Chapter 11

Geology and Soils Resources

11.1 Introduction

This chapter describes the geology and soils resources in the project area; and potential changes that could occur as a result of implementing the alternatives evaluated in this Environmental Impact Statement (EIS). Implementation of alternatives could affect geology and soils resources through potential changes in operation of the Central Valley Project (CVP) and State Water Project (SWP).

11.2 Regulatory Environment and Compliance Requirements

Potential actions that could be implemented under the alternatives evaluated in this EIS could affect reservoirs, streams, and lands served by CVP and SWP water supplies located on lands affected by seismic, landslide, and liquefaction hazards; subsidence; and unstable soils. Actions located on public agency lands; or implemented, funded, or approved by Federal and state agencies would need to be compliant with appropriate Federal and state agency policies and regulations, as summarized in Chapter 4, Approach to Environmental Analysis.

11.3 Affected Environment

This section describes the geological, 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 soils characteristics due to changes in CVP and SWP operations may occur in the Trinity River, Central Valley, San Francisco Bay Area, and Central Coast and Southern California regions. Geomorphic provinces in California are shown on Figure 11.1.

11.3.1 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 in Humboldt and Del Norte counties along the Klamath River from the confluence with the Trinity River to the Pacific Ocean.

11.3.1.1 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 2002a). 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 2002a, Reclamation 1997).

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, 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 belt (Reclamation 1997).

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 riverbed is underlain by rocks of the Klamath Mountains Province (NCRWQCB et al. 2009). The Klamath Mountains Province formations generally dip towards the east and are exposed along the riverbed. 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 riverbed extends towards 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 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, serpentinte, graywacke, chert, high-grade metamorphics, and limestone.

11.3.1.2 Regional 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 et al. 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 Oregon and Washington states. 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 towards 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 numerous earthquakes with magnitudes greater than 8. The Cascadia Subduction Zone is where the Gorda Plate and the associated the Juan de Fucca Plate descend under the North American Plate.

11.3.1.3 Regional Volcanic Potential

Active centers of volcanic activity occur in the vicinity of Mount Shasta, located near the northeastern edge of the Trinity River Region. Mount Shasta is located 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 2013a).

11.3.1.4 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 et al. 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 (DOI and DFG 2012). Alluvial deposits (river gravels) and dredge tailings provide important spawning habitat for salmon and steelhead.

11.3.1.5 Subsidence

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

11.3.2 Central Valley Region

The Central Valley Region extends from above Shasta Lake to the Tehachapi Mountains, and includes the Sacramento Valley, San Joaquin Valley, Delta, and Suisun Marsh.

11.3.2.1 Geologic Setting

The Central Valley Region is bounded by the Klamath Mountains, Cascade Range, Great Valley, Coast Ranges, and Sierra Nevada geomorphic provinces (CGS 2002a).

The Klamath Mountains Geomorphic Province was described in subsection 11.3.2, Trinity River Region. The Cascade Range Geomorphic Province consists of volcanic rocks of the Miocene to Pleistocene age. Several volcanoes within the Cascade Range Geomorphic Province and the Central Valley Region include Mount Shasta and Lassen Peak (Reclamation 2013a).

The Great Valley Geomorphic Province is an approximately 400 mile long, 50 mile wide valley that extends from the northwest to the southeast between the Sierra Nevada and Coast Ranges geomorphic provinces. The faulted and folded sediments of the Coast Range extend eastward beneath most of the Central Valley; and 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 2002a). 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). 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 in the southern San Joaquin Valley and composed of clay layers (Reclamation 1997).

The Sierra Nevada Geomorphic Province along the eastern boundary of the Great Valley Geomorphic Province is composed of pre-Tertiary igneous and metamorphic rocks. The Sierra Nevada Geomorphic Province is an uplifted fault block nearly 400 miles long with a series of metamorphic rock on the east and deep river cuts on a gentle slope, which disappears under sediments of the Central Valley on the west. Gold-bearing veins are present in the northwest trending

Mother Lode metamorphic bedrock. The province is bordered by the Cascade Range on the north (Placer County 2007).

The Coast Ranges Geomorphic Province is composed of pre-Tertiary and Tertiary semiconsolidated to consolidated marine sedimentary rocks. The Coast Ranges Province is characterized by active uplift related to the San Andreas Fault and plate boundary system tectonics. The province extends westward toward the coastline and eastward toward the Great Valley Geomorphic Province. Rocks in this region include mafic and ultramafic rock associated with the Coast Range ophiolite, and Miocene volcanic rocks (Sonoma Volcanics) and marine and terrestrial sedimentary from the Cretaceous to the Neogene period (Reclamation et al. 2010).

11.3.2.1.1 Sacramento Valley Geological Setting

Major watersheds within the Sacramento Valley that could be affected by CVP and SWP operations include the Sacramento River, Feather River, and the Lower American River watersheds.

