Chapter 4
Geology, Geomorphology, Minerals, and Soils

The evaluation in this chapter is based on a review of existing literature and data, along with information obtained from the shoreline erosion surveys, wetland delineation, and geotechnical investigations and surveys. The information included in the technical analysis is also derived from the following sources:

- CALFED Bay-Delta Program (CALFED). 2000a. CALFED Bay Delta Program Final Programmatic Environmental Impact Statement/Environmental Impact Report. Available at: http://calwater.ca.gov/CALFEDDocuments/Final_EIS_EIR.shtml. Accessed August 29, 2007.
- California Department of Water Resources. 2006. North-of-the-Delta Offstream Storage Investigation Initial Alternatives Information Report. Available at: http://www.usbr.gov/mp/nodos/docs/index.html. Accessed August 29, 2007.
- Contra Costa Water District. 2006. Contra Costa Water District Alternative Intake Project Draft Environmental Impact Report/Environmental Impact Statement.

4.1 Affected Environment

This section describes the affected environment related to geology, seismicity, soils/erosion, mineral resources, and geomorphology for the dam and reservoir modifications proposed under the SLWRI. The following evaluation is based on a review of existing literature and data, along with information obtained from shoreline erosion surveys, wetland delineation, and geotechnical investigations and surveys. For a more in-depth description, see the *Geology, Geomorphology, Minerals, and Soils Technical Report.*

The environmental setting for the geology, seismicity, soils/erosion, mineral resources, and geomorphology assessment of the Shasta Lake and vicinity portion of the primary study area comprises the watersheds draining to Shasta Lake, and the land area forming the shoreline of Shasta Lake. Five major drainages flow into Shasta Lake and form "arms" of the lake: Big Backbone Creek, the Sacramento River, the McCloud River, Squaw Creek, and the Pit River. This section also refers to the East and West "arms" of the main body of the lake as Main Body East Arm and Main Body West Arm.

4.1.1 Geology

The geology of the study area is described below for both the primary and extended study areas. The bedrock geology of the project study area is described in the following paragraphs. Boundaries of geomorphic provinces referenced in Section 4.1.1 are shown in Figure 4-1.

Shasta Lake and Vicinity

The Shasta Lake and vicinity portion of the primary study area is illustrated in Figure 4-2. The drainages contributing to Shasta Lake cover a broad expanse of land with a widely diverse and complicated geology. Shasta Lake is situated geographically at the interface between the Central Valley, Klamath Mountains, and Modoc Plateau and Cascades geomorphic provinces.

The bedrock geology for the Shasta Lake and vicinity area is shown in Figure 4-3. The mapping legend that accompanies Figure 4-3 is presented in Table 4-1. Shasta Lake itself and adjacent lands (i.e., Shasta Lake and Vicinity) are underlain by rocks of the Klamath Mountains and, to a much more limited extent, the Modoc Plateau and Cascades geomorphic provinces. The regional topography is highly dissected, consisting predominantly of ridges and canyons with vertical relief ranging from the surface of Shasta Lake at 1,070 feet above mean sea level (msl) to ridges and promontories more than 6,000 feet above msl. This diversity in topography is primarily a result of the structural and erosional characteristics of rock units in the Shasta Lake and vicinity area.

Klamath Mountains Geomorphic Province The Klamath Mountains Geomorphic Province is located in northwestern California between the Coast Range on the west and the Cascade Range on the east. The Klamath Mountains consist of Paleozoic metasedimentary and metavolcanic rocks and Mesozoic igneous rocks that make up individual mountain ranges extending to the north. The Klamath Mountain Geomorphic Province consists of four mountain belts: the eastern Klamath Mountain belt, central metamorphic belt, western Paleozoic and Triassic belt, and western Jurassic belt. Low-angle thrust faults occur between the belts and allow the eastern blocks to be pushed westward and upward. The central metamorphic belt consists of Paleozoic hornblende, mica schists, and ultramafic rocks. The western Paleozoic and Triassic belt, and the western Jurassic belt consist of slightly metamorphosed sedimentary and volcanic rocks.

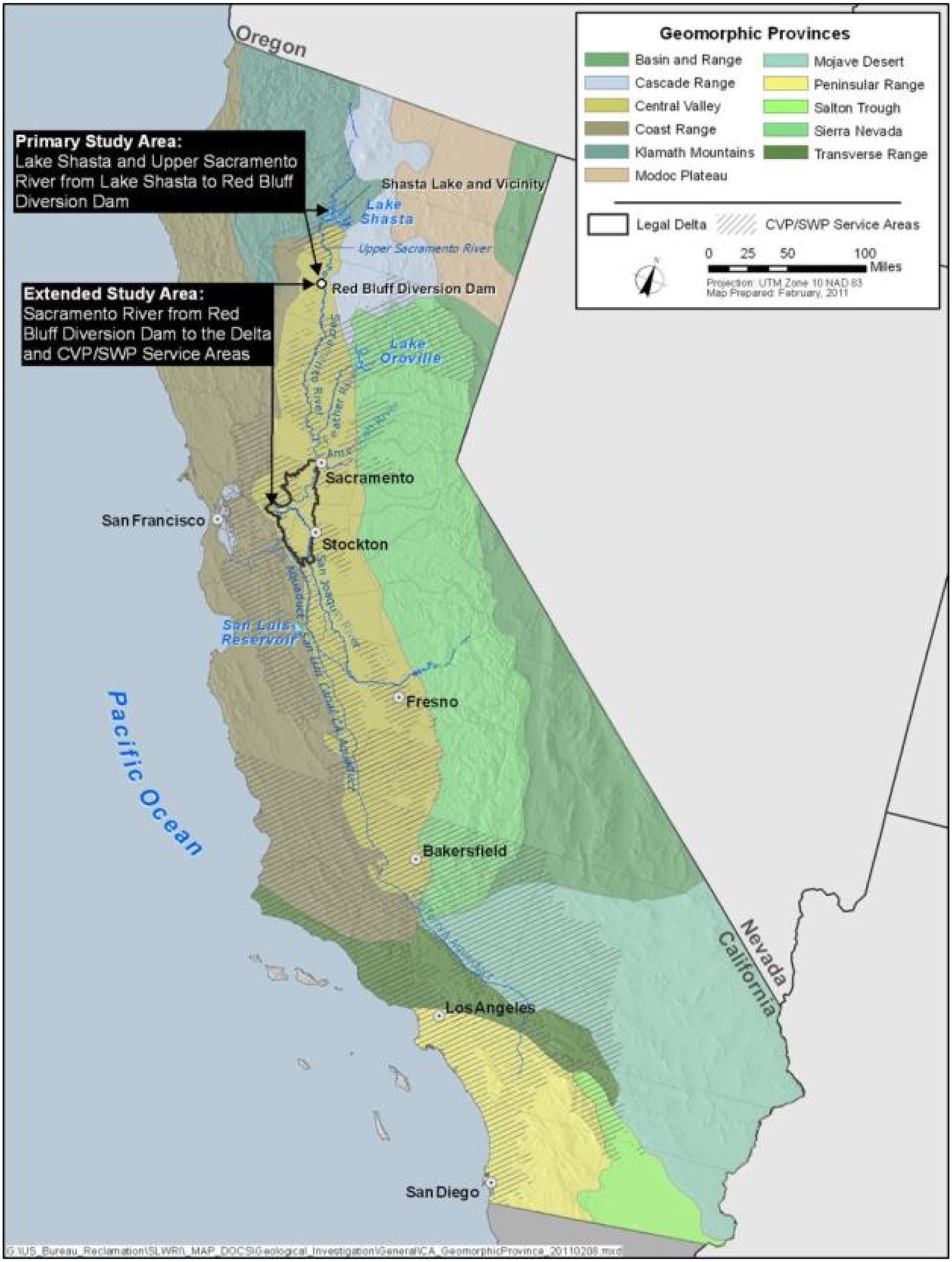


Figure 4-1. Geomorphic Provinces of California

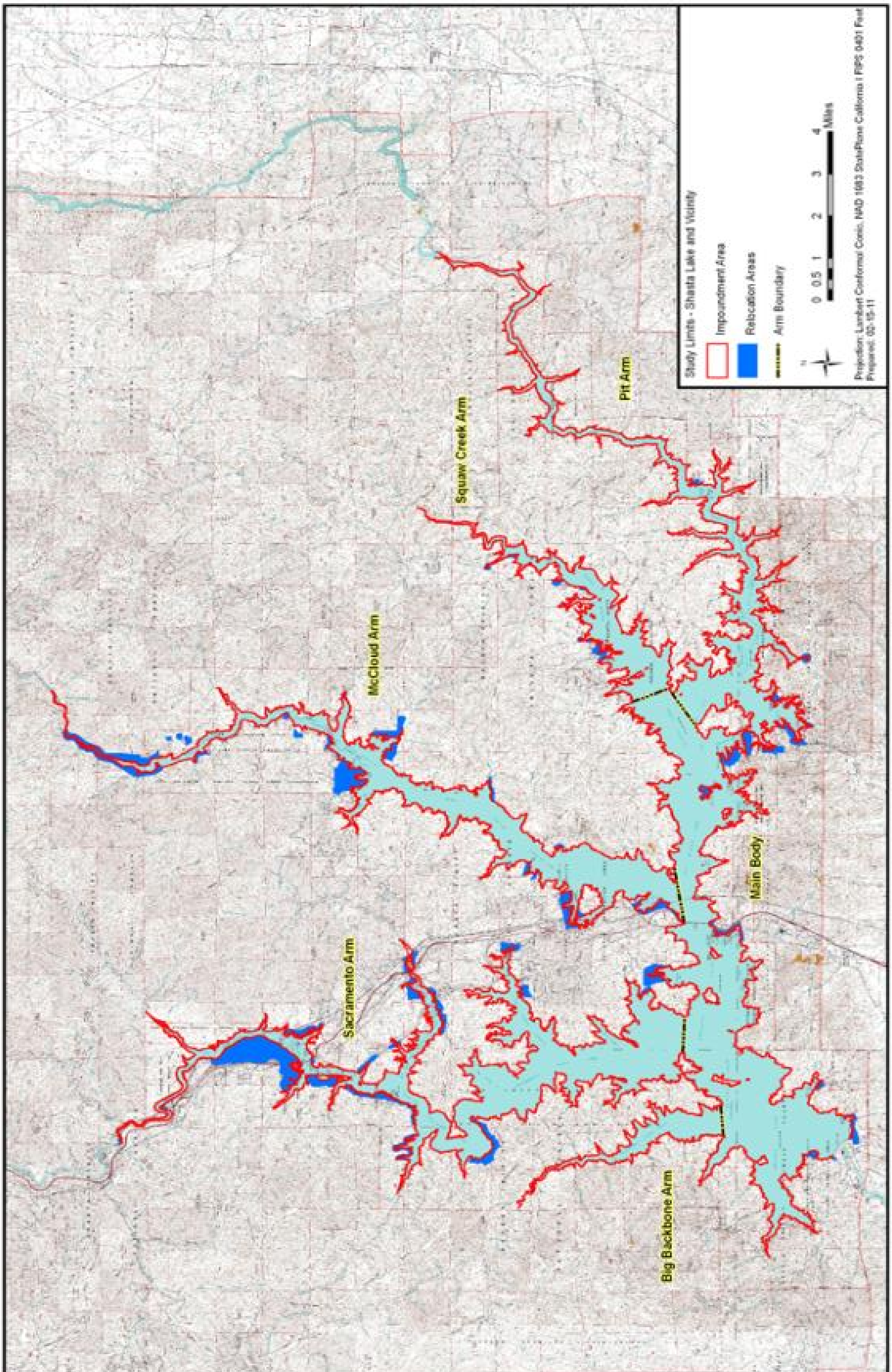


Figure 4-2. Shasta Lake and Vicinity Portion of the Primary Study Area

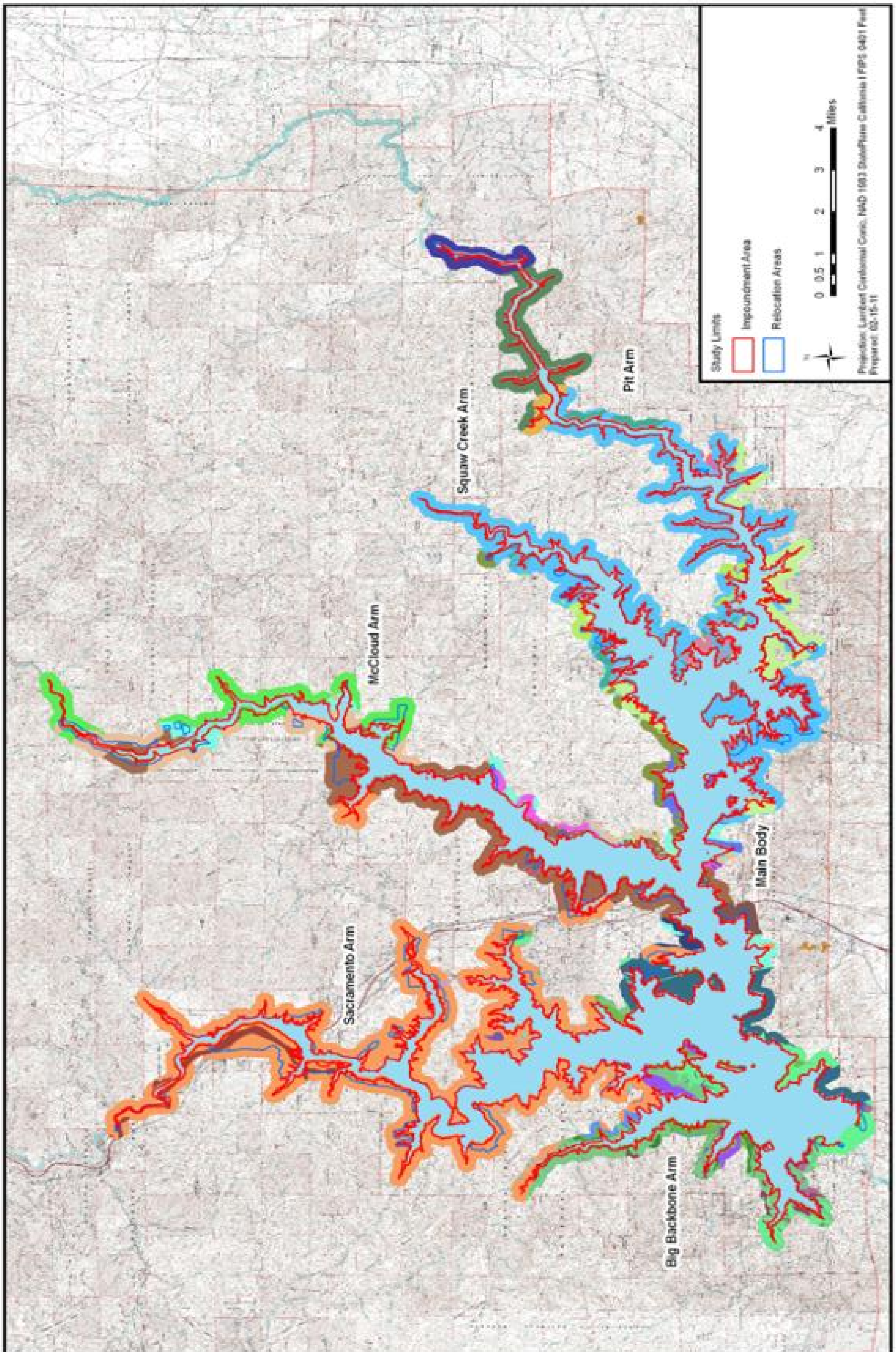


Figure 4-3. Bedrock Geology – Shasta Lake and Vicinity

Table 4-1. Key to Bedrock Geology Map Units – Shasta Lake and Vicinity

Map Unit, Formation, Description
Cb, Baird, meta-pyroclastic & keratophyre; & undiff.
Cbg, Bragdon, shale; graywacke; minor conglomerate
Cbgcp, Bragdon, chert-pebble & quartz conglomerate
Cbgp, Bragdon, pyroclastic; tuff; tuffaceous sediments
Cbgs, Bragdon, black siliceous shale
Cblss, Baird, skarn; lime silicate minerals; magnetite; locally
Cbmv, Baird, greenstone & greenstone breccia
Cbp, Baird, mafic pyroclastic rocks w/ minor tuffaceous mudsto
Db, Balaklala rhyolite, non-porphyritic & with small quartz phenocrysts (1
Dbc, Balaklala rhyolite, porphyritic with large quartz phenocrysts [>4 mm];
Dbp, Balaklala rhyolite, volcanic breccia; tuff breccia; volcanic conglomer
Dbt, Balaklala rhyolite, tuff & tuffaceous shale
Dc, Copley, greenstone; & undiff.
Dct, Copley, greenstone tuff & breccia; shaly tuff & shale
Dk, Kennett, siliceous shale & rhyolitic tuff; & undiff.
Dkls, Kennett, limestone
Dkt, Kennett, tuff; tuffaceous shale; shale
EHaev, , Andesite of Everitt Hill
Ja, Arvison, volcaniclastic & pyroclastic; & undiff.
Jp, Potem, argillite & tuffaceous sandstone; & undiff.
Pmbh, Bully Hill rhyolit, meta-andesite (quartz keratophyre); meta-dacite; p
Pmbhp, Bully Hill rhyolit, pyroclastic; tuff & tuff breccia
Pmd, , quartz diorite; albite - two pyroxene qd; mafic qd
Pmdk, Dekkas, mafic flows & tuff with minor mudstone & tuffaceou
Pmdkp, Dekkas, breccia; tuff; tuff breccia
Pmml, McCloud, limestone
Pmmls, McCloud, skarn; lime silicate minerals; magnetite; locally
Pmn, Nosoni, tuffaceous mudstone w/ lesser mafic flows; sandsto
Pmpr, Pit River stock, quartz diorite; granodiorite & plagiogranite; 261
Trh, Hosselkus Limeston, limestone; thin-bedded to massive; gray; fossilife
Trm, Modin, andesitic volcaniclastic & pyroclastic rocks; cong
Trp, Pit, shale; siltstone; metavolcanic; w/ limestone; & un
Trpmv, Pit, meta-andesite; meta-dacite; porphyritic & non-; ma
Trpp, Pit, pyroclastic; tuff & tuff breccia
Tt, Tuscan Formation, undivided: volcaniclastic; lahars; tuff; sandston
Tva, Western Cascades, andesite
Tvb, Western Cascades, basalt
di, , intermediate dikes
dia, , diabase dikes & small intrusive bodies
dpp, , plagioclase (+/- hornblende; quartz) porphyritic d
lake, , Shasta Lake; et al

A large portion of the Shasta Lake and vicinity area is underlain by rocks of the eastern Klamath Mountain belt. The strata of the eastern belt constitute a column 40,000 to 50,000 feet thick, and represent the time from Ordovician (about 490 years before present) to Jurassic (about 145 million years before present). The stratigraphic column of formations that comprise the eastern Klamath Mountain belt, including a scale of geologic time, is shown in Table 4-2 (Hackel 1966). Important eastern belt rocks that underlay Shasta Lake and vicinity include metavolcanics of Devonian age (i.e., Copley Greenstone and Balaklala Rhyolite formations), metasedimentary rocks of Mississippian age (i.e., Bragdon Formation), thin-bedded to massive sedimentary rocks of Permian age (i.e., McCloud Limestone Formation), and metasedimentary and metavolcanic rocks of Triassic age (i.e., Pit, Modin, and Bully Hill Rhyolite formations) (Reclamation 2009). Intrusive igneous rocks (e.g., localized granitic bodies) make up less than 5 percent of the rocks in the sub-area, but are well represented on the Shasta Lake shoreline, particularly in the south-central area of the lake. Mesozoic intrusive dikes are scattered in the western portion of the map area.

The McCloud Limestone is prominently exposed within the McCloud, Pit, Main Body, and Big Backbone arms of Shasta Lake. Within the lake footprint, the McCloud River Arm has the largest exposure of this limestone, followed by the Pit, Main Body, and Big Backbone arms. Along the McCloud River Arm, this limestone crops out on the eastern shore from the mouth at the main body of the lake to Hirz Bay. Above Hirz Bay, it is intermittently exposed on both sides of the McCloud Arm. Along the Pit Arm near the mouth of Brock Creek, the McCloud Limestone is exposed along the north and southern banks. The McCloud Limestone is exposed near the southern shore of Allie Cove in the eastern portion of the Main Body Arm. Along the Big Backbone Arm, the McCloud Limestone is exposed near the eastern shore between the outlets of Shoemaker and Limerock creeks. Outside the Shasta Lake footprint, an outcrop of the McCloud Limestone is exposed along the McCloud River approximately 10 miles upstream from the mouth into the McCloud River Arm. The McCloud Limestone is also exposed on the north side of Bohemotash Mountain, which is approximately 2 miles from the mouth of Big Backbone Creek at the Big Backbone Arm.

“Skarn” is a geologic term that refers to metamorphic rocks formed in the contact zone of magmatic intrusions (e.g., granite) with carbonate-rich rocks (e.g., limestone) Skarn deposits are rich in lime-silicate minerals, and locally contain magnetite. Permian-aged skarn deposits are present within the McCloud River Arm. The deposits are located near the mouths of Marble and Potter creeks and on the peninsula at the eastern margin of the inlet of the McCloud River Arm. The skarn deposits occur adjacent to the McCloud Limestone at the mouths of Marble and Potter creeks, but the McCloud Limestone is absent near skarn deposits on the peninsula.

