Long-Term Operation – Final Environmental Impact Statement

Appendix W – Geology and Soils Technical Appendix

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Appendix W Geology and Soils Technical Appendix

W.1 Background Information

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

W.1.1 Trinity River

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

W.1.1.1 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 (California Geological Survey 2002). The Klamath Mountains Geomorphic Province covers approximately 12,000 square miles of northwestern California between the Coast Range in the west and the Cascade Range in the east and is considered to be a northern extension of the Sierra Nevada (California Geological Survey 2002; Bureau of Reclamation 1997).

Figure W-1. Geomorphic Provinces in California.

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

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

The Trinity River flows into the Klamath River near Weitchpec. Downstream of 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 metasedimentary rocks with minor amounts of shale, chert, and conglomerate. The Central Belt is primarily composed of an argillite-matrix mélange with slabs of greenstone, serpentine, graywacke, chert, high-grade metamorphic rocks, and limestone.

W.1.1.2 Seismicity

The Trinity River watershed downstream of Lewiston Dam is distant from known, active faults and generally would experience infrequent, low levels of shaking during seismic events. However, infrequent earthquakes with stronger shaking could occur (California Geological Survey 2008). The closest areas to the lower reaches of the Trinity River watershed with known seismically active areas capable of producing an earthquake with a magnitude (M) 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 (California North Coast Regional Water Quality Control Board and Bureau of Reclamation 2009).

The areas along the lower Klamath River downstream of the confluence with the Trinity River have a slightly higher potential for greater ground shaking than areas along the Trinity River (California Geological Survey 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 extends north through Oregon and Washington. The Klamath River is approximately 30 to 40 miles from the Trinidad Fault, which extends from the area near Trinidad northwest to the coast near Trinidad State Beach. The Trinidad Fault is potentially capable of generating an earthquake with a moment magnitude of 7.3 (Humboldt County 2012). On December 20, 2022, a 6.4 M earthquake occurred 9.3 miles west-southwest of Ferndale in Humboldt County (information available here: www.earthquake.usgs.gov/earthquakes/browse/significant.php?year=2022). In the following year, a 4.8 M earthquake took place 12.4 miles east of Petrolia on October 16th (information available here: www.earthquake.usgs.gov/earthquakes/browse/significant.php?year=2023).

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

W.1.1.3 Volcanic Potential

Active centers of volcanic activity occur in the vicinity of Mount Shasta, just east of Trinity River headwaters. Mount Shasta is about 45 miles north of Shasta Reservoir. 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 (Bureau of Reclamation 2014).

W.1.1.4 Slope Stability

There are two types of processes that influence slope stability in the Trinity River watershed: mass wasting (e.g., landslides) and surficial erosion on both upland areas and the bed/bank of reservoirs and riverine features.

Mass Wasting

Mass wasting is dominated by deep-seated landslides and shallow debris slides. Initiation and/or reinitiation of slope movement occurs when these mass movement feature's toes are undercut by the rise and fall of reservoir water levels during dry period and wet period flow events. Normal wave action of the reservoir can also reactivate landslides. Seiches, wave action from seismicity and landslide movement, will also undercut unstable areas.

Surficial Erosion

Surface erosion occurs in response to rainfall and runoff events when overland flow occurs, resulting in soil movement in rills, gullies, and sheet erosion. Particle detachment during overland flow is controlled by slope gradient and soil texture. Fine-grained soils such as fine-grained sand and silt are more susceptible to particle detachment and transport. During high-flow events, the erosion of bed and banks of riverine environments occurs for some period of time as rivers rise above base flow conditions and volume and velocity of water mobilizes alluvial material.

W.1.1.5 Soil Characteristics

Soils in the southern region of the Klamath Mountain Geomorphic Province, including the Trinity River watershed, are generally composed of gravelly loam with some alluvial areas with dredge tailings, river wash, and xerofluvents, which is a gravelly soil (California North Coast Regional Water Quality Control Board and Bureau of Reclamation 2009).

Soils along the lower Klamath River are generally composed of gravelly clay loam and gravelly sandy loam with sand and gravels within the alluvial deposits (U.S. Department of the Interior and California Department of Fish and Game 2012). Alluvial deposits (river sands and gravels) and dredge tailings provide important spawning habitat for salmon and steelhead.

Throughout the Trinity River and lower Klamath River watersheds, large, dormant, deep-seated landslides occur where low shear strength soils are located. In most cases, slope movement occurs in geologic units known as mélanges found in the Franciscan Complex. Mélanges are a mishmash of rock units created during tectonic processes in subduction.

W.1.1.6 Subsidence

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

W.1.2 Central Valley

The Central Valley contains the largest collective watershed in California, including six subwatersheds: Sacramento River, Clear Creek, American River, Stanislaus River, and San Joaquin River watersheds. The Central Valley extends from above Shasta Reservoir in the north to the Tehachapi Mountains in the south and includes the Sacramento Valley and San Joaquin Valley.

W.1.2.1 Geologic Setting

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

The Great Valley Geomorphic Province is a vast elongated basin, approximately 430 miles long, and 50 miles wide, that extends from the northwest to the southeast, and is bounded between the Sierra Nevada and Coast Ranges Geomorphic Provinces to the east and west, respectively. The faulted and folded sediments of the Coast Ranges extend eastward beneath most of the Central Valley. The igneous and metamorphic rocks of the Sierra Nevada extend westward beneath the eastern Central Valley (Bureau of Reclamation 1997). The valley floor is an alluvial plain of sediments that have been deposited since the Jurassic Age (California Geological Survey 2002). Below these deposits are Cretaceous Great Valley Sequence shales and sandstones and upper Jurassic bedrock of metamorphic and igneous rocks associated in the east with the Sierra Nevada and in the west with the Coast Ranges (California Department of Water Resources 2007). The trough of the Great Valley Geomorphic Province is asymmetrically 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. Sediments deposited along the submarine fans within the Great Valley Geomorphic Province include mudstones, sandstones, and conglomerates from the Klamath Mountains and Sierra Nevada Geomorphic Provinces.

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

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

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

Dissected uplands, low alluvial fans and plains, river floodplains and channels, and overflow lands and lake bottoms are the several geomorphic land types within the San Joaquin Valley. Dissected uplands consist of slightly folded and faulted, consolidated, and unconsolidated Tertiary- and Quaternary-age continental deposits. The alluvial fans and plains, which cover most of the valley floor, consist of unconsolidated continental deposits that extend from the edges of the valley toward the valley floor. In general, alluvial sediments of the western and southern parts of the San Joaquin Valley tend to have lower permeability than deposits on the eastern side. River floodplains and channels lie along the major rivers and are well-defined where rivers incise their alluvial fans. Typically, these deposits are coarse and sandy in the channels and finer and silty in the floodplains (Bureau of Reclamation and California Department of Water Resources 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 Tulare Lake, 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 (Bureau of Reclamation 1997).

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

Sacramento River

The Sacramento River flows from Shasta Reservoir to the Delta. The Sacramento River watershed upstream of Shasta Reservoir east of the McCloud Arm is associated with the Klamath Mountain Geomorphic Province. West of the McCloud Arm, most of the land surrounding Shasta Reservoir is associated with the Cascade Geomorphic Province. The area along the Sacramento River from Shasta Reservoir 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 Bay-Delta Program 2000).

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

Clear Creek

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

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

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

American River

The Folsom Reservoir 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 Reservoir region primarily consists of rolling hills and upland plateaus between major river canyons. Three major geologic divisions within the area are a north-northwest trending belt of metamorphic rocks, granitic plutons that have intruded and obliterated some of the metamorphic belt, and deposits of volcanic ash, debris flows, and alluvial fans that are relatively flat. These deposits overlie older rocks (Bureau of Reclamation et al. 2005a).

Igneous, metamorphic, and sedimentary rock types are present within the Folsom Reservoir area. Major rock divisions are ultramafic intrusive rocks, metamorphic rocks, granodiorite intrusive rocks, and volcanic mud flows and alluvial deposits. Ultramafic rocks are most common on Flagstaff Mountain (Hill) on the Folsom Reservoir Peninsula between the North Fork American River and South Fork American River. This rock division may contain trace amounts of serpentine minerals, chromite, minor nickel, talc, and naturally occurring asbestos (Bureau of Reclamation et al. 2005b).

Metamorphic rocks are found in a north-northwest trending band primarily on the eastern portions of the Folsom Reservoir area through most of the peninsula between the North Fork American River and South Fork American River (California Geological Survey 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 (Bureau of Reclamation et al. 2005b).

Granodiorite intrusive rocks occur in the Rocklin Pluton on both sides of Folsom Reservoir extending to Lake Natoma and in the Penryn Pluton upstream of the Rocklin Pluton. Granodiorite intrusive rocks are composed of a coarse-grained crystalline matrix with slightly more iron and magnesium-bearing minerals and less quartz than granite. Of the granodiorite, the feldspar and hornblende are less resistant than the quartz crystals and easily weather. When weathering occurs, the remaining feldspars separate from the quartz, resulting in decomposed granite (Bureau of Reclamation et al. 2005b).

Volcanic mud flows and alluvial deposits are present downstream of Folsom Reservoir in the southwest corner of two major formations: Mehrten and Laguna. The Mehrten Formation contains volcanic conglomerate, sandstone, and siltstone, all derived from andesitic sources, and portions are gravels deposited by ancestral streams. The Laguna Formation, deposited predominately as debris flow on the Mehrten Formation, is a sequence of gravel, sand, and silt derived from granitic sources (Bureau of Reclamation et al. 2005b).

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

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

Stanislaus River and San Joaquin River

Stanislaus River

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

San Joaquin River

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

W.1.2.2 Seismicity

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

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

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

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 (Bureau of Reclamation and California Department of Water Resources 2011). Uplift and tilting of the Sierra Nevada block toward the west and tilting of the Coast Ranges block to the east appear to be causing gradual downward movement of the valley basement rock, in addition to subsidence caused by aquifer compaction and soil compaction discussed below. The San Joaquin Valley is bounded by the Stockton Fault of the Stockton Arch on the north and the Bakersfield Arch on the south. Most of the fault zones in the San Joaquin Valley do not appear to be active. However, numerous faults may not be known until future seismic events; an example of this fault discovery is the Nuñez reverse fault, which was not known until the 1983 Coalinga earthquake. In areas adjacent to the San Joaquin Valley, the dominant active fault structure is the Great Valley blind thrust associated with the San Andreas

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

W.1.2.3 Volcanic Potential

Active centers of volcanic activity occur in the vicinity of Mount Shasta and Lassen Peak within the Cascade Geomorphic Province north and east of the Central Valley.

Lassen Peak, about 50 miles southeast of Shasta Reservoir, 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 (U.S. Geological Survey 2000a).

W.1.2.4 Slope Stability

There are two types of processes that influence slope stability in the Shasta Reservoir watershed: mass wasting (e.g., landslides) and surficial erosion on both upland areas and the bed/bank of reservoirs and riverine features.

Mass Wasting

Mass wasting is dominated by deep-seated landslides and shallow debris slides. Initiation and/or reinitiation of slope movement occurs when these mass movement feature’s toes are undercut by the rise and fall of reservoir water levels during dry period and wet period flow events. Normal wave action of the reservoir also can reactivate landslides. Seiches, wave action from seismicity and landslide movement, will also undercut unstable areas.

Surficial Erosion

Surface erosion occurs in response to rainfall and runoff events when overland flow occurs, resulting in soil movement in rills, gullies, and sheet erosion. Particle detachment during overland flow is controlled by slope gradient and soil texture. Fine-grained soils such as fine-grained sand and silt are more susceptible to particle detachment and transport. During high-flow events, the erosion of bed and banks of riverine environments occurs for some period of time as rivers rise above base flow conditions and volume and velocity of water mobilizes alluvial material.

W.1.2.5 Soil Characteristics

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

Sacramento Valley and San Joaquin Valley Soil Characteristics

The Sacramento Valley and San Joaquin Valley contain terrace land and upland soils along the foothills. Alluvial, Aeolian, clayey, and saline/alkaline soils exist in various locations along the valley floors (CALFED Bay-Delta Program 2000; Bureau of 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 Reservoir are different from soils along other foothills in the Sacramento and San Joaquin Valleys. The soils near Shasta Reservoir are related to the geologic formations of the Klamath Mountains and Cascade Ranges Geomorphic Provinces. These soils are formed from weathered metavolcanic and metasedimentary rocks, from intrusions of granitic rocks, serpentine, and basalt and localized dormant, deep-seated landslide features. Other than the landslide features that may have high clay content with high water-holding capacity, 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 (Bureau of Reclamation 2014). Soils derived from in-place weathering of granitic rock, referred to as decomposed granite, are coarse-grained, quartz-rich, and erodible.

