7.9 Geology and Soils

This section describes the environmental setting, potential impacts, and mitigation measures for geology and soils impacts that may result from changes in hydrology or changes in water supply. Activities that affect geology and soils include those that would subject people or structures to potential adverse effects due to earthquake, seismic shaking, or landslides; result in soil erosion and loss; or be located on unstable or expansive soils. Changes in hydrology and changes in water supply would not result in new human-occupied structures or other construction that would have the potential to interact with or be affected by the geologic and soil environments. Therefore, the analysis in this section focuses on agricultural land use or fallowing for potential effects on soil erosion or loss, and increased groundwater pumping that could increase subsidence.

Changes in hydrology affecting flows and reservoir levels do not involve the building of any infrastructure that would expose people to adverse geologic conditions or be located on unstable or expansive soils.

Changes in water supply would not result in new human-occupied structures or other construction and would not have the potential to interact with or be affected by the geologic or soil environments. Water users may implement other water management actions, such as groundwater storage and recovery and increased use of recycled water, which could slow down or mitigate existing problems with subsidence.

Section 7.1, *Introduction, Project Description, and Approach to Environmental Analysis*, describes reasonably foreseeable methods of compliance and response actions, including actions that would require construction. These actions are analyzed for potential environmental effects in Section 7.21, *Habitat Restoration and Other Ecosystem Projects*, and Section 7.22, *New or Modified Facilities*.

7.9.1 Environmental Checklist

VI. Geology and Soils	Potentially Significant Impact	Less than Significant with Mitigation Incorporated	Less-than-Significant Impact	No Impact
Would the project:				
a. Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:				
1. Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42.	☐	☐	☐	☒
2. Strong seismic ground shaking?	☐	☐	☐	☒

VI. Geology and Soils	Potentially Significant Impact	Less than Significant with Mitigation Incorporated	Less-than-Significant Impact	No Impact
3. Seismic-related ground failure, including liquefaction?	☐	☐	☐	☒
4. Landslides?	☐	☐	☐	☒
b. Result in substantial soil erosion or the loss of topsoil?	☐	☐	☒	☐
c. Be located on a geologic unit or soil that is unstable or that would become unstable as a result of the project and potentially result in an onsite or offsite landslide, lateral spreading, subsidence, liquefaction, or collapse?	☒	☐	☐	☐
d. Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?	☐	☐	☐	☒
e. Have soils incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems in areas where sewers are not available for the disposal of wastewater?	☐	☐	☐	☒

7.9.2 Environmental Setting

This section describes the geology and soils setting to inform the impact discussion in this section and in Sections 7.21, *Habitat Restoration and Other Ecosystem Projects*; 7.22, *New or Modified Facilities*; and Chapter 9, *Proposed Voluntary Agreements*.

7.9.2.1 Physiography and Geology

Overall, the study area comprises mountain ranges and adjacent deep basins. Rivers and streams incise the mountain ranges and carry eroded sediment to the basins, which are generally filled with deep sediment (many thousands of feet) (^CGS 2002).

The study area's mountain range geomorphic provinces (geologic regions displaying distinct landscapes) (^CGS 2002) are the Sierra Nevada to the east, the Cascade Range to the northeast, the Klamath Mountains to the northwest, and the Coast Ranges to the west. The mountain range bedrock varies; however, in general, the Sierra Nevada and Klamath Mountains are composed of hard metamorphic and granitic rocks; the Cascade Range is composed of volcanic rocks, including the volcanoes of Lassen Peak and Mount Shasta; and the Coast Ranges are composed of sedimentary rocks (CGS 2006). Additionally, to the east and northeast of the Cascade Range is the Modoc Plateau, which is also composed of volcanic rocks, although they are flat-lying. The Central Valley (Great Valley geomorphic province) is a deep basin composed of river sediments (alluvium) derived from the adjacent mountains (^CGS 2002; CGS 2006). The southern portion of the study area exhibits similar mountain-incised rivers adjacent to sediment-filled basins. These areas include the Transverse Ranges, Peninsular Ranges, Mojave Desert, and Colorado Desert (^CGS 2002; CGS 2006).

A majority of the rivers and streams north of the Delta originate in the mountain ranges and Modoc Plateau. When these rivers and streams reach the Sacramento Valley, they deposit their sediment along their beds and banks. Over time, humans have enhanced the natural levees that form along the banks to minimize flooding of adjacent agricultural lands.

At times in the geologic past, marine waters extended into the Central Valley such that many older and deeper sediments are of marine origin or have intertidal components (^CGS 2002; CGS 2006). At present, marine water environments still occur in San Francisco Bay and extend inland to the Suisun Marsh and the Delta (Elder 2013). The Delta has groundwater very near the surface, creating saturated conditions in the adjacent landscape. Plants that grew and then died in this saturated environment did not completely decay and formed deep accumulations over time. Consequently, the Delta is underlain by peat (partially decayed plant material with some intermingled sediment). The Suisun Marsh is similar to the Delta but with more intertidal influence and a higher sediment content (Elder 2013).

7.9.2.2 Faults, Earthquakes, Liquefaction, and Landslides

Movements of major land masses along faults cause earthquakes, which generate ground shaking. The intensity of ground shaking that occurs at a given location is related to the size of the earthquake, the site's distance from the earthquake, and the geologic materials at the site. As a general rule, the greater the energy released from the fault rupture (the earthquake magnitude) and the closer to the fault rupture (epicenter), the greater the intensity of ground shaking. Also, bedrock will shake less, and unconsolidated sedimentary materials (e.g., alluvium) will shake more. Ground shaking is transferred to overlying structures (e.g., homes, other buildings); and there is greater structure shaking when structures are located on alluvium or other sedimentary deposits, such as intertidal sediments or peats, than when they are located on bedrock. Ground shaking can also cause liquefaction of unconsolidated sediments (i.e., sediments that behave as fluids) and landslides.