Table 4-2. Stratigraphic Column of Formations of the Eastern Klamath Mountain Belt

Period/Age Before Present (million years)	Formation	Thickness (feet)	General Features
Jurassic (145-200)	Potem Formation	1,000	Argillite and tuffaceous sandstones, with minor beds of conglomerate, pyroclastics, and limestone.
	Bagley Andesite	700	Andesitic flows and pyroclastics.
	Arvison Formation of Sanborn (1953)	5,090	Interbedded volcanic breccia, conglomerate, tuff, and minor andesitic lava flows.
Triassic (200-250)	Modin Formation	5,500	Basal member of volcanic conglomerate, breccia, tuff, and porphyry, with limestone fragments from the Hosselkus formation.
	Brock Shale	400	Dark massive argillite interlayered with tuff or tuffaceous sandstone.
	Hosselkus Limestone	0-250	Thin-bedded to massive light-gray limestone.
	Pit Formation	2,000-4,400	Predominantly dark shale and siltstone, with abundant lenses of metadacite and quartz-keratophyre tuffs.
	Bully Hill Rhyolite	100-2,500	Lava flows and pyroclastic rocks, with subordinate hypabyssal intrusive bodies.
Permian (250-300)	Dekkas Andesite	1,000-3,500	Chiefly fragmental lava and pyroclastic rocks, but includes mudstone and tuffaceous sandstone.
	Nosoni Formation	0-2,000	Mudstone and fine-grained tuff, with minor coarse mafic pyroclastic rocks and lava.
	McCloud Limestone	0-2,500	Thin-bedded to massive light-gray limestone, with local beds and nodules of chert.
Carboniferous (300-360)	Baird Formation	3,000-5,000	Pyroclastic rocks, mudstone, and keratophyre flows in lower part; siliceous mudstone, with minor limestone, chert, and tuff in middle part; and greenstone, quartz, keratophyre, and mafic pyroclastic rocks and flow breccia in upper part.
	Bragdon Formation	6,000±	Interbedded shale and sandstone, with grit and chert-pebble conglomerate abundant in upper part.
Devonian (360-420)	Kennett Formation	0-400	Dark, thin-bedded, siliceous mudstone and tuff.
	Balaklala Rhyolite	0-3,500	Light-colored quartz-keratophyre flows and pyroclastics.
	Copley Greenstone	3,700+	Keratophyric and spilitic pillow lavas and pyroclastic rocks.
Silurian (420-450 my	Gazelle Formation	2,400+	Siliceous graywackes, mudstone, chert-pebble conglomerate, tuff, and limestone.
Ordovician (450-490)	Duzel Formation	1,250+	Thinly layered phyllitic greywacke, locally with radiolarian chert and limestone.

A small area of the fossiliferous Cretaceous Chico Formation, consisting of Great Valley marine sedimentary rocks, occurs near Jones Valley Creek, a tributary to the Pit River Arm. Although this rock unit occurs in the immediate vicinity, it is not exposed along the shoreline of the lake and falls outside the Shasta Lake and vicinity area. Some outcrops of McCloud Limestone, especially in the vicinity of McCloud River Bridge, are also fossiliferous.

Modoc Plateau and Cascades Geomorphic Provinces The Cascade Range and Modoc Plateau together cover approximately 13,000 square miles in the northeast corner of California. The Cascade Range and Modoc Plateau (collectively the Modoc Plateau and Cascades Geomorphic Province) are very similar geologically and consist of young volcanic rocks that are Miocene to Pleistocene age. Included in this province are two composite volcanoes, Mt. Shasta and Mt. Lassen, and the Medicine Lake Highlands, a broad shield volcano.

The Cascade volcanics have been divided into the Western Cascade series and the High Cascade series. The Western Cascade series rocks consists of Miocene-aged basalts, andesites, and dacite flows interlayered with rocks of explosive origin, including rhyolite tuff, volcanic breccia, and agglomerate. This series is exposed at the surface in a belt 15 miles wide and 50 miles long from the Oregon border to the town of Mt. Shasta. After a short period of uplift and erosion that extended into the Pliocene, volcanism resumed creating the High Cascade volcanic series. The High Cascade series forms a belt 40 miles wide and 150 miles long just east of the Western Cascade series rocks. Early High Cascade rocks formed from very fluid basalt and andesite that extruded from fissures to form low shield volcanoes. Later eruptions during the Pleistocene contained more silica, causing more violent eruptions. Large composite cones like Mt. Shasta and Mt. Lassen had their origins during the Pleistocene (Norris and Webb 1990).

The Modoc Plateau consists of a high plain of irregular volcanic rocks of basaltic origin. The numerous shield volcanoes and extensive faulting on the plateau give the area more relief than otherwise may be expected for a plateau. The Modoc Plateau averages 4,500 feet in elevation and is considered a small part of the Columbia Plateau, which covers extensive areas of Oregon, Washington, and Idaho.

Volcanic rocks of the Modoc Plateau and Cascades Geomorphic Province are present adjacent to the eastern and northeastern boundaries of the Shasta Lake and vicinity area. In the vicinity of Shasta Lake they occur near the Pit River Arm and along the upper Sacramento River Arm. These rocks are generally younger than 4 million years old. Volcaniclastic rocks, mudflows, and tuffs of the Tuscan Formation occur in the Pit River area, and localized volcanic deposits occur in isolated locations.

The areal extent of bedrock types within the Shasta Lake and vicinity area is presented in Table 4-3 for the portion of the subarea between 1,070 feet and 1,090 feet above msl (i.e., Impoundment Area); and in Table 4-4 for the portion of the subarea potentially disturbed by construction activities (i.e., Relocation Areas).

Table 4-3. Areal Extent of Bedrock Types – Shasta Lake and Vicinity (Impoundment Area)

Map Unit	Formation	Bedrock Types	Study Area (acres)	Study Area (% Total Impoundment Area)
Cb	Baird	Meta-pyroclastic and keratophyre	145.3	5.82%
Cbg	Bragdon	Shale; graywacke; minor conglomerate	468.9	18.77%
Cbgcp	Bragdon	Chert-pebble and quartz conglomerate	3.3	0.13%
Cbgs	Bragdon	Black siliceous shale	0.0	0.00%
Cblss	Baird	Skarn; lime silicate minerals	1.2	0.05%
Cbmv	Baird	Greenstone and greenstone breccia	6.7	0.27%
Cbp	Baird	Mafic pyroclastic rocks	4.8	0.19%
Db	Balaklala rhyolite	Non-porphyritic and with small quartz phenocrysts	52.8	2.11%
Dbc	Balaklala rhyolite	Porphyritic with large quartz phenocrysts	3.3	0.13%
Dbp	Balaklala rhyolite	Volcanic breccia; tuff breccia; volcanic conglomer	12.9	0.52%
Dbt	Balaklala rhyolite	Tuff & tuffaceous shale	5.9	0.24%
Dc	Copley	Greenstone and undiff.	48.9	1.96%
Dct	Copley	Greenstone tuff & breccia	33.4	1.34%
di		Intermediate dikes	0.6	0.02%
dia		Diabase dikes	0.2	0.01%
Dk	Kennett	Siliceous shale and rhyolitic tuff	20.0	0.80%
Dkls	Kennett	Limestone	1.9	0.07%
Dkt	Kennett	Tuff; tuffaceous shale; shale	11.2	0.45%
dpp		Plagioclase	0.7	0.03%
Ehaev		Andesite	17.9	0.72%
Ja	Arvison	Volcaniclastic and pyroclastic	9.6	0.38%
lake	Shasta Lake		924.0	36.99%
Pmbh	Bully Hill rhyolite	Meta-andesite	84.6	3.39%
Pmbhp	Bully Hill rhyolite	Pyroclastic; tuff & tuff breccia	11.0	0.44%
Pmd		Quartz diorite	47.5	1.90%

Table 4-3. Areal Extent of Bedrock Types – Shasta Lake and Vicinity (Impoundment Area) (contd.)

Map Unit	Formation	Bedrock Types	Study Area (acres)	Study Area (% Total Impoundment Area)
Pmdk	Dekkas	Mafic flows and tuff	18.9	0.76%
Pmdkp	Dekkas	Breccia; tuff; tuff breccia	16.7	0.67%
Pmml	McCloud	Limestone	26.7	1.07%
Pmmls	McCloud	Skarn; lime silicate minerals; magnetite	2.2	0.09%
Pmn	Nosoni	Tuffaceous mudstone	66.4	2.66%
Pmpr	Pit River Stock	Quartz diorite; granodiorite	11.2	0.45%
Trh	Hosselkus Limestone	Limestone; thin-bedded to massive; gray; fossilife	7.5	0.30%
Trm	Modin	Andesitic volcaniclastic and pyroclastic rocks	27.9	1.12%
Trp	Pit	Shale; siltstone; metavolcanic; wi limestone	374.8	15.00%
Trpmv	Pit	Meta-andesite; meta-dacite	12.0	0.48%
Trpp	Pit	Pyroclastic; tuff and tuff breccia	16.6	0.66%
Tva	Western Cascades	Andesite	0.5	0.02%

Table 4-4. Areal Extent of Bedrock Types – Shasta Lake and Vicinity (Relocation Areas)

Map Unit	Formation	Bedrock Types	Study Area (acres)	Study Area (% Total Relocation Area)
Cb	Baird	Meta-pyroclastic and keratophyre	530.8	15.90%
Cbg	Bragdon	Shale; graywacke; minor conglomerate	1,088.4	32.59%
Cbgcp	Bragdon	Chert-pebble and quartz conglomerate	0.6	0.02%
Cbmv	Baird	Greenstone & greenstone breccia	25.6	0.77%
Db	Balaklala rhyolite	Non-porphyritic and with small quartz phenocrysts	9.8	0.29%
Dbc	Balaklala rhyolite	Porphyritic with large quartz phenocrysts	7.8	0.23%
Dbp	Balaklala rhyolite	Volcanic breccia; tuff breccia; volcanic conglomer	3.9	0.12%
Dbt	Balaklala rhyolite	Tuff and tuffaceous shale	1.1	0.03%
Dc	Copley	Greenstone and undiff.	61.5	1.84%
Dct	Copley	Greenstone tuff and breccia	84.9	2.54%

Table 4-4. Areal Extent of Bedrock Types – Shasta Lake and Vicinity (Relocation Areas) (contd.)

Map Unit	Formation	Bedrock Types	Study Area (acres)	Study Area (% Total Relocation Area)
Dk	Kennett	Siliceous shale and rhyolitic tuff	10.3	0.31%
Dkls	Kennett	Limestone	0.4	0.01%
Dkt	Kennett	Tuff; tuffaceous shale; shale	0.0	0.00%
Ehaev		Andesite	261.4	7.83%
Ja	Arvison	Volcaniclastic and pyroclastic	0.7	0.02%
lake	Shasta Lake		242.0	7.25%
Pmbh	Bully Hill rhyolite	Meta-andesite	53.0	1.59%
Pmbhp	Bully Hill rhyolite	Pyroclastic; tuff and tuff breccia	7.5	0.22%
Pmd		Quartz diorite	100.5	3.01%
Pmdk	Dekkas	Mafic flows and tuff	8.8	0.26%
Pmdkp	Dekkas	Breccia; tuff; tuff breccia	18.5	0.55%
Pmml	McCloud	Limestone	174.9	5.24%
Pmn	Nosoni	Tuffaceous mudstone	182.5	5.46%
Pmpr	Pit River Stock	Quartz diorite; granodiorite	42.8	1.28%
Trp	Pit	Shale; siltstone; metavolcanic; wi limestone	408.5	12.23%
Trpp	Pit	Pyroclastic; tuff and tuff breccia	11.5	0.34%
Tva	Western Cascades	Andesite	2.0	0.06%

Upper Sacramento River (Shasta Dam to Red Bluff)

The portion of the study area along the Sacramento River downstream to the Red Bluff Diversion Dam encompasses portions of the Cascade Range, Klamath Mountains, and Central Valley Geomorphic Provinces.

Central Valley Geomorphic Province The Central Valley Geomorphic Province is a large, asymmetrical, northwest-trending, structural trough formed between the uplands of the California Coast Ranges to the west and the Sierra Nevada to the east, and is approximately 400 miles long and 50 miles wide (Page 1985). The Coast Ranges to the west are made up of pre-Tertiary and Tertiary semiconsolidated to consolidated marine sedimentary rocks. The Coast Range sediments are folded and faulted and extend eastward beneath most of the Central Valley. The Sierra Nevada to the east side of the valley is composed of pre-Tertiary igneous and metamorphic rocks.

Along the western side of the Sacramento Valley, rocks of the Central Valley Geomorphic Province include Upper Jurassic to Cretaceous marine sedimentary rocks of the Great Valley Sequence; fluvial deposits of the Tertiary Tehama Formation; Quaternary Red Bluff, Riverbank, and Modesto Formations; and Recent alluvium.

The Great Valley Sequence was formed from sediments deposited within a submarine fan along the continental edge. The sediment sources were the Klamath Mountains and Sierra Nevada to the north and east, and include mudstones, sandstones, and conglomerates.

Tertiary and Quaternary fluvial sedimentary deposits unconformably overlie the Great Valley Sequence. The Pliocene Tehama Formation is the oldest, derived from erosion of the Coast Ranges and Klamath Mountains, and consists of pale green to tan semiconsolidated silt, clay, sand, and gravel. Along the western margin of the valley, the Tehama Formation is generally thin, discontinuous, and deeply weathered.

The Red Bluff Formation is a broad erosional surface, or pediment, of low relief formed on the Tehama Formation between 0.45 and 1.0 million years ago. Thickness varies to about 30 feet.

Recent alluvium consists of loose sedimentary deposits of clay, silt, sand, gravel, and boulders. The deposits may originate from landslides, colluvium, stream channel deposits, and floodplain deposits. Landslides occur along the project area but are generally small, shallow debris slides or debris flows.

Stream channel deposits generally consist of unconsolidated sand and gravel, with minor amounts of silt and clay. Floodplain deposits are finer grained and consist almost entirely of silt and clay (DWR 2003).

Lower Sacramento River and Delta

The study area along the lower Sacramento River and the Delta encompasses the Central Valley Geomorphic Province, as described above for the upper Sacramento River portion of the primary study area.

The Delta is a broad depression in the Franciscan bedrock that resulted from an east-west expansion of the San Andreas and Hayward fault systems, filled by sediments deposited over many millions of years via the Sacramento and San Joaquin Rivers and other tributary rivers and streams.

CVP/SWP Service Areas

The CVP/SWP service areas encompass portions of the Central Valley, Sierra Nevada, Coast Ranges, Cascade Range, Peninsular Ranges, Transverse Ranges, Mojave Desert, Modoc Plateau, and Klamath Mountains Geomorphic Provinces.

The south-of-Delta CVP/SWP service areas include two distinct, noncontiguous areas: in the north are the San Felipe Division's CVP service area and the South Bay SWP service area; to the south are the SWP service areas. The northern section of this region encompasses the Coast Ranges Geomorphic Province and the southern portion of this section includes portions of the Peninsular Ranges, Tranverse Ranges, and Mojave Desert Geomorphic Provinces. Additional information on the geomorphic provinces is available in the *Geology, Geomorphology, Minerals, and Soils Technical Report*.

4.1.2 Geologic Hazards

Geologic hazards are described below for both the primary and extended study areas.

Shasta Lake and Vicinity

Six types of geologic hazards have potential to occur within and near the Shasta Lake and vicinity project area: seismic hazards, volcanic eruptions and associated hazards, mudflows, snow avalanches, slope instability, and seiches.

Seismic Hazards Seismic hazards consist of the effects of ground shaking and surface rupture along and around the trace of an active fault. Ground shaking is the most hazardous effect of earthquakes because it is the most widespread and accompanies all earthquakes. Ground shaking can range from high to low intensity and is often responsible for structure failure leading to the largest loss of life and property damage during an earthquake. The Modified Mercalli intensity ratings reflect the relationship between earthquake magnitudes and shaking intensity. Higher magnitude earthquakes typically produce higher shaking intensities over wider areas, which may result in greater damage.

Surface rupture occurs when an earthquake results in ground rupture, causing horizontal and/or vertical displacement. Surface rupture typically is narrow in rock and wider in saturated soils, and also typically tends to occur along previous fault lines.

An active fault is defined by the Alquist-Priolo Earthquake Fault Zoning Act as a fault that has caused surface rupture within the last 11,000 years. The nearest active fault to the southern portion of the Shasta Lake and vicinity project area is the Battle Creek Fault Zone located approximately 27 miles south of the dam (CDC 2006a). The maximum credible earthquake for the southern portion of the Shasta Lake and vicinity area has a moment magnitude of 7.3. A maximum peak ground acceleration of 0.101 g[1] was calculated for the southern portion of the Shasta Lake and vicinity area based on an earthquake moment magnitude of 6.5 from the Battle Creek Fault Zone. The Northeastern California Fault system, located approximately 28 miles south of Shasta Dam, may be capable of causing the highest ground shaking at the site. A maximum peak ground acceleration of 0.126 g was calculated for the Shasta Dam location.

[1] Peak ground acceleration is expressed in units of "g", the acceleration due to Earth's gravity. Thus, 1g = 9.81m/s^2

According to the California Geological Survey Alquist-Priolo Act Active Fault Maps, the nearest active fault north of the Shasta Lake and vicinity area is the Hat Creek-Mayfield-McArthur Fault Zone, located about 50 miles to the northeast of Shasta Dam (Jennings 1975). This fault zone is composed of numerous parallel north-northwest trending normal faults. According to the Alquist-Priolo Act maps, the Hat Creek-Mayfield-McArthur Fault is capable of generating magnitude 7.0 earthquakes with a relatively long return period of 750 years (Petersen et al. 1996).

Other earthquake fault zones within or near the Shasta Lake and vicinity area include the following:

- Pittville Fault located in portions of the Day Bench
- Rocky Ledge Fault located north of Burney in Long Valley and east of Johnson Park

Northeast of the Shasta Lake and vicinity area, portions of Shasta and Siskiyou counties include the area between Lassen Peak and Medicine Lake Highlands. This area is cut by a series of active normal faults that are part of the Sierra Nevada-Great Basin dextral shear zone (Shasta County 2004). These faults are capable of affecting the upper watersheds northeast of the Sacramento Valley. These faults include the previously mentioned Hat Creek-Mayfield-McArthur Fault Zone, the Gillem-Big Crack faults near the California-Oregon border southeast of Lower Klamath Lake, and the Cedar Mountain Fault southwest of Lower Klamath Lake. The faults in this zone are capable of earthquakes up to magnitude 7.0. Farther northeast, the Likely Fault is judged capable of a magnitude 6.9 earthquake. In the northeast corner of the state, the Surprise Fault is capable of a magnitude 7.0 earthquake.

Seismic activity has been reported in the area of Shasta Dam and Shasta Lake, and has typically been in the 5.0 magnitude or lower range. The nearest seismic activity to Shasta Dam and Shasta Lake was a magnitude 5.2 earthquake that occurred 3 miles northwest of Redding, near Keswick Dam, in 1998 (Petersen 1999).

Volcanic Eruptions and Associated Hazards Volcanic hazards include potential eruptions, and their products and associated hazards. In the Shasta Lake and vicinity subarea these include lava flows, pyroclastic flows, domes, tephra, and mudflows and floods triggered by eruptions. Three active centers of volcanic activity, all associated with the Modoc Plateau and Cascades Geomorphic Province, occur near enough to this Shasta Lake and vicinity area to merit discussion: the Medicine Lake Highlands, Lassen Peak, and Mount Shasta.

Medicine Lake Highlands is located approximately 65 air miles northeast of Shasta Lake and includes a broad shield volcano that has a large caldera at its summit and more than 100 smaller lava cones and cinder cones on its flanks. The volcano developed over a period of 1,000,000 years, mainly through lava flows. The most recent activity was approximately 500 years ago, when a large tephra eruption was followed by an extrusion of obsidian. Volcanic activity is likely to persist in the future (USFS 1994), specifically local lava flows and tephra eruptions.

Lassen Peak lies 50 miles southeast of Shasta Lake. Lassen Peak is a cluster of dacitic domes and vents that have formed over the past 250,000 years. The most recent eruption occurred in 1914. That eruption began as a tephra eruption with steam blasts, and climaxed with a lateral blast, hot avalanches, and mudflows. Most ash from the 1914 eruption was carried to the east of the volcano.

The most prominent, active volcanic feature in the vicinity of Shasta Lake is Mount Shasta, which is located approximately 45 miles north of Shasta Lake. Mount Shasta has erupted at least once per 800 years during the last 10,000 years, and about once per 600 years during the last 4,500 years. Mount Shasta last erupted in 1786. Eruptions during the last 10,000 years produced lava flows and domes on and around the flanks of Mount Shasta. Pyroclastic flows extended up to 12 miles from the summit. Most of these eruptions also produced mudflows, many of which reached tens of miles from Mount Shasta.

Eruptions of Mount Shasta could endanger the communities of Weed, Mount Shasta, McCloud, and Dunsmuir. Such eruptions will most likely produce deposits of lithic ash, lava flows, domes, and pyroclastic flows that may affect low- and flat-lying ground almost anywhere within 12 miles of the summit. However, on the basis of its past behavior, Mount Shasta is not likely to erupt large volumes of pumiceous ash (tephra) in the future. Areas subject to the greatest risk from air-fall tephra are located mainly east and within about 30 miles of the summit (Miller 1980).

Floods commonly are produced by melting of snow and ice during eruptions of ice-clad volcanoes like Mount Shasta, or by heavy rains that may accompany eruptions. By incorporating river water as they move down valleys, mudflows may grade into slurry floods carrying unusually large amounts of rock debris. Eruption-caused floods can occur suddenly and can be of large volume. If floods caused by an eruption occur when rivers are already high, floods far larger than normal can result. Streams and valley floors around Mount Shasta could be affected by such floods as far downstream as Shasta Lake. The danger from floods caused by eruptions is similar to that from floods having other origins, but floods caused by eruptions may be more damaging because of a higher content of sediment that would increase the bulk specific gravity of the fluid (Miller 1980).

Mudflows Small mudflows, not caused by eruptions, are common at Mount Shasta. Relatively small but frequent mudflows have been produced historically (1924, 1926, 1931, and 1977) by melting of glaciers on Mount Shasta during warm summer months. Mudflows that occurred during the summer of 1924 entered the McCloud River and subsequently flowed into the Sacramento River (Miller 1980).

Snow Avalanches Avalanche hazards near the Shasta Lake and vicinity subarea typically occur in steep, high-elevation terrane. These areas are generally above the treeline or in sparsely vegetated areas. Significant avalanche areas are limited to locations on the upper slopes outside of the Shasta Lake and vicinity area.

Slope Instability (Mass Wasting) Slope instability hazards occur in areas of active and relict mass wasting features (e.g., active and relict landslides, debris flows, inner gorge landscape positions, and complexes of these features). Slope instability hazards occur throughout the Shasta Lake and vicinity area, and are most common in areas of steep topography. Locations in the Shasta Lake and vicinity area of mapped slope instability hazards are shown in Figure 4-4.

The terrane underlying the subarea and surrounding region has been influenced by a combination of tectonic uplift, mass wasting, and fluvial and surface erosion processes. The influence of these processes is ongoing, with evidence of ancient and more recent mass wasting features over the entire area, consisting of debris slides, torrents, and flows, with lesser amounts of rotational/translational landslides. The extent or distribution of mass wasting features across the region is believed not to have changed appreciably as a result of land use activities following Anglo-American settlement (USFS 1998).

