *Sherman Island Delta Project—Case Study Report*. Ante Meridiem Incorporated. Available: http://www.delta-alliance.org/media/default.aspx/emma/org/10838387/Case+Study+Report+Sherman+Island+Delta+Project.pdf. Accessed: March 25, 2019.

Atwater, B. F., and D. F. Belknap. 1980. Tidal-wetland Deposits of the Sacramento–San Joaquin Delta, California. In *Quaternary Depositional Environments of the Pacific Coast*, 89–103. Proceedings of the Pacific Coast Paleogeography, Symposium 4, eds. M. E. Field, A. H. Bouma, I. P. Colburn, R. G. Douglas, and J. C. Ingle. Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles.

CALFED Bay-Delta Program (CALFED). 2000. *Final Programmatic Environmental Impact Report/Environmental Impact Statement*. July. Sacramento.

CALFED Bay-Delta Program (CALFED). 2001. *A Framework for the Future: Yolo Bypass Management Strategy*. August.

California Department of Conservation, California Geological Survey (CGS). 2002. *California Geomorphic Provinces Note 36*.

California Department of Conservation, California Geological Survey (CGS). 2006. *Simplified Geologic Map of California*.

California Department of Conservation, California Geological Survey (CGS). 2008. *Earthquake Shaking Potential*.

California Department of Conservation, California Geological Survey (CGS). 2010. *Geological Map of California.*

California Department of Fish and Game (CDFG). 2008. *Yolo Bypass Wildlife Area, Land Management Plan.* Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84924&inline. Accessed: April 2019.

City of Davis (in association with University of California, Davis, and City of Woodland). 2007. *Davis-Woodland Water Supply Project, Draft Environmental Impact Report.* April.

City of Los Angeles, Department of Public Works. 2005. *Integrated Resources Plan, Draft Environmental Impact Report*. November.

Clark W. B. 1970. *Gold Districts of California*: California Division of Mines and Geology Bulletin 193, 186 p.

Coachella Valley Water District (CVWD). 2011. *Coachella Valley Water Management Plan 2010 Update, Administrative Draft Subsequent Program Environmental Impact Report*. July.

DeCourten, F. (2008), Geology of Northern California, 48 pp. Available: http://www.cengage.com/custom/regional_geology.bak/data/DeCourten_0495763829_LowRes_New.pdf. Accessed: May 7, 2019.

Deverel, S., and D. Leighton. 2010. Historic, Recent, and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. *San Francisco Estuary and Watershed Science* 8(2) pp. 23.

Drexler, J. Z., C. S. de Fontaine, and S. J. Deverel. 2009. The Legacy of Wetland Drainage on the Remaining Peat in the Sacramento-San Joaquin Delta, California, USA. *Wetlands* 29(1): 372–386.

California Department of Water Resources (DWR). 2007. *Draft Environmental Impact Report Oroville Facilities Relicensing—FERC Project No. 2100*. May.

California Department of Water Resources (DWR). 2009. *East Branch Extension Phase II, Final Environmental Impact Report*. January.

California Department of Water Resources (DWR), Bureau of Reclamation, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. 2013. *Bay Delta Conservation Plan, Draft Environmental Impact Report/Environmental Impact Statement. Chapter 9 Geology and Seismicity Maps*. November. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit4/docs/Public_Draft_BDCP_EIR-EIS_Chapter_9_-_Figures.sflb.pdf. Accessed: October 29, 2019.

California Department of Water Resources (DWR) and U.S. Geological Survey (USGS). 2008. *Twitchell Island Wetland Research.* Available: https://water.ca.gov/LegacyFiles/deltainit/docs/research_factsheet.pdf. Accessed: October 29, 2019.

California North Coast Regional Water Quality Control Board (NCRWQCB) and U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2009. *Channel Rehabilitation and Sediment Management for Remaining Phase 1 and Phase 2 Sites, Draft Master Environmental Impact Report and Environmental Assessment*. June.

Ferriz, H. 2001. Groundwater Resources of Northern California: An Overview. *Engineering Geology Practice in Northern California: Association of Engineering Geologists Special Publication 12 and California Division of Mines and Geology Bulletin 210*.

Galloway, D., and F. S. Riley, U.S. Geological Survey. 1999. *San Joaquin Valley, California, Largest Human Alteration of the Earth's Surface*. In Galloway, D. L., Jones, D. R., and Ingebritsen, S. E., eds., Land Subsidence in the United States: U.S. Geological Survey Circular 1182, p. 23–34.