Upland soils along other foothills in the Sacramento and San Joaquin Valleys are formed from the Sierra Nevada and Coast Ranges Geomorphic Provinces. Along the western boundary of the Central Valley, the soils primarily are formed from sedimentary rocks. Along the eastern boundary of the Central Valley, the soils primarily are formed from igneous and metamorphic rock. The soils include serpentine soils (which include magnesium, nickel, cobalt, chromium, iron, and asbestos); sedimentary sandstones; shales; conglomerates; and sandy loam, loam, and clay loam soils above bedrock (Bureau of Reclamation 1997, 2014; Bureau of Reclamation and California Department of Water Resources 2011; California Department of Water Resources 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 (Geotechnical Consultants 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) (California Department of Water Resources 2007; Bureau of Reclamation 1997, 2005b, 2013).

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

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

Basin soils occur in the San Joaquin Valley and portions of the Delta. These soils include organic soils, imperfectly drained soils, and saline alkali soils. The organic soils are typically dark, acidic, high in organic matter, and generally include peat. The organic soils occur in the Delta, as discussed below, and along the lower San Joaquin River adjacent to the Delta. The poorly drained soils contain dark clays and occur in areas with high groundwater in the San Joaquin Valley trough and as lakebed deposits (Bureau of Reclamation and California Department of Water Resources 2011). One of the most substantial stratigraphic features of the San Joaquin Valley and a major aquitard is the Corcoran Clay, located in the western and Central Valley (Galloway and Riley 1999). The Corcoran Clay generally extends from Mendota Pool area through the center of the valley to the Tehachapi Mountains. The depth to the Corcoran Clay varies from 160 feet under the Tulare Lake lakebed to less than a foot near the western edge of the Central Valley. The Corcoran Clay is composed of numerous aquitards (a geologic formation with slow or no water transmission that acts as a barrier to groundwater movement) 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. The Bureau of Reclamation (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 (Bureau of Reclamation and California Department of Water Resources 2011). As described in Appendix R, *Land Use and Agricultural Resources Technical Appendix*, areas in the western and southern San Joaquin Valley are affected by shallow, saline groundwater that accumulates because of irrigation, and the shallow groundwater is underlain by soils with poor drainage.

Soils in the eastern San Joaquin Valley come from the Sierra Nevada and contain low levels of salt and selenium. Most soils in the western and southern San Joaquin Valley are formed from Coast Range marine sediments and contain higher concentrations of salts as well as selenium and molybdenum. Soluble selenium moves from soils into drainage water and groundwater, especially during agricultural operations to leach salts from the soils. As described in Appendix D, *Draft Alternatives*, Reclamation and other agencies are implementing programs to reduce the discharge of selenium from the San Joaquin Valley into receiving waters (Bureau of Reclamation 2005c, 2009; Bureau of Reclamation and California Department of Water Resources 2011). Additional information related to concerns with salinity and selenium in the San Joaquin Valley is presented in Appendix G, *Water Quality Technical Appendix*, and Appendix R.

Soil wind erosion is related to soil erodibility, wind speeds, soil moisture, surface roughness, and vegetative cover. Aeolian soils are more susceptible to wind erosion than alluvial soils. 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), which include allergic reactions to dust, adverse impacts to plants due to dust, and increased risk of Valley fever (Bureau of Reclamation 2005c).

W.1.2.6 Sacramento and San Joaquin Valley Subsidence

Land subsidence occurs for different reasons throughout the Central Valley. Land subsidence in the Sacramento and San Joaquin Valleys occurs primarily due to aquifer-system compaction as groundwater elevations decline as a result of groundwater overdraft (i.e., groundwater withdrawals at rates greater than groundwater recharge rates) typically used for irrigation. To a lesser degree, subsidence is also caused by weathering of some types of underlying bedrock, such as limestone, decomposition of organic matter, and natural compaction of soils (Bureau of Reclamation 2014). Historic subsidence of the Sacramento Valley has been far less than that observed in the San Joaquin Valley. For example, the range of historic subsidence in the Sacramento Valley is generally less than ten feet, whereas historical subsidence in the San Joaquin Valley has caused changes in land elevations ranging from as much as 28 feet (U.S. Geological Survey 2019) to more than 30 feet (Bureau of Reclamation and California Department of Water Resources 2011). Figure I.1-1, Measured Subsidence, 2015 to 2018, in Appendix I, *Groundwater Technical Appendix,* shows the measured subsidence in the Sacramento Valley from 2015 to 2018 (California Department of Water Resources 2021). DWR measured subsidence in the Sacramento Valley from 2015 to 2018 (California Department of Water Resources 2021). There are areas on the west side of the valley near Arbuckle and Zamora/Woodland that have seen subsidence of 0.2 feet or more since 2021 (California Department of Water Resources 2023).

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

San Joaquin Valley subsidence primarily occurs when groundwater elevations decline due to pumping for irrigation water supply, which reduces water pressure in the soils and results in compressed clay lenses and subsided land elevations. Secondary factors that may influence the rate of subsidence in the San Joaquin Valley is the Sierran uplift, sediment loading and compressional down-warping or thrust loading from the Coast Ranges, and near surface compaction (Bureau of Reclamation and California Department of Water Resources 2011). Some of the first reports of land subsidence in the San Joaquin Valley occurred in 1935 in the area near Delano (Galloway and Riley 1999). By the late 1960s, San Joaquin Valley subsidence had occurred over 5,212 square miles, or almost 50% of the San Joaquin Valley (Bureau of Reclamation 2005c). The rate of subsidence decreased initially following implementation of CVP and SWP water supplies in the San Joaquin Valley during the 1970s and 1980s. Subsidence for the next 20 years appeared to continue at a rate of 0.008 to 0.016 inches per year (Bureau of Reclamation and California Department of Water Resources 2011). However, demand for groundwater has increased as surface water supply decreased during droughts in the past 20 years, mostly as a result of agricultural irrigation water demand (Liu et al. 2022). Continued drought conditions could increase the reliance on groundwater resources. Groundwater storage and surface water storage tend to be related in that greater availability of surface water from the CVP and SWP relieves stresses on groundwater, and lesser availability of surface water increases the use of groundwater (Liu et al. 2022).

In areas adjacent to the Delta-Mendota Canal, extensive groundwater withdrawal has caused land subsidence of up to 1.5 feet in some areas. Land subsidence can cause structural damage to the

Delta-Mendota Canal, which has caused operational issues for CVP water delivery. Historical widespread soil compaction and land subsidence between 1926 and 1970 caused reduced freeboard and flow capacity of the Delta-Mendota Canal, the California Aqueduct, other canals, and roadways in the area. To better understand subsidence issues near the Delta-Mendota Canal and improve groundwater management in the area, the U.S. Geological Survey evaluated and provided information on groundwater conditions and the potential for additional land subsidence in the San Joaquin Valley. Ground surface elevation data show that a subsidence rate of up to 0.8 foot per year between 2016 and 2022 has been measured near the San Joaquin River and the Eastside Bypass. The subsidence measured was primarily inelastic (or permanent, not reversible) due to the compaction of fine-grained material. The area of maximum active subsidence is shown to be located southwest of Mendota and extends into the Merced groundwater subbasin (GWSB) to the south of El Nido. Land subsidence in this area is expected to continue to occur due to uncertainties and limitations (especially climate-related changes) in surface water supplies to meet irrigation demand and the continuous need to supplement water supply with groundwater pumping (U.S. Geological Survey 2013). Canals such as the California Aqueduct and the Delta-Mendota Canal has been affected by land subsidence of up to 1.5 feet in the Dela-Mendota Subbasin (California Department of Water Resources 2020).

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 (Bureau of Reclamation 2005d). 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 two inches.

W.1.3 Bay-Delta Operations

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

W.1.3.1 Geologic Setting

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

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

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

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

Suisun Marsh

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

San Francisco Bay

The San Francisco Bay Area is located primarily within the Coast Ranges Geomorphic Province. Eastern Contra Costa and Alameda Counties are located in the Great Valley Geomorphic Province. The Coast Ranges and Great Valley Geomorphic Provinces were described in Section W.1.2, *Central Valley*. San Francisco Bay is a structural trough formed as a gap in the Coast Range, allowing the Sacramento, San Joaquin, Napa, Guadalupe, and Pajaro 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 Bay-Delta Program 2000). Initially, alluvial sands, silts, and clays filled the bays to form Bay Mud along the shoreline areas. More recently, sedimentation patterns have changed over the past 170 years due to development of upstream areas of the watersheds, including hydraulic mining and formation of levees and dams.

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

W.1.3.2 Seismicity

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

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

W.1.3.3 Volcanic Potential

There is no active volcanism or potential for volcanism in the Bay-Delta.

W.1.3.4 Soil Characteristics

The Bay-Delta region soils include basin floor/basin rim, floodplain/valley land, terrace, foothill, and mountain soils (CALFED Bay-Delta Program 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 (Soil Conservation Service 1977, 1981; CALFED Bay-Delta Program 2000). Well-drained sands and loamy sands and poorly drained silty loams, clay loams, and clays occur on gently sloping alluvial fans of the Bay-Delta that surround the floodplain and valley lands. Drained loams, silty loams, silty clay loams, and clay loams interbedded with sedimentary rock and some igneous rock occur in the foothills. Terrace loams are located along the southeastern edge of the Bay-Delta above the valley land. The upland landscapes of the Bay-Delta region are similar to those found throughout the foothills and mountains surrounding the Central Valley with respect to erosional processes and features. The flatter landscapes of the Bay-

Delta region are not conducive for mass wasting processes, and surficial erosion is typically localized in response to storm runoff events and tidal influences.

Delta Soil Characteristics

Soils in the Delta region include organic and/or highly organic mineral soils, deltaic soils along the Sacramento and San Joaquin Rivers, basin rim soils, floodplain and stream terrace soils, valley alluvial and low terrace soils, and upland and high terrace soils (Bureau of 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 soil contains 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 (Soil Conservation Service 1992, 1993). Floodplain and stream terrace soils are mineral soils adjacent to the Sacramento and San Joaquin Rivers and other major tributaries. These soils are typically deep and stratified, with relatively poor drainage and fine textures. Valley fill, alluvial fan, and low terrace soils are typically very deep with variable texture and ability to transmit water, ranging from somewhat poorly drained silt loams and silty clay loams to well-drained fine sandy loams and silt loams. Upland and high terrace soils are generally well drained, ranging in texture from loams to clays and are primarily formed in material weathered from sandstone, shale, and siltstone, and can occur on dissected terraces or on mountainous uplands.

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

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

W.1.3.5 Subsidence

Santa Clara Valley Subsidence

Subsidence in the Bay-Delta occurs primarily in the Santa Clara Valley of Santa Clara County. The Santa Clara Valley is underlain by a groundwater aquifer with layers of unconsolidated porous soils interspersed with clay lenses. The Santa Clara GWSB has historically experienced decreasing groundwater level trends; between 1900 and 1970, water level declines of more than 200 feet from groundwater pumping caused unrecoverable land subsidence of nearly 13 feet in San Jose (California Department of Water Resources 2010). Importation of surface water using CVP, SWP, and San Francisco Public Utilities District water supplies and the development of an artificial recharge program have resulted in rising groundwater levels and sustainable conditions since the late 1960s. The groundwater levels in some portions of this GWSB decreased by at least 10 feet between fall 2018 and fall 2021 (California Department of Water Resources 2023).

Delta and Suisun Marsh Subsidence

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

Recently, the California Department of Water Resources (DWR) has implemented several projects to reverse subsidence. The 274-acre Mayberry Farms Duck Club Subsidence Reversal Project on Sherman Island includes creation of emergent wetlands ponds and channels through excavation of peat soils, improvement of water circulation, and waterfowl habitat. The facility was constructed in 2010 and is being monitored to determine the effectiveness of subsidence reversal, methyl mercury management, and carbon sequestration (Angell et al. 2013). Prior to that, DWR and USGS implemented wetlands restoration for approximately 15 acres on Twitchell Island in 1997 (California Department of Water Resources and U.S. Geological Survey 2008) to encourage tule and cattail growth. After the growing season, the decomposed plant material accumulates and increases the land elevation. Between 1997 and 2005, the West Pond showed an accretion rate of 1.1 to 1.7 inches per year. Measurements from August 2016 to November 2017 found a range of accretion from 0.1 to 3.3 inches per year, though those measurements may have methodological issues or measurement errors (Duncan 2017).

W.1.4 Additional CVP and SWP Service Areas

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

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

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

W.1.4.1 Geologic Setting

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

Portions of San Luis Obispo and Santa Barbara Counties use SWP water supplies. These areas are located within the Coast Ranges and Transverse Ranges Geomorphic Provinces. The Coast Ranges Geomorphic Province was described in Section W.1.2. The Transverse Ranges Geomorphic Province consists of deeply folded and faulted sedimentary rocks (California Geological Survey 2002; Santa Barbara County Association of Governments 2013). Bedrock along the stream channels, coastal terraces, and coastal lowlands is overlain by alluvial and terrace deposits and, in some areas, ancient sand dunes. The geomorphic province is being uplifted at the southern border along San Andreas Fault and compressed at the northern border along the Coast Ranges Geomorphic Province. Therefore, the geologic structure of the ridges and valleys are oriented along an east–west orientation, or in a transverse orientation, compared with the north–south orientation of the Coast Range.