Figure 7.9-1 shows active faults in the study area.[1] Active faults that affect the Sacramento Valley are primarily along its west side and near the Delta. The eastern and northeastern Sacramento Valley are relatively far from active faults. The San Joaquin Valley is similarly affected by active faults on its west side, with the east side relatively far from faults. Active faults exist throughout the San Francisco Bay Area, Central Coast, and Southern California regions. The Alquist-Priolo Earthquake Fault Zoning Act (Pub. Resources Code, §§ 2621–2630) requires that active faults (less than 11,000 years old) be identified and that structures are not placed across these active faults (CGS 2018). No structure for human occupancy should be located within 50 feet of the mapped fault. Faults are well mapped in California, and maps of ground-shaking areas are assembled and regularly updated for the state (CGS 2010; CGS 2018; Branum et al. 2016; CGS 2021). Also provided are state-of-practice guidelines for geological evaluation of fault rupture hazards as well as information for permitting agencies and property owners (CGS 2018). The State of California has also established guidelines for evaluating and mitigating site-specific and broader seismic hazards (CGS 2008), including shaking and seismically induced instability, such as liquefaction and landslides. The standards also address seiches (a standing wave in an enclosed or partially enclosed body of water) and splash waves.

Liquefaction can occur when water-saturated, loose sandy layers below the ground surface liquefy during strong ground shaking. These liquefied layers can flow like a liquid or lose their strength and

[1] Active faults are faults that are likely to have another earthquake sometime in the future. Faults are commonly considered to be active if they have moved one or more times in the last 10,000 years (USGS 2021).

consistency so that they cannot support the ground above them. The loss of support for overlying layers may result in those overlying layers subsiding or moving laterally (lateral spreading). Liquefaction also causes the loss of bearing capacity to overlying building foundations. Liquefaction is more likely to take place in the water-saturated Delta but can happen in other areas if earthquakes occur after a series of wet years that result in deep saturation of alluvial sediments or soils.

Landslides can occur on steep slopes during strong ground shaking and are more likely to occur during winter when slopes are water-saturated. Where steep slopes abut water (e.g., lakes, reservoirs), fast-moving landslides that enter that water can cause splash waves, some of which can be large and destructive (Schuster 2006). Earthquake shaking can also cause the water within an enclosed or partially enclosed waterbody, such as a lake, reservoir, or bay, to oscillate. If the amount of sloshing water is sufficiently large, seiches may damage infrastructure along the waterbody shoreline.

The Seismic Hazards Mapping Act of 1990 (Pub. Resources Code, §§ 2690–2699.6) directs the California Geological Survey (formerly the California Division of Mines and Geology) of the California Department of Conservation to identify and map areas prone to earthquake hazards of liquefaction, earthquake-induced landslides, and amplified ground shaking. A development permit review is likely required for construction sites in the mapped seismic hazard zones. Site-specific geologic investigations and evaluations are carried out to identify the extent of hazards, and appropriate mitigation measures are incorporated into the development plans to reduce potential damage.

The Alquist-Priolo Earthquake Fault Zoning Act was passed in 1972 to identify known active faults in California and to prevent the construction of buildings used for human occupancy on the surface trace of active faults. The act directs the California Geological Survey to establish the regulatory zones, called Alquist-Priolo Earthquake Fault Zones, around the known surface traces of active faults and to publish maps showing these zones. Construction of buildings intended for human occupancy within the fault zone boundaries is strictly regulated, and site-specific faulting investigations are required.

Earthwork and construction activities are regulated at the local jurisdictional level through a multistaged permitting process. Grading permits are required for most types of earthwork, and additional permits are typically needed for various types of construction. Most jurisdictions have adopted either the Uniform Building Code or California Building Code as minimum standards. (See California Building Standards Law [Health & Saf. Code, §§ 18901–18949.31].) Depending on the nature, extent, and location of proposed earthwork and construction, the permit process may require the preparation of a site-specific geotechnical investigation to develop appropriate design criteria and assess bedrock and surficial geology, geologic structure, soils, and previous history of excavation and fill placement. The process may also include information from the Alquist-Priolo Earthquake Fault Zoning Act, Seismic Hazards Mapping Act of 1990, and other local regulations. Before a development permit can be issued or a subdivision approved, cities and counties must require a site-specific investigation to determine whether a significant hazard exists at the site and, if so, recommend measures to reduce the risk to an acceptable level. The investigation must be performed by state-licensed engineering geologists and/or civil engineers.