Much of the topography in the general vicinity of Shasta Lake is steep, with concave swales; therefore, landslides are relatively common, ranging from small mudflows and slumps to large debris slides, debris flows, and inner gorge landslides. Small shallow debris slides associated with localized alluvial/colluvial rock units occur along the shoreline of Shasta Lake. Rock slides caused by mining activities have also occurred on the slopes surrounding Shasta Lake.

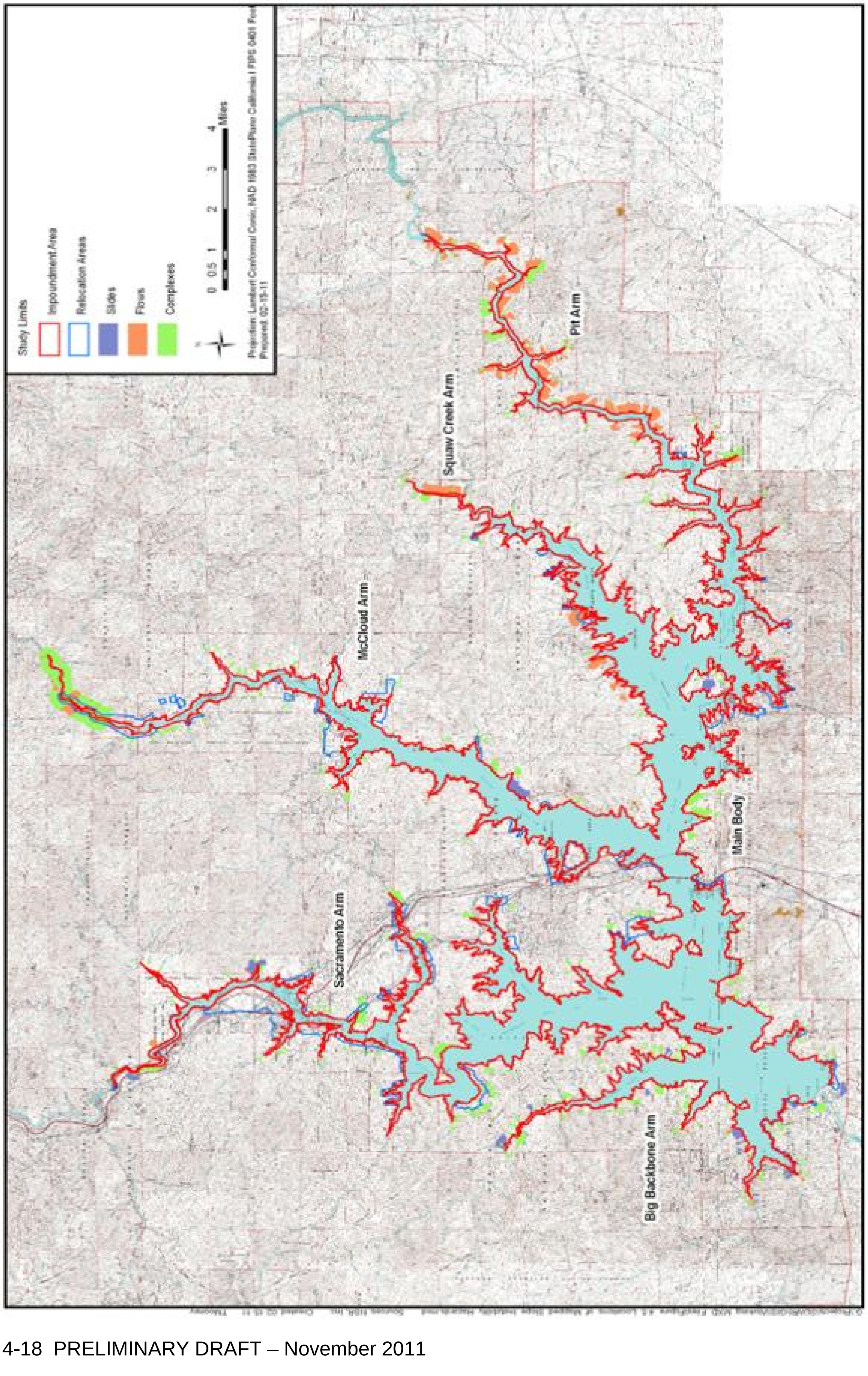


Figure 4-4. Locations of Mapped Slope Instability Hazards – Shasta Lake and Vicinity

The areal extent of mapped slope instability hazards within the Shasta Lake and vicinity area is presented in Table 4-5 for the portion of the subarea between 1,070 feet and 1,090 feet above msl (Impoundment Area); and in Table 4-6 for the portion of the subarea potentially disturbed by construction activities under the action alternatives (Relocation Areas). About 173 acres (7 percent) of the Impoundment Area is occupied by features that are potentially unstable. Potentially unstable features occupy about 232 acres (7 percent) of the Relocation Area. Most of the mapped slope instability hazards are debris flows.

Table 4-5. Areal Extent of Mapped Slope Instability Hazards – Shasta Lake and Vicinity (Impoundment Area)

Map Unit	Formation	Study Area (acres)	Study Area (% Total Sub-Area)
1050	Slides	9.5375	0.38%
1100	Flows	66.6091	2.67%
1200	Complexes	97.1695	3.89%

Table 4-6. Areal Extent of Mapped Slope Instability Hazards – Shasta Lake and Vicinity (Relocation Areas)

Map Unit	Formation	Study Area (acres)	Study Area (% Total Sub-Area)
1050	Slides	2.9947	0.09%
1100	Flows	52.9767	1.59%
1200	Complexes	175.8020	5.26%

Seiches A seiche is an oscillation of a body of water in an enclosed or semi enclosed basin that varies in period, depending on the physical dimensions of the basin, from a few minutes to several hours, and in height from a few millimeters to a few meters. Seiches arise chiefly as a result of sudden local changes in atmospheric pressure, aided by wind and occasionally tidal currents. Seiches can also be triggered by strong earthquake ground motion or large landslides entering a body of water.

If Mount Shasta were to erupt again, volcanic ash could fall in the study area, though as previously described, Mount Shasta is not likely to erupt large volumes of pumiceous ash (tephra) in the future. Minor seiches in Shasta Lake also could be generated by debris flows in the arms of the lake where its tributaries enter (City of Redding 2000). A large megathrust on the Cascadia subduction zone off the Pacific coast could generate enough ground shaking to generate a seiche in Shasta Lake.

Regardless of its cause, the effects of a seiche would depend on the local conditions at the time. If the reservoir were filled to capacity, there may be some overspill by way of the dam spillways. Substantial overtopping of the dam itself is extremely unlikely, as such an event would require a seiche more than 6 meters high, even if the reservoir were filled to capacity. Excess flows into the Sacramento River triggered by a seiche in Shasta Lake would be attenuated by Keswick Reservoir (City of Redding 2000).

Upper Sacramento River (Shasta Dam to Red Bluff)

The upper Sacramento River portion of the primary study area could potentially be affected by geologic hazards in the region attributed to seismic hazards and volcanic eruptions and associated hazards. Mudflows, snow avalanches, slope instability, and seiches are not considered to be geologic hazards in this portion of the primary study area.

Seismic Hazards The northeastern area of Shasta County is part of an area between Lassen Peak and the Medicine Lake Volcano (in Siskiyou County), which is cut by a series of active normal faults that are part of the Sierra Nevada-Great Basin dextral shear zone (Shasta County 2004). These faults are likely to affect the upper watersheds northeast of the Sacramento Valley. These faults include the Mayfield-MacArthur-Hat Creek faults, 25 to 85 miles north of Lake Almanor; the Gillem-Big Crack Faults near the California-Oregon border southeast of Lower Klamath Lake; and the Cedar Mountain Fault southwest of Lower Klamath Lake. The faults in this zone are capable of earthquakes up to magnitude 7.0.

Shasta County, is a seismically active region, but has not experienced significant property damage or loss of life from earthquakes in the past 120 years. The City of Redding (2005) reported that maximum recorded intensities have reached Modified Mercalli VII. The majority of intense seismic activity in Shasta County has occurred in the eastern half of the county, around Lassen Peak (City of Redding 2005).

The Shasta County General Plan states that the maximum intensity event expected to occur in eastern Shasta County is Modified Mercalli VIII (Shasta County 2004). In the western half of Shasta County, the maximum intensity event is expected to be Modified Mercalli VII (City of Redding 2005). Shasta County is entirely within Seismic Zone 3 of the Uniform Building Code. Redding is an area of “moderate seismicity” and the Hat Creek and McArthur areas are of “moderate-to-high seismicity” (Shasta County 2004).

South of Shasta County along the upper Sacramento River, potential surface faulting could be associated with the Great Valley thrust fault system, which is capable of earthquakes up to magnitude 6.8 along the west side of the Sacramento Valley. This fault system forms the boundary between the Coast Ranges and the Sacramento and San Joaquin Valleys.

The San Andreas Fault system is located west of the Sacramento and San Joaquin Valleys and is made up of a series of faults that lie along a 150-mile-long northwest trending zone of seismicity. This zone is 10 to 45 miles west of the Sacramento Valley and extends from Suisan Bay past Lake Berryessa and Lake Pillsbury to near the latitude of Red Bluff. The Green Valley, Hunting Creek, Bartlett Springs, Round Valley, and Lake Mountain Faults are the mapped active faults of the San Andreas Fault system most likely to affect the upper watersheds west of the Sacramento Valley. The faults within this system are capable of earthquakes up to 7.1 in magnitude.

The Indian Valley Fault southeast of Lake Almanor and the Honey Lake Fault zone east of Lake Almanor are likely to affect the upper watersheds east of the Sacramento Valley, and are capable of a magnitude 6.9 earthquake. Surface rupture occurred in 1975 along the Cleveland Hill Fault south of Lake Oroville. The Foothills Fault system, which borders the east side of the Sacramento and San Joaquin Valleys, is judged to be capable of a magnitude 6.5 earthquake.

Volcanic Eruptions and Associated Hazards Shasta County is at the southern end of the Cascade Range (as described above for geology of the upper Sacramento River). The most recent volcanic activity in Shasta County occurred between 1914 and 1917, when Lassen Peak erupted, producing lava flows, numerous ash falls, and a large mudflow. The mudflow, a result of melting snow and ash, flowed down Lost Creek and Hat Creek (Shasta County 2004).

It is unlikely that a large mudflow from Mt. Shasta would endanger Shasta County (Shasta County 2004).

Lower Sacramento River and Delta

The lower Sacramento River and Delta portion of the extended study area could potentially be affected by geologic hazards in the region attributed to seismic hazards. Volcanic eruptions and associated hazards, mudflows, snow avalanches, slope instability, and seiches are not considered to be geologic hazards in this portion of the extended study area.

The nearest active fault to the lower Sacramento River below Red Bluff is the Dunnigan Hills Fault, which has experienced fault displacement within the last 10,000 years (Jennings 1994). The Dunnigan Hills Fault runs along the Sacramento River and is located between 6 and 10 miles west of the river near the Town of Dunnigan. The Cleveland Fault is located approximately 30 miles east of the Sacramento River near the Town of Oroville. In addition, the Great Valley thrust fault system and San Andreas fault system extend along the Sacramento River to the west, as described above for the upper Sacramento River portion of the primary study area.

Failure of Delta levees is the primary threat to the region as a result of seismic activity. The Delta levees are located in a region of relatively low seismic activity compared to the San Francisco Bay Area (Bay Area). The major strike-slip faults in the Bay Area (San Andreas, Hayward, and Calaveras faults) are located over 16 miles from the Delta region. The less active Green Valley and Marsh Creek–Clayton faults are over 9 miles from the Delta region. Small but significant local faults are situated in the Delta region, and there is a possibility that blind thrust faults occur along the west Delta.

CVP/SWP Service Areas

The CVP/SWP service areas portion of the extended study area could potentially be affected by geologic hazards in the region attributed to seismic hazards. Volcanic eruptions and associated hazards, mudflows, snow avalanches, slope instability, and seiches are not considered to be geologic hazards in this portion of the extended study area. A number of active faults exist along the Sacramento and San Joaquin rivers in the CVP/SWP service areas.

Major earthquake activity has centered along the San Andreas Fault zone, including the great San Francisco earthquake of 1906 in the Bay Area. Since that earthquake, four events of magnitude 5.0 on the Richter scale or greater have occurred in the Bay Area. The San Andreas and Hayward Faults remain active, with evidence of recent slippage along both faults.

In the San Joaquin River region, the Great Valley thrust fault system forms the boundary between the Coast Ranges and the west boundary of the San Joaquin Valley. This fault system is capable of earthquakes up to magnitude 6.7 along the west side of the San Joaquin Valley.

Active faults likely to affect the upper watersheds at the end of the San Joaquin Valley include the White Wolf Fault, which ruptured in 1952 with a magnitude 7.2 earthquake; the Garlock Fault, capable of a magnitude 7.3 earthquake; and several smaller faults l0 to 30 miles north of the White Wolf Fault.

A list of all of the reported faults, fault zones, and systems, according to the California Geological Survey, that are located south-of-Delta within the CVP/SWP service areas is presented in the California Public Resources Code, Division 2 Geology, Mines and Mining, Chapter 7.5 Earthquake Fault Zoning (CDC 2006a).

4.1.3 Geomorphology

Geomorphology in the study area is described below for both the primary and extended study areas.

Shasta Lake and Vicinity

As previously described, most of Shasta Lake and vicinity area is within the Klamath Geomorphic Province. The topography of the study area ranges from moderate to steep, and elevation ranges from approximately 1,070 to more than 6,000 feet above msl. The orientation and slopes of the ridges are controlled by the bedrock geology and structure. Generally speaking, the eastern slopes of the ridges are steeper than the western slopes. Hillslope gradient ranges from 0 percent to more than 100 percent within the Shasta Lake and vicinity area.

The regional stream network and boundaries of watersheds adjacent to Shasta Lake are shown in Figure 4-5. The boundaries of watersheds adjacent to Shasta Lake (shown in Figure 4-5) are the same as the boundaries of 6th Field

Hydrologic Unit Code watersheds defined in the subarea by the USFS. Regional-scale characteristics of the streams that are tributary to Shasta Lake are presented in Figure 4-6, where they are organized by arm. The total area of watersheds draining to the lake on a regional scale is 6,665 square miles. Of this total, watersheds that are immediately adjacent and contribute directly to Shasta Lake (i.e., 6th Field Hydrologic Unit Code watersheds) comprise about 512 square miles (see Table 4-7). These immediately adjacent watersheds include small portions of the five major tributaries to the lake (i.e., Big Backbone Creek, Sacramento River, McCloud River, Squaw Creek, and Pit River), and small watersheds that are adjacent and directly contributory to the Main Body Arm of the lake.

In general, the stream networks adjacent and directly tributary to Shasta Lake are irregular and dendritic. The drainages are steep, and the drainage density ranges from 3.0 to 6.4 miles of stream per square mile of drainage area (Table 4-7). The drainage density is the lowest in the Main Body Arm because this area has several small catchments. The density is the highest in the more well-defined arms, a function of their larger catchment areas of the tributary watersheds.

The lengths of streams within watersheds that are adjacent to Shasta Lake are also reported in Figure 4-6, where they again are aggregated by arm and further subdivided by flow regime (i.e., intermittent or perennial) and stream gradient. There are about 2,903 miles of ephemeral, intermittent, and perennial stream channels within these adjacent watersheds. Most (64 percent) of the stream channels are intermittent and have a stream slope greater than 10 percent. About 14 percent of the stream channels are perennial, with slopes less than 7 percent. Generally speaking, channels with gradients of less than 7 percent are known to support fish and other aquatic organisms. About 79 percent of these potential fish-bearing tributaries occur within the Sacramento River, Squaw Creek, and Pit River arms.

Again, the values reported in Table 4-7 do not include large parts of the Sacramento River, Squaw Creek, Pit, McCloud, and Big Backbone watersheds; only the “face drainages” within the arms themselves are included in the reported values.

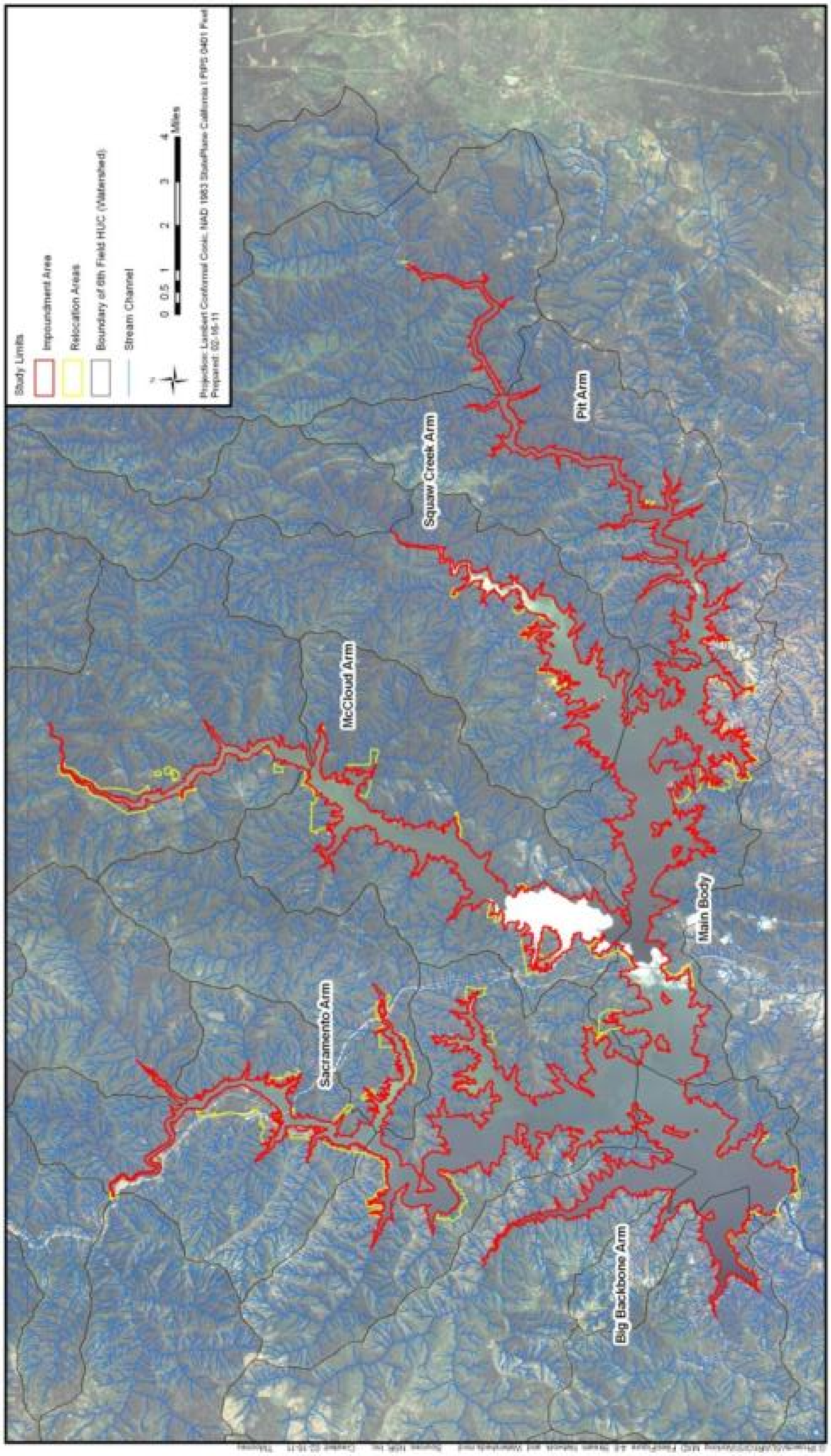
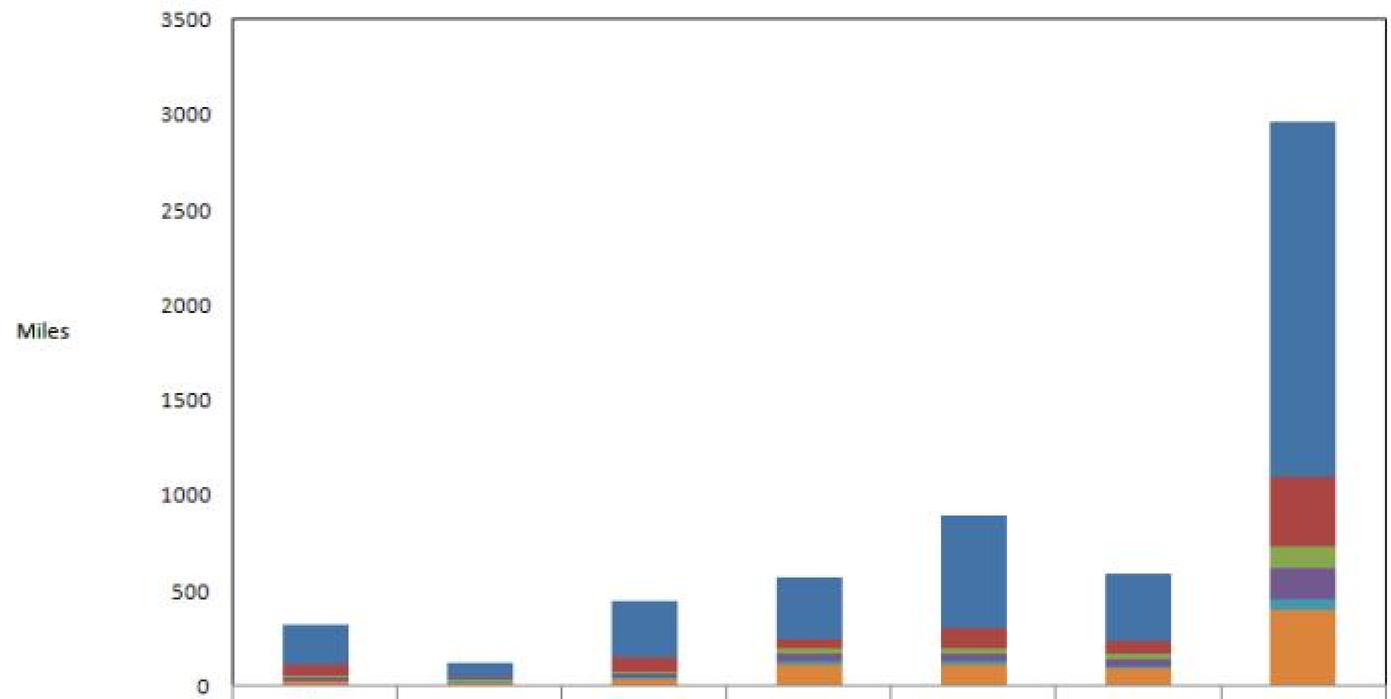


Figure 4-5. Regional Stream Network and Boundaries of Watersheds Adjacent to Shasta Lake and Vicinity



	Big Backbone Creek	Main Body	McCloud River	Pit River	Sacramento River	Squaw Creek	Total Length
Intermittent >10% Grade	214	83	297	321	597	355	1867
Perennial >10% Grade	60	6	75	51	101	71	364
Intermittent 7-10% Grade	4	10	9	31	30	24	108
Perennial 7-10% Grade	18	3	25	36	41	38	161
Intermittent <7% Grade	2	10	5	21	20	8	66
Perennial <7% Grade	30	14	38	109	109	96	396

Figure 4-6. Regional-Scale Characteristics of Streams Tributary to Shasta Lake

Table 4-7. Characteristics of Watersheds Adjacent and Directly Tributary to Shasta Lake

Lake Arm	Drainage Area (square miles)	Stream Length (miles)	Drainage Density (miles/square miles)	Average Elevation (feet)	Max Elevation (feet)	Mean Annual Precipitation (inches)
Big Backbone Creek	60	325	5.4	2,185	4,633	74
Main Body	37	112	3.0	1,260	2,723	67
McCloud River	77	444	5.7	1,911	4,669	79
Pit River	100	551	5.5	1,700	3,246	73
Sacramento River	137	880	6.4	1,825	4,589	76
Squaw Creek	100	583	5.8	2,100	5,046	83
Total	512	2,903	5.7	1,885	5,046	77

Using existing data and information (NSR 2003), the following observations were made concerning the relative stability of the riverine reaches. Of the five main tributaries influencing Shasta Lake, all except Big Backbone Creek and the Sacramento River are underlain by shallow bedrock that limits channel incision. For this reason, Squaw Creek, and the Pit and McCloud rivers are relatively stable streams that are unlikely to be changed significantly in response to average floods. Although they occur infrequently, debris flows have the potential to substantially affect particularly shallow bedrock reaches of these tributaries, as is evident in Dekkas Creek. The Sacramento River and Big Backbone Creek are relatively dynamic because the channel bed has the potential to undergo physical changes in response to a moderate flood. Although Big Backbone Creek and Squaw Creek have similar watershed areas, Squaw Creek has more bedrock reaches than Big Backbone Creek and is therefore inherently more stable.