Sacramento River Watershed Geological Setting

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 occur due to past and current land use practices on the tributary streams.

Feather River Watershed Geological Setting

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 non-marine Ione formation of the Eocene Epoch; the extrusive volcanic Lovejoy basalt of the late Oligocene to early Miocene; and volcanic flows and volcaniclastic 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-Pliestocene Laguna formation, the Riverbank and Modesto formations of the Pleistocene, riverbed sediments of the Holocene, and historical dredge and mine tailings from 20th 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 significantly 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.

American River Watershed Geological Setting

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 include 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 lying. 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. Ultramific rocks are most common on Flagstaff Mountain (Hill) on the Folsom Reservoir Peninsula located on a 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 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 weathers. 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, the Mehrten and Laguna Formation. 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 Reservoir 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 deposits of Tertiary and Quaternary that have been slightly folded and faulted (Reclamation 2005).

The alluvial fans and plains consist of unconsolidated continental deposits that extend from the edges of the valleys toward the valley floor (Reclamation 2005). The alluvial plains in the American River watershed include older Quaternary deposits (Sacramento County 2010). River flood plains and channels lay along the American River and 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 2005; Sacramento County 2010).

11.3.2.1.2 Delta Geological Setting

The Delta 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 Range (CWDD 1981). The Delta 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 Delta include peat and organic soils, alluvium, levee and channel deposits, dune sand deposits, older alluvium, and bedrock.

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 well-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 et al. 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.

11.3.2.1.3 Suisun Marsh Geological Setting

The Suisun Marsh area is located within the Coast Ranges Geomorphic Province. The Suisun Marsh is bounded by the steep Coast Range 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).

11.3.2.1.4 San Joaquin Valley Geological Setting

The San Joaquin Valley is located within the southern half of the Great Valley Geomorphic Province. The 250-mile-long and 50-to-60-mile-wide valley lies between the Coast Ranges on the west, the Sierra Nevada on the east, and extends northwestward to the Delta near the City of Stockton. The San Joaquin Valley is the southern portion of a large, northwest-to-southeast-trending asymmetric trough filled with up to six 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. 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 et al. 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 valleys 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 et al. 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).

The valley floor and foothills portions of the San Joaquin Valley and San Joaquin River area, and the Stanislaus River watershed could be affected by CVP and SWP operations. 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 towards 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 1977). The oldest Tertiary geologic unit, 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 1977; 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.

11.3.2.2 Regional Seismicity

Most of the areas in the Central Valley Region 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 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 located to the west of the Central Valley Region along a 150-mile northwest-trending fault zone (Reclamation 2013a). 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 Zone located 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 Interstate 5 near Dunnigan, Cleveland Fault located near Oroville, and Great Valley Fault system along the west side of the Sacramento Valley (Reclamation 2005a, Reclamation 2013a, USGS 2013a).

The Delta and Suisun Marsh are located in proximity to several major fault systems, including the San Andreas, Hayward-Rodgers Creek, Calaveras, Concord-Green Valley, and Greenville faults (DWR et al. 2013a). 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 include 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.

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 et al. 2011). Uplift and tilting of the Sierra Nevada block towards 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, such as 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 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).

11.3.2.3 Regional Volcanic Potential

Active centers of volcanic activity occur in the vicinity of Mount Shasta and Lassen Peak in the Central Valley Region. Mount Shasta is located 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 2013a).

Lassen Peak, located 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).

11.3.2.4 Soil Characteristics

The Central Valley Region includes the Sacramento Valley, Delta, Suisun Marsh, 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.

11.3.2.4.1 Sacramento Valley and San Joaquin Valley Soil Characteristics

The Sacramento Valley and San Joaquin Valley contain terrace land and upland soils along the foothills; and alluvial, Aeolian, clayey, and saline/alkaline soils 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 2013a). 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 et al. 2011, Reclamation 2013a, 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 2012).

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 “calcerous” 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 calcerous soils occur with less organic matter than the brown soils (Reclamation 1997).

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 et al. 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 et al. 1999). The western boundary of the Corcoran Clay is generally located along the Delta-Mendota Canal and California Aqueduct (as described in Chapter 5, Surface Water Resources and Water Supply). 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 compromised 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 et al. 2011). As described in Chapter 12, Agricultural Resources, many portions of the western and central San Joaquin Valley are no longer supporting irrigated crops or are experiencing low crop yields due to the saline soils.

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 Chapter 3, Description of Alternatives, Reclamation and other agencies are implementing programs to reduce the discharge of selenium from the San Joaquin Valley into receiving waters (Reclamation 2005d, Reclamation et al. 2011, Reclamation 2009). Additional information related to concerns with salinity and selenium in the San Joaquin Valley is presented in Chapter 6, Surface Water Quality, and Chapter 12, Agricultural Resources.