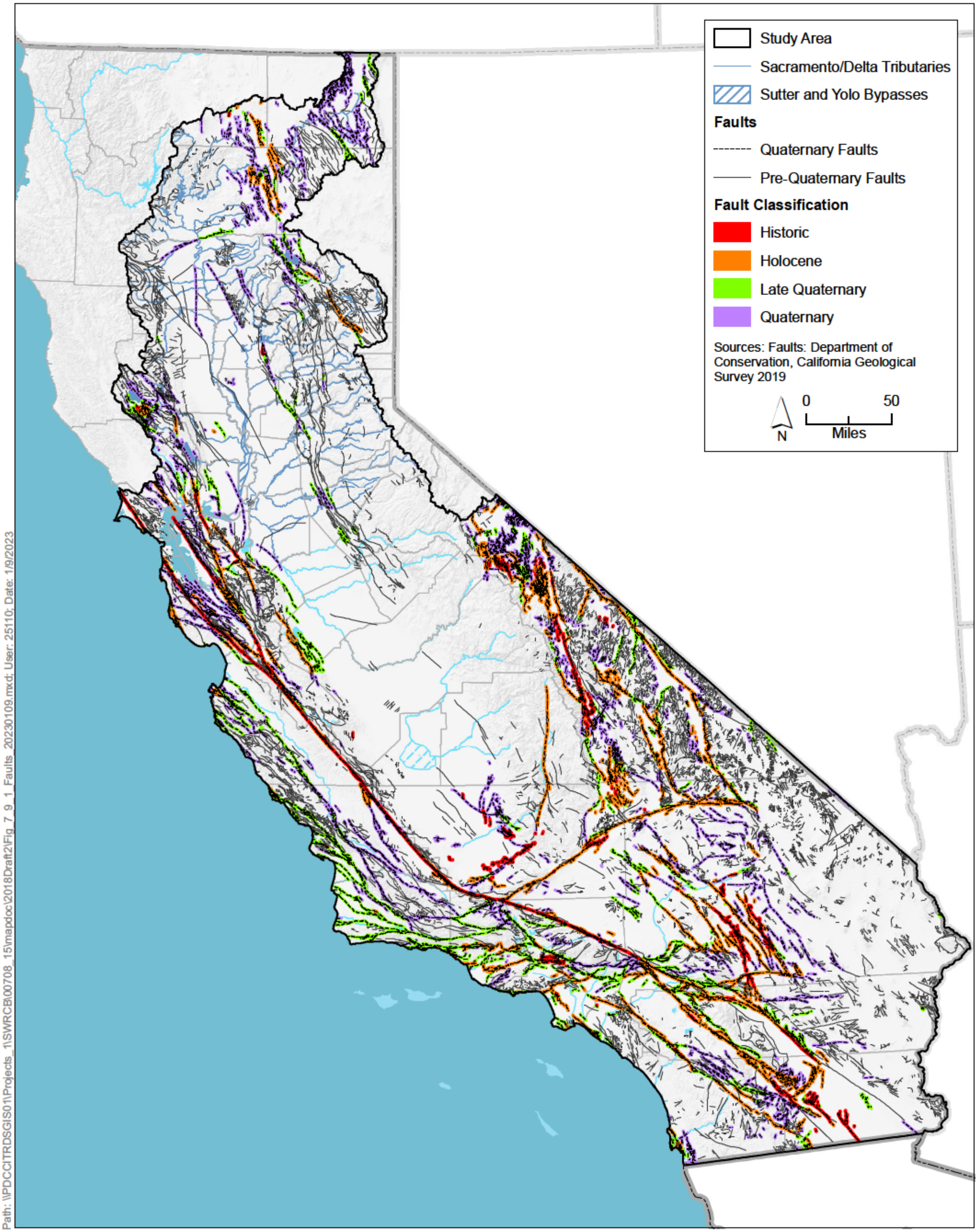

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Figure 7.9-1
Faults and Fault Classifications in the Study Area

7.9.2.3 Soils and Erosion

There are two primary types of soils: organic and mineral. Organic soils are dominated by decayed plant materials. Much of the Delta is composed of deep organic soils (peat) (Ingebritsen et al. 2000). Mineral soils form from the weathering (chemical and physical decay) of the earth's rock or alluvial surface, including interaction with vegetation whose decay adds organic matter and organic acids. Soil erosion in excess of natural background erosion can reduce soil productivity for plant growth (natural plant communities or agriculture) and can deliver sediment to streams, lakes, and wetlands, causing water quality degradation or damage to aquatic life. Water erosion is generally greater on steeper slopes and minimal on flat-lying surfaces. Vegetation growth can minimize erosion. Wind erosion may also occur on unvegetated soils. Detailed soil information for most sites in California is available at the Natural Resources Conservation Service Web Soil Survey website (NRCS 2017). That information includes soil erodibility data that assist in the evaluation of erosional susceptibility.

Soils may also be dominated by certain clay minerals that expand when wet and contract when dry. If sufficiently deep or widespread, repeated expansion and contraction can damage structure foundations; linear features, such as canals; and roadbeds. Soil drainage characteristics are also important for septic tank drain fields. The soils must allow water to drain freely at depth so that the water does not reach the ground surface. However, drainage must be sufficiently slow such that included pathogens decay before reaching the groundwater or adjacent streams.

Cities and counties have developed ordinances, policies, and other regulatory mechanisms for controlling pollutant discharges in construction site runoff, including grading and erosion control ordinances and drainage and land-leveling ordinances. Development and implementation of local controls for managing stormwater, including adoption of ordinances, are generally requirements of municipal separate storm sewer system permits issued by regional water boards. An application for a grading permit typically includes vicinity and site maps; a grading plan; and an engineered erosion, sediment, and runoff control plan. Local permits are generally required for construction activities, and construction projects must conform to local drainage and erosion control policies and ordinances.

7.9.2.4 Subsidence

Subsidence (sinking of the land surface) occurs primarily in the organic soils of the Delta and in deep alluvial sediment-filled basins of the Sacramento Valley and San Joaquin Valley, as well as southern California. Land subsidence has also occurred in the San Joaquin Valley, the Santa Clara Valley at the south end of San Francisco Bay, and in several intermountain alluvial basins in southern California (Borchers and Carpenter 2014). Figure 7.9-2 shows recent and historical land subsidence in the study area.

Much of the Delta is composed of deep saturated organic soils or peat. Because agriculture generally requires nonsaturated soils, farmers have drained Delta soils over time. In these nonsaturated soils, the organic matter oxidizes, substantially reducing soil volume. Consequently, these Delta organic soils have subsided 10 to 25 feet over the last 100-plus years (Ingebritsen et al. 2000). The agricultural fields were also protected by constructed levees, and now the agricultural field surfaces have sunk substantially below the adjacent stream levels.