Upper Sacramento River (Shasta Dam to Red Bluff)

The geomorphology of the Sacramento River is a product of several factors: the geology of the Sacramento Valley, hydrology, climate, vegetation, and human activity. Large flood events drive lateral channel migration and remove large flow impediments. Riparian vegetation stabilizes riverbanks and reduces water velocities, inducing deposition of eroded sediment. In the past, a balance existed between erosion and deposition along the Sacramento River. However, construction of dams, levees, and water projects has altered streamflow and other hydraulic characteristics of the Sacramento River. In some areas, human-induced changes have stabilized and contained the river, while in other reaches, the loss of riparian vegetation has reduced sediment deposition and led to increased erosion.

Lower Sacramento River and Delta

Downstream from Red Bluff, the lower Sacramento River is relatively active and sinuous, meandering across alluvial deposits within a wide meander belt. The active channel consists of point bars composed of sand on the inside of meander bends, and is flanked by active floodplain and older terraces. While most of these features consist of easily eroded, unconsolidated alluvium, there are also outcrops of resistant, cemented alluvial units such as the Modesto and Riverbank Formations. Geologic outcroppings and man-made structures, such as bridges and levees, act as local hydraulic controls and confine movement of much of the lower Sacramento River. Natural geomorphic processes in the Delta have been highly modified by changes to upstream hydrology (reservoirs and streamflow regulation) and construction of levees, channels, and other physical features.

Since construction of Shasta Dam in the early 1940s, flood volumes on the river have been reduced, which has reduced the energy available for sediment transport. Straightening and a reduced rate of meander migration of the river may be associated with flow regulation because of Shasta Dam. The reduction in active channel dynamics is compounded by the physical effects of riprap bank protection structures, which typically eliminate shaded bank habitat and associated deep pools, and halt the natural processes of channel migration.

CVP/SWP Service Areas

Geomorphology in the CVP/SWP service areas is a product of the same factors mentioned above, which include geology, hydrology and climate, vegetation, and human activity. Geomorphology in the CVP service areas is summarized in the descriptions of the primary study area and the lower Sacramento River and Delta portions of the extended study area.

Geomorphology in the SWP service areas extends into the southern geomorphic provinces of California and along part of the coast. The southern geomorphic provinces and coastal province include the Transverse Ranges, Peninsular Ranges, Mojave Desert, and Coast Ranges. The Transverse Ranges, composed of overlapping mountain blocks, consist of parallel and subparallel ranges and valleys. The Peninsular Ranges Geomorphic Province is composed of northwest to southeast trending fault blocks, extending from the Transverse Ranges into Mexico. The Peninsular Ranges are similar to the Sierra Nevada in that they have a gentle westerly slope and generally consist of steep eastern faces. Mojave Desert Geomorphic Province topography is controlled by two faults: the San Andreas Fault, trending northwest to southeast, and the Garlock Fault, trending east to west (Jennings 1938). Before development of the Garlock Fault, sometime during the Miocene, the Mojave Desert was part of the Basin and Range Geomorphic Province. The Mojave Desert is now dominated by alluvial basins, which are aggrading surfaces from adjacent upland continental deposits (Norris and Webb 1990). The Coast Ranges have been greatly affected by plate tectonics. The Coast Ranges Geomorphic Province consists of elongate ranges and narrow valleys that run subparallel to the coast. Some of the mountain ranges along the Coast Range terminate abruptly at the sea (Norris and Webb 1990).

4.1.4 Mineral Resources

This section describes the known mineral resources of commercial or otherwise documented economic value in both the primary and extended study areas. The mineral resources of concern include metals and industrial minerals (e.g., aggregate, sand, and gravel, oil and gas, and geothermal resources that would be of value to the region).

Shasta Lake and Vicinity

The following section describes mineral resources in the Shasta Lake and vicinity portion of the primary study area.

Metals The lands within the Shasta Lake and Vicinity area are highly mineralized, with a history of significant mineral production. The Shasta Lake and vicinity area encompasses portions of two historic base metal mining districts, the west Shasta and east Shasta copper-zinc districts. The two districts focused on development of massive sulfide (Kuroko-Type) deposits of submarine volcanogenic origin that formed contemporaneously with, and by the same process as, the host volcanic rocks. Similar to other areas in the Klamath Mountains, copper was by far the predominant commodity produced. Zinc, sulfur, iron, limestone, gold, and silver were produced as byproducts of copper production.

The Golinsky mine complex is located in the west Shasta district, approximately 7 miles west of Shasta Dam in the headwaters of Dry Creek and Little Backbone Creek. This inactive, abandoned mine complex is the only large historic producing mine within the Shasta Unit of the National Recreation Area (NRA). Other mines within the Shasta NRA occur in the east Shasta district, concentrated between the McCloud and Squaw arms of Shasta Lake. The east Shasta district includes the Bully Hill, Copper City, and Rising Star mines, all of which are located in the Bully Hill area. These mines ceased operation before Shasta Dam was built.

These types of mineral deposits, in conjunction with the historic lode mining methods, have resulted in the discharge of toxic mine waste and acidic waters to Shasta Lake and some tributaries on a recurring basis (USFS 2000). The Golinsky mine complex has been subject to extensive remediation to reduce the discharge of toxic mine waste and acidic waters to Shasta Lake.

Industrial Minerals Industrial minerals occurring in the vicinity of the Shasta Lake include alluvial sand and gravel, crushed stone, volcanic cinders, limestone and diatomite. In 2002, Shasta County produced 462,000 tons of sand and gravel, 852,000 tons of crushed stone (including limestone), and 51,000 tons of volcanic cinders. Limestone used to produce portland cement and diatomite are not included in these figures.

The supply of portland cement concrete (PCC) grade alluvial sand and gravel within the region is more limited than non-PCC grade material. The primary sources for alluvial sand and gravel near the Shasta Lake and vicinity area are the Sacramento River (downstream from Keswick Dam), Clear Creek, Cottonwood Creek, and Hat Creek. Crushed stone has been produced at a limestone quarry in Mountain Gate, a granite quarry in Keswick, an andesite quarry in Mountain Gate, a shale quarry in Oak Run, and at two basalt quarries in the Lake Britton area near Burney. Volcanic cinders are produced at sites east of the Shasta Lake and vicinity area.

Limestone is used in a variety of industrial applications, but the bulk of limestone is used for the production of portland cement concrete. Most of the limestone resources within and near the Shasta Lake and vicinity area are located in fairly remote mountainous areas where extraction is uneconomical. However, significant mining of limestone for PCC production occurs immediately south of Shasta Lake, in Mountain Gate. Diatomite is produced from sources near Lake Britton, east of the Shasta Lake and vicinity area.

Geothermal Resources Significant geothermal resources occur in the Medicine Lake Highlands, approximately 65 air miles northeast of Shasta Lake. The potential capacity at Medicine Lake overall has been estimated at 480 megawatts (PacifiCorp 2010). Development of the Medicine Lake geothermal resources has been the subject of extensive litigation of environmental issues and Native American concerns.

Upper Sacramento River (Shasta Dam to Red Bluff)

Economically viable minerals found within the upper Sacramento River portion of the primary study area consist of alluvial sand and gravel, crushed stone, volcanic cinders, limestone, and diatomite. Additional mineral resources are found in the surrounding regions within Shasta and Tehama Counties. These mineral resources include asbestos, barium, calcium, chromium, copper, gold, iron, lead, manganese, molybdenum, silver, and zinc (USGS 2005).

Lower Sacramento River and Delta

Economically viable minerals found within the lower Sacramento River and Delta portion of the extended study area consist of alluvial sand and gravel, crushed stone, calcium, and clay. Additional mineral resources are found in the surrounding regions, including chromium, gold, granite, lithium, manganese, mercury, pumice, and silver (USGS 2005).

CVP/SWP Service Areas

The U.S. Geologic Survey mineral resources database indicates that numerous minerals resources are currently mined or have been mined within the CVP/SWP service areas. These minerals include antimony, asbestos, barium, bismuth, boron, calcium, chromium, clay, copper, diatomite, feldspar, fluorite, gold, gypsum-anhydrite, halite, iron, lead, limestone, magnetite, manganese, marble, mercury, molybdenum, pumice, quartz, sand and gravel, silica, silver, slate, stone (crushed/broken), talc, tin, titanium, tungsten, uranium, and vanadium (USGS 2005).

4.1.5 Soils

Soils and erosion area are described below for both the primary and extended study areas. Soils in the project study area are described in the following sections in terms of their biomass productivity, susceptibilities to erosion, subsidence, liquefaction and expansion, and suitability for onsite application of waste material.

Soil biomass productivity is a measure of the capability of a site to produce biomass. The purpose of this management interpretation is to measure site productive capability when vegetative indicators (e.g., crop yields, site trees, and other vegetative biomass data) are not directly available (Miles 1999). Factors that influence soil biomass productivity include soil depth, parent material, available water-holding capacity, precipitation, soil temperature regime, aspect, and reaction (i.e., pH). Soil biomass productivity is characterized using four relative rankings: high, moderate, low, and nonproductive.

Susceptibility to erosion is characterized in terms of erosion hazard rating. The ratings indicate the hazards of topsoil loss in an unvegetated condition as might occur following disturbance by construction. Ratings are based on soil erosion factor K (a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff, based primarily on soil texture but also considering structure, organic matter, and permeability), slope, and content of rock fragments. Three ratings are recognized: slight, moderate, and severe. A rating of slight indicates that no post-disturbance acceleration of naturally occurring erosion is likely; moderate indicates that some acceleration of erosion is likely, and that simple erosion-control measures are needed; and severe indicates that significant erosion is expected, and that extensive erosion-control measures are needed.

Land subsidence is broadly defined to mean the sudden sinking or gradual downward settling of the land surface with little or no horizontal motion. Land subsidence can arise from a number of causes, including the weathering characteristics of the underlying bedrock (e.g., as occurs for certain limestone formations), decomposition of the organic matter fraction of soils that are derived from peaty or mucky parent materials, aquifer-system compaction, underground mining, and natural compaction. Three processes account for most instances of water-related subsidence: compaction of aquifer systems, drainage and subsequent oxidation of organic soils, and dissolution and collapse of susceptible rocks.

Soil liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction occurs in saturated soils when the pore spaces between individual soil particles are completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Before an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. When liquefaction occurs, the strength of soils decrease, and the ability of soils to support foundations for buildings and bridges are reduced.

Expansive soils are soils that contain water absorbing minerals, mainly “active” clays (e.g., montmorillonite). Such soils may expand by 10 percent or more when wetted. The cycle of shrinking and expanding exerts continual pressure on structures, and over time can reduce structural integrity. Soil susceptibility to expansion (i.e., shrinking and swelling) is tested using Uniform Building Code Test Standard 18-1.

Soil suitability for onsite application of waste material focuses on the suitability of the soil to support the use of septic tanks or alternative wastewater disposal systems. Suitability interpretations are based on consideration of soil depth, permeability, rock content, depth to groundwater (including seasonally perched water), and slope.

Shasta Lake and Vicinity

Soils in the Shasta Lake and vicinity area derive from materials weathered from metavolcanic and metasedimentary rocks and from intrusions of granitic rocks, serpentine, and basalt. Soils derived from the metavolcanic sources, such as greenstone, include the Goulding and Neuns families. Soils derived from metasedimentary materials include the Marpa family. Holland family soils are derived from metasedimentary and granitic rocks.

In general, metamorphosed rocks do not weather rapidly, and shallow soils are common in the subarea, especially on steep landscape positions. Soils from metamorphosed rocks generally contain large percentages of coarse fragments (e.g., gravels, cobbles, stones), which reduce their available water holding capacity and topsoil productivity. Granitic rocks may weather deeply, but soils derived from them may be droughty due to high amounts of coarse quartz grains and low content of “active” clay. Soils derived from granitic rocks commonly are highly susceptible to erosion.

Soil map units in the Shasta Lake and vicinity area are shown in Figure 4-7. The mapping legend that accompanies Figure 4-7 is presented in Table 4-8. The areal extent of soil map units within the Shasta Lake and vicinity area is presented in Table 4-9 for the portion of the subarea between 1,070 feet and 1,090 feet above msl (Impoundment Area); and in Table 4-10 for the portion of the subarea potentially disturbed by construction activities (Relocation Areas). Sixty soil map units, comprised of soil families and miscellaneous land types (e.g., rock outcrop, limestone) are recognized to occur in the subarea. Common soil families are Marpa, Neuns, Goulding, and Holland. These are well-drained soils with fine loamy or loamy-skeletal (i.e., gravelly or cobbly) profiles.

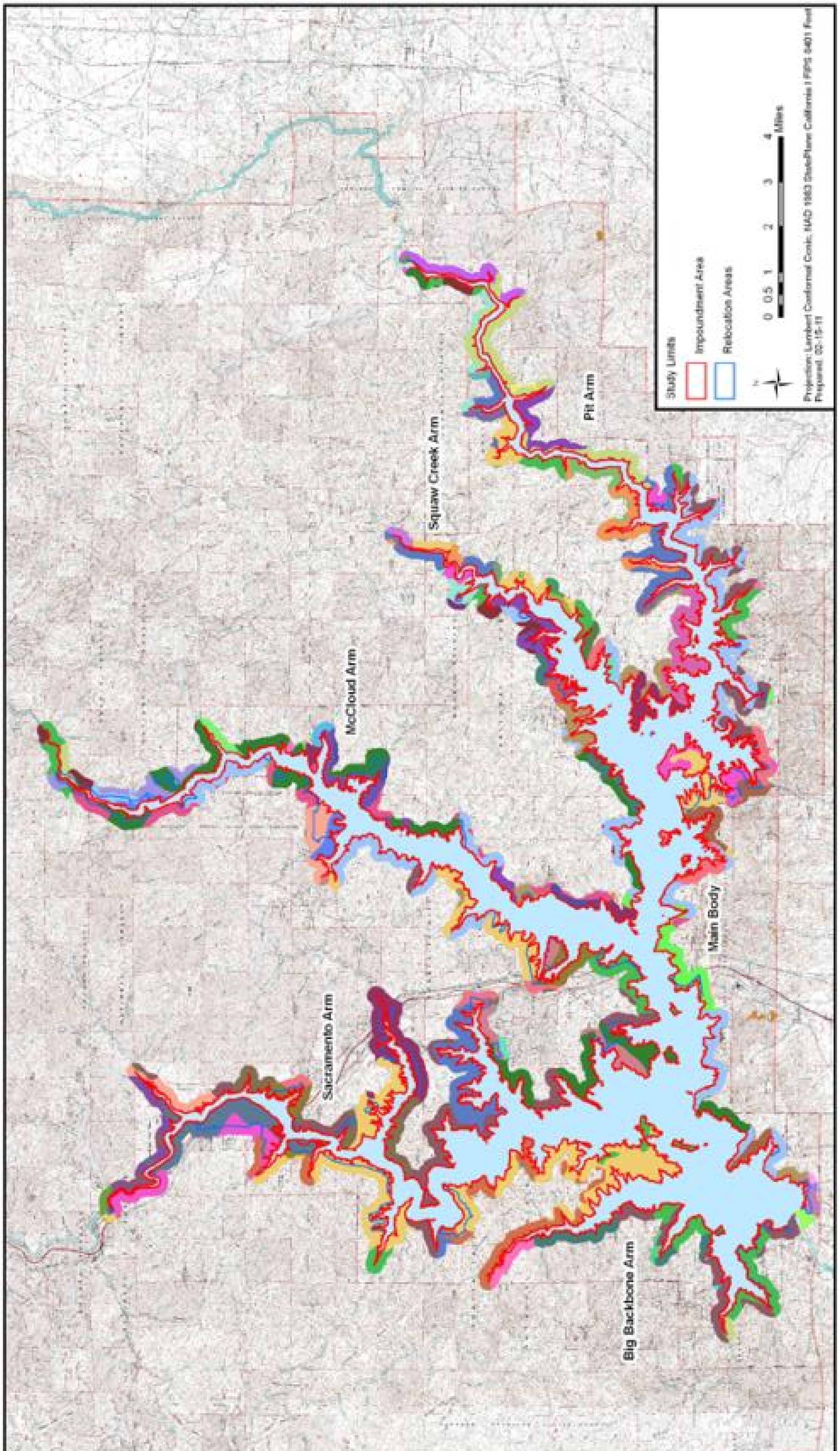


Figure 4-7. Soil Map Units – Shasta Lake and Vicinity

Table 4-8. Key to Soil Map Units – Shasta Lake and Vicinity

Map Unit	Map Unit Name
101	Holland-Goulding families association, 20 to 40 percent slopes.
102	Holland-Goulding families association, 40 to 60 percent slopes.
103	Holland-Goulding families association, 60 to 80 percent slopes.
104	Holland family-Holland family, deep complex, 20 to 40 percent slopes.
105	Holland family-Holland family, deep complex, 40 to 60 percent slopes.
107	Holland-Neuns families complex, 40 to 60 percent slopes.
109	Holland family, ashy, 0 to 20 percent slopes.
111	Holland, ashy-Leadmount families association, 0 to 20 percent slopes.
114	Holland, ashy-Washougal families complex, 25 to 65 percent slopes.
115	Holland family, deep, 0 to 20 percent slopes.
116	Holland family, deep, 20 to 40 percent slopes.
117	Holland family, deep, 40 to 60 percent slopes.
119	Holland family, deep-Holland families complex, 20 to 40 percent slopes.
120	Holland family, deep-Holland family complex, 40 to 60 percent slopes.
123	Holland, deep-Marpa families complex, 20 to 40 percent slopes.
127	Holland, deep-neuns families complex, 40 to 60 percent slopes.
133	Hugo family, 60 to 80 percent slopes.
139	Hugo-Neuns families complex, 60 to 80 percent slopes.
174	Marpa family, 20 to 40 percent slopes.
175	Marpa family, 40 to 60 percent slopes.
176	Marpa family, 60 to 80 percent slopes.
177	Marpa-Chawanakee families complex, 40 to 60 percent slopes.
178	Marpa-Goulding families association, 20 to 40 percent slopes.
179	Marpa-Goulding families association, 40 to 60 percent slopes.
18	Chaix family, 40 to 60 percent slopes.
180	Marpa-Goulding families association, 60 to 80 percent slopes.
182	Marpa-Holland, deep families complex, 20 to 40 percent slopes.
183	Marpa-holland, deep families complex, 40 to 60 percent slopes.
187	Marpa-Neuns families complex, 40 to 60 percent slopes.
188	Marpa-Neuns families complex, 60 to 80 percent slopes.
195	Millsholm family, 20 to 60 percent slopes.
203	Neuns family, 40 to 60 percent slopes.
204	Neuns family, 60 to 80 percent slopes.
209	Neuns-Goulding families association, 60 to 80 percent slopes.
214	Neuns-Holland, deep families complex, 40 to 80 percent slopes.
218	Neuns-Marpa families complex, 40 to 60 percent slopes.
219	Neuns-Marpa families complex, 60 to 80 percent slopes.
224	Neuns family-Typic Xerorthents association, 50 to 80 percent slopes.
228	Neuns family, deep-Neuns family complex, 40 to 70 percent slopes.
24	Chawanakee-Chaix families complex, 40 to 60 percent slopes.
250	Rock outcrop, limestone.

Table 4-8. Key to Soil Map Units – Shasta Lake and Vicinity (contd.)