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. Non-irrigated 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 (as discussed in Chapter 18, Public Health) (Reclamation 2005d).

11.3.2.4.2 Delta Soil Characteristics

Soils in the Delta 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 fine sandy loams and silty clay loams to well-drained silt loams and silty clay 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.

Soils within the Yolo Bypass area range from clays to silty clay loams and alluvial soils (CALFED 2001, DFG et al. 2008). The higher clay content soils occur in the western portion of the basin north of Interstate 80 and in the eastern portion of the basin south of Interstate 80. The silty clay loams and alluvial soils occur in the western portion of the basin south of Interstate 80, including soils within the Yolo Bypass Wildlife Area.

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 is erodible. Organic soil (peat) in the Delta is also susceptible to wind erosion (deflation). Clay soils are erosion resistant.

11.3.2.4.3 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 1977a, 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 are poorly drained organic soils 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 1977a, Reclamation et al. 2010).

11.3.2.5 Subsidence

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

11.3.2.5.1 Sacramento and San Joaquin Valley Subsidence

Land subsidence in the Sacramento Valley primarily occurs due to aquifer-system compaction as groundwater elevations decline; weathering of underlying of some-types of bedrock, such as limestone; decomposition of organic matter; and natural compaction of soils (Reclamation 2013a). Historic subsidence of the Sacramento Valley has been far less than that observed in the San Joaquin Valley. For example, the range of recent historic subsidence in the Sacramento Valley is generally less than 10 feet. Historical subsidence in the San Joaquin Valley has caused changes in land elevations of more than 30 feet.

In the 1970s, land subsidence exceeded 1 foot near Zamora; however, additional subsidence has not been reported since 1973 (Reclamation 2013a). Subsidence has been reported of two feet near Davis and three to four feet over the last several decades in the areas north of Woodland and east of Davis and Woodland (Davis 2007).

San Joaquin Valley subsidence primarily occurs when groundwater elevations decline which reduces water pressure in the soils and results in compressed clay lenses and subsided land elevations. Other 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 et al. 2011). Some of the first reports of land subsidence in the San Joaquin Valley occurred in 1935 in the area near Delano (Galloway et al. 1999). By the late 1960s, San Joaquin Valley subsidence had occurred over 5,212 square miles, or almost 50 percent of the San Joaquin Valley (Reclamation 2005d). During that period, some areas subsided over 33 vertical feet since the late 1880s. The rate of subsidence reduced initially following implementation of CVP and SWP water supplies in the San Joaquin Valley during the 1970s and 1980s. The rate of subsidence for the next twenty years appeared to continue at a rate of 0.008 to 0.016 inches/year in recent years (Reclamation et al. 2011). However, the amount of water available for irrigation from the CVP and SWP has declined more than 20 to 30 percent since the early 1980s due to hydrologic, regulatory, and operational concerns, as described in Chapter 1, Introduction. 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 2013b) 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.

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.

11.3.2.5.2 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 shrunk (Reclamation et al. 2013, Drexler et al. 2009). Agricultural burning of peat (which 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 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, improving of water movement, 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 (DWR 2013). The Department of Water Resources and USGS implemented wetlands restoration for about 15 acres on Twitchell Island in 1997 (DWR et al. 2013b) 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.

11.3.3 San Francisco Bay Area Region

The San Francisco Bay Area Region includes portions of Contra Costa, 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 that use water diverted from Barker Slough in the Sacramento River watershed for portions of Solano and Napa counties. Solano County was discussed under the Delta area of the Central Valley Region. Napa County is described under the San Francisco Bay Area Region.

11.3.3.1 Geologic Setting

The San Francisco Bay Area Region primarily is located 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 11.3.2, Central Valley Region. San Francisco Bay is a structural trough formed as a gap in the Coast Range down-dropped to allow 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. Sedimentation patterns have changed over the past 150 years due to development of upstream areas of the watersheds which changed sedimentation and hydraulic flow patterns, hydraulic mining, and formation of levees and dams.

The San Francisco Bay Area is formed from the Salinian block located west of the San Andreas Fault; Mesozoic Franciscan complex located between the San Andreas and Hayward faults; and the Great Valley sequence located 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 due to 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 primarily includes marine sedimentary rocks.

11.3.3.2 Regional Seismicity

Large earthquakes have occurred in the San Francisco Bay Area 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. The San Andreas Fault remains active, as does the Hayward Fault, based on evidence of slippage along both (CALFED 2000).

11.3.3.3 Soil Characteristics

The San Francisco Bay Area 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 1977b, 1981a; 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 San Francisco Bay Area Region 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 San Francisco Bay Area Region above the valley land.