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

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

The Mojave Desert Geomorphic Province lies between the Garlock Fault along the southern boundary of the Sierra Nevada Geomorphic Province and the San Andreas Fault (California Geological Survey 2002; Southern California Association of Governments 2011; Riverside County Integrated Project 2000). This geomorphic province includes extensive alluvial basins with nonmarine sediments from the surrounding mountains and foothills; many isolated ephemeral lakebeds (also known as playas) occur within this region with tributary streams from isolated mountain ranges. The Mojave Desert Geomorphic Province includes portions of Kern, Los Angeles, Riverside, and San Bernardino Counties.

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

W.1.4.2 Seismicity

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

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

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

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

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

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

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

W.1.4.3 Volcanic Potential

There is no active volcanism or potential for volcanism in the CVP and SWP service areas.

W.1.4.4 Soil Characteristics

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

Central Coast region are similar to those in the upland regions of the Sacramento and San Joaquin Valley with respect to slope stability.

Southern California soils include gravelly loams and gravelly sands, sands, sandy loams and loamy sands, and silty loams along the Pacific Coast shorelines and on alluvial plains. The mountains and foothills of the region include silty loams, cobbly silty loam, gravelly loam, sandy clay loams, clay loams, silty clays, and clays (Southern California Association of Governments 2011; University of California Cooperative Extension 2014; Soil Conservation Service 1973, 1978, 1986). The inland region in Riverside and San Bernardino Counties have sand, silty clays, cobbles, and boulders on the alluvial fans, valley floor, terraces, and mountains, and dry lake beds (Coachella Valley Water District 2011). The topographic features and hydrologic processes throughout Southern California are similar to those in the upland regions of the Sacramento and San Joaquin Valley and Central Coast with respect to slope stability.

W.1.4.5 Subsidence

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

Several groundwater basins (e.g., Antelope Valley, Lucerne) in Kern, Los Angeles, and San Bernardino Counties are associated with water-bearing formations. These formations contain interbedded, unconsolidated alluvial and lacustrine deposits (primarily compact gravels, sand, silt, and clay) (California Department of Water Resources 2004). Several fault zones restrict groundwater movement. Groundwater is recharged along streams from the surrounding mountains. Extensive groundwater pumping has caused subsidence and reduced the groundwater storage and flow direction within these basins.

W.2 Evaluation of Alternatives

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

W.2.1 Methods and Tools

The impact assessment considers changes in geology and soil resources related to changes in CVP and SWP operations under the alternatives as compared with the No Action Alternative. This section details methods and tools used to evaluate those effects. It should be noted that Alternative 2 consists of four phases that could be utilized under its implementation. All four phases are considered in the assessment of Alternative 2 to bracket the range of potential impacts. Changes in CVP and SWP operations under the action alternatives compared with the No Action Alternative may result in changes to geology and soils resources. Changes in surface water deliveries may result in changes in reservoir water surface elevations that could influence shoreline erosion rates throughout the extent of the reservoir as water surface elevations fluctuate on an annual and interannual basis. While shoreline rock content and slope directly influence shoreline erodibility, the extent of time and surface area exposed to wave and surficial erosion are also key factors in the loss of soil resources along reservoir shorelines. Changes in surface water deliveries could also result in modification of flow regimes, including high flows[1] in rivers downstream of CVP and SWP reservoirs, that could affect stream channel erosion. Changes in water deliveries and the extent of irrigated acreage have the potential to result in soil erosion on crop-idled lands over the long-term average condition and in dry and critically dry years. Changes in water delivery amounts may also result in increased use of groundwater resources to maintain crops, which could affect land subsidence. Changes in the water transfer program could also potentially affect soil.

Data available did not include information to complete detailed surface erosion or mass wasting analyses (i.e., slope angle, friction angle, cohesion, saturated and unsaturated unit weights) for either reservoir shoreline or riverine reaches at a scale necessary to develop a predictive erosional model. The approach acknowledges that processes that influence erosion of both reservoir shorelines and the bed shoreline erosion are not static temporally or spatially and are not conducive for analysis at the scale presented in the following discussions. Evaluation of changes in reservoir water surface elevations and flow rates was derived from the surface water supply analysis conducted using the CalSim 3 model, as described in Appendix F, *Modeling*, to simulate the operational assumptions of each alternative that were described in Chapter 3, *Alternatives*. The CalSim 3 results were used to evaluate changes in reservoir storage levels at Reclamation's five largest storage reservoirs: Trinity Reservoir, Shasta Reservoir, Folsom Reservoir, New Melones Reservoir, and Millerton Reservoir. Flows at select points on the Trinity River, Sacramento River, Stanislaus River, and San Joaquin River under the action alternatives compared with the No Action Alternative with regards to potential effects of stream channel erosion. The No Action Alternative and action alternatives are analyzed under future conditions, so this model run also includes median climate change projections.

Evaluation of the reservoir storage levels and river flows also used CalSim 3 results. For the analysis presented in the following sections, the unit of metric is thousands of acre-feet (TAF). Statistics within CalSim 3 used for this evaluation of alternatives include minimum level, maximum level, average level, 10% exceedance, and 90% exceedance. Driest and wettest periods were the time periods evaluated to determine reservoir shoreline drawdown[2] in terms of storage in TAF. The 90% exceedance statistic was applied for the driest period and 10% exceedance statistic was applied for the wettest period. These two statistics were chosen as conservative representations of dry and wet storage levels in the reservoirs and dry and wet flows for representative river locations. The appropriate seasonal time period is the period with the wettest or driest No Action Alternative scenario storage level or river flow. This process is shown below in Figure W-2. Driest periods usually occurred in the three-month period of August to

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[1] High flows are defined as flows from the CalSim 3 model that exceed the No Action Alternative and thus could result in an increase in erosion of the bed and banks of the riverine reach selected when compared with the No Action Alternative.

[2] In surface water hydrology and civil engineering, drawdown refers to the lowering of the surface elevation of a body of water where the exposed shoreline is exposed to the atmosphere due to water-level fluctuations.

October but in some cases this period occurs later. Wettest periods usually occurred in the three-month period of March to May or the four-month period of March to June. In terms of scale, the TAF for the driest periods is in general in the hundreds of TAF, whereas the wettest periods are in the thousands of TAF. There are limitations in values for dry and wet period. The values used in this analysis are consistent with those representative of the seasonal monthly period selected from the CalSim 3 output data as described in the footnotes of the table prepared for each watershed presented below. This analysis also acknowledges that many of the outputs available from the CalSim 3 model essentially reflect the inherent variability (i.e., noise) that may introduce discrepancies in the water mass balance. This issue is addressed using percent change and negligible distinctions, described in more detail following Table W-1. The difference in TAF between the dry and wet periods was applied as the drawdown for the reservoirs. The dry (90% exceedance) and wet (10% exceedance) output statistics of the five storage reservoirs are shown below in Table W-1 to Table W-5. The percent change of drawdown values compared with the No Action Alternative is also shown in these tables. In addition to these tables, Attachment 1 (*Reservoir Storage and Release Figures for No Action and Action Alternatives*) has been developed to illustrate the changes in reservoir storage and releases to rivers strictly using hydrologic outputs from CalSim 3. Due to the size of these reservoirs and lengths of river reaches, this analysis is not intended to describe with specificity the magnitude or intensity of the various erosional processes when comparing the No Action Alternative to the action alternatives recognizing these processes are influenced by other factors not influenced by changes in operation of the CVP.

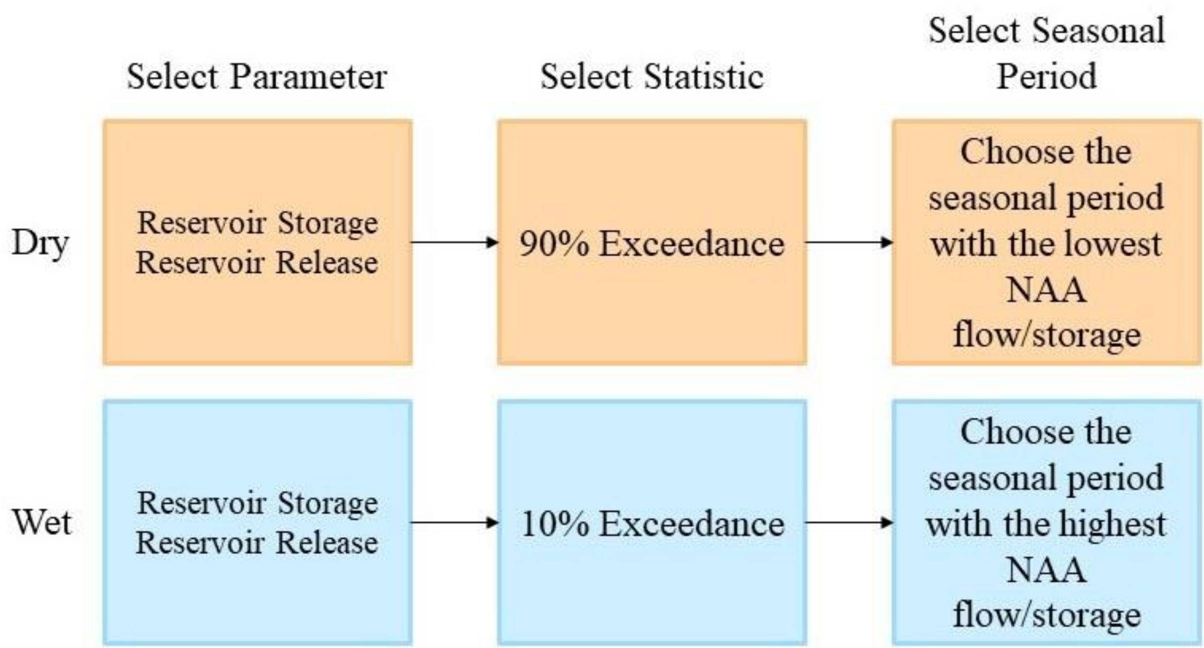

Figure W-2. Method of Determining Reservoir and River Flows

The analysis of land use changes, as described in Appendix R, was used to identify potential changes in irrigated acreage as a result in changes to water deliveries under the alternatives compared with the No Action Alternative, to evaluate potential effects on soil erosion. The

Sacramento River and San Joaquin River regions were modeled using SWAP[3] to identify the amount of irrigable acreage subject to change under each action alternative. SWAP modeling was not conducted for the Trinity River, Bay-Delta, and CVP/SWP service areas.

The surface water supply analysis was conducted using CalSim 3, as described in Appendix F, to simulate the operational assumptions of each alternative. The CalSim 3 results were then applied to the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) groundwater flow model (see Appendix F) to simulate changes in groundwater conditions, including the changes to pumping, groundwater-surface water interaction, and groundwater elevation. The C2VSim modeling was conducted for the basins and GWSBs in the Sacramento and San Joaquin Valleys. A qualitative assessment was conducted in the other project areas. The analysis of potential changes in land subsidence presented in Appendix I, *Groundwater Technical Appendix*, was used to characterize project effects upon land subsidence.

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

W.2.2 No Action Alternative

Under the No Action Alternative, Reclamation would continue with current operation of the CVP, as described in the 2020 Record of Decision and subject to the 2019 Biological Opinions. The 2020 Record of Decision for the CVP and the 2020 Incidental Take Permit for the SWP represent current management direction or intensity pursuant to 43 CFR Section 46.30.

The No Action Alternative is based on 2040 conditions. Changes that would occur ahead of the 2040 horizon without implementation of the action alternatives are not analyzed in this technical appendix. However, the changes to geology and soils that are assumed to occur by 2040 under the No Action Alternative are summarized in this section.

Conditions in 2040 would be different from existing conditions because of the following factors:

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

Under the No Action Alternative, land uses in 2040 would occur in accordance with adopted general plans. Development under the general plans could affect geology and soils, depending on

[3]Further information on the development and applicability of the SWAP model is provided in Appendix R (Section R.2.1.2.1 (Changes in Irrigated Agricultural Acreage and Total Production Value).

the type of development. Development in urbanized areas that are already developed is less likely to result in substantial erosion because areas are already disturbed. However, development in non-urbanized areas could convert natural or rural areas to developed areas, resulting in erosion during construction activities. Additionally, increased development may increase water use in areas reliant on groundwater. Depending on the source of groundwater, this could increase subsidence. Flows and reservoir levels would remain as under current conditions. Municipal and industrial water uses and agricultural deliveries, and thereby land use and agricultural resources, including potential for erosion of irrigable lands taken out of production, would continue to vary according to available water supply.