Map Unit, Map Unit Name
- 251, Rock outcrop, metamorphic.
- 252, Rock outcrop, sedimentary.
- 259, Rock outcrop-Goulding family complex, 40 to 80 percent slopes.
- 27, Chawanakee family-Rock outcrop complex, 60 to 80 percent slopes.
- 35, Deadwood-Neuns families complex, 40 to 60 percent slopes.
- 61, Etsel family, 40 to 80 percent slopes.
- 79, Goulding family, 20 to 40 percent slopes.
- 80, Goulding family, 40 to 60 percent slopes.
- 81, Goulding family, 60 to 80 percent slopes
- 82, Goulding-Holland families association, 40 to 60 percent slopes.
- 83, Goulding-Marpa families association, 40 to 60 percent slopes.
- 85, Goulding family-Rock outcrop complex, 50 to 80 percent slopes
- 98, Holland family, 40 to 60 percent slopes.
- 99, Holland family, 60 to 80 percent slopes
- AtE2sh, Auburn very stony clay loam, 30 to 50 percent slopes, eroded
- AuF2sh, Auburn very rocky clay loam, 50 to 70 percent slopes, eroded
- BoF3sh, Boomer very stony clay loam, 50 to 70 percent slopes, severely eroded
- GeF2sh, Goulding very rocky loam, 50 to 70 percent slopes, eroded
- W, Water

Table 4-9. Areal Extent of Soil Map Units – Shasta Lake and Vicinity (Impoundment Area)

Map Unit	Map Unit Name	Study Area (acres)	Study Area (% Total Sub-Area)
18	Chaix family, 40-60% slopes	43.6	1.75%
27	Chawanakee family-Rock outcrop complex, 60-80% slopes	0.8	0.03%
35	Deadwood-Neuns families complex, 40-60% slopes	2.5	0.10%
61	Etsel family, 40-80% slopes	39.4	1.58%
79	Goulding family, 20-40% slopes	32.0	1.28%
80	Goulding family, 40-60% slopes	153.1	6.13%
81	Goudling family, 60-80% slopes	7.3	0.29%
82	Goulding-Holland families association, 40-60% slopes	45.3	1.81%
83	Goulding-Marpa families association, 40-60% slopes	118.5	4.74%
85	Goulding family-Rock outrcrop complex, 50-80% slopes	10.8	0.43%
98	Holland family, 40-60% slopes	3.6	0.14%
99	Holland family, 60-80% slopes	8.4	0.34%
101	Holland-Goulding families association, 20-40% slopes	66.5	2.66%

Table 4-9. Areal Extent of Soil Map Units – Shasta Lake and Vicinity (Impoundment Area) (contd.)

Map Unit	Map Unit Name	Study Area (acres)	Study Area (% Total Sub-Area)
102	Holland-Goulding families association, 40-60% slopes	145.0	5.80%
103	Holland-Goulding families association, 60-80% slopes	4.6	0.18%
104	Holland family-Holland family, deep complex, 20-40% slopes	60.6	2.43%
105	Holland family-Holland family, deep complex, 40-60 % slopes	215.3	8.62%
109	Holland family, ashy, 0-22% slopes	0.1	0.00%
111	Holland, ashy-Leadmount families association, 0-20% slopes	93.4	3.74%
114	Holland, ashy-Washougal families complex, 25-65% slopes	6.2	0.25%
115	Holland family, deep, 0-20% slopes	38.6	1.54%
116	Holland family, deep, 20-40% slopes	8.5	0.34%
117	Holland family, deep, 40-60% slopes	32.1	1.29%
119	Holland family, deep-Holland families complex 20-40% slopes	111.5	4.46%
120	Holland family, deep-Holland family complex, 40-60% slopes	70.4	2.82%
123	Holland, deep-Marpa families complex, 20-40% slopes	66.7	2.67%
127	Holland, deep Neuns families complex, 40-60% slopes	4.1	0.16%
133	Hugo family, 60-80% slopes	5.2	0.21%
139	Hugo-Neuns families complex, 60-80% slopes	4.3	0.17%
174	Marpa family, 20-40% slopes	28.2	1.13%
175	Marpa family, 40-60% slopes	28.4	1.14%
177	Marpa-Chawanakee families complex, 40-60% slopes	47.1	1.89%
178	Marpa-Goulding families association, 20-40% slopes	74.7	2.99%
179	Marpa-Goulding families association, 40-60% slopes	309.8	12.40%
180	Marpa-Goulding families association, 60-80% slopes	10.2	0.41%
182	Marpa-Holland, deep families complex, 20-40% slopes	89.1	3.57%
183	Marpa-Holland, deep families complex, 40-60% slopes	162.4	6.50%
187	Marpa-Neuns families complex, 40-60% slopes	5.6	0.22%
188	Marpa-Neuns families complex, 60-80% slopes	0.2	0.01%
195	Millsholm family, 20-60% slopes	39.7	1.59%
203	Neuns family, 40-60% slopes	7.6	0.30%
204	Neuns family, 60-80% slopes	43.5	1.74%
209	Neuns-Goulding families association, 60-80% slopes	1.7	0.07%
214	Neuns-Holland, deep families complex, 40-80% slopes	8.5	0.34%
218	Neuns-Marpa families complex, 40-60% slopes	1.1	0.04%
219	Neuns-Marpa families complex, 60-80% slopes	23.9	0.96%
250	Rock outcrop, limestone	9.3	0.37%
251	Rock outcrop, metamorphic	0.0	0.00%
259	Rock outcrop-Goulding family complex, 40-80% slopes	0.5	0.02%
AtE2sh	Auburn very stony clay loam, 30-50% slopes, eroded	0.1	0.01%
BoF3sh	Boomer very stony clay loam, 50-70% slopes, severely eroded	7.4	0.30%
W	Water	200.7	8.03%

Table 4-10. Areal Extent of Soil Map Units – Shasta Lake and Vicinity (Relocation Areas)

Map Unit	Map Unit Name	Study Area (acres)	Study Area (% Total Sub-Area)
18	Chaix family, 40-60% slopes	48.6	1.46%
35	Deadwood-Neuns families complex, 40-60% slopes	1.5	0.04%
61	Etsel family, 40-80% slopes	42.2	1.26%
79	Goulding family, 20-40% slopes	50.4	1.51%
80	Goulding family, 40-60% slopes	179.3	5.37%
82	Goulding-Holland families association, 40-60% slopes	13.9	0.42%
83	Goulding-Marpa families association, 40-60% slopes	6.6	0.20%
85	Goulding family-Rock outrcrop complex, 50-80% slopes	14.6	44.00%
102	Holland-Goulding families association, 40-60% slopes	280.0	8.38%
103	Holland-Goulding families association, 60-80% slopes	2.0	0.06%
104	Holland family-Holland family, deep complex, 20-40% slopes	79.1	2.37%
105	Holland family-Holland family, deep complex, 40-60 % slopes	170.9	5.12%
109	Holland family, ashy, 0-22% slopes	1.1	0.03%
111	Holland, ashy-Leadmount families association, 0-20% slopes	533.6	15.98%
114	Holland, ashy-Washougal families complex, 25-65% slopes	1.5	0.05%
115	Holland family, deep, 0-20% slopes	120.0	3.59%
117	Holland family, deep, 40-60% slopes	71.2	2.13%
119	Holland family, deep-Holland families complex 20-40% slopes	163.5	4.90%
120	Holland family, deep-Holland family complex, 40-60% slopes	28.6	0.86%
123	Holland, deep-Marpa families complex, 20-40% slopes	86.8	2.60%
174	Marpa family, 20-40% slopes	150.5	4.51%
175	Marpa family, 40-60% slopes	17.0	0.51%
177	Marpa-Chawanakee families complex, 40-60% slopes	3.1	0.09%
178	Marpa-Goulding families association, 20-40% slopes	107.6	3.22%
179	Marpa-Goulding families association, 40-60% slopes	545.8	16.34%
180	Marpa-Goulding families association, 60-80% slopes	11.7	0.35%
182	Marpa-Holland, deep families complex, 20-40% slopes	247.0	7.40%
183	Marpa-Holland, deep families complex, 40-60% slopes	167.2	5.01%
195	Millsholm family, 20-60% slopes	36.7	1.10%
204	Neuns family, 60-80% slopes	19.4	0.58%
250	Rock outcrop, limestone	43.3	1.30%
259	Rock outcrop-Goulding family complex, 40-80% slopes	20.1	0.60%
AtE2sh	Auburn very stony clay loam, 30-50% slopes, eroded	2.7	0.08%
BoF3sh	Boomer very stony clay loam, 50-70% slopes, severely eroded	43.6	1.30%
W	Water	28.6	0.86%

Soil Biomass Productivity Soil biomass productivity in the Shasta-Trinity National Forest (STNF) ranges from nonproductive to high (USFS 1994). Using Forest Service Site Class (FSSC) as a surrogate metric for soil biomass productivity, approximately 36 percent of the study area is occupied by soils of low biomass productivity, about 39 percent of the area is occupied by soils of moderate productivity, and about 13 percent is occupied by “nonproductive” soils and miscellaneous land types (e.g., rock outcrop). Soils of high biomass productivity are unlikely to occur in the Shasta Lake and vicinity area.

Soil Susceptibility to Erosion (Uplands) Interpretations of soil susceptibility to erosion are presented in Table 4-11 for the portion of the subarea between 1,070 feet and 1,090 feet above msl (Impoundment Area); and in Table 4-12 for the portion of the subarea potentially disturbed by construction activities. Of the approximately 5,837 acres in the Shasta Lake and vicinity area, 5,377 acres (92 percent of total area) are assigned a hazard rating of severe.

Table 4-11. Summary of Soil Erosion Hazard – Shasta Lake and Vicinity (Impoundment Area)

Soil Erosion Hazard	Study Area (acres)	Study Area (% Total Sub-Area)
Moderate	38.55	1.54%
Severe	2248.81	90.03%
Not Rated	210.00	8.41%

Table 4-12. Summary of Soil Erosion Hazard – Shasta Lake and Vicinity (Relocation Areas)

Soil Erosion Hazard	Study Area (acres)	Study Area (% Total Sub-Area)
Moderate	119.97	3.59%
Severe	3127.62	93.65%
Not Rated	92.01	2.76%

Soil Susceptibility to Erosion (Shoreline) There are more than 420 miles of shoreline around Shasta Lake. As described below under Methods and Assumptions, a conceptual model was developed to quantify current erosion rates and predict future erosion rates (see Attachment 1, Shoreline Erosion Technical Memorandum).

Based on the model output, about 50 percent of the shoreline has a low erosion severity. The remaining shoreline has moderate (35 percent) to high (15 percent) erosion severity. Most of the shoreline that is exposed during routine drawdown periods (i.e., drawdown zone) has been subject to substantial erosion, and very little soil remains after more than 60 years of reservoir operations.

Soil Susceptibility to Subsidence Published interpretations of soil susceptibility to subsidence are generally not available for the Shasta Lake and vicinity area. The likelihood that subsidence would occur due to decomposition of soil organic matter is low due to the absence of soils derived from peaty or mucky parent materials. Similarly, the likelihood of subsidence due to aquifer-system compaction is low due to the absence of significant, widespread groundwater withdrawal in the Shasta Lake and vicinity area. Land subsidence has potential to occur in areas underlain by highly-weatherable, carbonate-rich rocks (e.g., certain limestones), and in areas affected by underground construction.

Soil Susceptibility to Liquefaction Published interpretations of soil susceptibility to liquefaction are generally not available for the Shasta Lake and vicinity area. The likelihood that soil liquefaction would occur is low because of the absence of the necessary high groundwater conditions in the Shasta Lake and vicinity area.

Soil Susceptibility to Expansion Published interpretations of soil susceptibility to expansion (i.e., shrinking and swelling) are generally not available for most of the Shasta Lake and vicinity area. The likelihood that expansive soils occur is low because the weathering products derived from the local bedrock typically contain low concentrations of “active” clays (e.g., montmorillonite).

Soil Suitability for Onsite Application of Waste Material Published interpretations of soil suitability for onsite application of waste material (i.e., capability to support use of septic tanks or alternative wastewater disposal systems) are generally not available for the Shasta Lake and vicinity area. In general, soils in the Shasta Lake and vicinity area are poorly suited to these uses due to shallow soil depth, high rock content, and excessive slope.

Upper Sacramento River (Shasta Dam to Red Bluff)

The following section describes soil susceptibility to erosion (channel shoreline), soil susceptibility to erosion (wind), soil susceptibility to subsidence, soil susceptibility to liquefaction, and soil susceptibility to expansion in the upper Sacramento River portion of the primary study area.

Soils in the Sacramento River Basin are divided into four physiographic groups: upland soils, terrace soils, valley land soils, and valley basin soils. Upland soils are prevalent in the hills and mountains of the region and are composed mainly of sedimentary sandstones, shales, and conglomerates originating from igneous rocks. Terrace and upland soils are predominant between Redding and Red Bluff; however, valley land soils border the Sacramento River through this area. Valley land and valley basin soils occupy most of the Sacramento Valley floor south of Red Bluff. Valley land soils consist of deep alluvial and aeolian soils that make up some of the best agricultural land in the State. The valley floor was once covered by an inland sea, and sediments were formed by deposits of marine silt followed by mild uplifting earth movements. After the main body of water disappeared, the Sacramento River began eroding and redepositing silt and sand in new alluvial fans.

Soil Susceptibility to Erosion (Channel Shoreline) Shasta and Keswick Dams have a significant influence on sediment transport in the Sacramento River because they block sediment that would normally be transported downstream. The result has been a net loss of coarse sediment, including salmon spawning gravels, in the Sacramento River below Keswick Dam. In alluvial river sections, bank erosion and sediment deposition cause river channel migrations that are vital to maintaining instream and riparian habitats, but which can cause loss of agricultural lands and damage to roads and other structures.

Soil Susceptibility to Erosion (Wind) Soil erodibility, climatic factors, soil surface roughness, width of field, and quantity of vegetative coverage affect the susceptibility of soils to wind erosion. Wind erosion leaves the soils shallower and can remove organic matter and needed plant nutrients. In addition, blowing soil particles can damage plants, particularly young plants. Blowing soils also can cause off-site problems such as reduced visibility and increased allergic reaction to dust.

Soil Susceptibility to Subsidence Land subsidence in the Sacramento Valley is localized and concentrated in areas of overdraft from groundwater pumping. Land subsidence had exceeded 1 foot by 1973 in two main areas in the southwestern part of the valley near Davis and Zamora; however, additional subsidence since then has not been reported.

Soil Susceptibility to Expansion Most of Shasta County is characterized by moderately expansive soils with areas of low expansiveness in the South Central Region and southeastern corner of the county. Small scattered areas of highly expansive soils exist in the mountains of the Western Upland, French Gulch, and North East Shasta County planning areas. The hazard associated with expansive soils is that areas of varying moisture or soil conditions can differentially expand or shrink, causing stresses on structures that lead to cracking or settling. Effects of expansive soils on structures can be mitigated through requiring proper engineering design and standard corrective measures.

Lower Sacramento River and Delta

The following section describes soil susceptibility to erosion (channel shoreline), soil susceptibility to erosion (wind), soil susceptibility to subsidence, soil susceptibility to liquefaction, and soil susceptibility to expansion in the lower Sacramento River and Delta portion of the extended study area.

The soils of the Sacramento River basin are divided into four physiographic groups, as described above for the upper Sacramento River portion of the study area.

The soils of the Delta region vary primarily as a result of differences in geomorphological processes, climate, parent material, biological activity, topography, and time. The soils are divided into the following four general soil types:

- Delta organic soils and highly organic mineral soils
- Sacramento River and San Joaquin River deltaic soils
- Basin and basin rim soils
- Moderately well to well-drained valley, terrace, and upland soils

The Delta region contains soils primarily with the required physical and chemical soil characteristics, growing season, drainage, and moisture supply necessary to qualify as Prime Farmland. This includes 80 to 90 percent of the area of organic and highly organic mineral soils, Sacramento River and San Joaquin River deltaic soils, and basin and basin rim soils. Most of the remaining soils of the Delta region qualify as farmland of statewide importance.

Soil Susceptibility to Erosion (Channel Shoreline) The extended study area downstream from the Red Bluff Diversion Dam along the Sacramento River is a major alluvial river section that is active and sinuous, meandering across alluvial deposits within a wide meander belt. In alluvial river sections, bank erosion and sediment deposition cause migrations of the river channel that are extremely important in maintaining instream and riparian habitats, but also can cause loss of agricultural lands and damage to roads and other structures. Geologic outcroppings and man-made structures, such as bridges and levees, act as local hydraulic controls along the river. Bank protection, consisting primarily of rock riprap, has been placed along various sections of the Sacramento River to reduce erosion and river meandering.

The great quantities of sediment transported by the rivers into the Delta move primarily as suspended load. Of the estimated 5 million tons per year of sediment inflow into the Delta, about 80 percent originates from the Sacramento River and San Joaquin River drainages; the remainder is contributed by local streams. Approximately 15 percent to 30 percent of the sediment is deposited in the Delta; the balance moves into the San Francisco Bay system or out through CVP and SWP facilities.

Soil Susceptibility to Erosion (Wind) The Delta organic soils and highly organic mineral soils have wind erodibility ratings of 2 to 4 on a scale where 1 is most erodible and 8 is least erodible. The high wind erodibility of Delta soils is caused by the organic matter content of the soil. The rate of wind erosion is estimated at 0.1 inches per year.

Soil Susceptibility to Subsidence Subsidence of the Delta's organic soils and highly organic mineral soils is attributable primarily to biochemical oxidation of organic soil material as a result of long-term drainage and flood protection. The highest rates of subsidence occur in the central Delta islands, where organic matter content in the soils is highest.

Development of the islands resulted in subsidence of the island interiors and greater susceptibility of the topsoil to wind erosion. Subsidence, as it relates to Delta islands, refers generally to the falling level of the land surface from primarily the oxidation of peat soil. Levee settlement may be partially caused by peat oxidation if land adjacent to levees is not protected from subsidence.

Soil Susceptibility to Expansion Soils within the lower Sacramento River and Delta portion of the extended study area vary from having low to high shrink-swell potential. In general, soils in the narrow corridor upstream along the Sacramento River have low shrink-swell potential according the United States Department of Agriculture's State Soil Geographic (STATSGO) Database Soil Surveys, with the exception of some soils with moderate shrink-swell potential near the Red Bluff Diversion Dam (USDA 1995). Downstream, the shrink-swell potential of soils near the Delta is generally classified by the STATSGO Soil Surveys as "high." The hazard associated with expansive soils is that areas of varying moisture or soil conditions can differentially expand or shrink, causing stresses on structures that lead to cracking or settling. This hazard is identifiable through standard soil tests. Its effects on structures can be mitigated through the requirements of proper engineering design and standard corrective measures.

CVP/SWP Service Areas

As described above for the upper Sacramento River portion of the primary study area, soils in the CVP/SWP service areas are divided into four physiographic groups: valley land, valley basin, terrace land, and upland soils. According to the U.S. Department of Agriculture's STATSGO Database, soils within the CVP/SWP service areas consist of clay, loam, silt, and sand, some of which is gravelly. The CVP/SWP service areas also consist of unweathered and weathered bedrock that is evident through outcrops at the ground surface (USDA 1995).

4.2 Regulatory Framework

The following section describes the Federal, State, and local regulatory setting for geological resources.

4.2.1 Federal

This section discusses the Federal regulatory setting for water quality, runoff, air quality, earthquakes, paleontological resources, and natural resources.

Clean Water Act

The Clean Water Act (CWA) includes provisions for reducing soil erosion for the protection of water quality. The CWA made it unlawful for any person to discharge pollutants from a point source (including construction sites), into navigable waters, unless a permit was obtained under its provisions. This pertains to construction sites where soil erosion and storm runoff and other pollutant discharges could affect downstream water quality.

National Pollutant Discharge Elimination System

The National Pollutant Discharge Elimination System process, established by the CWA, is intended to meet the goal of preventing or reducing pollutant runoff. Projects involving construction activities (e.g., clearing, grading, or excavation) with land disturbance greater than 1 acre must file a Notice of Intent with the applicable Regional Water Quality Control Board (RWQCB) to indicate the intent to comply with the State General Permit for Storm Water Discharges Associated with Construction Activity (General Permit). This permit establishes conditions to minimize sediment and pollutant loading and requires preparation and implementation of a Storm Water Pollution Prevention Plan before construction.

Clean Air Act

The Clean Air Act also has provisions for reducing soil erosion relevant to air and water quality. On construction sites, exposed soil surfaces are vulnerable to wind erosion, and small soil particulates are carried into the atmosphere. Suspended particulate matter (PM10 and PM2.5) is one of the six criteria air pollutants of the Clean Air Act.

Earthquake Hazards Reduction Act

In October 1977, the U.S. Congress passed the Earthquake Hazards Reduction Act to “reduce the risks to life and property from future earthquakes in the United States through the establishment and maintenance of an effective earthquake hazards and reduction program.” To accomplish this, the act established the National Earthquake Hazards Reduction Program. The National Earthquake Hazards Reduction Program Act (NEHRPA) significantly amended this program in November 1990 by refining the description of agency responsibilities, program goals, and objectives. The NEHRPA designates the Federal Emergency Management Agency as the lead agency of the program and assigns it several planning, coordinating, and reporting responsibilities. Other NEHRPA agencies include the National Institute of Standards and Technology, the National Science Foundation, and U.S. Geologic Survey.

Antiquities Act of 1906

Federal protection for significant paleontological resources would apply to the project if any construction or other related project impacts occurred on Federally owned or managed lands. Federal legislative protection for paleontological resources stems from the Antiquities Act of 1906 (Public Law 59-209; 16 United States Code 431 et seq.; 34 Stat. 225), which calls for protection of historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest on federal land.

Shasta-Trinity National Forest Land and Resource Management Plan

The STNF Land and Resource Management Plan (LRMP) (USFS 1995) contains forest goals, standards, and guidelines designed to guide the management of the STNF. The following goals, standards, and guidelines related to geologic and seismic hazards and soils issues associated with the study area were excerpted from the STNF LRMP.

- Goals (LRMP, p. 4-5):
  - Maintain or improve soil productivity and prevent excessive surface erosion, mass wasting, and cumulative watershed impacts.
- Standard and Guidelines (LRMP, p. 4-25):
  - Determine the sensitivity of each 2nd or 3rd order watershed using soil, geologic, and streamflow characteristics.
  - Implement Forest Soil Quality Standards and Best Management Practices for areas identified as having highly erodible soils. Specifically, apply the special practices dealing with timber harvest, site preparation, and road construction in highly erodible soils.
  - Forest Soil Quality Standards in relation to ground cover, soil organic matter, and soil porosity will be used to protect soil productivity (as referenced in Appendix O of the LRMP).1/Environmental Consequences/Impacts and Mitigation Measures

Bureau of Land Management Resource Management Plan

The Bureau of Land Management's (BLM) Resource Management Plan, which is its plan for managing federal lands in Shasta County, was amended by the 1994 Record of Decision for the Northwest Forest Plan (Final Supplemental Environmental Impact Statement for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl). This amendment required preparation of watershed analyses prior to initiating BLM activities. As a party to the Northwest Forest Plan, BLM, like the USFS, is also required to ensure that projects are consistent with the Aquatic Conservation Strategy.

Federal Minerals Management

Mineral development is permitted on all public lands not withdrawn from mineral entry. The U.S. Mining Laws (30 United States Codee 21-54) confer statutory right to enter upon public lands in search of minerals. Regulations found in 36 Code of Federal Regulations 228, Subpart A, set forth rules and procedures to minimize adverse environmental impacts on national forest resources. Access for mineral exploration and development is generally unrestricted, subject to the mitigation of adverse impacts to surface resources.