11.3.3.4 Subsidence

Subsidence in the San Francisco Bay Area Region primarily occurs in the Santa Clara Valley of Santa Clara County. The Santa Clara Valley is characterized by a groundwater aquifer with layers of non-consolidated 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 (SCVWD 2000). Under these conditions, salt water 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 (Ingerbritsen et al. 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 also are used to directly recharge the groundwater through spreading basins in Santa Clara Valley.

11.3.3.5 Central Coast and Southern California Regions

The Central Coast Region includes portions of San Luis Obispo and Santa Barbara counties served by the SWP. The Southern California Region includes portions of Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino counties served by the SWP.

As described in Chapter 4, Approach to Environmental Analysis, the Southern California Region includes areas affected by operations of the SWP, including 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 Chapter 5, Surface Water Resources and Water Supplies. The Imperial Valley, located to the southeast of the Southern California Region, receives irrigation water from the Colorado River through Reclamation canals; and does not use CVP or SWP water.

11.3.3.6 Geologic Setting

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

The Central Coast Region includes portions of San Luis Obispo and Santa Barbara counties that 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 11.3.2, Central Valley Region. The Transverse Ranges Geomorphic Province consists of deeply folded and faulted sedimentary rocks (CGS 2002a, 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, as compared to the north-south orientation of the Coast Range.

The Southern California Region includes portions of Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino counties that use SWP water supplies. These areas are located within the Transverse Ranges, Peninsular Ranges, Mojave Desert, and Colorado Desert geomorphic provinces. 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 plants are separating.

The Peninsular Ranges Geomorphic Province is composed of granitic rock with metamorphic rocks (CGS 2002a, 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 Santa Catalina, Santa Barbara, San Clemente, and San Nicolas islands. 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 is located between the Garlock Fault along the southern boundary of the Sierra Nevada Geomorphic Province and the San Andreas Fault (CGS 2002a, SCAG 2011, RCIP 2000). This geomorphic province includes extensive alluvial basins with non-marine sediments from the surrounding mountains and foothills; and 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) towards the Mojave Desert Geomorphic Province where the Pacific and North American plants are separating (CGS 2002a, 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 historic 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 occurs 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 and Imperial counties that are located outside of the study area.

11.3.3.7 Regional Seismicity

Most of the areas in the Central Coast and Southern California regions 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 and extends 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 2010a).

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 include the Oak Ridge Fault that 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 that 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; Sycamore Canyon and Boney Mountain faults that extend from the Pacific Ocean towards Thousand Oaks (CGS 2006, Ventura County 2011).

Los Angeles County major fault zones include 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 that extend into Los Angeles and Orange counties (CGS 2006, Los Angeles 2005). Recent major seismic events that have occurred in Southern California along faults in Los Angeles include 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, Riverside County 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 located along the Pacific Ocean shoreline and extends into the City of San Diego (San Diego County 2011).

11.3.3.8 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 areas are located along the coast with soils that range from sands and loamy sands in areas near the shoreline to shaly loams, clay loams, and clays in the terraces and foothills located along the eastern boundaries of these communities (SBCAG 2010b, NRCS 2014a, NRCS 2014b). In Santa Barbara County, the Santa Maria, Vandenberg Air Force Base, Santa Ynez, Goleta, Santa Barbara, and Carpenteria areas are located 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, shaly loams, and clay loams in the alluvial soils and along the shoreline. The terrace deposits include silty clays, clay loams, and clays (NRCS 2014c, NRCS 2014d, NRCS 2014e, SCS 1972, SCS 1981b).

Southern California Region 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 include sand to silty clays to cobbles and boulders on the alluvial fans, valley floor, terraces, and mountains, and dry lake beds (CVWD 2011).

11.3.3.9 Subsidence

Subsidence in the Central Coast and Southern California regions occur due to soil compaction following groundwater withdrawals at rates greater than groundwater recharge rates, oil and gas withdrawal, seismic activity, and hydroconsolidation of soils along alluvial fans (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, 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 2013c). 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 Chapter 5, Surface Water Resources and Water Supply, the availability of 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 have 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 have occurred in parts of the valley between 1996 and 2005 (CVWD 2011).

11.4 Impact Analysis

This section describes the potential mechanisms and analytical methods for change in soils resources, results of the impact analysis, potential mitigation measures, and cumulative effects.

11.4.1 Potential Mechanisms for Change in Soils Resources

As described in Chapter 4, Approach to Environmental Analysis, the impact analysis considers changes in soils resources conditions related to changes in CVP and SWP operations under the alternatives as compared to the No Action Alternative and Second Basis of Comparison.

Changes in CVP and SWP operations under the alternatives as compared to the No Action Alternative and Second Basis of Comparison could change soil erosion potential due to crop idling on lands irrigated with CVP and SWP water supplies and along rivers downstream of CVP and SWP reservoirs, and potential changes in soils as lands are converted to seasonal floodplain or tidal-influenced wetlands.