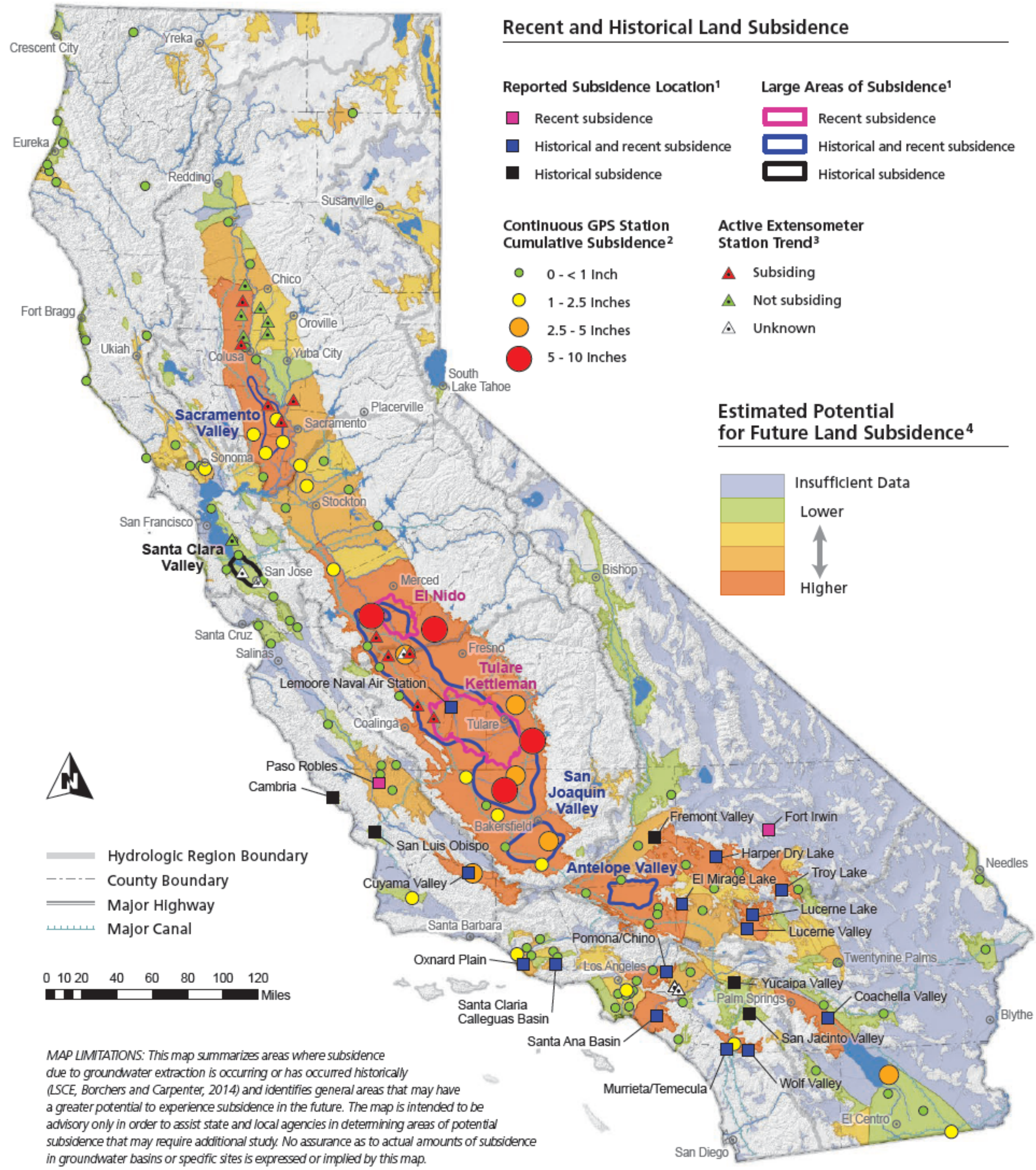
Land subsidence also occurs when groundwater is pumped out of deep alluvial aquifers at a faster rate than it is replaced. The groundwater supports the sedimentary particle grains by intergranular pressure, particularly in fine-grained sediments (Borchers and Carpenter 2014). As the groundwater is removed, the pressure is reduced, and the particles shift closer together, cumulatively resulting in compaction and ground surface elevation reduction. This type of subsidence has occurred in a portion of the Sacramento Valley and widely in the San Joaquin Valley, Santa Clara Valley, and southern California (Figure 7.9-2) (Borchers and Carpenter 2014; ^DWR 2014b). Subsidence in urban and suburban areas can particularly affect building foundations and associated structural integrity because subsidence does not occur uniformly, causing uneven stresses on foundations and linear infrastructure (e.g., pipelines, roads, canals). Damage and associated costs are greater in urban and suburban areas because of the much greater amount of infrastructure.

California Department of Water Resources (DWR) reports show subsidence levels up to 2014 ranging from less than 1 inch to 2.5 inches in the southwestern Sacramento Valley (^DWR 2014c; ^DWR 2014b). In the Sacramento Valley, Farr et al. (2017) report that the Davis-Woodland area subsided about 2 inches between March 2015 and June 2016. In the same period, a small area near Arbuckle subsided by about 12 inches. These amounts of ground surface lowering, and the resulting underlying aquifer compaction, have caused groundwater well damage (well casing failure and collapse) and damage to concrete pads at irrigation wells, and previous subsidence increased the extent of flooding in the southern Sacramento Valley between Knights Landing and Stockton (Borchers and Carpenter 2014). The entire western side of the Sacramento Valley and the Delta are within a zone of higher estimated potential for future land subsidence (Figure 7.9-2) (^DWR 2014b). The remainder of the Sacramento Valley has lower estimated potential for subsidence. The indicated pattern was verified by the 2017 resurvey of topographic monuments distributed throughout the Sacramento Valley (DWR 2018). These monuments were previously surveyed in 2008, with the new survey conducted at the end of the 2012–2016 drought (DWR 2018). Over the 9-year period, the data show 2.14 feet of subsidence in the Arbuckle area; 0.3 to 1.1 feet of subsidence in the Davis-Woodland area; three monuments with 0.44 to 0.59 foot of subsidence in Glenn County; and five monuments with 0.2 to 0.36 foot of subsidence in Sutter County (DWR 2018). Interferometric synthetic aperture radar subsidence data for these areas also have been assembled during the 2020–2022 drought (between October 1, 2020 and October 1, 2021), showing a maximum of 0.7 foot of subsidence in the Arbuckle area; 0.2 foot in the Davis-Woodland area; and 0.1 foot in Glenn and Sutter Counties (DWR 2022, p. 4). Interferometric synthetic aperture radar data for these areas show continued subsidence of similar magnitude between October 2021 and October 2022 (DWR 2022). The rest of the Sacramento Valley shows little to no statistically significant subsidence.[2] Specific impacts associated with the reported subsidence were not part of the topographic resurvey.