Access for mineral exploration on STNF land is restricted in wildernesses, the "wild" portions of Wild and Scenic Rivers, botanical areas, Research Natural Areas, NRAs, and areas that have been withdrawn from mineral entry. Minerals in the NRA are not locatable (minerals that may be acquired under the Mining Law of 1872, as amended) but they are leasable (USFS 1994).

Access for mineral-related activities to wilderness, the NRA, and other lands typically withdrawn from mineral entry is subject to valid existing rights. The type of access authorized must be consistent with the proposed use and of a type that would maintain the special character of the areas to the fullest extent possible.

The Federal lands within the Shasta Unit of the NRA were withdrawn from mineral entry under the 1872 Mining Law by the NRA legislation, subject to valid existing rights. Five claims in the Shasta NRA predate the withdrawal. Currently, there are no approved operating plans for these five mining claims.

4.2.2 State

This section discusses the State regulatory setting for soil erosion, water quality, earthquakes, mining, air quality (related to asbestos) paleontological resources, and building design.

Porter-Cologne Act

State regulations, including the Porter-Cologne Act and Fish and Game Code 1600, have provisions to reduce soil erosion. The Porter-Cologne Act established the State Water Resources Control Board and nine RWQCBs that regulate water quality. The RWQCBs carry out the National Pollutant Discharge Elimination System permitting process for point source discharges and the CWA Section 401 certification program.

Fish and Game Code 1600

Fish and Game Code 1600 requires notification for projects that are planned to occur in, or in close proximity to, a river, stream, or lake, or their tributaries. Applicants are to enter into a "streambed alteration agreement" with DFG when a construction activity would (1) divert, obstruct, or change the natural flow or the bed, channel, or bank of any river, stream, or lake, (2) use material from a streambed, or (3) result in the disposal of debris, waste, or other material containing crumbled, flaked, or ground pavement that could pass into a river, stream, or lake. The Federal Government is not required to submit a Fish and Game code 1600 permit; however, the same impacts will be addressed under CWA Section 401 and 404 permits.

Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Earthquake Fault Zoning Act (Public Resources Code Section 2621 et seq.) was passed by the California Legislature to mitigate the hazard of surface faulting to structures. The act's main purpose is to prevent the construction of buildings used for human occupancy on the surface trace of active faults. The act addresses only the hazard of surface fault rupture and is not directed toward other earthquake hazards. Local agencies must regulate most development in fault zones established by the State Geologist. Before a project can be permitted in a designated Alquist-Priolo Earthquake Fault Zone, cities and counties must require a geologic investigation to demonstrate that proposed buildings would not be constructed across active faults.

1990 Seismic Hazards Mapping Act

The 1990 Seismic Hazards Mapping Act (California Public Resources Code Sections 2690-2699.6) addresses strong ground shaking, liquefaction, landslides, or other ground failures as a result of earthquakes. This act requires statewide identification and mapping of seismic hazard zones, which would be used by cities and counties to adequately prepare the safety element of their general plans and protect public health and safety (California Geological Survey 2003). Local agencies are also required to regulate development in any seismic hazard zones, primarily through permitting. Permits for development projects are not issued until geologic investigations have been completed and mitigation measures have been developed to address identified issues.

Surface Mining and Reclamation Act of 1975

The Surface Mining and Reclamation Act of 1975 (California Public Resources Code Sections 2710 et seq.) addresses surface mining and requires mitigation to reduce adverse impacts to public health, property, and the environment. Surface Mining and Reclamation Act applies to anyone (including a government agency) that disturbs more than 1 acre or removes more than 1,000 cubic yards of material through surface mining activities, even if activities occur on Federally managed lands (CDC 2006b). Local city and county "lead agencies" develop ordinances for permitting that provide the regulatory framework for mining and reclamation activities. The permit generally includes a permit to mine, a reclamation plan to return the land to a useable condition, and financial reports to ensure reclamation would be feasible. The State Mining and Geology Board reviews lead agency ordinances to ensure they comply with Surface Mining and Reclamation Act (CDC 2006b).

Asbestos Airborne Toxic Control Measure for Construction, Grading, Quarrying, and Surface Mining Operations

The Asbestos Airborne Toxic Control Measure for Construction, Grading, Quarrying, and Surface Mining Operations (see Title 17 California Code of Regulations (CCR) Section 93105) (CCR 2001a) contains the requirements for construction operations that would disturb any portion of an area that is located in a geographic ultramafic rock unit or that has naturally occurring asbestos, serpentine, or ultramafic rock. Construction or grading operations on property where the area to be disturbed is greater than 1 acre require an Asbestos Dust Mitigation Plan to be submitted and approved by the air quality management district before the start of construction. The Asbestos Dust Mitigation Plan must be implemented at the beginning and must be maintained throughout the operation. To receive an exemption from this Asbestos Airborne Toxic Control Measure, a State registered professional geologist must conduct a geologic evaluation of the property and determine that no serpentine or ultramafic rock is likely to be found in the area to be disturbed. This report must be presented to the executive officer or air pollution control officer of the air pollution control or air quality management district, who may then grant or deny the exemption.

Asbestos Airborne Toxic Control Measure for Surfacing Applications

The Asbestos Airborne Toxic Control Measure for Surfacing Applications (17 CCR Section 93106) applies to any person who produces, sells, supplies, offers for sale or supply, uses, applies, or transports any aggregate material extracted from property where any portion of the property is located in a geographic ultramafic rock unit or the material has been determined to be ultramafic rock, or serpentine, or material that has an asbestos content of 0.25 percent or greater. Unless exempt, the use, sale, application, or transport of material for surfacing is restricted, unless it has been tested using an approved asbestos bulk test method and determined to have an asbestos content that is less than 0.25 percent. Any recipient of such materials may need to be provided a receipt with the quantity of materials, the date of the sale, verification that the asbestos content is less than 0.25 percent, and a warning label. Anyone involved in the transportation of the material must keep copies of all receipts with the materials at all times.

California Public Resources Code Chapter 1.7

No State or local agency requires a paleontological collecting permit to allow for the recovery of fossil remains discovered as a result of construction-related earthmoving on State or private land in a project site. California Public Resources Code Chapter 1.7 (Archaeological, Paleontological, and Historical Sites), Section 5097.3, specifies that State agencies may undertake surveys, excavations, or other operations as necessary on State lands to preserve or record paleontological resources.

California Building Standards Code

The State of California provides minimum standards for building design through the California Building Standards Code (CBC) (CCR 2001b). Where no other building codes apply, Chapter 29 regulates excavation, foundations, and retaining walls. The CBC also applies to building design and construction in the State and is based on the Federal Uniform Building Code used widely throughout the country (generally adopted on a state-by-state or district-by-district basis). The CBC has been modified for California conditions with numerous more detailed and/or more stringent regulations.

The State's earthquake protection law (California Health and Safety Code Section 19100 et seq.) requires that structures be designed to resist stresses produced by lateral forces caused by wind and earthquakes. Specific minimum seismic safety and structural design requirements are set forth in Chapter 16 of the CBC. The CBC identifies seismic factors that must be considered in structural design.

Chapter 18 of the CBC regulates the excavation of foundations and retaining walls, and Appendix Chapter A33 regulates grading activities, including drainage and erosion control, and construction on unstable soils such as expansive soils and liquefaction areas.

4.2.3 Regional and Local

The following section describes the regional and local regulatory setting for geological resources.

County General Plans

Section 65302(g) of the California Government Code requires that county general plans include an element that identifies and appraises seismic and geologic hazards.

Seismic hazards that must be addressed in this section include the following:

- Surface faulting
- Ground shaking
- Ground failure

Non-seismic hazards addressed include the following:

- Volcanoes
- Erosion
- Expansive soils

Local Guiding Ordinances

In addition to identifying and appraising seismic and geologic hazards, counties and municipalities in the project study area also commonly set requirements for grading and erosion control, including prevention of sedimentation or damage to off-site property. Usually these requirements are established via a grading ordinance, which is administered through issuance of grading permits. Grading permits typically require a vested map and the following information:

- Detailed grading plan
- Geological studies if located within an area prone to slippage, having highly erodible soils, or of known geologic hazards

- Detailed drainage or flood control information as required by the department of public works
- Final plan for development if the project is located in a zone district that requires a final development plan
- Noise analysis if the project is located in the vicinity of a high noise generating use

4.3 Environmental Consequences and Mitigation Measures

This chapter is organized by the project alternatives described in Chapter 1, Affected Environment, and discusses environmental consequences to geology, geologic hazards, geomorphology, minerals, and soils associated with implementation of the project alternatives. It also describes potential mitigation measures associated with impacts to geology that are significant or potentially significant.

4.3.1 Methods and Assumptions

In general, the analysis presented in this section is qualitative and is based on general information on geology, geologic hazards, geomorphology, minerals, and soils, as reported in Section 4.1. Environmental consequences associated with geologic resources that could result from implementing alternatives were evaluated qualitatively based on expected construction methods; environmental commitments common to all action alternatives; and the locations, materials, and durations of project construction and related activities.

As described in following paragraphs, for the Shasta Lake and vicinity project area more quantitative analyses were undertaken to address geomorphology (i.e., stream characteristics in watersheds that are adjacent and directly tributary to Shasta Lake) (also see Section 4.1.3) and shoreline erosion (also see Section 4.1.5).

Geomorphology

The analysis of fluvial characteristics of watersheds that are adjacent and directly tributary to Shasta Lake evaluated the impact of raising Shasta Dam on stream channel equilibrium, focusing on the balance between sediment transport capacity and channel stability. The average gradient and flow regime of a watercourse are often the variables that control the sediment transport capacity of a given stream channel. The flow regime of a stream is determined by the measure of the average flow of surface water. The analysis assumed that any stream that has a predicted average annual flow above 0.1 cubic feet per second (cfs) functions as a perennial stream, and any stream with a predicted flow of less than 0.1 cfs functions as an intermittent stream.

Typically, over time, streams reach a natural state of equilibrium based on their gradient and sediment transport capacity. Raising the water level of Shasta Lake may affect the equilibrium of watercourses that are controlled by the present reservoir level. Raising the dam may destabilize these streams by altering the length of stream that will be incorporated into the drawdown. Raising the dam will affect the gradient of adjacent watercourses by altering the length of the watercourse and the change in elevation due to seasonal fluctuations in lake water levels. This is the rationale behind analyzing the gradient and flow regime of watercourses that are adjacent and directly tributary to Shasta Lake.

The stream networks in the Shasta Lake and vicinity area were characterized using the Net Trace model generated in a geographic information system (GIS) environment. Net Trace was used because existing California and USFS stream layers lack the level of detail and necessary variables needed to assess the impact of raising the water level of Shasta Lake on stream channel equilibrium. Initially, sub-10-meter digital elevation models covering the Shasta Lake and vicinity were imported into GIS. Using the methods described in Programs for digital elevation model Analysis (Miller 2003), a surface stream network with user-selected attributes was created using Net Trace. The following characteristics were then calculated for each stream segment: drainage area, riparian area, length, flow direction (degrees), stream order, elevation, gradient statistics, mean precipitation, and mean annual stream flow (cfs).

To verify the accuracy of the Net Trace stream model, the measured bed gradient along surveyed transects on Squaw Creek and Big Backbone Creek was compared to the modeled gradient values calculated by Net Trace along the same transect. The combined average difference between the measured and modeled bed gradient was approximately 4.5 percent, meaning that the measured stream bed gradient is steeper than the modeled gradient. A sampling bias is believed to be the cause of the disparity. For example, 22 segments were surveyed along the Squaw Creek transect and used to determine the measured bed gradient; however, only 5 segments were available from the Net Trace model to calculate the gradient. Simply, the surveyed transects were measured at greater level of detail than were calculated in the Net Trace model.

Although the surveyed gradient values are more accurate than the modeled values, it would be impractical to survey every watercourse within a study area as large as that of the SLWRI. Since this study seeks to characterize the stream channel, a more reasonable approach was to compare the surveyed water surface gradient to the modeled values. This approach eliminates the topographic details of the streambed surface and measures the surface gradient of the stream over the entire transect. The combined average difference between the measured surface gradient and modeled bed gradient was about 2 percent, meaning the measured stream bed gradient is 2 percent steeper than the modeled gradient. Although this disparity is noteworthy, the modeled stream network is considered an accurate representation of the hydrologic system of the study area, and the lower gradient values produce a more conservative estimate of sediment transport within the system. These results suggest that the digital elevation model-generated stream network is accurate enough to be used as a measure of the potential impacts of raising Shasta Dam on stream channel equilibrium.

Using GIS, the Net Trace stream network was intersected with polygons representative of shoreline area affected through the inundation by each alternative. These intersections were completed for each arm of Shasta Lake. The total stream length and riparian area affected by the inundation were calculated for each arm and summarized to calculate the value for the entire shoreline of Shasta Lake. The affected stream length and riparian areas were also calculated in further detail for perennial and intermittent streams by stream-gradient categories of less than or greater than 10 percent.

Soil Erosion (Shoreline)

A conceptual model was developed to predict the rate and volume of shoreline erosion. The methods and assumptions used for the model are described in Attachment 1, Shoreline Erosion Technical Memorandum. The conceptual model represents the spatial and temporal components of shoreline erosion, and was developed as a framework for field investigations, quantifying present erosion rates, and predicting future erosion rates. The process-based model characterizes the primary causes of shoreline erosion and uses external erosion triggers to weight the relative erodibility of the shoreline. The model was developed using results from similar studies; available precipitation, wind, and lake level data; information concerning the engineering properties of the bedrock geology and soils; the shoreline and hillslope topography; measured erosion processes and rates from sequential historical aerial photographs; and field investigations. Because there were very few shoreline erosion studies for reservoirs as large as Shasta Lake to use as background and support for the analysis, readily available references were used to help characterize the process of shoreline erosion, verify the predicted shoreline erosion rates, and design mitigation measures.

The model divided the shoreline into two zones, which helped account for the episodic nature of erosional events. The nearshore zone is classified as the area above the 1,070-foot contour, and represents the “bathtub” ring around the reservoir. The drawdown zone is classified as the area between the 1,070-foot contour and the 1,020-foot contour. The latter contour was used to represent the drawdown level that typically occurs to meet USACE requirements for flood storage capacity. The nearshore zone is eroded by wave action when the reservoir is full. During drawdown periods, this zone erodes as a result of upland surface runoff, subsurface flow, and fluvial incision along stream channels and gullies.

To represent the temporal component of shoreline erosion, the model compartmentalizes shoreline development into three time steps. The first step lasts for about 15 years and is when most of the erosion occurs (Morris and Fan

1997). During this time, the inundated soils are fully saturated; as a result, they lose cohesion and are subject to rapid erosion, transport, and deposition. Shoreline exposed in the drawdown zone is typically eroded to bedrock or to resilient soil layers, leaving an exposed surface that supports little vegetation. Within this zone, stream channels and gullies rapidly incise the underlying soil and rock.

The second time step can last between about 0 and 150 years. During this time, stable shoreline topography is developing through a sequence of slope-forming events. For modeling purposes, the types of slope-forming events were classified by lithotopo unit because several common processes trigger and control erosion. The shoreline erosion survey data suggest that stable hillslopes are typically associated with shallow soils on coherent bedrock, forming steep topography (greater than 65 percent slope gradient). Unstable hillslopes are associated with deep soils on moderately steep areas (between 30 percent and 65 percent). Around Shasta Lake, stable shoreline formed rapidly during the first 15 years of lake management. Conversely, about 60 years later, unstable hillslopes are still responding to erosional forces and, in some locations, continue to erode at a very high rate (greater than 900 cubic yards/acre/year).

The third time step is used to represent a period when the shoreline slope is stable and soil shear strength remains greater than the shear stresses acting on the slope. During this time, the erosion rate continues to decrease and eventually equals the upslope erosion rates. The analysis assumes that most of the shoreline around Shasta Lake will become stable as the reservoir ages, and the data show that about half of the shoreline is presently stable.

4.3.2 Criteria for Determining Significance of Effects

An environmental document prepared to comply with NEPA must consider the context and intensity of the environmental consequences that would be caused by, or result from, the proposed action. Under NEPA, the significance of an environmental consequence is used solely to determine whether an Environmental Impact Statement must be prepared. An environmental document prepared to comply with CEQA must identify the potentially significant environmental effects of a proposed project. A “[s]ignificant effect on the environment” means a substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project (State CEQA Guidelines, Section 15382). CEQA also requires that the environmental document propose feasible measures to avoid or substantially reduce significant environmental effects (State CEQA Guidelines, Section 15126.4(a).

The following significance criteria were developed based on guidance provided by the State CEQA Guidelines, and consider the context and intensity of the environmental effects as required under NEPA. At a minimum, impacts of an alternative on geology, geologic hazards, geomorphology, mineral resources, and soils would be significant under CEQA if project implementation would do the following:

- Expose people or structures to potential substantial adverse effects, including the risk of loss, or injury, or death involving the following:
  - 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
  - Strong seismic ground shaking
  - Seismic-related ground failure, including liquefaction
  - Landslides
- Result in substantial soil erosion or loss of topsoil
- 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 on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse
- Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (CCR 2001b), creating substantial risks to life or property
- Have soils incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems where sewers are not available for disposal of wastewater
- Result in the loss or availability of known mineral resources that would be of future value to the region

Significance statements are relative to both existing conditions (2005) and future conditions (2030), unless stated otherwise.

4.3.3 Topics Eliminated from Further Discussion

The topics of snow avalanches, expansive soil, and soil liquefaction are eliminated from the discussion of environmental consequences owing to the low likelihood of their occurrence as previously discussed (see Sections 4.1.2 for snow avalanches and 4.15 for other eliminated topics).

Paleontological resources are not included in the discussion of environmental consequences. As described in Section 4.1.1, a small area of the fossiliferous Cretaceous Chico Formation occurs near Jones Valley Creek, a tributary to the

Pit River Arm, but this rock unit is not exposed along the shoreline of the lake, and falls outside the study sub-area. Some outcrops of McCloud Limestone, especially in the vicinity of McCloud River Bridge, also contain fossil corals and other microinvertebrates. Some areas underlain by limestone are likely to be disturbed regardless of the action alternative being considered. However, the fossils that comprise the McCloud Limestone are well documented in the scientific literature, and it is unlikely that paleontological resources of scientific or cultural significance occur in this formation.

Paleontological resources have been eliminated from further discussion in the upper Sacramento River (Shasta Dam to Red Bluff), lower Sacramento River and Delta, and CVP/SWP service areas because no impacts are anticipated to these resources as a result of reoperation of the dam.

4.3.4 Direct and Indirect Effects

The following section describes the potential environmental consequences of the project, and impacts and mitigation measures.

No-Action Alternative

This section describes potential impacts that would occur under the NEPA No-Action Alternative. Under the No-Action Alternative, no additional Federal action would be taken to address water reliability issues or increase anadromous fish survival. Shasta Dam would not be modified, and the CVP would continue operating similar to the existing condition. No new construction would occur under the No-Action Alternative and the full pool elevation of the reservoir would remain at approximately 1,070 feet above msl.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake and vicinity portion of the primary study area.

Impact Geo-1 (No-Action): Exposure of Structures and People to Geologic Hazards Resulting From Seismic Conditions, Slope Instability, and Volcanic Eruption Under the No-Action Alternative, no new construction would occur and the full pool level would not be increased. Therefore, there would be no increase in the risk of geologic hazards to people or structures. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-2 (No-Action): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats Under the No-Action Alternative, the full pool level would not be increased. Therefore, there would be no change to streams tributary to Shasta Lake. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-3 (No-Action): Loss or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region Under the No-Action Alternative, no new construction would occur and the full pool level would not be increased. Therefore, there would be no loss or diminished availability of known mineral resources that would be of future value to the region. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-4 (No-Action): Lost or Diminished Soil Biomass Productivity Under the No-Action Alternative, no new construction would occur and the full pool level would not be increased. Therefore, there would be no lost or diminished soil biomass productivity. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-5 (No-Action): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under the No-Action Alternative, the full pool level would not be increased. Therefore, there would be no increase in soil erosion or loss of topsoil due to shoreline processes. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-6 (No-Action): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Under the No-Action Alternative, there would be no disturbance of upland landscape positions. Therefore, there would be no increase in soil erosion or loss of topsoil due to upland processes. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-7 (No-Action): 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 Subsidence Under the No-Action Alternative, no new construction would occur and the full pool level would not be increased. Therefore, there would be no increase in the risk of land subsidence. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-8 (No-Action): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils That Are Unsuited to Land Application of Waste Under the No-Action Alternative, no new construction would occur and the full pool level would not be increased. Therefore, there would be no increase in the risk of failure of septic tanks or alternative wastewater disposal systems. There would be no impact. Mitigation is not required for the No-Action Alternative.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes impacts to the upper Sacramento River portion of the primary study area.

Impact Geo-9 (No-Action): Substantial Increase in Channel Erosion and Meander Migration No Shasta Dam enlargement activities would be implemented, and no new water releases from the dam would occur as a result of the No-Action Alternative. The water releases from the dam would continue to vary based on time of year, water year-types, and system conditions. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-10 (No-Action): Substantial Soil Erosion or Loss of Topsoil Due to Construction No Shasta Dam enlargement activities would be implemented, and no gravel augmentation activities would occur as a result of the No-Action

Alternative. Therefore, no soil additional soil erosion would be anticipated on the banks along the river channel. There would be no impact. Mitigation is not required for the No-Action Alternative.

Impact Geo-11 (No-Action): Alteration of Fluvial Geomorphology Under the No-Action Alternative, no activities to breach the levee to Reading Island would occur and therefore, no changes in fluvial geomorphology would be anticipated along Anderson Creek. There would be no impact. Mitigation is not required for the No-Action Alternative.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with the No-Action Alternative.

Impact Geo-12 (No-Action): Substantial Increase in Channel Erosion and Meander Migration No Shasta Dam enlargement activities would be implemented, and no new water releases from the dam would occur as a result of the No-Action Alternative. The water releases from the dam would continue to vary based on time of year, water year-types, and system conditions. Therefore, there would be no impact.

This impact would be similar to Impact Geo-9 (No-Action) for the primary study area.

For the same reasons described above for Impact Geo-9 (No-Action), there would be no impact. Mitigation is not required for the No-Action Alternative.

CVP/SWP Service Area This section describes the impacts associated with the No-Action Alternative to the CVP/SWP service areas within the extended study area.