11.4.1.1 Changes in Soil Erosion

Changes in CVP and SWP operations under the alternatives could change the extent of irrigated acreage and the potential for soil erosion on crop idled lands over the long-term average condition and in dry and critical dry years as compared to the No Action Alternative and the Second Basis of Comparison.

Changes in CVP and SWP operations under the alternatives also could change peak flows in rivers downstream of CVP and SWP reservoirs in the Trinity River and Central Valley regions as compared to historical conditions which could lead to soil erosion during high peak flow events during storms in wet years along the river banks as compared to the No Action Alternative and the Second Basis of Comparison. However, as described in Chapter 5, Surface Water Resources and Water Supplies, the results of the analysis indicate that peak flows would be within historical range of peak flows in these rivers and would be similar under Alternatives 1 through 5, No Action Alternative, and Second Basis of Comparison. Therefore, changes in CVP and SWP operations would not result in changes to peak flow events that could result in soil erosion along these rivers. Therefore, these changes are not analyzed in this EIS.

11.4.1.2 Changes in Soils at Restored Wetlands

Restoration of seasonal floodplains and tidally-influenced wetlands would affect soils resources at the restoration locations. However, these actions would occur in a similar manner under the No Action Alternative, Alternatives 1 through 5, and Second Basis of Comparison, as described in Chapter 3, Description of Alternatives; in addition, the conditions of the soils would be the same under all of the alternatives and the Second Basis of Comparison. Therefore, these changes are not analyzed in this EIS.

11.4.1.3 Effects Related to Water Transfers

Historically water transfer programs have been developed on an annual basis.

The demand for water transfers is dependent upon the availability of water supplies to meet water demands. Water transfer transactions have increased over time as CVP and SWP water supply availability has decreased, especially during drier water years.

Parties seeking water transfers generally acquire water from sellers who have available surface water who can make the water available through releasing previously stored water, pump groundwater instead of using surface water (groundwater substitution), idle crops, or substitute crops that use less water in order to reduce normal consumptive use of surface water.

Water transfers using CVP and SWP Delta pumping plants and south of Delta canals generally occur when there is unused capacity in these facilities. These conditions generally occur drier water year types when the flows from upstream reservoirs plus unregulated flows are adequate to meet the Sacramento Valley water demands and the CVP and SWP export allocations. In nonwet years, the CVP and SWP water allocations would be less than full contract amounts; therefore, capacity may be available in the CVP and SWP conveyance facilities to move water from other sources.

Projecting future soil conditions related to water transfer activities is difficult because specific water transfer actions required to make the water available, convey the water, and/or use the water would change each year due to changing hydrological conditions, CVP and SWP water availability, specific local agency operations, and local cropping patterns. Reclamation recently prepared a long-term regional water transfer environmental document which evaluated potential changes in surface water conditions related to water transfer actions (Reclamation 2014c). Results from this analysis were used to inform the impact assessment of potential effects of water transfers under the alternatives as compared to the No Action Alternative and the Second Basis of Comparison.

11.4.2 Conditions in Year 2030 without Implementation of Alternatives 1 through 5

This EIS includes two bases of comparison, as described in Chapter 3, Description of Alternatives: the No Action Alternative and the Second Basis of Comparison. Both of these bases are evaluated at 2030 conditions. Changes that would occur over the next 15 years without implementation of the alternatives are not analyzed in this EIS. However, the changes to soils resources that are assumed to occur by 2030 under the No Action Alternative and the Second Basis of Comparison are summarized in this section. Many of the changed conditions would occur in the same manner under both the No Action Alternative and the Second Basis of Comparison.

11.4.2.1 Common Changes in Conditions under the No Action Alternative and Second Basis of Comparison

Conditions in 2030 would be different than existing conditions due to:

- Climate change and sea-level rise
- General plan development throughout California, including increased water demands in portions of Sacramento Valley
- Implementation of reasonable and foreseeable water resources management projects to provide water supplies

It is anticipated that climate change would result in more short-duration high-rainfall events and less snowpack in the winter and early spring months. The reservoirs would be full more frequently by the end of April or May by 2030 than in recent historical conditions. However, as the water is released in the spring, there would be less snowpack to refill the reservoirs. This condition would reduce reservoir storage and available water supplies to downstream uses in the summer. The reduced end-of-September storage would also reduce the ability to release stored water to downstream regional reservoirs. These conditions would occur for all reservoirs in the California foothills and mountains, including non-CVP and SWP reservoirs.

These changes would result in a decline of the long-term average CVP and SWP water supply deliveries by 2030 as compared to recent historical long-term average deliveries under the No Action Alternative and the Second Basis of Comparison. However, the CVP and SWP water deliveries would be less under the No Action Alternative as compared to the Second Basis of Comparison, as described in Chapter 5, Surface Water Resources and Water Supplies, which could result in more crop idling that could be subject to erosion.