The No Action Alternative would also rely upon increased use of Livingston-Stone National Fish Hatchery during droughts to increase production of winter-run Chinook salmon. However, this component requires no physical changes to the facility and would have no effect on geology and soils.

W.2.3 Alternative 1

W.2.3.1 Potential Changes in Soil Erosion

The analysis of soil erosion presented in the following discussion of each action alternative is organized to consider shoreline erosion, dry period and wet period flows (channel erosion), and erosion of irrigable lands. As described in the methods section, the discussion of shoreline erosion is focused on changes in reservoir storage at Reclamation's five largest storage reservoirs operated as part of the CVP: Trinity, Shasta, Folsom, New Melones, and Millerton. Table W-1 through Table W-5 illustrate the variation in drawdowns for the No Action Alternative and the four alternatives. As described in the methods section, the discussion of channel erosion is focused on changes in dry period and wet period flows released from Reclamation dams to the Trinity River, Sacramento River, American River, Stanislaus River, and San Joaquin River during spring runoff periods, assuming that this portion of the water year is most representative of seasonal flow events that could influence riverine erosional processes in these river systems. Table W-1 through Table W-5 illustrate the variation for the No Action Alternative and the four alternatives' channel dry period and wet period flows (channel erosion).

Data from tables in Appendix R related to potential changes in irrigated agricultural acreage were utilized in calculating potential erosion of irrigable lands. These data include the acres under long-term average conditions and the acres for the average of dry and critical years. The values provided in the analysis represent changes in irrigable lands compared with the No Action Alternative.

Trinity River

Changes in shoreline erosion associated with operation of Trinity Dam are expected in Trinity Reservoir Storage under Alternative 1 compared with the No Action Alternative. As illustrated in Table W-1, these changes range between 46 TAF (6% change) during dry period drawdown conditions and 1 TAF (0% change) during wet period drawdown conditions. Changes in shoreline erosion of Trinity Reservoir Storage are negligible in wet years. Releases to the Trinity River would decrease under both dry and wet conditions under Alternative 1, changing between -

1.3 TAF (-3% change) and -14 TAF (-2% change). Changes in erosion to the bed and bank of the Trinity River would be negligible.

Table W-1. Trinity Reservoir Storage and Trinity River Release Prediction for No Action Alternative and Alternatives 1 through 4

	Alternative	Dry Period Drawdown (TAF)[1,3]	Wet Period Drawdown (TAF)[2,4]	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
Trinity Lake Storage	No Action Alternative	781	2188	—	0%	—	0%
Trinity Lake Storage	Alternative 1	827	2189	46	6%	1	0%
Trinity Lake Storage	Alternative 2 Without TUCP Without VA	805	2172	24	3%	-16	-1%
Trinity Lake Storage	Alternative 2 With TUCP Without VA	806	2172	25	3%	-16	-1%
Trinity Lake Storage	Alternative 2 Without TUCP With Delta VA	807	2172	26	3%	-16	-1%
Trinity Lake Storage	Alternative 2 Without TUCP All VA	800	2172	19	2%	-16	-1%
Trinity Lake Storage	Alternative 3	846	2172	65	8%	-16	-1%
Trinity Lake Storage	Alternative 4	820	2189	39	5%	-1	0%
Trinity River Release	No Action Alternative	41.4	813	—	0%	—	0%
Trinity River Release	Alternative 1	40.1	798	-1.3	-3%	-14	-2%
Trinity River Release	Alternative 2 Without TUCP Without VA	37.8	811	-3.6	-9%	-2	0%
Trinity River Release	Alternative 2 With TUCP Without VA	37.8	811	-3.6	-9%	-2	0%
Trinity River Release	Alternative 2 Without	37.8	831	-3.6	-9%	18	2%

	Alternative	Dry Period Drawdown (TAF)[1,3]	Wet Period Drawdown (TAF)[2,4]	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
	TUCP With Delta VA						
	Alternative 2 Without TUCP All VA	37.8	816	-3.6	-9%	3	0%
	Alternative 3	43.8	750	2.4	6%	-63	-8%
	Alternative 4	39.6	797	-1.8	-4%	-16	-2%

Notes:
[1] Dry period releases for Trinity Lake Storage are based upon the 90% exceedance for the months of September to November only for the 1922 – 2021 CalSim 3 simulation period.
[2] Wet period releases for Trinity Lake Storage are based upon the 10% exceedance for the months of March to June only for the 1922 – 2021 CalSim 3 simulation period.
[3] Dry period releases for Trinity River Release are based upon the 90% exceedance for the months of December to February only for the 1922 – 2021 CalSim 3 simulation period.
[4] Wet period releases for Trinity River Release are based upon the 10% exceedance for the months of June to September only for the 1922 – 2021 CalSim 3 simulation period.

Negative reservoir storage values in Table W-1 represent alternatives that have drawdowns less than those in the No Action Alternative. Positive drawdown values for storage indicate drawdowns greater than the No Action Alternative, and hence are susceptible to mass wasting (i.e., landslides) and surface erosion (i.e., sheet erosion, rilling, and gullying).

Positive drawdown values in Table W-1 for release denote drawdowns greater than the No Action Alternative; therefore, there is more water entering the river from the upstream reservoir, also termed high flow, and are therefore more susceptible to mass wasting and surface erosion due to approaching bankfull conditions. This logic is shown visually below in Figure W-3 and Figure W-4.[4]

The percent change is shown in the column to the right of the drawdown values. The percent change between -5% and 5% is considered negligible and attributed to noise in the CalSim 3 model. The tolerance level in percent change aims to prevents instances in surface erosion and mass wasting in which there are increases in both dry and wet periods, which are due to noise in the CalSim 3 model.

[4] For a reservoir, Alternative drawdown values > No Action Alternative drawdown values imply a larger erosional surface exposed for the alternative than the No Action Alternative, possibly resulting in surface erosion and mass-wasting. For river releases, Alternative drawdown values > No Action Alternative drawdown values imply more releases into the river and possibly results in flooding with subsequent bank failures.

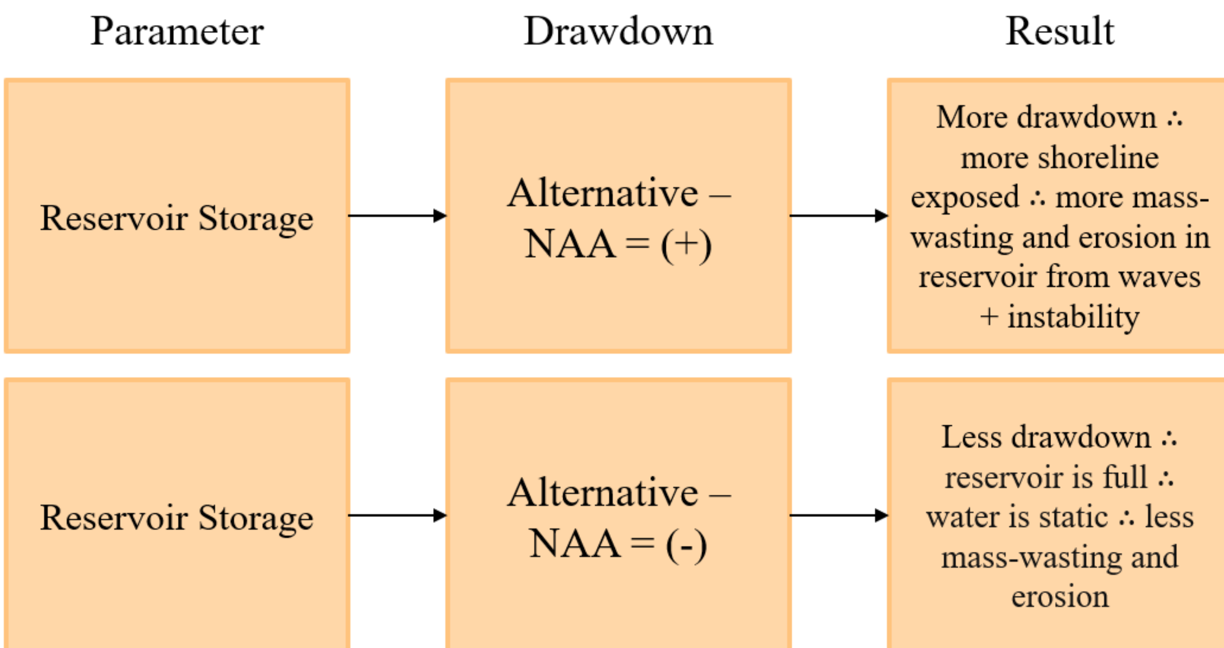

Figure W-3. Reservoir Storage Drawdown Logic

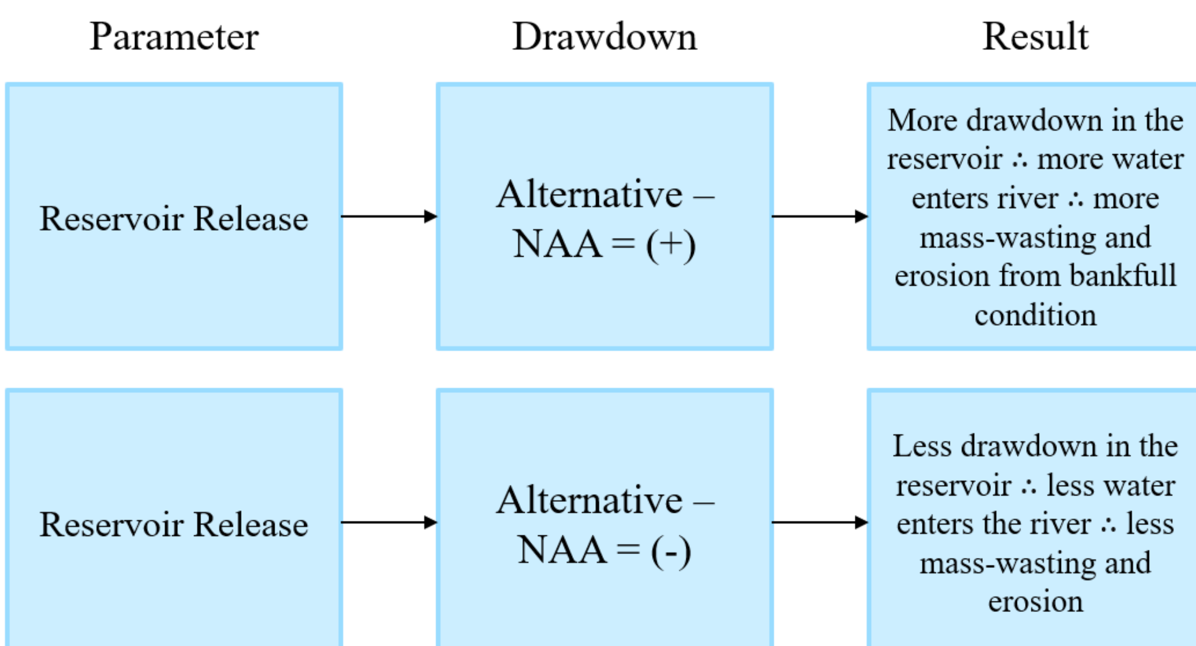

Figure W-4. Reservoir Release Drawdown Logic

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

Sacramento Valley

Shoreline erosion associated with the operation of Shasta Reservoir and Folsom Reservoir are displayed in Table W-2 and Table W-3, respectively. Erosion associated with changes in Shasta Reservoir storage would increase under Alternative 1, 16 TAF (1% change) for dry periods and 14 TAF (0% change) for wet periods, compared with the No Action Alternative. Though positive reservoir release values represent flow events in which bankfull conditions mass wasting and bank erosion are likely to occur, the percent change of Shasta Reservoir under Alternative 1 is negligible under both dry and wet conditions. Under Alternative 1, releases to the Sacramento River for wet periods (51 TAF and 1% change), would be positive, but negligible, and therefore are not likely to result in erosion to the bed and bank of the Sacramento River when compared with the No Action Alternative. Releases to the Sacramento River in dry years are negative and negligible (-16 TAF and -3% change, respectively) and are not likely to result in erosion in the bed and bank compared with the No Action Alternative.

Table W-2. Shasta Reservoir Storage and Sacramento River Release Prediction for No Action Alternative and Alternatives 1 through 4.