Geotechnical Consultants, Inc. (GCI). 2003. *Environmental Conditions, Geology, Folsom Lake State Recreation Area*. April.

Helley, E. J., and D. S. Harwood. 1985. Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, 24 p., scale 1:62,500, 5 sheets.

Humboldt County. 2012. *Humboldt 21st Century General Plan Update, Draft Environmental Impact Report*. April 2. Available: http://co.humboldt.ca.us/countycode/t6-div3.pdf.

Ingebritsen, S. E., and D. R. Jones, U.S. Geological Survey. 1999. *Santa Clara Valley, California, A Case of Arrested Subsidence*. In Galloway, D. L., Jones, D. R., and Ingebritsen, S. E., eds., Land Subsidence in the United States: U.S. Geological Survey Circular 1182, p. 23–34.

Riverside County Integrated Project (RCIP). 2000. *Existing Setting Report*. Prepared by LSA Associates, Inc. March.

Rojstaczer, S. A., R. E. Hamon, S. J. Deverel, and C. A. Massey. 1991. *Evaluation of selected data to assess the causes of subsidence in the Sacramento San Joaquin Delta. California: U.S. Geological Survey Open-File Report 91-193*, 16 pp.

Sacramento County. 2010. *Sacramento County General Plan Update, Final Environmental Impact Report*. April.

San Diego County. 2011. *San Diego County General Plan Update, Final Environmental Impact Report*. August.

San Luis Obispo County. 2010. *County of San Luis Obispo General Plan, Conservation and Open Space Element, Appendix 7, Open Space Resources*. May.

Santa Barbara County Association of Governments (SBCAG). 2013. *2040 Santa Barbara County Regional Transportation Plan and Sustainable Communities Strategy, Draft Environmental Impact Report*. May.

Shlemon, R. J., and E. L. Begg. 1975. *Holocene Evolution of the Sacramento–San Joaquin Delta, California. International Union for Quaternary Research* Sponsored by the Royal Society of New Zealand.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1972. Soil Survey of Northern Santa Barbara Area, California. Available: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/california/CA672/0/ca_Northern_SB.pdf. Accessed: October 29, 2019.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station, U.S. Department of the Interior, Bureau of Indian

Affairs, Department of the Navy, and U.S. Marine Corps. 1973. *Soil Survey San Diego Area, California*. December.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1977. *Soil Survey of Contra Costa County, California*.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1978. *Soil Survey of Orange County and Western Part of Riverside County, California*.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1981. *Soil Survey-Santa Barbara County, California, Coastal Part*. Available: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/california/CA673/0/ca_SB_Coastal.pdf. Accessed: October 29, 2019.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1984. *Soil Survey-San Luis Obispo County, California, Coastal Part*. Available: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/california/sanluiscoastalCA1984/sanluiscoastalCA1984. Accessed: October 29, 2019.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station. 1986. *Soil Survey of San Bernardino County, California, Mojave River Area*.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station and California Department of Conservation. 1992. *Soil Survey of San Joaquin County, California*. October. Available: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/california/CA077/0/san%20joaquin.pdf. Accessed: October 29, 2019.

Soil Conservation Service (SCS), U.S. Department of Agriculture, in cooperation with University of California Agricultural Experiment Station). 1993. *Soil Survey of Sacramento County, California*. April. Available: https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/california/CA067/0/sacramento.pdf.

Southern California Association of Governments (SCAG). 2011. 2012–2035 *Regional Transportation Plan/Sustainable Communities Strategy Draft Program Environmental Impact Report*.

University of California Cooperative Extension (UCCE). 2014. *University of California Cooperative Extension, Agricultural and Natural Resources Ventura County, General Soil Map*. Available: http://ceventura.ucanr.edu/Com_Ag/Soils. Accessed: March 25, 2019.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 1997. *Central Valley Project Improvement Act, Draft Programmatic Environmental Impact Statement*. September.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2005a. *Long-Term Renewal of Water Service Contracts in the Black Butte Unit, Corning Canal Unit, and Tehama-Colusa Canal*