Under the No Action Alternative and the Second Basis of Comparison, land uses in 2030 would occur in accordance with adopted general plans. Development under the general plans would result in disruption of soils resources; however, the development of general plans includes preparation of environmental documentation that would identify methods to minimize adverse impacts to soils resources.

Under the No Action Alternative and the Second Basis of Comparison, development of future water resources management projects by 2030 which would result in disruption of soils resources. However, the development of these future programs would include preparation of environmental documentation that would identify methods to minimize adverse impacts to soils resources.

By 2030 under the No Action Alternative and the Second Basis of Comparison, it is assumed that ongoing programs would result in restoration of more than 10,000 acres of intertidal and associated subtidal wetlands in Suisun Marsh and Cache Slough; and 17,000 to 20,000 acres of seasonal floodplain restoration in the Yolo Bypass.

11.4.3 Evaluation of Alternatives

Alternatives 1 through 5 have been compared to the No Action Alternative; and the No Action Alternative and Alternatives 1 through 5 have been compared to the Second Basis of Comparison. The evaluation of alternatives is focused on portions of the Central Valley, San Francisco Bay Area, Central Coast, and Southern California regions that use CVP and SWP water for irrigation.

During review of the numerical modeling analyses used in this EIS, an error was determined in the CalSim II model assumptions related to the Stanislaus River operations for the Second Basis of Comparison, Alternative 1, and Alternative 4 model runs. Appendix 5C includes a comparison of the CalSim II model run results presented in this chapter and CalSim II model run results with the error corrected. Appendix 5C also includes a discussion of changes in the comparison of groundwater conditions for the following alternative analyses.

- No Action Alternative compared to the Second Basis of Comparison
- Alternative 1 compared to the No Action Alternative
- Alternative 3 compared to the Second Basis of Comparison
- Alternative 5 compared to the Second Basis of Comparison

11.4.3.1 No Action Alternative

The No Action Alternative is compared to the Second Basis of Comparison.

11.4.3.1.1 Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under the No Action Alternative would be similar (within 5 percent) to the conditions under the Second Basis of Comparison over long-term conditions (throughout the 81-year model simulation period) and during dry and critical dry years due to the increased use of groundwater.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c). Potential effects to soils resources were identified as increased erosion and shrinking of expansive soils in the seller’s service areas if crop idling is used to provide water for transfers; and increased potential for shrinking of expansive soils and soil movement in areas that use the transferred water. The analysis indicated that these potential impacts would not be substantial because farmers manage idle fields as part of normal agricultural operations and they would continue to use the same practices to avoid erosion impacts. The analysis also indicated that shrinking and soil movement occur as part of normal planting and harvesting practices and the changes with the water transfer programs would not result in substantial changes.

Under the No Action Alternative, the timing of cross Delta water transfers would be limited to July through September and include annual volumetric limits, in accordance with the 2008 U.S. Fish and Wildlife Service (USFWS) Biological Opinion (BO) and the 2009 National Marine Fisheries Service (NMFS) BO. Under the Second Basis of Comparison, water could be transferred throughout the year without an annual volumetric limit. Overall, the potential for cross Delta water transfers would be less under the No Action Alternative than under the Second Basis of Comparison.

11.4.3.1.2 San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under the No Action Alternative is anticipated to be similar as conditions under the Second Basis of Comparison due to the increased use of groundwater.

11.4.3.2 Alternative 1

Alternative 1 is identical to the Second Basis of Comparison. Alternative 1 is compared to the No Action Alternative and the Second Basis of Comparison. However, because CVP and SWP operations conditions under Alternative 1 are identical to conditions under the Second Basis of Comparison; Alternative 1 is only compared to the No Action Alternative.

11.4.3.2.1 Alternative 1 Compared to the No Action Alternative

Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 1 would be similar to conditions under the No Action Alternative over long-term conditions and during dry and critical dry years due to the increased availability of CVP and SWP water supplies.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c) as described above under the No Action Alternative compared to the Second Basis of Comparison. For the purposes of this EIS, it is anticipated that similar conditions would occur during implementation of cross Delta water transfers under Alternative 1 and the No Action Alternative, and that impacts on soils resources would not be substantial in the seller's service area due to implementation requirements of the transfer programs.

Under Alternative 1, water could be transferred throughout the year without an annual volumetric limit. Under the No Action Alternative, the timing of cross Delta water transfers would be limited to July through September and include annual volumetric limits, in accordance with the 2008 USFWS BO and 2009 NMFS BO. Overall, the potential for cross Delta water transfers would be increased under Alternative 1 as compared to the No Action Alternative.

San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 1 is anticipated to be similar as conditions under the No Action Alternative due to increased availability of CVP and SWP water supplies.