	Alternative	Dry Period Drawdown (TAF)	Wet Period Drawdown (TAF)	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
Shasta Lake Storage	No Action Alternative	1441	4237	—	0%	—	0%
	1	1457	4251	16	1%	14	0%
	Alternative 2 Without TUCP Without VA	1600	4238	159	11%	1	0%
	Alternative 2 With TUCP Without VA	1763	4238	322	22%	1	0%
	Alternative 2 Without TUCP With Delta VA	1599	4236	158	11%	-1	0%
	Alternative 2 Without TUCP All VA	1539	4236	98	7%	-1	0%
	3	1902	4254	461	32%	17	0%

	Alternative	Dry Period Drawdown (TAF)	Wet Period Drawdown (TAF)	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
	4	1563	4238	122	8%	1	0%
Sacramento River Release	No Action Alternative	487	4554	—	0%	—	0%
Sacramento River Release	1	471	4605	-16	-3%	51	1%
Sacramento River Release	Alternative 2 Without TUCP Without VA	492	4652	5	1%	98	2%
Sacramento River Release	Alternative 2 With TUCP Without VA	494	4637	7	1%	83	2%
Sacramento River Release	Alternative 2 Without TUCP With Delta VA	492	4577	5	1%	23	1%
Sacramento River Release	Alternative 2 Without TUCP All VA	492	4606	5	1%	52	1%
Sacramento River Release	3	505	4687	18	4%	133	3%
Sacramento River Release	4	494	4598	7	1%	44	1%

Notes:
[1] Dry period releases for Shasta Lake Storage are based upon the 90% exceedance for the months of September to November only for the 1922 – 2021 CalSim 3 simulation period.
[2] Wet period releases for Shasta Lake Storage are based upon the 10% exceedance for the months of March to June only for the 1922 – 2021 CalSim 3 simulation period.
[3] Dry period releases for Sacramento River Release are based upon the 90% exceedance for the months of December to February only for the 1922 – 2021 CalSim 3 simulation period.
[4] Wet period releases for Sacramento River Release are based upon the 10% exceedance for the months of November to March only for the 1922 – 2021 CalSim 3 simulation period.

Table W-3. Folsom Reservoir Storage and American River Release Prediction for No Action Alternative and Alternatives 1 through 4.

	Alternative	**Dry Period Drawdown (TAF)**	**Wet Period Drawdown (TAF)**	**Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)**		**Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)**	
Folsom Lake Storage	No Action Alternative	323	876	—	0%	—	0%
	Alternative 1	399	876	76	24%	0	0%
	Alternative 2 Without TUCP Without VA	315	872	-8	-2%	-4	0%
	Alternative 2 With TUCP Without VA	334	875	11	3%	-1	0%
	Alternative 2 Without TUCP With Delta VA	316	872	-7	-2%	-4	0%
	Alternative 2 Without TUCP All VA	334	871	11	3%	-5	-1%
	Alternative 3	338	874	15	5%	-2	0%
	Alternative 4	351	875	28	9%	-1	0%
American River Release	No Action Alternative	175	2827	—	0%	—	0%
	Alternative 1	100	2827	-75	-43%	0	0%
	Alternative 2 Without TUCP Without VA	117	2827	-58	-33%	0	0%
	Alternative 2 With TUCP Without VA	150	2827	-25	-14%	0	0%
	Alternative 2 Without TUCP With Delta VA	127	2826	-48	-27%	-1	0%

	Alternative	Dry Period Drawdown (TAF)	Wet Period Drawdown (TAF)	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
	Alternative 2 Without TUCP All VA	150	2801	-25	-14%	-26	-1%
	Alternative 3	139	2827	-36	-20%	0	0%
	Alternative 4	152	2807	-23	-13%	-20	-1%

Notes:
[1] Dry period releases for Folsom Lake Storage are based upon the 90% exceedance for the months of x to x only for the 1922 – 2021 CalSim 3 simulation period.
[2] Wet period releases for Folsom Lake Storage are based upon the 10% exceedance for the months of x to x only for the 1922 – 2021 CalSim 3 simulation period.
[3] Dry period releases for American River Release are based upon the 90% exceedance for the months of x to x only for the 1922 – 2021 CalSim 3 simulation period.
[4] Wet period releases for American River Release are based upon the 10% exceedance for the months of x to x only for the 1922 – 2021 CalSim 3 simulation period.

Under Alternative 1, Folsom Reservoir drawdowns for dry periods is 76 TAF (24% change) more than the No Action Alternative. Therefore, there is a greater likelihood for mass wasting and surface erosion to occur for this alternative during dry periods than what would occur under the No Action Alternative. Wet periods are equal to those in the No Action Alternative (0 TAF); therefore, there would be no changes in erosion or mass wasting.

In the American River, Alternative 1 would release up to 75 TAF (-43% change) less during dry periods and would likely not result in erosion in the American River as compared with the No Action Alternative. During wet periods, conditions are equal to those in the No Action Alternative (0 TAF) and, therefore, mass wasting and surface erosion would be comparable to the No Action Alternative.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, with the highest flows occurring typically December through February. Flows through the Yolo Bypass are expected to increase by 1.6% under Alternative 1 compared with the No Action Alternative, increasing from 28,132 cubic feet per second (cfs) to 28,592 cfs. This minor increase in winter flood flows through the Yolo Bypass is negligible given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of the bypass and is not expected to result in a change in erosion.

When compared with the No Action Alternative, Alternative 1 would decrease lands subject to fallowing in the Sacramento River region by 955 acres during average water years, which is 0.05% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be a decrease of 4,379 acres of fallowed land, which is a 0.22% decrease of the total irrigated lands subject to erosion. Therefore, erosion could decrease under Alternative 1 compared with the No Action Alternative.

San Joaquin Valley

Table W-4 and Table W-5 provide information for New Melones Reservoir and Millerton Reservoir storage and release information on the Stanislaus River and San Joaquin River used to evaluate changes for action alternatives compared with the No Action Alternative.

Table W-4. New Melones Reservoir Storage and Stanislaus River Release for No Action Alternative and Alternatives 1 through 4.

	Alternative	**Dry Period Drawdown (TAF)**	**Wet Period Drawdown (TAF)**	**Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)**		**Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)**	
New Melones Lake Storage	No Action Alternative	1009	2202	—	0%	—	0%
	Alternative 1	1055	2189	46	5%	-13	-1%
	Alternative 2 Without TUCP Without VA	1003	2226	-6	-1%	24	1%
	Alternative 2 With TUCP Without VA	1004	2226	-5	-1%	24	1%
	Alternative 2 Without TUCP With Delta VA	1003	2226	-6	-1%	24	1%
	Alternative 2 Without TUCP All VA	1004	2226	-5	-1%	24	1%
	Alternative 3	1020	2149	11	1%	-53	-2%
	Alternative 4	1004	2226	-5	-1%	24	1%
Stanislaus River Release	No Action Alternative	41	671	—	0%	—	0%
	Alternative 1	47	719	6	13%	48	7%
	Alternative 2 Without TUCP Without VA	44	693	3	7%	22	3%

	Alternative	Dry Period Drawdown (TAF)	Wet Period Drawdown (TAF)	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
	Alternative 2 With TUCP Without VA	44	693	3	7%	22	3%
	Alternative 2 Without TUCP With Delta VA	44	693	3	7%	22	3%
	Alternative 2 Without TUCP All VA	44	693	3	7%	22	3%
	Alternative 3	43	740	2	4%	69	10%
	Alternative 4	44	693	3	7%	22	3%

Notes:
[1] Dry period releases for New Melones Lake Storage are based upon the 90% exceedance for the months of September to November only for the 1922 – 2021 CalSim 3 simulation period.
[2] Wet period releases for New Melones Lake Storage are based upon the 10% exceedance for the months of June to September only for the 1922 – 2021 CalSim 3 simulation period.
[3] Dry period releases for Stanislaus River Release are based upon the 90% exceedance for the months of December to February only for the 1922 – 2021 CalSim 3 simulation period.
[4] Wet period releases for Stanislaus River Release are based upon the 10% exceedance for the months of March to June only for the 1922 – 2021 CalSim 3 simulation period.

Negative reservoir storage values for New Melones Reservoir presented in Table W-4 represent alternatives that have drawdowns less than those in the No Action Alternative. Positive drawdown values indicate greater drawdowns than the No Action Alternative and hence susceptible to mass wasting (i.e., landslides) and surface erosion (i.e., sheet erosion, rilling, and gullying). For New Melones Reservoir Storage, during dry periods, Alternative 1 has positive values, 46 TAF, though only a 5% change, and therefore would not experience changes in mass wasting and surface erosion when compared with the No Action Alternative because the percent change is negligible. During wet periods, Alternative 1 would result in a negative drawdown, -13 TAF (-1% change), and would not experience changes in mass wasting and surface erosion.

For the Stanislaus River Release, positive reservoir release values represent high-flow events in which mass wasting and bank erosion during bankfull conditions are likely to occur. Alternative 1 has larger drawdowns during both dry and wet periods, 6 TAF (13% change) and 48 TAF (7% change), than the No Action Alternative and has a greater likelihood to result in mass wasting and bank erosion during dry and wet periods than the No Action Alternative. These numbers may be attributed to noise in the CalSim 3 model simulation and may not accurately represent dry and wet conditions.

Under Alternative 1, there are no changes in the operation of Millerton Reservoir storage or release. In addition, the operations of Millerton Reservoir would not be affected by changes elsewhere in the CVP. There would be no change in erosion associated with Millerton Reservoir shoreline levels or releases to the San Joaquin River.

Table W-5. Millerton Reservoir Storage and San Joaquin River Release Prediction for No Action Alternative and Alternatives 1 through 4.

	Alternative	**Dry Period Drawdown (TAF)**	**Wet Period Drawdown (TAF)**	**Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)**		**Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)**	
Millerton Lake Storage	No Action Alternative	139	475	—	0%	—	0%
	Alternative 1	139	474	0	0%	-1	0%
	Alternative 2 Without TUCP Without VA	139	475	0	0%	0	0%
	Alternative 2 With TUCP Without VA	139	475	0	0%	0	0%
	Alternative 2 Without TUCP With Delta VA	139	475	0	0%	0	0%
	Alternative 2 Without TUCP All VA	139	475	0	0%	0	0%
	3	138	474	-1	-1%	-1	0%
	4	139	475	0	0%	0	0%
San Joaquin River Releases	No Action Alternative	11.8	520	—	0%	—	0%
	Alternative 1	11.5	520	-0.3	-2%	0	0%
	Alternative 2 Without TUCP Without VA	11.9	520	0.1	1%	0	0%
	Alternative 2 With TUCP Without VA	11.9	520	0.1	1%	0	0%

	Alternative	Dry Period Drawdown (TAF)	Wet Period Drawdown (TAF)	Difference between No Action Alternative and Alternative Dry Period Drawdown (TAF) and (% Change)		Difference between No Action Alternative and Alternative Wet Period Drawdown (TAF) and (% Change)	
	Alternative 2 Without TUCP With Delta VA	11.7	520	-0.1	-1%	0	0%
	Alternative 2 Without TUCP All VA	11.7	520	-0.1	-1%	0	0%
	Alternative 3	12.4	519	0.6	5%	-1	0%
	Alternative 4	11.8	520	0	0%	0	0%

Notes:
[1] Dry period releases for Millerton Lake Storage are based upon the 90% exceedance for the months of September to November only for the 1922 – 2021 CalSim 3 simulation period.
[2] Wet period releases for Millerton Lake Storage are based upon the 10% exceedance for the months of March to June only for the 1922 – 2021 CalSim 3 simulation period.
[3] Dry period releases for San Joaquin River Release are based upon the 90% exceedance for the months of June to September only for the 1922 – 2021 CalSim 3 simulation period.
[4] Wet period releases for San Joaquin River Release are based upon the 10% exceedance for the months of March to June only for the 1922 – 2021 CalSim 3 simulation period.

When compared with the No Action Alternative, Alternative 1 would result in a decrease in lands subject to fallowing in the San Joaquin River region by 91,372 acres during average water years, which is 2.88% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be a decrease of 87,164 acres of fallowed land, a 3.01% decrease of the total irrigated lands subject to erosion. This decrease in fallowed lands could reduce the potential for erosion compared with the No Action Alternative.

Bay-Delta Operations

No changes in flows are expected in the Bay-Delta region under Alternative 1 compared with the No Action Alternative; therefore, stream channel erosion would not be associated with Alternative 1 in this area. No changes in flows are expected in the Suisun Marsh or the San Francisco Bay under Alternative 1; therefore, there is no expected change to erosion rates.

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

Additional CVP and SWP Service Areas

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

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

W.2.3.2 Potential Changes in Rate of Land Subsidence Due to Increased Use of Groundwater

Trinity River

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

Central Valley

Land subsidence is caused by the consolidation of certain subsurface soils when the pore pressure in those soils is reduced. In the Sacramento and San Joaquin Valleys, that reduction in pore pressure is usually caused by groundwater pumping that causes groundwater levels to fall below historical low levels. Given that groundwater levels are generally expected to increase or remain unchanged due to Alternative 1, it is unlikely that Alternative 1 would cause additional subsidence compared with the No Action Alternative.