In general, groundwater pumping does not lead to subsidence in the Delta because the existing Delta stream channels contribute to the underlying groundwater (Farr et al. 2017, p. 6). Although groundwater level increases in the Delta may reduce or stop subsidence, they cannot reverse the subsidence that has already occurred (Borchers and Carpenter 2014).

The San Joaquin Valley has experienced substantial subsidence related to groundwater use for agriculture. By 1970, more than 5,200 square miles had subsidence of more than 1 foot, with a maximum subsidence of 28 feet near Mendota (Galloway and Riley 1999). DWR reports show many San Joaquin Valley locations with recent subsidence between 2.5 and 5 inches and other locations with subsidence between 5 and 10 inches (^DWR 2014c; ^DWR 2014b). Areas of subsidence related to the 2012–2016 drought show that one of the two major subsidence zones is centered on

[2] Any change in land subsidence less than 0.17 foot is not considered statistically significant (DWR 2018, p. 16).



¹ Land subsidence data modified from LSCE, Borchers and Carpenter, 2014. ² Continuous GPS data from UNAVCO.org.
³ Extensometer data from DWR (http://www.water.ca.gov/waterdatalibrary) and LSCE, Borchers and Carpenter, 2014
⁴ For more information on how the estimated potential for land subsidence was calculated see: http://www.water.ca.gov/groundwater/docs/Summary_of_Recent_Historical_Potential_Subsidence_in_CA_Final_with_Appendix.pdf

Data current as of May 2014.

Source: DWR 2014.

Figure 7.9-2
Recent and Historical Land Subsidence

Corcoran. In the Corcoran zone, for the period May 2015 through September 2016, Farr et al. (2017) reported subsidence of about 22 inches. For the period October 2020 through October 2021 (during the 2020–2022 drought), using interferometric synthetic aperture radar data, DWR reports subsidence in the Corcoran zone at a maximum of about 13 inches (DWR 2022). Interferometric synthetic aperture radar data for this area show continued subsidence of similar magnitude between October 2021 and October 2022 (DWR 2022). Virtually the entire San Joaquin Valley is within a zone of higher estimated potential for future land subsidence (^DWR 2014c; ^DWR 2014b). Farr et al. (2017) also reported subsidence measurements for the Ventura, Oxnard, and Santa Barbara areas for the period May 2015 through August 2016. The data show broad zones with 0 to 1 inch, less extensive zones with 1 to 2 inches, and smaller zones with 2 to 3 inches of subsidence. For the period October 2020 through October 2021, interferometric synthetic aperture radar data show about 1 inch of subsidence for the Ventura and Oxnard areas (no data are presented for the Santa Barbara area during this period) (DWR 2022).

Recharging a groundwater aquifer would not restore the land-surface elevation to its original condition because the compressed, fine-grained sediment layers do not re-expand. Generally, subsidence can be stopped by reducing groundwater extraction or by allowing groundwater levels to rise via recharge (natural or enhanced). Utilizing other water supplies or management actions can reduce groundwater extraction. Determining better extraction locations, such as sand and gravel layers, which are more easily recharged and are less susceptible to permanent compaction, may also be useful.

Some jurisdictions have addressed groundwater extraction–related subsidence. For example, the Santa Clara Valley Water District developed remedial actions so that subsidence was halted by 1969 (Ingebritsen and Jones 1999). Using a variety of groundwater enhancement actions, the district keeps groundwater levels above historical lows even during drought periods. The City of Chino addressed subsidence impacts by developing a management plan and appointing a water master to implement the plan and monitor subsidence (City of Chino 2010; Chino Basin Watermaster 2015). These actions and agreements were stimulated by damage to infrastructure in urban environments and recognition of its costs.

The Sustainable Groundwater Management Act (SGMA) addresses subsidence, including it as one of six specific sustainability indicators to be addressed in required groundwater management plans (DWR 2017). This indicator addresses significant and unreasonable land subsidence that interferes with surface land uses and must consider the local rate and extent of subsidence and effects on land use and infrastructure. Additionally, specific or localized management areas may be identified or established to address individual issues such as land subsidence (DWR 2017).

Broadly, managed aquifer recharge projects seek to increase groundwater recharge to address overall reduced water availability and to increase water access flexibility, which also reduces future land subsidence. Because groundwater depletion and related subsidence occurred earlier and with greater magnitude in the San Joaquin Valley, recharge projects there are more common (Faunt et al. 2016). San Joaquin Valley projects include the Semitropic Water Storage District and the Kern Water Bank Authority. Sacramento Valley–managed aquifer recharge projects are under consideration as part of overall improvements in water use management and as part of SGMA implementation. The City of Roseville has implemented a series of groundwater wells capable of injecting drinking water to augment existing supplies (GEI Consulting Engineers and Scientists 2017).

Related to aquifer recharge and use, the State Water Board has issued general waste discharge requirements for aquifer storage and recovery projects that inject drinking water into groundwater (SWRCB 2021a). The State Water Board also has permits for capturing and storage of surface water for groundwater recharge, including allowing fields to flood from adjacent stream channels and allowing the water to soak into the ground. There are standard and temporary permits as well as streamlined processing for Groundwater Sustainability Agency applicants implementing SGMA (SWRCB 2021b).