11.4.3.2.2 Alternative 1 Compared to the Second Basis of Comparison

Alternative 1 is identical to the Second Basis of Comparison.

11.4.3.3 Alternative 2

The CVP and SWP operations under Alternative 2 are identical to the CVP and SWP operations under the No Action Alternative; therefore, the soils resources conditions under Alternative 2 are only compared to the Second Basis of Comparison.

11.4.3.3.1 Alternative 2 Compared to the Second Basis of Comparison

Changes to soils resources under Alternative 2 as compared to the Second Basis of Comparison would be the same as the impacts described in Section 11.4.3.1, No Action Alternative.

11.4.3.4 Alternative 3

The CVP and SWP operations under Alternative 3 are similar to the Second Basis of Comparison and Alternative 1 with modified Old and Middle River flow criteria.

11.4.3.4.1 Alternative 3 Compared to the No Action Alternative

Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 3 would be similar to the conditions under the No Action Alternative over long-term conditions and during dry and critical dry years due to the increased availability of CVP and SWP water supplies.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c) as described above under the No Action Alternative compared to the Second Basis of Comparison. For the purposes of this EIS, it is anticipated that similar conditions would occur during implementation of cross Delta water transfers under Alternative 3 and the No Action Alternative, and that impacts on soils resources would not be substantial in the seller's service area due to implementation requirements of the transfer programs.

Under Alternative 3, water could be transferred throughout the year without an annual volumetric limit. Under the No Action Alternative, the timing of cross Delta water transfers would be limited to July through September and include annual volumetric limits, in accordance with the 2008 USFWS BO and 2009 NMFS BO. Overall, the potential for cross Delta water transfers would be increased under Alternative 3 as compared to the No Action Alternative.

San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 3 is anticipated to be similar to conditions under the No Action Alternative due to increased availability of CVP and SWP water supplies.

11.4.3.4.2 Alternative 3 Compared to the Second Basis of Comparison

Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 3 would be similar to the conditions under the Second Basis of Comparison over long-term conditions and during dry and critical dry years due to the increased use of groundwater.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c) as described above under the No Action Alternative compared to the Second Basis of Comparison. For the purposes of this EIS, it is anticipated that similar conditions would occur during implementation of cross Delta water transfers under Alternative 3 and the Second Basis of Comparison, and that impacts on soils resources would not be substantial in the seller's service area due to implementation requirements of the transfer programs.

Under Alternative 3 and the Second Basis of Comparison, water could be transferred throughout the year without an annual volumetric limit. Overall, the potential for cross Delta water transfers would be similar under Alternative 3 and the Second Basis of Comparison.

San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 3 is anticipated to be similar to conditions under the Second Basis of Comparison due to the increased use of groundwater.

11.4.3.5 Alternative 4

Soil resources conditions under Alternative 4 would be identical to the conditions under the Second Basis of Comparison; therefore, Alternative 4 is only compared to the No Action Alternative.

11.4.3.5.1 Alternative 4 Compared to the No Action Alternative

The CVP and SWP operations under Alternative 4 is identical to the CVP and SWP operations under the Second Basis of Comparison and Alternative 1. Therefore, changes in soil resources conditions under Alternative 4 as compared to the No Action Alternative would be the same as the impacts described in Section 11.4.3.2.1, Alternative 1 Compared to the No Action Alternative.

11.4.3.6 Alternative 5

The CVP and SWP operations under Alternative 5 are similar to the No Action Alternative with modified Old and Middle River flow criteria and New Melones Reservoir operations.

11.4.3.6.1 Alternative 5 Compared to the No Action Alternative

Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 5 would be similar to conditions under the No Action Alternative over long-term conditions and during dry and critical dry years because the availability of CVP and SWP water supplies would be similar.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c) as described above under the No Action Alternative compared to the Second Basis of Comparison. For the purposes of this EIS, it is anticipated that similar conditions would occur during implementation of cross Delta water transfers under Alternative 5 and the No Action Alternative, and that impacts on soils resources would not be substantial in the seller's service area due to implementation requirements of the transfer programs.

Under Alternative 5 and the No Action Alternative, the timing of cross Delta water transfers would be limited to July through September and include annual volumetric limits, in accordance with the 2008 USFWS BO and 2009 NMFS BO. Overall, the potential for cross Delta water transfers would be similar under Alternative 5 and the No Action Alternative.

San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 5 is anticipated to be similar as conditions under the No Action Alternative because CVP and SWP water deliveries would be similar.

11.4.3.6.2 Alternative 5 Compared to the Second Basis of Comparison

Central Valley Region

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 5 would be similar to the conditions under the Second Basis of Comparison over long-term conditions and during dry and critical dry years due to increased use of groundwater.