Impact Geo-13 (No-Action): Substantial Increase in Channel Erosion and Meander Migration No Shasta Dam enlargement activities would be implemented, and no new water releases from the dam would occur as a result of the No-Action Alternative. No changes in operations would occur under the No-Action Alternative. The water releases from the from Shasta Dam, Folsom Dam, and Oroville Dam would continue to vary based on time of year, water year-types, and system conditions, but would not be anticipated to be outside of normal operating conditions. Therefore, there would be no impact.

This impact would be similar to Impact Geo-9 (No-Action) for the primary study area.

For the same reasons described above for Impact Geo-9 (No-Action), there would be no impact. Mitigation is not required for the No-Action Alternative.

CP1 – 6.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply Reliability

This section describes impacts associated with CP1, which focuses on increasing water supply reliability while contributing to increased anadromous fish survival by raising Shasta Dam 6.5 feet. The dam raise would increase the reservoir's full pool by 8.5 feet, and enlarge total storage space in the reservoir by 256,000 acre-feet.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake and vicinity portion of the primary study area.

Impact Geo-1 (CP1): Exposure of Structures and People to Geologic Hazards Resulting from Seismic Conditions, Slope Instability, and Volcanic Eruption Implementing CP1 has the potential to increase the exposure of structures and people to geologic hazards.

There are very few seismic hazard areas within the Shasta Lake and vicinity area. No active faults are known to be present within or immediately adjacent to the Shasta Lake and vicinity area, and there is a low risk of fault rupture (CDC 2006a) According to Jennings (1994) and CDC (1997), all known faults around the Shasta Lake and vicinity area are classified as inactive. (Inactive faults show no evidence of movement in the last 10,000 years (i.e., Holocene). Because there are few active faults in close proximity to the Shasta Lake and vicinity area the likelihood of strong seismic ground shaking also is low. Detailed, site-specific geologic and foundation investigations will be completed to develop design criteria to withstand reasonably probable seismic events. This impact would be less than significant.

Under CP1, the pool level increase would inundate 78 acres of mapped slope instability hazards (i.e., active and relict landslides, debris flows, inner gorge landscape positions, and complexes of these features). Relocation of infrastructure is proposed to occur in the vicinity of about 232 acres of mapped slope instability hazards. Inundation of bedrock and soils resulting from the increased pool elevation, and earthwork and vegetation removal associated with new construction, could reduce the stability of hillslopes prone to mass wasting. The existing relict and active mass wasting features may become less stable. The risks associated with increased slope instability due to the rise in pool elevation and relocation of infrastructure have been considered in formulating the description of CP1. Areas of known instability have been addressed via avoidance or through design measures intended to minimize the risk of increased instability. This impact would be less than significant.

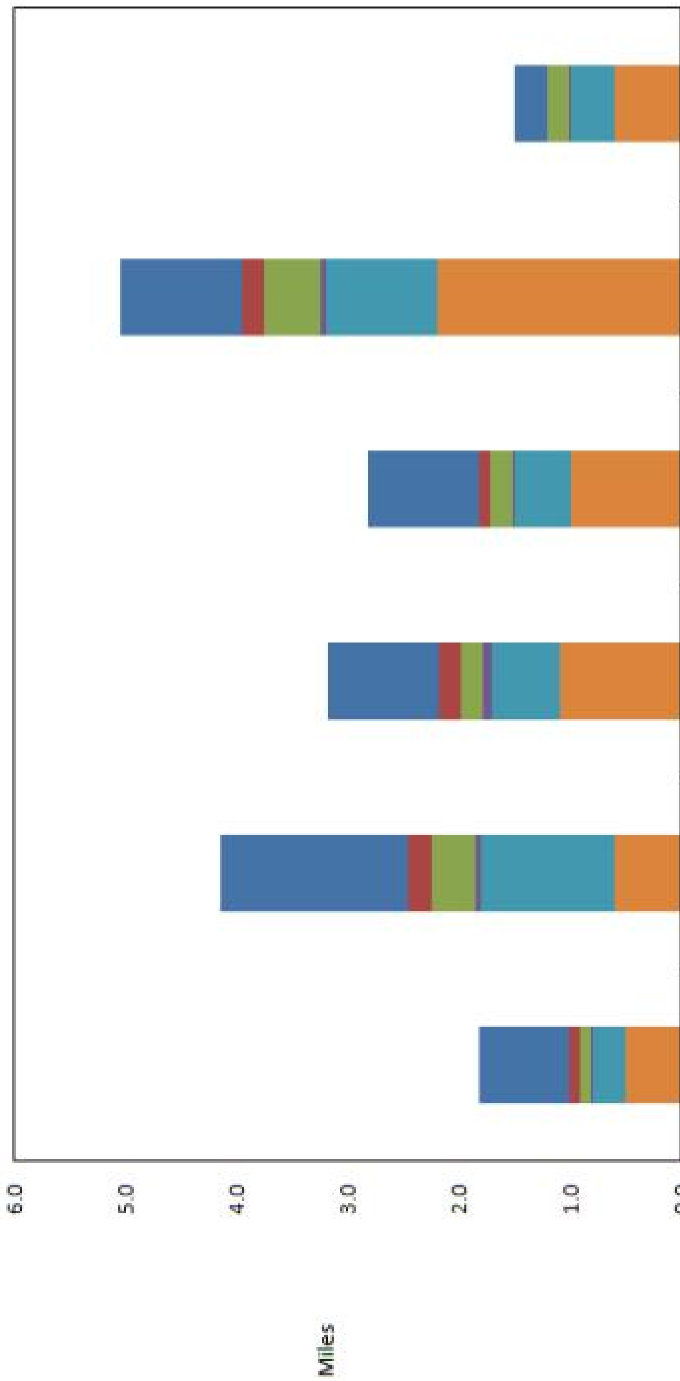
Hazards associated with volcanic eruptions have a low probability of occurring within the Shasta Lake and vicinity area. Significant impacts resulting from eruptions in the Medicine Lake Highlands and at Lassen Peak are unlikely due to their distance from Shasta Lake and the lack of drainage connections. Eruptions of Mount Shasta are not likely to deposit lithic ash, lava flows, domes, or pyroclastic flows within the reservoir, and Mount Shasta is not likely to erupt large volumes of pumiceous ash. The danger from floods caused by eruptions is similar to that from floods having other origins, and would be mitigated via the proposed dam modifications (e.g., increased spillway capacity) and operational procedures. This impact would be less than significant.

Similarly, the dangers from mudflows and seiche hazards are low, and would be mitigated via the proposed dam modifications (e.g., increased spillway capacity) and operational procedures. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-2 (CP1): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats   Under CP1, stream channel equilibrium and geomorphology would be affected by an increase in full pool level. Lower gradient channels (less than 7 percent slope) with existing delta deposits would be affected more than higher gradient channels. It is likely that the delta deposits would expand both upstream and downstream as a result of this alternative. When the lake is full and regional flooding occurs, sediment transported from the uplands would be deposited as deltas at the confluence of the streams and lake. When the lake level is low during baseflow periods, stream channels within the inundation zone are likely to be channelized as they downcut into the Delta deposits. In the lower gradient channels, the stream type could shift to an unstable braided channel.

Inundation of lower gradient streams draining to Shasta Lake could result in long-term changes to channel equilibrium by changing the sediment transport capacity of the stream channels between 1,070 and 1,080 feet of elevation. CP1 could also destabilize the stream channels as a result of riparian vegetation loss on the lower and upper banks and a more mobile stream bed.

Based on a GIS-generated stream network, the total stream length inundated as a result of CP1 is estimated to be 18.5 miles (see Figure 4-8), which equates to about 0.7 percent of the total length of the streams in watersheds that are directly adjacent and contributory to Shasta Lake. Of the 18.5 miles inundated, about 6.2 miles are streams with a gradient of less than 7 percent. This impact would be significant. Mitigation for this impact is proposed in Section 4.3.5.



	Big Backbone Creek	Main Body	McCloud River	Pit River	Sacramento River	Squaw Creek
Intermittent >10% Grade	0.8	1.7	1.0	1.0	1.1	0.3
Perennial >10% Grade	0.1	0.2	0.2	0.1	0.2	0.0
Intermittent 7-10% Grade	0.1	0.4	0.2	0.2	0.5	0.2
Perennial 7-10% Grade	0.02	0.05	0.08	0.02	0.05	0.01
Intermittent <7% Grade	0.3	1.2	0.6	0.5	1.0	0.4
Perennial <7% Grade	0.5	0.6	1.1	1.0	2.2	0.6

Figure 4-8. Stream Lengths in Watersheds Adjacent to Shasta Lake that Would Be Periodically Inundated Under Alternative CP1

Impact Geo-3 (CP1): Loss or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region Significant quantities of cement, concrete sand and aggregate, and coarse aggregate would be needed under CP1. Cement Types I, II, III, and V are produced locally but supplies are limited. Required quantities of concrete sand and aggregate are available from local commercial suppliers. The tonnage of sand anticipated to be needed is roughly more than 150 percent of the annual Shasta County production of sand and gravel. Embankment material (i.e., coarse aggregate) could be obtained from local sources, including from within Shasta Lake itself. Implementation of CP1 has the potential to diminish the availability of cement, and of concrete sand and aggregate, in the region. This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-4 (CP1): Lost or Diminished Soil Biomass Productivity Under CP1, soil productivity would be lost due to periodic inundation caused by increasing the full pool elevation and by construction including relocation of infrastructure. Using Equivalent FSSC as a surrogate metric for soil biomass productivity, implementation of CP1 would result in loss of the following acreages by productivity rank: moderate productivity – 1,954.6 acres; low productivity – 1,604.5 acres; nonproductive - 565 acres.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-5 (CP1): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under CP1, the area of shoreline that would be periodically inundated would be about 1,229 acres. Substantial soil erosion and loss of topsoil would result.

The inundated area would be subjected to shoreline erosional processes. For the first 15 years after raising the dam, the average rate of shoreline erosion would increase substantially, from 90 cubic yards per acre per year to about 300 cubic yards per acre per year. For the first time step (i.e., 15 years), the total average annual volume of potential shoreline erosion from CP1 would be about 421,000 cubic yards per year. Within 60 years of raising the dam, the average annual volume is predicted to decrease to 107,000 cubic yards per year.

Sediment delivery from shoreline erosion would likely be greatest in the Sacramento River Arm, eastern portion of the Main Body Arm, and McCloud River Arm. These three arms are predicted to deliver more than 66,000 cubic yards per year for the first 15 years after raising the dam. Within 60 years of raising the dam, the average rate for these arms is predicted to decrease to 19,000 cubic yards per year. The western portion of the Main Body Arm and the Backbone Creek Arm are predicted to have the lowest shoreline erosion rates, resulting in a 15-year average annual potential erosion volume of less than 26,000 cubic yards per year. The Pit River Arm is predicted to produce about

50,000 cubic yards per year and the Squaw Creek Arm about 35,000 cubic yards per year.

Assuming the available vegetation removal prescriptions between the 1,070-foot and 1,080-foot contours, for the first time step (i.e., 15 years after raising Shasta Dam), there would be about 421,000 cubic yards per year of shoreline erosion. After about 15 to 20 years, depending on climatic variability, the new shoreline would form and would start to stabilize. Total reservoir erosion is predicted to decrease by 70 percent between 15 and 60 years after raising the dam. The wetter the climate cycle, the more rapidly the shoreline is predicted to form.

The analysis also calculated the 15-year erosion volume using the prescribed vegetation treatments and modeled higher erosion rates for shoreline with partial and complete vegetation removal. The Big Backbone, Squaw Creek, and Pit River arms would have very little vegetation removal, which would not affect the short-term rate of shoreline erosion. The Main Body, Sacramento River, and McCloud River arms would have substantial amounts of vegetation removal, which would result in higher short-term erosion rates. For these arms, areas treated by vegetation removal represent about half of the total predicted erosion.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-6 (CP1): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Interpretations of soil susceptibility to erosion are presented in Table 4-12 for the portion of the subarea potentially disturbed by construction activities. Up to approximately 3,340 acres in the upland portion of the Shasta Lake and vicinity area could be disturbed, and up to 3,128 acres (94 percent of total area) are assigned a hazard rating of severe. A severe rating indicates that significant erosion is expected, and that extensive erosion-control measures are needed.

Construction-related erosion will be avoided and minimized via implementation of the stormwater pollution prevention plans (i.e., erosion and sediment control plans including site revegetation) that are a part of the environmental commitments common to all action alternatives. These plans will address the necessary local jurisdiction requirements regarding erosion control and site revegetation, and would implement best management practices for erosion and sediment control. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-7 (CP1): 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 Subsidence Of the approximately 3,340 acres in the upland portion of the Shasta Lake and vicinity area, 175.5 acres (5.3 percent of total area) occupy landscape positions underlain by limestone. Land subsidence has potential to occur in areas underlain by certain limestones, and in areas affected by underground construction. Detailed, site-specific geologic and foundation investigations will be completed to inform project design as to how to avoid potential subsidence due to these potential causes. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-8 (CP1): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste In general, soils in the Shasta Lake and vicinity area are poorly suited to use as septic tank leach fields or alternative waste disposal systems due to shallow soil depth, high rock content, and excessive slope. Relocated wastewater facilities will be designed and constructed to satisfy the conditions of the Shasta County Environmental Health Division Sewage Disposal System Permit. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes impacts to the upper Sacramento River portion of the primary study area associated with CP1.

Impact Geo-9 (CP1): Substantial Increase in Channel Erosion and Meander Migration This impact would be similar to Impact Geo-9 for the No-Action Alternative. However, by altering storage and operations at Shasta Lake as compared to the No-Action Alternative and existing condition, this alternative would change the maximum pool elevation and seasonal pool elevations at Shasta Lake and the flow regime in the Sacramento River and potentially several other reservoirs and downstream waterways. Alterations to river flows could potentially change downstream stream erosion and change downstream geomorphologic characteristics. However, the frequency and duration of high flow events resulting from this action are expected to be reduced as compared to existing conditions with current operations. Therefore, downstream erosion would not be anticipated to increase. This impact would be less than significant.

Reductions of stream bedload contribution are greatest during high flow events. Bed and bank conditions in streams and rivers are created, maintained, and destroyed by natural geomorphic processes whose rates and patterns are regulated through complex interactions of flow, sediment transport, and properties of the channel and floodplain (including slope, erodibility, and morphology). Because large fluvial systems, such as the Sacramento River and its floodplain, are affected by the interaction of a wide variety of geomorphic processes, quantifying and understanding how they evolve can be complex. The legacy of land and water use in a region add to the complexity, modulating factors such as flow, sediment supply, and floodplain erodibility, thus affecting the dynamics of riverine and floodplain characteristics.

High flow events can mobilize and scour gravel stored in the channel bed, routing the sediment downstream. In the alluvial reaches of unregulated rivers, the sediment scoured from a local reach is generally replaced by sediment transported from upstream, supplied from tributaries, or recruited from storage in riverbanks. There may be short-term or local changes in the amount of gravel stored in a channel bed due to episodic sediment delivery (e.g., mass wasting events in the watershed) or extreme flow events, but over a broader time span, unregulated rivers generally achieve a balance between sediment supply and routing so that in-channel sediment storage is maintained.

The first significant natural source of sediment to the Sacramento River is nearly 30 miles (48 kilometers) downstream from Keswick Dam at Cottonwood Creek (River Mile 273.5). Tributaries between Keswick Dam and Cottonwood Creek contribute little sediment to the mainstem because they drain small basins of erosion-resistant material or, as is the case for Clear Creek, are themselves regulated by dams and are affected by aggregate mining. Much of the upper Sacramento River (i.e., from River Mile 302 to approximately River Mile 273.5) is bounded by erosion-resistant bedrock and terrace deposits, such that bank erosion is not fast enough, relative to in-channel transport, to provide a significant source of coarse sediment. In other words, the rate of supply from erosion of banks due to meander migration in the upper river is minimal.

Meander migration and bank erosion occur by two processes: progressive channel migration, in which flows erode banks incrementally, and episodic meander-bend cutoff, in which the channel avulses to a completely new course. Cutoffs may be partial or complete, depending on initial meander bend geometry and the resistance of bank and floodplain materials to erosion, among other factors. Complete cutoffs are often referred to as "chute cutoffs." Partial cutoffs are sometimes also referred to as "neck cutoffs" in geomorphology texts and literature. While progressive migration and episodic cutoff can generally be thought of as distinct (i.e., mutually exclusive) processes, they are nevertheless interrelated because they simultaneously regulate and are affected by sinuosity and other channel characteristics.

An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, *Environmental Commitments Common to All Action Alternatives*, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-10 (CP1): Substantial Soil Erosion or Loss of Topsoil Due to Construction Under implementation of CP1 no gravel augmentation activities or construction activities to breach the levee to Reading Island would occur and therefore, no soil additional soil erosion would be anticipated on the banks along the river channel. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-11 (CP1): Alteration of Fluvial Geomorphology Under implementation of CP1, no activities to breach the levee to Reading Island would occur and therefore, no changes in fluvial geomorphology would be anticipated along Anderson Creek. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with CP1.

Impact Geo-12 (CP1.): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP1 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Under implementation of CP1, there would be a potential reduction in high flow events. Therefore, increases in Sacramento River flow would be limited and affects to reservoirs and rivers in the extended study area would be attenuated and dissipated by the large number of these water bodies, as well as flood bypasses in the extended study area. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), but would take place in the lower Sacramento River and Delta and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CVP/SWP Service Areas This section describes impacts to the CVP/SWP service areas within the extended study area associated with CP1.

Impact Geo-13 (CP1): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP1 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Changes in water operations in the CVP/SWP service areas could potentially result in small changes in flow in the American and Feather rivers, as a result of operations at Folsom Dam and Oroville Dam. However, changes in flow affecting these reservoirs and rivers in the extended study area would be within the normal range of conditions and would not be expected to result in an increase in channel erosion or meander migration. This would be a less than significant impact.

This impact would be very similar to Impact Geo-9 (CP1), but would be associated with the CVP/SWP service areas that extend along the Sacramento River and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CP2 – 12.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply Reliability

This section describes impacts associated with CP2, which focuses on enlarging Shasta Dam and Reservoir by raising Shasta Dam 12.5 feet. The dam raise would increase the reservoir's full pool by 14.5 feet, and enlarge total storage space in the reservoir by 443,000 acre-feet.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake portion of the primary study area.

Impact Geo-1 (CP2): Exposure of Structures and People to Geologic Hazards Resulting From Seismic Conditions, Slope Instability, and Volcanic Eruption Implementing CP2 has the potential to increase the exposure of structures and people to geologic hazards similar to CP1. For the same reasons as apply to CP1, impacts resulting from seismic conditions would be less than significant for CP2.

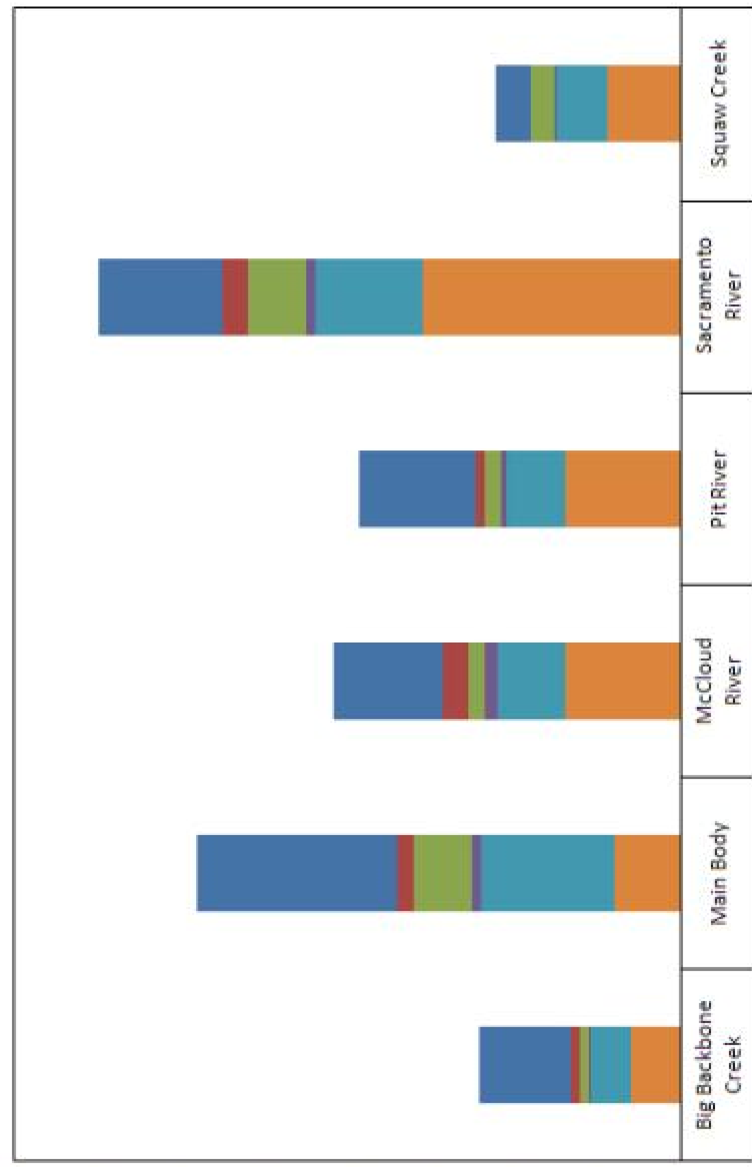
Under CP2, the pool level increase would inundate 110 acres of mapped slope instability hazards. Relocation of infrastructure is proposed to occur in the vicinity of about 232 acres of mapped slope instability hazards. For the same reasons as apply to CP1, impacts resulting from slope instability hazards would be less than significant for CP2.

For the same reasons as apply to CP1, impacts resulting from hazards associated with volcanic eruptions would be less than significant for CP2. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-2 (CP2): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats Like CP1, under CP2 stream channel equilibrium and geomorphology would be affected by an increase in full pool level. Inundation of lower gradient streams draining to Shasta Lake could result in long-term changes to channel equilibrium by changing the sediment transport capacity of the stream channels between 1,070 and 1,084 feet of elevation.

Based on a GIS-generated stream network, the total stream length inundated as a result of CP2 would be 25.5 miles (see Figure 4-9), which equates to about 0.9 percent of the total length of the streams in watersheds that are directly adjacent and contributory to Shasta Lake. Of the 25.5 miles inundated, about 8.2 miles are streams with a gradient less than 7 percent. This impact would be significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-3 (CP2): Loss or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region Implementing CP2 has the same potential as CP1 to diminish the availability in the region of cement, and of concrete sand and aggregate. For the same reasons as apply to CP1, this impact would be significant and unavoidable for CP2. Mitigation for this impact is not available.