Southern California Region

The Southern California region is not known to be highly susceptible to subsidence, as noted in Appendix I, Section I.2.3.4.4, *Southern California Region*. Groundwater pumping is not expected to increase in this region, suggesting that subsidence would not be a concern in this area.

W.2.4 Alternative 2

W.2.4.1 Potential Changes in Soil Erosion

Trinity River

During dry periods, for all phases of Alternative 2, the changes in drawdown values of Trinity Reservoir Storage are negligible and positive (19 TAF to 26 TAF, 2 to 3% change) compared with the No Action Alternative, as shown in Table W-1. Therefore, there would be no changes in shoreline exposure resultant in mass wasting and surface erosion. Similarly, during wet conditions, Alternative 2 phases have negligible negative values at -16 TAF (approximately -1% change), as shown in Table W-1, and therefore no mass wasting and surface erosion would result in comparison with the No Action Alternative.

Changes in flows during wet periods are expected in the Trinity River below Lewiston Dam under all phases of Alternative 2 ranging from -2 TAF to 18 TAF (approximately 0% to 2%

change), as shown in Table W-1. All phases under wet periods are negligible. During dry periods, all phases of Alternative 2 in the Trinity River are negative (-3.6 TAF, -9% change), indicating less erosion and mass wasting than the No Action Alternative.

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

Sacramento Valley

During dry periods in Shasta Reservoir, all phases of Alternative 2 have positive drawdown values ranging from 98 TAF (7% change) to 322 TAF (22% change), as shown in Table W-2. Positive drawdown values indicate the likelihood for mass wasting and surface erosion would be greater under Alternative 2 than those for the No Action Alternative. For wet periods, all phases of Alternative 2 have negligible percent changes (approximately 0% change), and therefore there are no changes in mass wasting and surface erosion expected under wet conditions.

The Sacramento River Release's drawdown is negligible during both dry and wet periods. The drawdown values for dry periods range between 5 TAF (1% change) to 7 TAF (1% change) and wet periods of 23TAF (1% change) to 98TAF (2% change), as shown in Table W-2. No change for mass wasting and surface erosion is expected to occur for this alternative compared with the No Action Alternative.

During dry periods, Folsom Reservoir drawdown for all phases are negligible, 11 TAF (3% change) to -8 TAF (-2% change), as shown in Table W-3. No changes in likelihood of mass wasting and surface erosion are expected. For wet periods, all phases of Alternative 2 are negligible and negative, -1 (approximately 0% change) to -5 TAF (-1% change), as shown in Table W-3. No change in the likelihood for mass wasting and surface erosion for Alternative 2 is expected relative to the No Action Alternative.

The American River Release during dry periods has negative drawdown values, ranging from -25 TAF to -58 TAF (-14% to -33% change), for all phases of Alternative 2, predicting a lower likelihood for mass wasting and surface erosion to occur for this alternative than what would occur for the No Action Alternative (Table W-3). During wet periods, all phases have negligible negative values ranging from 0 TAF (0% change) to -26 TAF (-1% change), as shown in Table W-3.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, typically December through February. Flows through the Yolo Bypass are expected to increase 0.5% under both Alternative 2 Without TUCP Without VA and Alternative 2 With TUCP Without VA, increasing from 28,132 cfs under the No Action Alternative to 28,264 cfs and 28,272 cfs, respectively. However, these winter flows through the Yolo Bypass are expected to decrease between 1% and 1.4% under Alternative 2 Without TUCP With Delta VA and Alternative 2 Without TUCP All VA, decreasing from 28,132 cfs in the No Action Alternative to 27,838 cfs and 27,728 cfs, respectively. These minor increases and decreases in winter flood flows through the Yolo Bypass would result in negligible changes in riverine erosion given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of the bypass.

When compared with the No Action Alternative, Alternative 2 With TUCP Without VA would increase lands subject to fallowing in the Sacramento River region by 8,929 acres during average water years, which is 0.44% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 11,917 acres of fallowed land, a 0.59% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion due to fallowing would increase compared with the No Action Alternative.

When compared with the No Action Alternative, Alternative 2 Without TUCP Without VA would increase lands subject to fallowing in the Sacramento River region by 4,758 acres during average water years, which is 0.23% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 6,026 acres of fallowed land, a 0.3% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion would increase compared with the No Action Alternative.

When compared with the No Action Alternative, Alternative 2 Without TUCP Delta VA would increase lands subject to fallowing in the Sacramento River region during average water years by 5,545 acres, which is 0.27% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 5,013 acres of fallowed land, a 0.25% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion associated with fallowing would increase compared with the No Action Alternative.

When compared with the No Action Alternative, Alternative 2 Without TUCP Systemwide VA would increase lands subject to fallowing in the Sacramento River region during average water years by 6,401 acres, which is 0.31% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 5,885 acres of fallowed land, a 0.29% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion would increase compared with the No Action Alternative.

San Joaquin Valley

During dry periods, all phases of Alternative 2 for the New Melones Reservoir have negligible negative drawdown values ranging between -5 TAF and -6 TAF (approximately -1% change), as shown in Table W-4. This negative drawdown indicates no changes to mass wasting and surface erosion associated with reservoir drawdown than predicted for the No Action Alternative for. For wet periods, all phases of Alternative 2 are negligible and positive, 24 TAF (1% change), as shown in Table W-4, denoting no changes for mass wasting and surface erosion when compared with the No Action Alternative. Releases to the Stanislaus River from the New Melones Reservoir under all phases for dry periods (3 TAF, 7% change) show an increased likelihood of mass wasting and surface erosion during high flow; however, wet periods (22 TAF, 3% change) have negligible, positive values denoting no changes for mass wasting and surface erosion for this alternative than what is predicted for the No Action Alternative.

Under Alternative 2, there is no changes in operations to the CVP with respect to storage of water in Millerton Reservoir or release of water to the San Joaquin River (Table W-5).

When compared with the No Action Alternative, Alternative 2 With TUCP Without VA would increase lands subject to fallowing in the San Joaquin River region by 35,880 acres during average water years, which is 1.13% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 53,681 acres of fallowed land, a 1.85% increase of the total irrigated lands subject to erosion. This increase in irrigated lands would increase the potential for erosion during average water years and increase the potential for erosion during critical and dry water year types.

When compared with the No Action Alternative, Alternative 2 Without TUCP Without VA would increase lands subject to fallowing in the San Joaquin River region by 3,806 acres during average water years, which is 0.12% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 20,097 acres of fallowed land, a 0.69% increase of the total irrigated lands subject to erosion. This would increase the potential for erosion.

When compared with the No Action Alternative, Alternative 2 Without TUCP Delta VA would increase lands subject to fallowing in the San Joaquin River region by 37,982 acres during average water years, which is 1.2% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 40,017 acres of fallowed land, a 1.38% increase of the total irrigated lands subject to erosion. This increase in fallowed land would increase the potential for erosion.

When compared with the No Action Alternative, Alternative 2 Without TUCP Systemwide VA would increase lands subject to fallowing in the San Joaquin River by 33,061 acres during average water years, which is 1.04% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 39,212 acres of fallowed land, a 1.35% increase of the total irrigated lands subject to erosion. This increase in fallowed land would increase the potential for erosion.

Bay-Delta Operations

There are no storage reservoirs associated with the Bay-Delta region so no changes in reservoir water levels would occur that could result in shoreline erosion. No changes in flows are expected in the Bay-Delta under Alternative 2 (all phases), compared with the No Action Alternative; therefore, changes to erosion rates associated with Alternative 2 would not occur in this area. No changes in flows are expected in the Suisun Marsh or the San Francisco Bay under Alternative 2; therefore, there is no expected change to erosion rates.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP. Flows on average would decrease in this region under the phases of Alternative 2 compared with the No Action Alternative. Therefore, an increase in fallowing of agricultural land is anticipated. The potential for soil erosion would increase compared with the No Action Alternative.

Additional CVP and SWP Service Areas

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

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

W.2.4.2 Potential Changes in Land Subsidence Due to Increased Use in Groundwater

Trinity River

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

Central Valley Region

In the Sacramento and San Joaquin Valleys, average groundwater levels are generally expected to remain the same or decrease the potential for additional subsidence exists. Average groundwater levels are simulated to decrease up to approximately 13 to 14 feet for Alternative 2 With TUCP Without VA and Alternative 2 Without TUCP Without VA in some water year types compared to the No Action Alternative. Groundwater levels may decrease closer to 19 to 20 feet for Alternative 2 Without TUCP Delta VA and Alternative 2 Without TUCP Systemwide VA compared to the No Action Alternative. The largest decreases in simulated groundwater levels would occur along the western portion of the Central Valley in the Sacramento Valley and in the San Joaquin Valley. Portions of these areas are known to have historic subsidence, and further reductions in groundwater level may cause additional subsidence. Alternatives with larger decreases in groundwater levels have a higher likelihood of additional subsidence under all phases of Alternative 2 when compared with the No Action Alternative. The location and amount of subsidence is highly dependent on the local soil conditions and historical low groundwater levels throughout the Central Valley region.

Southern California Region

The Southern California region is not known to be susceptible to subsidence and, as was noted in Appendix I, Section I.2.4.4.4, *Southern California Region*, groundwater pumping is not expected to increase in this region, suggesting that subsidence would not be a concern in this area.

W.2.5 Alternative 3

W.2.5.1 Potential Changes in Soil Erosion

Trinity River

Alternative 3 during dry periods has the largest drawdown for Trinity Reservoir compared with the No Action Alternative with 65 TAF (8% change) (Table W-1); therefore, shoreline erosion would increase relative to the No Action Alternative. During wet periods, the potential for shoreline erosion would be less than the No Action Alternative (-16 TAF) (-1% change) and would be negligible. During releases from Trinity Reservoir during dry periods, Alternative 3 would have an increase in releases with 2.4 TAF (6% change) that would likely result in an increase in erosion of the bed and banks of the Trinity River when compared with the No Action Alternative when it experiences high flow, as shown in Table W-1. During wet periods, Alternative 3 would result in -63 TAF (-8% change), which could lead to a decrease in erosion compared with the No Action Alternative.

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

Sacramento Valley

Alternative 3 for Shasta Reservoir storage, during dry and wet periods, has positive drawdown values (461 TAF for dry and 17 TAF for wet periods, 32% change and 0 % change, respectively), as shown in Table W-2. Therefore, there is a greater likelihood for mass wasting and surface erosion compared with No Action Alternative in dry years only. During release from Shasta Reservoir, the drawdown values are positive, 18 TAF (4% change) in dry years and 133 TAF (3% change) in wet years, denoting a negligible change in likelihood for mass wasting and surface erosion in the Sacramento River to occur in comparison to the No Action Alternative.

Storage for Folsom Reservoir during dry periods has a positive drawdown value (15 TAF, 5% change), denoting a negligible change in potential for mass wasting and surface erosion to occur than for the No Action Alternative, as shown in Table W-3. For wet periods, this value is negative (-2 TAF, approximately 0% change), indicating a negligible change for mass wasting and surface erosion to occur than what is predicted for the No Action Alternative. During release from Folsom Reservoir, the dry periods have a negative drawdown, -36 TAF (-20% change), showing a smaller likelihood for erosion in the American River to occur than for the No Action Alternative, as shown in Table W-3. Wet periods would show no change (0 TAF) compared with the No Action Alternative.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, typically December through February. Flows through the Yolo Bypass are expected to increase by 9.5% under Alternative 3, compared with the No Action Alternative, increasing from 28,132 cfs to 30,811 cfs. This minor increase in winter flood flows through the Yolo Bypass would result in negligible riverine erosion given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of the bypass.

When compared with the No Action Alternative, Alternative 3 would increase lands subject to fallowing in the Sacramento River region by 22,818 acres during average water years, which is 1.11% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 21,123 acres of fallowed land, a 1.03% increase of the total irrigated lands subject to erosion. This would increase the potential for erosion.

San Joaquin Valley

During dry periods, Alternative 3 would result in a positive drawdown, 11 TAF (1% change), and therefore the shoreline of New Melones Reservoir is not likely to experience mass wasting and surface erosion when compared with the No Action Alternative because the percent change is negligible, as shown in Table W-4. During wet periods, Alternative 3 has a negligible negative drawdown (-53 TAF, -2% change), and thus the shoreline of New Melones Reservoir is less likely to experience mass wasting and surface erosion when compared with the No Action Alternative. Releases from New Melones Reservoir to the Stanislaus River would result in positive drawdown values during dry periods (2 TAF, 4% change) and wet periods (69 TAF, 10% change), denoting that there is a greater likelihood for channelized erosion in the Stanislaus River during wet periods when compared with the No Action Alternative, as shown in Table W-4.

Under Alternative 3, there would be no changes to the operation of Millerton Reservoir, nor releases to the San Joaquin River relative to the No Action Alternative. Therefore, no impacts related to shoreline erosion surrounding Millerton Reservoir or flow erosion of the San Joaquin River beyond those associated with the No Action Alternative.