Effects Related to Cross Delta Water Transfers

Potential effects to soils resources could be similar to those identified in a recent environmental analysis conducted by Reclamation for long-term water transfers from the Sacramento to San Joaquin valleys (Reclamation 2014c) as described above under the No Action Alternative compared to the Second Basis of Comparison. For the purposes of this EIS, it is anticipated that similar conditions would occur during implementation of cross Delta water transfers under Alternative 5 and the Second Basis of Comparison, and that impacts on soils resources would not be substantial in the seller's service area due to implementation requirements of the transfer programs.

Under Alternative 5, the timing of cross Delta water transfers would be limited to July through September and include annual volumetric limits, in accordance with the 2008 USFWS BO and 2009 NMFS BO. Under Second Basis of Comparison, water could be transferred throughout the year without an annual volumetric limit. Overall, the potential for cross Delta water transfers would be less under Alternative 5 as compared to the Second Basis of Comparison.

San Francisco Bay Area, Central Coast, and Southern California Regions

Potential Changes in Soil Erosion

As described in Chapter 12, Agricultural Resources, the extent of irrigated acreage under Alternative 5 is anticipated to be similar to conditions under the Second Basis of Comparison due to the increased use of groundwater.

11.4.3.7 Summary of Impact Analysis

The results of the environmental consequences of implementation of Alternatives 1 through 5 as compared to the No Action Alternative and the Second Basis of Comparison are presented in Tables 11.1 and 11.2, respectively.

Table 11.1 Comparison of Alternatives 1 through 5 to No Action Alternative

Alternative	Potential Change	Consideration for Mitigation Measures
Alternative 1	No effects on soils resources	None needed
Alternative 2	No effects on soils resources	None needed
Alternative 3	No effects on soils resources	None needed
Alternative 4	No effects on soils resources	None needed
Alternative 5	No effects on soils resources	None needed

Table 11.2 Comparison of No Action Alternative and Alternatives 1 through 5 to Second Basis of Comparison

Alternative	Potential Change	Consideration for Mitigation Measures
No Action Alternative	No effects on soils resources	Not considered for this comparison
Alternative 1	No effects on soils resources	Not considered for this comparison
Alternative 2	No effects on soils resources	Not considered for this comparison
Alternative 3	No effects on soils resources	Not considered for this comparison
Alternative 4	No effects on soils resources	Not considered for this comparison
Alternative 5	No effects on soils resources	Not considered for this comparison

11.4.3.8 Potential Mitigation Measures

Changes in CVP and SWP operations under Alternatives 1 through 5 as compared to the No Action Alternative would not result in changes in soils resources. Therefore, there would be no adverse impacts to soils resources; and no mitigation measures are required.

11.4.3.9 Cumulative Effects Analysis

As described in Chapter 3, the cumulative effects analysis considers projects, programs, and policies that are not speculative; and are based upon known or reasonably foreseeable long-range plans, regulations, operating agreements, or other information that establishes them as reasonably foreseeable.

The No Action Alternative, Alternatives 1 through 5, and Second Basis of Comparison include climate change and sea level rise, implementation of general plans, and completion of ongoing projects and programs (see Chapter 3, Description of Alternatives). The effects of these items were analyzed quantitatively and qualitatively, as described in the Impact Analysis of this chapter. The discussion below focuses on the qualitative effects of the alternatives and other past, present, and reasonably foreseeable future projects identified for consideration of cumulative effects (see Chapter 3, Description of Alternatives).

11.4.3.9.1 No Action Alternative and Alternatives 1 through 5

Continued coordinated long-term operation of the CVP and SWP under the No Action Alternative would result in reduced CVP and SWP water supply availability as compared to recent conditions due to climate change and sea-level rise by 2030. These conditions are included in the analysis presented above.

Future water resource management projects considered in cumulative effects analysis could increase water supply availability, as described in Chapter 5, Surface Water Resources and Water Supplies, and change soils resources. These projects would result in disruption of soils resources due to construction. However, the development of these future programs would include preparation of environmental documentation that would identify methods to minimize adverse impacts to soils resources.

There also are several ongoing programs that could result in reductions in CVP and SWP water supply availability due to changes in flow patterns in the Sacramento and San Joaquin rivers watersheds and the Delta that could reduce availability of CVP and SWP water deliveries as well as local and regional water supplies, as described in Chapter 5, Surface Water Resources and Water Supplies. Reduction in available surface water supplies as compared to projected water supplies under the No Action Alternative and Alternatives 1 through 5 could result in reduction of irrigated lands if additional groundwater of appropriate quality is not available.

There would be no adverse soils resources impacts associated with implementation of the alternatives as compared to the No Action Alternative or the Second Basis of Comparison. Therefore, Alternatives 1 through 5 would not contribute cumulative impacts to soils resources.

11.5 References

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Figure 11.1 Geomorphic Provinces in California