7.9.3 Impact Analysis

This impact analysis considers how and to what extent changes in hydrology and changes in water supply would affect or be affected by the geology and soils environment. Activities that affect geology and soils include those that would subject people or structures to potential adverse effects due to earthquake, seismic shaking, or landslides; result in soil erosion and loss; or be located on unstable or expansive soils. Changes in hydrology and changes in water supply would not result in new human-occupied structures or other construction that would have the potential to interact with or be affected by the geologic and soil environments. The analysis in this section focuses on reduced Sacramento/Delta water supply and subsequent increased groundwater pumping and extraction that could contribute to potential earthquakes under Impact GEO-a, agricultural land use or fallowing for potential effects on soil erosion or loss under Impact GEO-b, and groundwater pumping and groundwater storage and recovery that could contribute to subsidence under Impact GEO-c.

Changes in hydrology (flow conditions and reoperation of reservoirs) would not expose people or structures to substantial adverse effects from earthquake fault rupture; strong seismic ground shaking; seismic-related ground failure, including liquefaction; or landslides. Earthquake damage that may occur to existing Delta levees, reservoirs, or other water infrastructure would not be any different than those that would occur under the baseline condition. Reservoir drawdown below baseline condition levels could reveal previously unexposed erodible bedrock or sediments, but no natural vegetation community or agricultural soils would be affected. There would be no impacts, and changes in hydrology are not evaluated further under Impact GEO-a and Impact GEO-b.

Similarly, changes in flows and reservoir levels would not result in an on-site or off-site landslide, lateral spreading, subsidence, liquefaction, or collapse. The geologic and soil materials underlying streams and reservoirs are saturated with water. Lowering reservoir levels has the potential to cause localized landslides as the water drains from these materials, increasing pore water pressure and decreasing internal friction. However, this effect is more common during the initial years after reservoir construction and operation as existing unstable materials move downslope (Schuster 2006). These movements diminish with time as the available unstable materials are removed by landslides. Existing reservoirs have been in operation for decades, and there is limited additional movement associated with reservoir drawdown. The geologic and soil materials at depth would have moved if they had been potentially unstable and subject to landslides. During drawdown, unconsolidated reservoir margin sediments also have the potential to be destabilized by lateral spreading, subsidence, liquefaction, or collapse. Similar to landslides, susceptible unstable materials have been progressively removed by these processes over time. There would be no impact, and changes in hydrology are not further evaluated under Impact GEO-c.

Changes in water supply include other water management actions taken in response to reduced Sacramento/Delta supply, including groundwater storage and recovery, water transfers, increased use of recycled water, and water conservation. These actions would not substantially increase the number of people exposed to the risk of earthquakes or geologic hazards because these practices would not draw people to earthquake areas or hazard locations not already frequented. Further, these actions would be within the capacity of existing facilities and would not result in new ground disturbance interacting with local geologic or soil conditions, and the facilities would not be affected by geologic or soil conditions that differ from baseline conditions. Consequently, these actions would not expose people or structures to substantial adverse effects, including the risk of loss, injury, or death, from earthquake fault rupture; strong seismic ground shaking; or seismic-related ground failure. These actions also would not interact with the geology and soil environments and would not affect soil erosion or topsoil loss. There would be no impact. With the exception of the discussion on the potential influence of groundwater extraction on earthquakes under Impact GEO-a and the subsidence discussion under Impact GEO-c, these activities are not evaluated further in this section.

Changes in hydrology and changes in water supply would not result in new human-occupied structures or other construction that would be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property. There would be no impact, and Impact GEO-d is not further evaluated in this section.

Conditions or actions associated with changes in hydrology and changes in water supply would not involve constructing or operating septic tanks; therefore, septic tanks would not be affected by soils incapable of supporting their use or other alternative wastewater disposal systems. There would be no impact, and Impact GEO-e is not further evaluated in this section.

Section 7.21, *Habitat Restoration and Other Ecosystem Projects*, and Section 7.22, *New or Modified Facilities*, describe and analyze potential geology and soils impacts from various actions that involve construction.

Impact GEO-a: Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving: (1) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault (2) Strong seismic ground shaking (3) Seismic-related ground failure, including liquefaction (4) Landslides

Changes in water supply could lead to increased groundwater pumping and other water management actions such as groundwater storage and recovery operations in response to reduced Sacramento/Delta supply. Several studies have identified the potential influence of groundwater extraction on earthquakes, including studies by González et al. (2012), Kraner et al. (2018), Wang et al. (2019), and Wetzler et al. (2019). Respectively, these papers present data and other analyses suggesting temporal, and potentially causal, relationships between extensive groundwater pumping and the 2011 M5.1 Lorca earthquake (Spain), the 2014 M6.0 South Napa earthquake (California), the 2016 M6.0 Petermann Ranges earthquake (Australia), and the 2013 and 2018 earthquake swarms (up to M4.5) in the northern Dead Sea (Israel).

Conclusions by Kraner et al. (2018) regarding the 2014 M6.0 South Napa earthquake considered regional and seasonal changes in natural water storage that have been demonstrated to cause very small (i.e., fractions of an inch [1 or 2 millimeters to 1 centimeter]) elevation changes of mountains and valleys. That is, water-related seasonal changes in the mass of the earth’s surface can be documented by elevation changes detected by highly sensitive satellite-based global positioning system and interferometric synthetic aperture radar. These mass/elevation changes reflect seasonal rainfall adding to soil moisture and groundwater, increased water accumulation in lakes and reservoirs, and snow accumulation. For example, Argus et al. (2014) evaluated seasonal water storage across much of California with winter storage causing 0.5 inch (12 millimeters) of subsidence in winter followed by the same amount of uplift in summer. Argus et al. (2017) documented elevation changes in the Sierra Nevada of 1 inch (24 millimeters) and used the associated change in mass to calculate Sierra Nevada water losses during drought from 2011 to 2015. Kraner et al. (2018) were able to separate these broader seasonal precipitation-mass changes and groundwater-mass changes for the South Napa earthquake area. They showed stronger relationships with the changes in the groundwater extraction/recharge of the adjacent Sonoma and Napa groundwater basins and indicated that change as a potential earthquake trigger.