When compared with the No Action Alternative, Alternative 3 would decrease lands subject to fallowing in the San Joaquin River region by 303,764 acres during average water years, which is 9.56% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 210,633 acres of fallowed land, a 7.27% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion would decrease during average water years and increase during critical and dry water year types.

Bay-Delta Operations

As mentioned above, a minor increase in flow under Alternative 3 is expected through the Delta during January (1,284 TAF); however, this 7 % increase is well below flows during winter flood events through the Bay-Delta. Therefore, erosion is not a substantial concern in this area.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows on average would decrease in this region under Alternative 3 compared with the No Action Alternative. Therefore, an increase in lands subject to fallowing is anticipated. The potential for soil erosion would increase compared with the No Action Alternative.

Additional CVP and SWP Service Areas

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

Flows would increase in this region under Alternative 3, compared with the No Action Alternative. Therefore, no conversion of agricultural land or crop idling is anticipated, and soil erosion caused by these factors would not occur.

W.2.5.2 Potential Changes in Land Subsidence Due to Increased Use of Groundwater

Trinity River

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

Central Valley

In the Sacramento and San Joaquin Valleys, groundwater levels are generally expected to remain the same or decrease, thereby increasing the potential for additional subsidence to occur at various locations throughout the region. Average groundwater levels are simulated to decrease up to approximately 160 feet for Alternative 3 in some water year types compared to the No Action Alternative. The largest decreases in groundwater levels are simulated to occur along the western portion of the Sacramento Valley and San Joaquin Valley. Additional areas of decreased groundwater levels appear north of Modesto and south of Fresno. Given the relatively large decreases in simulated groundwater elevations and the fact that portions of these areas are known to have historic subsidence, the potential for additional subsidence is high. The location and amount of subsidence is highly dependent on the local soil conditions and historical low groundwater levels in the area.

Southern California Region

The Southern California region is not known to be susceptible to subsidence and, as was noted in Appendix I, Section I.2.5.4.4, *Southern California Region*, groundwater pumping is not expected to increase in this region, suggesting that subsidence would not be a concern in this area.

W.2.6 Alternative 4

W.2.6.1 Potential Changes in Soil Erosion

Trinity River

During Alternative 4, both dry and wet periods in Trinity Reservoir would have a negligible negative drawdown in comparison to the No Action Alternative, 39 TAF (5% change) and -1 TAF (0% change), as shown in Table W-1. No change in the potential for mass wasting and surface erosion along the shoreline of Trinity Reservoir is expected when compared with the No Action Alternative. Similarly, in reservoir release situations, Alternative 4 during dry periods (-1.8 TAF, -4% change) is negligible when compared with the No Action Alternative, as shown in Table W-1. Alternative 4 during wet periods is negative though negligible (-16 TAF, -2% change). This indicates that there are no changes expected in flow-related erosion of the Trinity River when compared with the No Action Alternative.

No agricultural lands in the Trinity River area are served by CVP and SWP water supplies. Thus, the Trinity River region was not included in the SWAP model used to evaluate effects of the project upon irrigated acreage. No conversion of agricultural land or crop idling is anticipated. Soil erosion due to changes in irrigated acreage is not affected by CVP or SWP activity.

Sacramento Valley

Under Alternative 4, dry periods for Shasta Reservoir would have an increase in drawdown value (122 TAF, 8% change), as shown in Table W-2, resulting in increased potential for shoreline erosion at Shasta Reservoir when compared with the No Action Alternative. During wet periods, Alternative 4 would have an increased drawdown value (1 TAF, approximately 0% change), resulting in negligible changes in shoreline erosion at Shasta Reservoir when compared with the No Action Alternative. Releases into the Sacramento River during both dry (7 TAF, 1% change) and wet (44 TAF, 1% change) periods compared with the No Action Alternative, as shown in Table W-2, are negligible.

Folsom Reservoir drawdown during wet periods has small, negligible negative values (-1 TAF, approximately 0% change), as shown in Table W-3, indicating that Alternative 4 would result in no changes to shoreline erosion around Folsom Reservoir compared with the No Action Alternative. Folsom Reservoir drawdown during dry periods would have an increase in drawdown (28 TAF, 9% change) resulting in increased potential for shoreline erosion at Folsom Reservoir when compared with the No Action Alternative.

Releases to the American River during both dry and wet periods compared with the No Action Alternative have negative values, -23 (-13% change) and -20 TAF (-1% change), as shown in Table W-3, denoting a lower probability for erosion in dry years of the American River when compared with the No Action Alternative.

The Yolo Bypass carries flood flows that spill from the Sacramento River at the Fremont Weir during large winter storm events, with the highest flows occurring typically December through February. Flows through the Yolo Bypass are expected to increase by 1.2% under Alternative 4 compared with the No Action Alternative, increasing from 28,132 cfs to 28,457 cfs. This minor increase in winter flood flows through the Yolo Bypass would result in negligible riverine erosion given the low channel gradient, large cross-sectional area for flow, and low flow velocities at the margins of the bypass.

When compared with the No Action Alternative, Alternative 4 would decrease lands subject to fallowing in the Sacramento River region by 1,151 acres during average water years, which is 0.06% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be a decrease of 1,889 acres of fallowed land, a 0.09% decrease of the total irrigated lands subject to erosion. Therefore, there would be a decrease in the potential for erosion during average water years and a decrease in the potential for erosion during critical and dry water year types.

San Joaquin Valley

Under Alternative 4, dry periods would be negligible negative drawdown values for New Melones Lake (-5 TAF, -1% change), as shown in Table W-4. During wet periods, Alternative 4 has a negligible positive drawdown (24 TAF, 1% change), resulting in no changes in shoreline erosion when compared with the No Action Alternative. Releases to the Stanislaus River would be positive during dry periods (3 TAF, 7% change) and negligible during wet periods (22 TAF, 3% change), as shown in Table W-4, indicating a greater potential for erosion of the Stanislaus River high flow in dry periods when compared with the No Action Alternative.

Under Alternative 4, there would be no changes to the operation of Millerton Reservoir, nor releases to the San Joaquin River, relative to the No Action Alternative, as shown in Table W-5. Therefore, there would be no impacts related to shoreline erosion surrounding Millerton Reservoir or flow erosion of the San Joaquin River beyond those associated with the No Action Alternative.

When compared with the No Action Alternative, Alternative 4 would decrease lands subject to fallowing in the San Joaquin River region by 28,406 acres during average water years, which is 0.89% of the total irrigated lands subject to surface erosion throughout the region. During the average of critical and dry water year types, there would be an increase of 1,907 acres of fallowed land, a 0.07% increase of the total irrigated lands subject to erosion. Therefore, the potential for erosion would decrease during average water years and increase during critical and dry water year types.

Bay-Delta Operations

No changes in flows are expected in the Bay-Delta region under Alternative 4 compared with the No Action Alternative; therefore, stream channel erosion associated with Alternative 4 would not occur in this area. Changes in flows are not expected in the Suisun Marsh or the San Francisco Bay under Alternative 4; therefore, there is no expected change to erosion rates.

With regards to changes in irrigated acreage, as described in Appendix R, this region was not modeled under SWAP and flows on average would increase by 1% in this region under Alternative 4 compared with the No Action Alternative. Therefore, a decrease in lands subject to fallowing is anticipated. The potential for soil erosion would decrease compared with the No Action Alternative.

Additional CVP and SWP Service Areas

There are no Reclamation storage reservoirs or affected stream reaches in the CVP and SWP service areas; therefore, erosion as a result in changes to flow is not a concern in these areas. There are no affected stream reaches associated with the Central Coast or Southern California regions; therefore, erosion as a result of changes to flow is not a concern in this area.

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

W.2.6.2 Potential Changes in Land Subsidence Due to Increased Use of Groundwater

Trinity River

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

Central Valley

In the Sacramento and San Joaquin Valleys, average simulated groundwater levels are generally expected to decrease up to 7 feet in certain water year types under Alternative 4 compared with the No Action Alternative. The largest decreases in these simulated groundwater levels occur along the western portion of the Sacramento Valley. The relatively small decreases in groundwater levels are not expected to cause large amounts of additional subsidence. However, portions of these areas are known to have historic subsidence, and additional decreases in groundwater elevation may induce additional localized subsidence. The location and amount of subsidence is highly dependent on the local soil conditions and historical low groundwater levels in the area. It is unlikely that Alternative 4 would cause additional subsidence compared with the No Action Alternative.

Southern California Region

The Southern California region is not known to be susceptible to subsidence, and as noted in Appendix I, Section I.2.6.4.4, *Southern California Region*, groundwater pumping is not expected to increase in this region under Alternative 4. Thus, subsidence is not expected to be a concern in this area.

W.2.7 Mitigation Measures

No avoidance and minimization measures or mitigation measures have been identified for geology and soils.

W.2.8 Summary of Impacts

Table W-6 includes a summary of impacts, the magnitude and direction of those impacts, and potential mitigation measures for consideration.