Unit of the Sacramento River Division, Central Valley Project, California, Final Environmental Assessment. February.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2005b. *Central Valley Project Long-Term Water Service Contract Renewal American River Division Environmental Impact Statement*. June.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2005c. *San Luis Drainage Feature Re-evaluation Draft Environmental Impact Statement*. May.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2005d. *Central Valley Project Long-Term Water Service Contract Renewal San Luis Unit, Public Draft Environmental Impact Statement and Appendices*. September.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2009. *Delta-Mendota Canal/California Aqueduct Intertie Draft Environmental Impact Statement*. July.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2010. *New Melones Lake Area, Final Resource Management Plan and Environmental Impact Statement*. February.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2013. San Luis Reservoir State Recreation Area, Final Resource Management Plan/General Plan and Final Environmental Impact Statement/Final Environment Impact Report. June 2013. Available: https://www.usbr.gov/mp/nepa/includes/documentShow.php?Doc_ID=14009. Accessed: October 29, 2019.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation). 2014. *Shasta Lake Water Resources Investigation Final Environmental Impact Statement*. Dec. Available: https://www.usbr.gov/mp/nepa/includes/documentShow.php?Doc_ID=22669. Accessed: October 29, 2019.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation), California Department of Fish and Game, and U.S. Fish and Wildlife Service. 2010. *Suisun Marsh Habitat Management, Preservation, and Restoration Plan Draft Environmental Impact Statement/Environmental Impact Report*.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR). 2011. *San Joaquin River Restoration Program Environmental Impact Statement/Report*.

U.S. Department of the Interior, Bureau of Reclamation (Reclamation), U.S. Army Corps of Engineers, California Reclamation Board, Sacramento Area Flood Control Agency. 2006. *Folsom Dam Safety and Flood Damage Reduction Draft Environmental Impact Statement/Environmental Impact Report*. December.

U.S. Department of the Interior (USDOI) and California Department of Fish and Game (CDFG). 2012. *Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report*. December.

U.S. Geological Survey (USGS). 1982. *Geologic Maps of the Sacramento-San Joaquin Delta, California*. Pamphlet to accompany Map MF-1401. Available: https://pubs.er.usgs.gov/publication/mf1401. Accessed: October 29, 2019.

U.S. Geological Survey (USGS). 1999. *USGS Circular 1182. Part 1 – Mining Ground Water*. Available: https://pubs.usgs.gov/circ/circ1182/pdf/partI_pt1.pdf. Accessed: October 29, 2019.

U.S. Geological Survey (USGS). 2000a. *Volcano Hazards of the Lassen Volcanic National Park Area, California*.

U.S. Geological Survey (USGS). 2000b. *Delta Subsidence in California: The Sinking Heart of the State*. April.

U.S. Geological Survey (USGS). 2001. *Earthquakes, Faults and Tectonics,* in *Beyond the Golden Gate – Oceanography, Geology and Biology and Environmental Issues in the Gulf of the Farallones, Circular 1198.* Available: https://pubs.usgs.gov/circ/c1198/c1198_short.pdf. Accessed: March 15, 2019.

U.S. Geological Survey (USGS). 2008. *Mercury geochemistry of gold placer tailings, sediments, bedrock, and waters in the lower Clear Creek area, Shasta County, California; Report of Investigations, 2001–2003: U.S. Geological Survey, Open-file Report 2008-1122.* Available: http://pubs.usgs.gov/of/2008/1122/. Accessed: March 18, 2019.

U.S. Geological Survey (USGS). 2013a. *Land Subsidence along the Delta-Mendota Canal in the Northern Part of the San Joaquin Valley, California, 2003–10, Scientific Investigations Report 2013-5142*.

U.S. Geological Survey (USGS). 2013b. *Detection and Measurement of Land Subsidence Using Global Positioning System Surveying and Interferometric Synthetic Aperture Radar, Coachella Valley, California, 1996–2005*. Scientific Investigations Report 2007-5251. Version 2.0. June.

U.S. Geological Survey (USGS). 2017. *Physical Characteristics of the Lower San Joaquin River California, in Relation to White Sturgeon Spawning Habitat, 2011-14. Scientific Investigations Report 2017-5069.* Available: https://pubs.usgs.gov/sir/2017/5069/sir20175069.pdf. Accessed: May 7, 2019.

U.S. Geological Survey (USGS). 2019. *Current Land Subsidence in the San Joaquin Valley*. Available: https://ca.water.usgs.gov/projects/central-valley/land-subsidence-san-joaquin-valley.html.

Ventura County. 2011. *Ventura County General Plan, Hazards Appendix*. June.

Weir, Walter W. 1949. *Peat Lands of the Delta.* California Agriculture. July.

Water Transit Authority (WTA). 2003. *Final Program Environmental Impact Report Expansion of Ferry Transit Service in the San Francisco Bay Area.* June.