Amos et al. (2014) demonstrated that seasonal changes in Coast Ranges and Sierra Nevada elevations were related to the lowering and rising of the Central Valley due to summer groundwater extraction and winter replenishment. The mountains adjacent to the Central Valley experienced sequential summer uplift and winter depression produced by flexing of the earth's crust. Amos et al. (2014) also suggested that stress changes associated with the Central Valley's seasonal groundwater changes were related to increased earthquakes greater than M1.25 on the San Andreas Fault at Parkfield. Johnson et al. (2017) evaluated water storage during seasonal hydrologic cycles and associated seismicity across the entire Central Valley and faults in the adjacent mountains. They documented that earthquakes occur more frequently during winter hydrologic loading. However, they explicitly excluded data points reflecting Central Valley groundwater pumping effects because they were examining broader climatological-scale effects (Johnson et al. 2017).

Based on these studies, potential earthquakes associated with groundwater pumping and extraction are recognized as a potential effect. However, these observations are just one part of wide-ranging research seeking to understand earthquake triggers; they are not an earthquake prediction system. Earthquake prediction is an area of active research but has not reached functional application (e.g., Mignan and Broccardo 2019; NEPEC 2017; NEPEC 2019). There are no predictive methods for quantifying when and where earthquake triggering caused by groundwater extraction may occur or for determining what an associated earthquake magnitude might be. Consequently, the potential effects of groundwater extraction on earthquake occurrence are considered speculative and are not considered further.

Impact GEO-b: Result in substantial soil erosion or the loss of topsoil

Changes in water supply include reduced Sacramento/Delta supply to agriculture, which could lead to changes in agricultural land use or the fallowing of agricultural land resulting in agricultural fields with unvegetated (bare) soils. Lack of vegetation allows surface water or wind to increase soil erosion. However, some fallowed fields would retain crop stubble cover, ultimately experience vegetation regrowth, or both. The root material and regrowth would stabilize soils to some extent and reduce their potential for increased erosion. These soils would also be undisturbed for periods of time, which would allow the surfaces to consolidate, in turn reducing their erosion potential. Active agricultural production includes substantial soil disturbance from tillage, crop harvesting, and other activities (O'Geen 2006; Grismer et al. 2006; Singer 2003). Additionally, even unfallowed agricultural soil may be bare during the rainy season and subject to greater surface water erosion than vegetated soil. In contrast, lands subject to less intensive use due to a reduction in surface water irrigation (e.g., dryland farming, deficit irrigation, grazing) would experience no change or potentially less erosion and sedimentation. While there may be an initial period of increased erosion and sedimentation if active agriculture is reduced, the reduced tillage and other activities would result in less erosion and sedimentation in the long run. Therefore, reducing existing levels of soil disturbance resulting from active agricultural practices and irrigation may thereby reduce erosion and loss of topsoil compared with baseline conditions. Consequently, there would not be substantial soil erosion or loss of topsoil due to agricultural land fallowing. The impacts would be less than significant.

Impact GEO-c: Be located on a geologic unit or soil that is unstable or that would become unstable as a result of the project and potentially result in an onsite or offsite landslide, lateral spreading, subsidence, liquefaction, or collapse

Changes in water supply include reduced Sacramento/Delta supply for some water uses. Increased groundwater pumping and reduced groundwater recharge from applied irrigation could lower groundwater levels and contribute to subsidence. Changes in water supply also include the use of other water management actions such as groundwater storage and recovery, water transfers, increased use of recycled water, and water conservation. Other water management actions could potentially help ameliorate subsidence conditions, for example, use of recycled water to recharge groundwater levels, or groundwater storage and recovery to sustainably manage groundwater basins. Some water management actions could also contribute to lower groundwater levels and subsidence such as groundwater substitution transfers and agricultural conservation.

Subsidence from Lowered Groundwater Levels

As discussed in Section 7.12.2, *Groundwater*, the proposed Plan amendments have the potential to lower groundwater levels due to increased groundwater pumping and/or changes in incidental groundwater recharge (see Section 7.12.2 *Groundwater*).

On the higher end of the flow range, and under the most conservative estimate of substitute pumping, groundwater declines could result in subsidence in the same areas and of approximately the same amounts as for the 2012–2016 drought (DWR 2018) and the 2020–2022 drought (DWR 2022). Groundwater levels are generally adequate in much of the Sacramento River watershed, with some localized areas of decline. Ground subsidence in the Sacramento Valley (excluding the Delta) would be near zero if groundwater levels do not further decline. At the higher levels of groundwater level decline, subsidence could continue at approximately the same rate that has occurred over the 2012–2016 and 2020–2022 drought periods (see Section 7.9.2.4, *Subsidence*). Further subsidence would continue the current effects on groundwater well damage (Borchers and Carpenter 2014). Additional impacts on other infrastructure, such as roads, canals, and structure foundations, may result. The impact would be potentially significant for existing infrastructure, particularly in the Arbuckle area and to a lesser extent in the Davis-Woodland area.

The Delta eastside tributaries region is identified as having a medium to intermediate susceptibility to estimated potential for future ground subsidence (Figure 7.9-2). Ground subsidence in the area would be near zero if groundwater levels do not decline. However, continuous global positioning system measurements of surface elevation indicate that this area experienced slight uplift (less than 0.5 inch), rather than subsidence, during drought conditions measured between 2011 and 2017 (^USGS 2018). Consequently, the area would be expected to have minor subsidence under higher levels of groundwater decline.