Table W-6. Impact Summary

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
Potential Changes in Soil Erosion and Mass Wasting	No Action	No Impact	--
Potential Changes in Soil Erosion and Mass Wasting	Alternative 1	Under dry conditions, the Trinity Reservoir Storage may see changes in surface erosion and mass wasting. Under wet conditions, the drawdown is negligible, and the Trinity Reservoir Storage will not see changes in surface erosion and mass wasting. The Trinity River Release's values are negligible both dry and wet periods. In the Sacramento Valley region, in both dry and wet periods, Shasta Reservoir is not expected to see changes of surface erosion and mass wasting because drawdown is negligible. Folsom	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
		Reservoir will see an increase of erosion and mass wasting in dry periods and see no change in wet periods. The Sacramento River Release will see no changes in surface erosion and mass wasting in dry periods or wet periods because drawdown is negligible. The American River Release will also see a decreased likelihood of surface erosion and mass wasting in dry periods and no change in wet periods. In the San Joaquin Valley, New Melones Reservoir will see periods of no changes in wet or dry periods because the drawdown is negligible. The Stanislaus River Release may see an increased likelihood of surface erosion and mass wasting in both wet and dry periods. Millerton Reservoir and the San Joaquin River Release will see no changes in erosion. There are no expected changes to erosion under Alternative 1 in the Bay-Delta region.	
Potential Changes in Soil Erosion and Mass Wasting	Alternative 2	In Trinity Reservoir, under all phases of Alternative 2 in both dry and wet periods, there are no changes to likelihood of surface erosion and mass wasting because the drawdown values are negligible. The Trinity River Release sees a decreased likelihood of surface erosion and mass wasting in dry periods for all phases. In wet periods, all phases of the drawdown are negligible and, thus, there is no change in surface erosion and mass wasting expected. In the Sacramento Valley at Shasta Reservoir in dry periods, all phases of Alternative 2 show an increased likelihood of a surface erosion and mass wasting period. There are no changes expected under wet periods because drawdown is negligible. The Sacramento River Release, in both dry and wet	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
		periods, sees no likelihood of changes of surface erosion and mass wasting for all phases because drawdown is negligible. At Folsom Reservoir, it is not expected to see changes in both dry and wet periods for all phases. In American River Releases, all phases in dry periods see a decreased likelihood of surface erosion and mass wasting. Wet periods will see no change in erosion because drawdown is negligible. In the San Joaquin Valley, New Melones Reservoir sees no changes in period surface erosion and mass wasting in dry and wet periods for all phases because drawdown is negligible. Stanislaus River Releases will see an increased likelihood of surface erosion and mass wasting in dry periods and negligible changes in wet periods for all phases. Millerton Reservoir and San Joaquin River Release see no changes in erosion for all phases in both wet and dry periods. There are no expected changes to erosion under Alternative 2 (all phases) in the Bay-Delta region. There are no Reclamation storage reservoirs or affected stream reaches in the CVP and SWP service areas, thus erosion will not be affected by Alternative 2 (all phases).	
Potential Changes in Soil Erosion and Mass Wasting	Alternative 3	At Trinity Reservoir, there is a higher likelihood of surface erosion and mass wasting in dry periods compared with the No Action Alternative. The drawdown is negligible in wet periods. Trinity River Releases may see an increased likelihood of surface erosion and mass wasting in dry periods and a lower likelihood in wet periods. In the Sacramento Valley, Shasta Reservoir sees an increased likelihood of surface erosion and mass wasting in dry periods but no changes in wet periods. Sacramento River Releases sees no	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
		changes in surface erosion and mass wasting in both wet and dry periods. Folsom Reservoir storage shows no changes in likelihood of erosion and mass wasting in dry and wet periods. American River Release sees a decreased likelihood of surface erosion and mass wasting in dry periods and no change in wet periods. In the San Joaquin Valley, New Melones Reservoir will see no changes in surface erosion and mass wasting in dry periods and wet periods because drawdown is negligible. Stanislaus River Releases will see an increased likelihood of surface erosion and mass wasting in wet periods and negligible changes in dry periods. Millerton Reservoir and San Joaquin River Releases will see no changes in erosion. Though there is a minor increase in flow through the Bay-Delta region from Alternative 3, compared with the No Action, erosion is not a substantial concern in this area. There are no Reclamation storage reservoirs or affected stream reaches in the CVP and SWP service areas, thus erosion will not be affected by Alternative 3.	
Potential Changes in Soil Erosion and Mass Wasting	Alternative 4	Trinity Reservoir in both dry and wet periods sees no change in likelihood of surface erosion and mass wasting because drawdown values are negligible. Trinity River Releases sees no change of surface erosion and mass wasting in wet periods because the drawdown is negligible in both dry and wet years. In the Sacramento Valley, Shasta Reservoir Storage sees an increased likelihood of surface erosion and mass wasting in dry periods and no changes in wet periods because drawdown is negligible. The Sacramento River	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
		Releases sees no changes of surface erosion and mass wasting in both wet and dry periods because drawdown is negligible. Folsom Reservoir sees no changes in the likelihood of surface erosion and mass wasting in wet periods because drawdown is negligible. Dry periods would see an increased likelihood of surface-erosion and mass-wasting. American River Releases sees a decreased likelihood of surface erosion and mass wasting dry periods and no changes in wet periods because drawdown is negligible. In the San Joaquin Valley, New Melones Reservoir shows no changes to surface erosion and mass wasting in dry and wet periods because drawdown is negligible. Stanislaus River Releases will see an increased likelihood of surface erosion and mass wasting in dry periods and negligible changes in wet periods. Millerton Reservoir and the San Joaquin River Release will see no changes to erosion. There are no expected changes to erosion under Alternative 4 in the Bay-Delta region. There are no Reclamation storage reservoirs or affected stream reaches in the CVP and SWP service areas, thus erosion will not be affected by Alternative 4.	
Potential Changes in Irrigated Acreage	No Action	No impact	--
Potential Changes in Irrigated Acreage	Alternative 1	Under Alternative 1, lands in the Trinity River region are not served by CVP and SWP water supplies, thus, no conversion of agricultural land or crop idling is anticipated. In both the Sacramento Valley and the San Joaquin Valley, the lands subject to fallowing are anticipated to decrease, thus erosion is likely to decrease.	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
		The Bay-Delta Operations, and CVP and SWP Service Areas, will not see impacts related to changes in irrigated acreage.	
Potential Changes in Irrigated Acreage	Alternative 2	Under Alternative 2, lands in the Trinity River region are not served by CVP and SWP water supplies, thus, no conversion of agricultural land or crop idling is anticipated. The Sacramento Valley would see an increase in fallowing and thus an increase in erosion for all phases. San Joaquin Valley would see an increase in fallowing and thus an increase in erosion for all phases. It is anticipated that the Bay-Delta Operations will see an increase in fallowing of agricultural land, thus the potential for soil erosion would increase. The CVP and SWP Service Areas will not see impacts related to changes in irrigated acreage.	--
Potential Changes in Irrigated Acreage	Alternative 3	Under Alternative 3, lands in the Trinity River region are not served by CVP and SWP water supplies, thus, no conversion of agricultural land or crop idling is anticipated. The Sacramento Valley is anticipated to see an increase in lands subjected to fallowing, thus the likelihood for erosion would increase. In the San Joaquin Valley, fallowing would decrease in average wet periods, decreasing the likelihood of erosion. In critical and dry periods, fallowing would increase, increasing the total irrigated lands subject to erosion. It is anticipated that the Bay-Delta Operations will see an increase in fallowing of agricultural land, thus the potential for soil erosion would increase. The CVP and SWP Service Areas will not see impacts related to changes in irrigated acreage.	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
Potential Changes in Irrigated Acreage	Alternative 4	Under Alternative 4, lands in the Trinity River region are not served by CVP and SWP water supplies, thus, no conversion of agricultural land or crop idling is anticipated. In the Sacramento Valley, fallowing would decrease in both average wet and in critical and dry periods, decreasing the total irrigated lands subject to erosion. In the San Joaquin Valley, fallowing would decrease in average wet periods, decreasing the likelihood of erosion. In critical and dry periods, fallowing would increase, increasing the total irrigated lands subject to erosion. It is anticipated that the Bay-Delta Operations will see a decrease in fallowing of agricultural land, thus the potential for soil erosion would decrease. The CVP and SWP Service Areas will not see impacts related to changes in irrigated acreage.	--
Potential Changes in Land Subsidence	No Action	No Impact	--
Potential Changes in Land Subsidence	Alternative 1	It is not anticipated that the Trinity River region will see impacts related to potential land subsidence. The Sacramento Valley, San Joaquin Valley, Bay-Delta Operations, and CVP and SWP Service Areas will not see impacts related to land subsidence.	--
Potential Changes in Land Subsidence	Alternative 2	It is not anticipated that the Trinity River region will see impacts related to potential land subsidence. In the Sacramento and San Joaquin Valleys, average groundwater levels are generally expected to remain the same or decrease under all phases. The Bay-Delta Operations, and CVP and SWP Service Areas, will not see impacts related to potential land subsidence.	--

Impact	Alternative	Magnitude and Direction of Impacts	Potential Mitigation Measures
Potential Changes in Land Subsidence	Alternative 3	It is not anticipated that the Trinity River region will see impacts related to potential land subsidence. In the Sacramento and San Joaquin Valleys, average groundwater levels are generally expected to remain the same or decrease. The Bay-Delta Operations, and CVP and SWP Service Areas, will not see impacts related to potential land subsidence.	--
Potential Changes in Land Subsidence	Alternative 4	It is not anticipated that the Trinity River region will see impacts related to potential land subsidence. In the Sacramento and San Joaquin Valleys, average groundwater levels are generally expected to remain the same or decrease. The Bay-Delta Operations, and CVP and SWP Service Areas, will not see impacts related to potential land subsidence.	--

W.2.9 Cumulative Impacts

Past, present, and reasonably foreseeable projects, described in Appendix Y, *Cumulative Impacts Technical Appendix*, may have cumulative effects on geology and soils, to the extent that they could affect agricultural land fallowing, soil erosion and the rate of land subsidence.

Past and present actions contribute to the existing condition of the affected environment in the project area while reasonably foreseeable actions are those that are likely to occur in the future that are not speculative. Past, present, and reasonably foreseeable projects include actions to develop water storage capacity, water conveyance infrastructure, water recycling capacity, the reoperation of existing water supply infrastructure, including surface water reservoirs and conveyance infrastructure, and habitat restoration actions.

The projects identified in Appendix Y that have the most potential to contribute to cumulative impact on geology and soils are related to water supply (e.g. B.F. Sisk Dam Raise and Reservoir Expansion Project, Bay-Delta Water Quality Control Plan Update, Los Vaqueros Reservoir Expansion Phase 2, and habitat restoration).

The No Action Alternative would continue with the current operation of the CVP and may result in potential changes in geology and soils resources at reservoirs that store CVP water, tributaries, and agricultural land across the CVP and SWP service area.

W.2.9.1 Potential Changes in Soil Erosion

Trinity River

In this region, Alternative 1 and 3 under dry conditions are the scenarios in which shoreline and riverine erosion may increase relative to the No Action Alternative. Therefore Alternative 1 and 3 under dry conditions may minimally contribute to the cumulative soil erosion condition in this region. Changes in reservoir storage and river releases under Alternative 1, all phases of Alternative 2, Alternative 3 under wet conditions, and Alternative 4 would have either a negligible impact on or would lessen the cumulative condition for geology and soils in this area.

Central Valley

For Shasta Reservoir, Alternatives 2, 3 and 4, all under dry conditions, are the scenarios in which shoreline erosion may increase relative to the No Action Alternative. Therefore, these conditions may contribute to the cumulative soil erosion condition in this region. Changes in shoreline erosion under Alternative 1 and under wet conditions for Alternatives 2, 3, and 4 would be negligible and would therefore have minimal impact on the cumulative condition for geology and soils in this area. Changes in riverine erosion for all action alternatives would be negligible and would therefore have minimal impact on the cumulative condition for geology and soils in this area.

For Folsom Reservoir, Alternative 1 and 4 under dry conditions are the scenarios in which shoreline erosion may increase relative to the No Action Alternative; this alternative may minimally contribute to the cumulative soil erosion condition in this region. Changes in shoreline erosion for Alternative 1 and 4 under wet conditions and Alternatives 2, and 3would be negligible and would therefore have minimal impact on the cumulative condition for geology and soils in this area. Changes in riverine erosion under wet conditions for Alternatives 1, 2, 3, and 4 would be negligible and would therefore have minimal impact on the cumulative condition for geology and soils in this area. Changes in riverine erosion under dry conditions for Alternative 1, 2, 3, and 4 would decrease and would therefore less the impact on the cumulative condition for geology and soils in this area.

Compared to the No Action Alternative, Alternative 3 had the largest increase in lands that would be subject to fallowing in the Sacramento River Region (average year = 1.11%), which would increase the potential for wind erosion. Changes in wind erosion would contribute to the cumulative condition for geology and soils in this area.

Bay-Delta Region

For the Bay-Delta region, no changes in riverine erosion would occur under Alternatives 1, 2 and 4 relative to the No Action Alternative. Therefore, it is unlikely these alternatives would contribute to the cumulative soil erosion condition in this region. A minor increase in flow under Alternative 3 is expected through the Bay-Delta Region during January; however, this increase is within the range of high flows through the Bay-Delta Region during winter flood events through the Bay-Delta; therefore, riverine erosion is not a substantial concern but may contribute to the cumulative soil erosion condition in this region.

No conversion of agricultural land or crop idling is anticipated, and erosion of fallowed land would not change compared with the No Action Alternative. Under all phases of Alternative 2 and Alternative 3, agricultural flows to the San Francisco Bay Area would decrease, which could result in erosion of fallowed land. Under Alternative 4, agricultural flows to the San Francisco Bay Area would increase, which could increase erosion of fallowed land. These scenarios may contribute to the cumulative soil erosion condition of this region.

San Joaquin Valley

There are no changes to erosion in New Melones Reservoir in dry or wet years under any alternative. Releases to the Stanislaus River would result in negligible increases during wet periods under Alternatives 2 and 4. Alternatives 1 and 4 would result in increases of 7% and 10 %, respectively, which could increase the potential for channel erosion slightly. During dry periods, Alternative 3, channel erosion would be negligible; however, Alternatives 1, 2, and 4 would have a slight increase in potential (4% to 13 %) for channel erosion. These scenarios may contribute to the cumulative soil erosion condition of this region.

Compared to the No Action Alternative, Alternative 3 had the largest increase in lands that would be subject to fallowing in the Sacramento River Region (average year = 9.56%, dry year = 7.27%), which would increase the potential for wind erosion. Changes in wind erosion would contribute to the cumulative condition for geology and soils in this area.

Additional CVP and SWP Service Areas

There are no Reclamation storage reservoirs or affected stream reaches in the additional CVP and SWP service areas; therefore, erosion of fallowed land would not change relative to the No Action Alternative and would not contribute to the cumulative soil erosion condition of this region.

W.2.9.2 Potential Changes in Land Subsidence Due to Increased Use of Groundwater

Numerous groundwater storage and recovery projects are proposed or have been completed (Appendix Y). However, these projects largely involve groundwater banking, in which water is stored in groundwater and then withdrawn. Therefore, they would not exacerbate land subsidence. Additionally, the Eastern San Joaquin Integrated Conjunctive Use Program would support groundwater recharge and include groundwater banking, as described in Appendix Y, in part to address groundwater overdraft. There are also several projects meant to benefit agricultural users, such as the South Delta Temporary Barriers Project and the Red Bluff Diversion Dam Fish Passage Improvement Project. Most action alternatives would result in no change in groundwater levels and no impact on subsidence. Alternative 2 (in some phases), Alternative 3, and Alternative 4 could decrease groundwater levels in the Sacramento and San Joaquin Valleys. However, the location and amount of subsidence is highly dependent on the local soil conditions and historical low groundwater levels in the area. Average groundwater levels are simulated to decrease up to approximately 160 feet for Alternative 3 in some water year types compared to the No Action Alternative. The largest decreases in groundwater levels are simulated to occur along the western portion of the Central Valley in the Sacramento Valley and in the San Joaquin Valley. Additional areas of decreased groundwater levels appear north of Modesto and south of Fresno. Given the relatively large decreases in groundwater elevations and the fact that portions of these areas are known to have historic subsidence, there is potential for additional subsidence. The location and amount of subsidence is highly dependent on the local soil conditions and historical low groundwater levels in the area. Given that many of the reasonably foreseeable projects have the stated intent to address groundwater overdraft and agricultural supply, cumulative land subsidence impacts would not be exuberated.

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