Increased subsidence is not expected in the Delta region. Delta groundwater elevations are controlled by the water levels in the Sacramento River and internal Delta channels (Ingebritsen et al. 2000). Consequently, higher Sacramento River flows under the proposed Plan amendments would maintain groundwater levels in the Delta. (Also, see Impact GW-b in Section 7.12.2, *Groundwater*.)

High interannual variability in precipitation generally leads to variability in surface water demand in the San Francisco Bay Area, San Joaquin Valley, Central Coast, and Southern California regions, with lower demand and related recharge during wet years and higher demand and related recharge during dry years (if supplies can meet demand). However, long-term impacts likely would be proportional to the amount of irrigation water decline and associated groundwater pumping to replace that water. If irrigation water restrictions are low, then impacts would be minimal. However, as the restrictions increase, the level of impact could approach that seen on a near-annual basis during the 2012–2016 drought (Farr et al. 2017) and 2020–2022 drought (DWR 2022) if groundwater withdrawals were of similar magnitude (see Section 7.9.2.4, *Subsidence*).

As indicated in Section 7.12.2, *Groundwater*, the portions of the San Joaquin Valley region that may be affected by reduced Sacramento/Delta supply include the western San Joaquin Valley, the southern San Joaquin Valley, and the Friant Division service area. These areas have experienced high historical and recent drought subsidence rates related to groundwater use (although the area within the Kern Water Bank Authority did not experience subsidence during the 2012–2016 drought) (Borchers and Carpenter 2014; Farr et al. 2017). If groundwater withdrawal continued at the rates of the 2012–2016 and 2020–2022 droughts, similar subsidence rates could be expected. However, because these areas experienced the greatest historical subsidence, specific infrastructure and associated issues are well known (Borchers and Carpenter 2014).

In general, restrictions on groundwater pumping have been relatively limited, and agencies and jurisdictions across the study area have been addressing groundwater management to varying degrees. Many local groundwater management plans have been developed and implemented; however, these plans have had varying levels of regulatory control and have often been voluntary.

Because groundwater overdraft issues are a region-wide and statewide issue and have been exacerbated by drought, the state legislature passed SGMA. SGMA addresses numerous groundwater management issues, including subsidence. The law imposes a mandate for sustainable groundwater management on local agencies. The SGMA subsidence indicator and associated management must consider the local subsidence rate and extent and its effects on land use and infrastructure.

As explained previously, lower groundwater levels from increased groundwater pumping and reduced incidental recharge from irrigation could exacerbate existing problems associated with ground subsidence. Several management strategies could be implemented at the local or regional level, including groundwater storage and recovery, water transfers, increased use of recycled water, and water conservation. These measures are likely to have positive effects on some groundwater basins and reduce or slow ground subsidence by replacing water that would otherwise be extracted. However, groundwater substitution transfers and water conservation measures that reduce runoff that would otherwise recharge groundwater could also lower groundwater levels, and reduced groundwater levels may lead to or exacerbate existing subsidence conditions. These impacts would be potentially significant.

Reducing reliance on the Delta is state policy, along with an associated mandate for improving regional self-reliance (Wat. Code, § 85021), and reducing reliance is a prominent component of the Delta Plan. Reduced reliance on the Delta can be achieved by diversifying water supply portfolios at the regional and local levels, which would provide greater overall supply reliability during periods when Sacramento/Delta supply is reduced. Many agencies have made significant investments in developing their local and regional supplies, including groundwater banking, onstream and offstream surface water storage, increased use of recycled water, and desalinated supplies, while also achieving significant decreases in imported water demand through water conservation and water use efficiency efforts. Further, SGMA addresses numerous groundwater management issues, including subsidence. Other actions that can increase groundwater levels include percolation ponds, reduced groundwater use, appointment of water masters to address conflicting water use needs, and creation of water banks. While these actions would increase groundwater levels, they could take many years to implement.

Implementation of Mitigation Measure MM-GEO-c could reduce impacts. However, no immediate mitigation is available to minimize the impacts of increased groundwater pumping and reduced groundwater recharge over the long term. Implementing SGMA and other actions to increase groundwater levels or reduce groundwater extraction could reduce or halt subsidence. The State Water Board also has SGMA oversight and can intervene if proposed or implemented measures are considered insufficient (see Section 7.12.2, *Groundwater*, Mitigation Measure MM-GW-b). While the State Water Board has some authority to ensure that mitigation is implemented for some actions, other mitigation measures are largely within the jurisdiction and control of other agencies or depend on how water users respond to the proposed Plan amendments. The State Water Board cannot guarantee that measures will always be adopted or applied in a manner that fully mitigates the impact. Therefore, unless and until the mitigation is fully implemented, the impacts remain potentially significant.

Increased utilization of conjunctive use, groundwater recharge, or groundwater storage and recovery efforts may occur in response to reduced Sacramento/Delta supply. These actions could be implemented by municipal water agencies or local irrigation districts, either as individual or cooperative efforts. Although site-specific actions cannot be predicted, all such actions would result in additional groundwater storage. Efforts are already underway to recharge groundwater using recycled water, flood flows, and stormwater. While these actions would involve the increased use of existing infrastructure, they may take several years to implement.

7.9.4 Mitigation Measures

MM-GEO-c: Mitigate impacts associated with unstable soils and steep slopes (landslide, lateral spreading, subsidence, liquefaction, or collapse)

1. **Actions to Reduce Subsidence:**
    i. Continue implementation of existing groundwater basin management plans.
    ii. Implement groundwater sustainability plans pursuant to SGMA.
    iii. Implement other actions that can increase groundwater levels, including percolation ponds, reduction in groundwater use, appointment of water masters to address conflicting water use needs, or creation of groundwater banks.
2. **Reduce Impacts on Groundwater:** Implementation of Mitigation Measure MM-GW-b will reduce impacts of lowered groundwater levels that could contribute to subsidence.

7.9.5 References Cited

7.9.5.1 Common References

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