	Big Backbone Creek	Main Body	McCloud River	Pit River	Sacramento River	Squaw Creek
Intermittent >10% Grade	1.1	2.4	1.3	1.4	1.5	0.4
Perennial >10% Grade	0.1	0.2	0.3	0.1	0.3	0.0
Intermittent 7-10% Grade	0.1	0.7	0.2	0.2	0.7	0.3
Perennial 7-10% Grade	0.02	0.1	0.16	0.06	0.1	0.02
Intermittent <7% Grade	0.5	1.6	0.8	0.7	1.3	0.6
Perennial <7% Grade	0.6	0.8	1.4	1.4	3.1	0.9

Figure 4-9. Stream Lengths in Watersheds Adjacent to Shasta Lake that Would Be Periodically Inundated Under Alternative CP2

Impact Geo-4 (CP2): Lost or Diminished Soil Biomass Productivity Like CP1, under CP2 soil productivity would be lost due to periodic inundation caused by increasing the full pool elevation and by construction including relocation of infrastructure. Using Equivalent FSSC as a surrogate metric for soil biomass productivity, implementation of CP2 would result in loss of the following acreages by productivity rank: moderate productivity, 2,128 acres; low productivity, 1,751 acres; nonproductive, 638 acres.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-5 (CP2): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under CP2, the area of shoreline that would be inundated would be about 1,734 acres. Substantial soil erosion and loss of topsoil would result.

For the first 15 years after raising the dam, the average rate of shoreline erosion would increase substantially, from 90 cubic yards per acre per year to about 300 cubic yards per acre per year. For the first time step (i.e., 15 years), the total average annual volume of potential shoreline erosion from CP2 would be about 549,000 cubic yards per year. Within 60 years of raising the dam, the average annual volume is predicted to decrease to 150,000 cubic yards per year.

Sediment delivery from shoreline erosion would likely be greatest in the Sacramento River Arm, eastern portion of the Main Body Arm, and McCloud River Arm. These three arms are predicted to deliver more than 90,000 cubic yards per year for the first 15 years after raising the dam. Within 60 years of raising the dam, the average rate for these arms is predicted to decrease to 27,000 cubic yards per year. The western portion of the Main Body Arm and the Backbone Creek Arm are predicted to have the lowest shoreline erosion rates, a 15-year average annual potential erosion volume of less than 43,000 cubic yards per year. The Pit River Arm is predicted to produce about 67,000 cubic yards per year and the Squaw Creek Arm about 63,000 cubic yards per year.

Assuming the available vegetation removal prescriptions between the 1,070-foot and 1,084-foot contours, for the first time step (i.e., 15 years after raising Shasta Dam), there would be about 549,000 cubic yards per year of shoreline erosion. After about 15 to 20 years, depending on climatic variability, the new shoreline would form and would start to stabilize. Total reservoir erosion is predicted to decrease by 70 percent between 15 and 60 years after raising the dam. The wetter the climate cycle, the more rapidly the shoreline is predicted to form.

The analysis also calculated the 15-year erosion volume using the prescribed vegetation treatments and modeled higher erosion rates for shoreline with partial and complete vegetation removal. The Big Backbone, Squaw Creek, and Pit River Arms would have very little vegetation removal, which would not affect the short-term rate of shoreline erosion. The Main Body, Sacramento River, and McCloud River arms would have substantial amounts of vegetation removal, which would result in higher short-term erosion rates. For these arms, areas treated by vegetation removal represent about half of the total predicted erosion.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-6 (CP2): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Alternative CP2 is similar to Alternative CP1 with respect to its potential to cause substantial soil erosion or loss of topsoil due to upland processes. The area disturbed by construction activities under CP2 is roughly the same as the area disturbed under CP1, up to approximately 3,340 acres. Of this area, up to approximately 3,128 acres are assigned a hazard rating of severe. For the same reasons as apply to CP1, this impact would be less than significant for CP2. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-7 (CP2): 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 Subsidence Alternative CP2 is similar to Alternative CP1 with respect to its potential to cause or be effected by subsidence. For the same reasons as apply to CP1, this impact would be less than significant for CP2 Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-8 (CP2): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste Alternative CP2 is similar to Alternative CP1 with respect to its potential to cause or be effected by failure of septic tanks or alternative wastewater disposal systems due to soils that are unsuited to land application of waste. For the same reasons as apply to CP1, this impact would be less than significant for CP2. Mitigation for this impact is not needed, and thus not proposed.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes the impacts to the upper Sacramento River portion of the primary study area associated with CP2.

Impact Geo-9 (CP2): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP2 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. However, by altering storage and operations at Shasta Lake as compared to the No-Action Alternative and existing condition, this alternative would change the maximum pool elevation and seasonal pool elevations at Shasta Lake and the flow regime in the Sacramento River and potentially several other reservoirs and downstream waterways. Alterations to river flows could potentially change downstream stream erosion and change downstream geomorphologic characteristics.

However, the frequency and duration of high flow events resulting from this action are expected to be reduced as compared to existing conditions with current operations. Therefore, downstream erosion would not be anticipated to increase. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, *Environmental Commitments Common to All Action Alternatives*, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be slightly greater under CP2. This impact would be less than significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-10 (CP2): Substantial Soil Erosion or Loss of Topsoil Due to Construction Under implementation of CP2 no gravel augmentation activities would occur and therefore, no soil additional soil erosion would be anticipated on the banks along the river channel. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-11 (CP2): Alteration of Fluvial Geomorphology Under implementation of CP2, no activities to breach the levee to Reading Island would occur and therefore, no changes in fluvial geomorphology would be anticipated along Anderson Creek. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with CP2.

Impact Geo-12 (CP2): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP2 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Under implementation of CP1, there would be a potential reduction in high flow events. Therefore, increases in Sacramento River flow would be limited and affects to reservoirs and rivers in the extended study area would be attenuated and dissipated by the large number of these water bodies, as well as by flood bypasses in the extended study area. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be slightly greater under CP2. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CVP/SWP Service Areas This section describes impacts to the CVP/SWP service areas within the extended study area associated with CP2.

Impact Geo-13 (CP2): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP2 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Changes in water operations in the CVP/SWP service areas could potentially result in small changes in flow in the American and Feather rivers, as a result of operations at Folsom Dam and Oroville Dam. However, changes in flow affecting these reservoirs and rivers in the extended study area would be within the normal range of conditions and would not be expected to result in an increase in channel erosion or meander migration. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be slightly greater under CP2. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CP3 – 18.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply

This section describes impacts associated with CP3, which focuses on the greatest practical enlargement of Shasta Dam and Reservoir consistent with the goals of the 2000 CALFED Bay-Delta Program Record of Decision (CALFED 2000b). CP3 was formulated for the primary purposes of increased water supply reliability and increased anadromous fish survival by raising Shasta Dam 18.5 feet. The dam raise would raise the reservoir's full pool by 20.5 feet, and enlarge total storage space in the reservoir by 5.19 million acre-feet.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake portion of the primary study area for CP3.

Impact Geo-1 (CP3): Exposure of Structures and People to Geologic Hazards Resulting from Seismic Conditions, Slope Instability, and Volcanic Eruption Implementing CP3 has the potential to increase the exposure of structures and people to geologic hazards similar to CP1. For the same reasons as apply to CP1, impacts resulting from seismic conditions would be less than significant for CP3.

Under CP3, the pool level increase would inundate 173 acres of mapped slope instability hazards (i.e., active and relict landslides, debris slides, and inner gorge landscape positions). Relocation of infrastructure is proposed to occur in the vicinity of about 232 acres of mapped slope instability hazards. For the same reasons as apply to CP1, impacts resulting from slope instability hazards would be less than significant for CP3

For the same reasons as apply to CP1, impacts resulting from hazards associated with volcanic eruptions would be less than significant for CP3. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-2 (CP3): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats Similar to CP1, under CP3 stream channel equilibrium and geomorphology would be affected by an increase in full pool level. Inundation of lower gradient streams draining to Shasta Lake could result in long-term changes to channel equilibrium by changing the sediment transport capacity of the stream channels between 1,070 and 1,090 feet of elevation.

Based on a GIS-generated stream network, the total stream length inundated as a result of CP3 would be 36.5 miles (see Figure 4-10), which equates to about 1.3 percent of the total length of the streams in watersheds that are directly adjacent and contributory to Shasta Lake. Of the 36.5 miles inundated, about 12.1 miles are streams with a gradient less than 7 percent. This impact would be significant. Mitigation for this impact is proposed in Section 4.3.5.

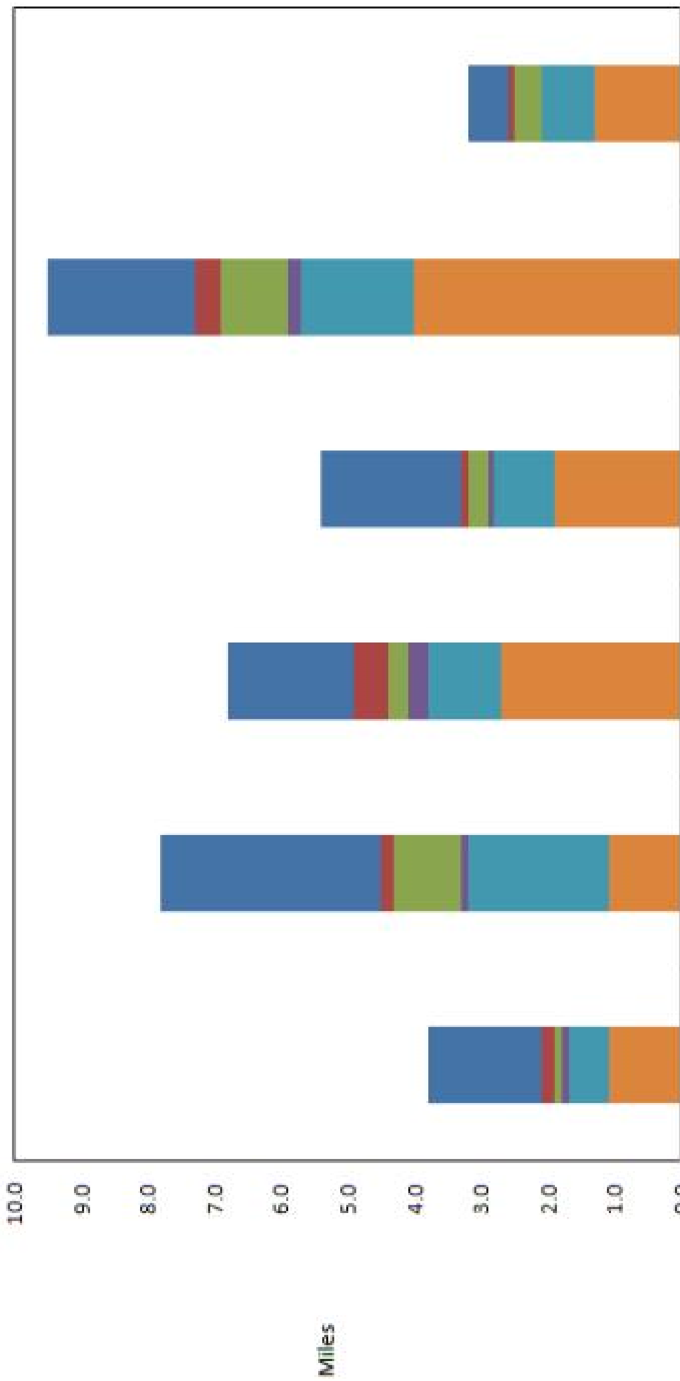
Impact Geo-3 (CP3): Loss or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region Implementing CP3 has the same potential as CP1 to diminish the availability in the region of cement, and of concrete sand and aggregate. For the same reasons as apply to CP1, this impact would be significant and unavoidable for CP3. Mitigation for this impact is not available.

Impact Geo-4 (CP3): Loss or Diminished Soil Biomass Productivity Like CP1, under CP3 soil productivity would be lost due to periodic inundation caused by increasing the full pool elevation and by construction including relocation of infrastructure. Using Equivalent FSSC as a surrogate metric for soil biomass productivity, implementation of CP3 would result in loss of the following acreages by productivity rank: moderate productivity – 2,301 acres; low productivity – 2,092 acres; nonproductive – 760 acres.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-5 (CP3): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under CP3, the area of shoreline that would be inundated would be about 2,498 acres. Substantial soil erosion and loss of topsoil would result.

For the first 15 years after raising the dam, the average rate of shoreline erosion would increase substantially, from 90 cubic yards per acre per year to about 300 cubic yards per acre per year. For the first time step (i.e., 15 years), the total average annual volume of potential shoreline erosion from CP3 would be about 767,000 cubic yards per year. Within 60 years of raising the dam, the average annual volume is predicted to decrease to 216,000 cubic yards per year.



	Big Backbone Creek	Main Body	McCloud River	Pit River	Sacramento River	Squaw Creek
Intermittent >10% Grade	1.7	3.3	1.9	2.1	2.2	0.6
Perennial >10% Grade	0.2	0.2	0.5	0.1	0.4	0.1
Intermittent 7-10% Grade	0.1	1.0	0.3	0.3	1.0	0.4
Perennial 7-10% Grade	0.1	0.1	0.3	0.1	0.2	0.0
Intermittent <7% Grade	0.6	2.1	1.1	0.9	1.7	0.8
Perennial <7% Grade	1.1	1.1	2.7	1.9	4.0	1.3

Figure 4-10. Stream Lengths in Watersheds Adjacent to Shasta Lake that Would Be Periodically Inundated Under Alternatives CP3, CP4, and CP5

Sediment delivery from shoreline erosion would likely be greatest in the Sacramento River Arm, eastern portion of the Main Body Arm, and McCloud River Arm. These three arms are predicted to deliver more than 140,000 cubic yards per year for the first 15 years after raising the dam. Within 60 years of raising the dam, the average rate for these arms is predicted to decrease to 39,000 cubic yards per year. The western portion of the Main Body Arm and Backbone Creek Arm are predicted to have the lowest shoreline erosion rates, a 15-year average annual potential erosion volume of less than 57,000 cubic yards per year. The Pit River Arm is predicted to produce about 99,000 cubic yards per year and the Squaw Creek Arm about 68,000 cubic yards per year.

Assuming the available vegetation removal prescriptions between the 1,070-foot and 1,090-foot contours, for the first time step (i.e., 15 years after raising Shasta Dam), there would be about 767,000 cubic yards per year of shoreline erosion. After about 15 to 20 years, depending on climatic variability, the new shoreline would form and would start to stabilize. Total reservoir erosion is predicted to decrease by 70 percent between 15 and 60 years after raising the dam. The wetter the climate cycle, the more rapidly the shoreline is predicted to form.

The analysis also calculated the 15-year erosion volume using the prescribed vegetation treatments and modeled higher erosion rates for shoreline with partial and complete vegetation removal. The Big Backbone, Squaw Creek, and Pit River Arms would have very little vegetation removal, which would not affect the short-term rate of shoreline erosion. The Main Body, Sacramento River, and McCloud River arms would have substantial amounts of vegetation removal, which would result in higher short-term erosion rates. For these arms, areas treated by vegetation removal represent about half of the total predicted erosion.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-6 (CP3): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Alternative CP3 is similar to Alternative CP1 with respect to its potential to cause substantial soil erosion or loss of topsoil due to upland processes. The area disturbed by construction activities under CP3 is about 3,340 acres. Of this area, approximately 3,128 acres are assigned a hazard rating of severe. For the same reasons as apply to CP1, this impact would be less than significant for CP3. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-7 (CP3): 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 Subsidence Alternative CP3 is similar to Alternative CP1 with respect to its potential to cause or be effected by subsidence. For the same reasons as apply to CP1, this would be less than significant for CP3. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-8 (CP3): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste Alternative CP3 is similar to Alternative CP1 with respect to its potential to cause or be effected by failure of septic tanks or alternative wastewater disposal systems due to soils that are unsuited to land application of waste. For the same reasons as apply to CP1, this would be less than significant for CP3. Mitigation for this impact is not needed, and thus not proposed.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes impacts to the upper Sacramento River portion of the primary study area associated with CP3.

Impact Geo-9 (CP3): Potential Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP3 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. However, by altering storage and operations at Shasta Lake as compared to the No-Action Alternative and existing condition, this alternative would change the maximum pool elevation and seasonal pool elevations at Shasta Lake and the flow regime in the Sacramento River and potentially several other reservoirs and downstream waterways. Alterations to river flows could potentially change downstream stream erosion and change downstream geomorphologic characteristics. However, the frequency and duration of high flow events resulting from this action are expected to be reduced as compared to existing conditions with current operations. Therefore, downstream erosion would not be anticipated to increase. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, *Environmental Commitments Common to All Action Alternatives*, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be greater under CP3. This impact would be less than significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-10 (CP3): Substantial Soil Erosion or Loss of Topsoil Due to Construction Under implementation of CP3 no gravel augmentation activities would occur and therefore, no soil additional soil erosion would be anticipated on the banks along the river channel. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-11 (CP3): Alteration of Fluvial Geomorphology Under implementation of CP3, no activities to breach the levee to Reading Island would occur and therefore, no changes in fluvial geomorphology would be anticipated along Anderson Creek. There would be no impact. Mitigation for this impact is not needed, and thus not proposed.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with CP3.

Impact Geo-12 (CP3): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP3 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Under implementation of CP1, there would be a potential reduction in high flow events. Therefore, increases in Sacramento River flow would be limited and affects to reservoirs and rivers in the extended study area would be attenuated and dissipated by the large number of these water bodies, as well as by flood bypasses in the extended study area. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be greater under CP3. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CVP/SWP Service Areas This section describes impacts to the CVP/SWP service areas within the extended study area associated with CP3.

Impact Geo-13 (CP3): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP3 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Changes in water operations in the CVP/SWP service areas could potentially result in small changes in flow in the American and Feather rivers, as a result of operations at Folsom Dam and Oroville Dam. However, changes in flow affecting these reservoirs and rivers in the extended study area would be within the normal range of conditions and would not be expected to result in an increase in channel erosion or meander migration. This impact would be less than significant.

This impact would be very similar to Impact Geo-9 (CP1), except the modification of flow regimes would be slightly greater under CP3. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CP4 – 18.5-Foot Dam Raise, Anadromous Fish Focus With Water Supply Reliability

This section describes impacts associated with CP4, which focuses on increasing the volume of cold water available to the Shasta Dam temperature control device through reservoir reoperations, and on raising Shasta Dam by raising Shasta Dam 18.5 feet. The dam raise would increase the reservoir's full pool by 20.5 feet, and enlarge total storage space by 634,000 acre-feet. This additional storage space would expand the Shasta Lake cold-water supply available to the temperature control device by 378,000 acre-feet, a feature that would help regulate cooler water temperatures in the upper Sacramento River.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake portion of the primary study area for CP4.

Impact Geo-1 (CP4): Exposure of Structures and People to Geologic Hazards Resulting from Seismic Conditions, Slope Instability, and Volcanic Eruption Implementing CP4 has the potential to increase the exposure of structures and people to geologic hazards similar to CP1. For the same reasons as apply to CP1, impacts resulting from seismic conditions would be less than significant for CP4.

Like CP3, under CP4, the pool level increase would inundate 173 acres of mapped slope instability hazards. Relocation of infrastructure is proposed to occur in the vicinity of about 232 acres of mapped slope instability hazards. For the same reasons as apply to CP1, impacts resulting from slope instability hazards would be less than significant for CP4.

For the same reasons as apply to CP1, impacts resulting from hazards associated with volcanic eruptions would be less than significant for CP4. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-2 (CP4): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats Like CP3, under CP4 stream channel equilibrium and geomorphology would be affected by an increase in full pool level. Inundation of lower gradient streams draining to Shasta Lake could result in long-term changes to channel equilibrium by changing the sediment transport capacity of the stream channels between 1,070 and 1,090 feet of elevation.

Based on a GIS-generated stream network, the total stream length inundated as a result of CP4 would be the same as for CP3, about 36.5 miles (see Figure 4-10). This value equates to about 1.3 percent of the total length of the streams in watersheds that are directly adjacent and contributory to Shasta Lake. Of the 36.5 miles inundated, about 12.1 miles are streams with a gradient less than 7 percent. This impact would be significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-3 (CP4): Loss or Diminished Availability of Known Mineral Resources That *Would Be of Future Value to the Region* Implementing CP4 has the same potential as CP1 to diminish the availability in the region of cement, and of concrete sand and aggregate. For the same reasons as apply to CP1, this impact would be significant and unavoidable for CP4. Mitigation for this impact is not available.

Impact Geo-4 (CP4): Lost or Diminished Soil Biomass Productivity Like CP3, under CP4 soil productivity would be lost due to periodic inundation caused by increasing the full pool elevation and by construction including relocation of infrastructure. The acreages of these losses would be the same as those reported for CP3.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-5 (CP4): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under CP4, the area of shoreline that would be inundated would be the same as the area reported under CP3, about 2,498 acres. Substantial soil erosion and loss of topsoil would result. The previous descriptions of the time steps and associated volumes of soil lost due to shoreline processes under CP3 also apply to CP4.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-6 (CP4): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Alternative CP4 is similar to Alternative CP3 with respect to its potential to cause substantial soil erosion or loss of topsoil due to upland processes. The area disturbed by construction activities under CP4 is roughly the same as the area disturbed under CP3, about 3, 340 acres. Of this area, approximately 3,128 acres are assigned a hazard rating of severe. For the same reasons as apply to CP1, this impact would be less than significant for CP4. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-7 (CP4): 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 Subsidence Alternative CP4 is similar to Alternative CP1 with respect to its potential to cause or be effected by subsidence. For the same reasons as apply to CP1, this impact would be less than significant for CP4. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-8 (CP4): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste Alternative CP4 is similar to Alternative CP1 with respect to its potential to cause or be effected by failure of septic tanks or alternative wastewater disposal systems due to soils that are unsuited to land application of waste. For the same reasons as apply to CP1, this impact would be less than significant for CP4. Mitigation for this impact is not needed, and thus not proposed.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes impacts to the upper Sacramento River portion of the primary study area associated with CP4.

Impact Geo-9 (CP4): Potential Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP4 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. However, by altering storage and operations at Shasta Lake as compared to the No-Action Alternative and existing condition, this alternative would change the maximum pool elevation and seasonal pool elevations at Shasta Lake and the flow regime in the Sacramento River and potentially several other reservoirs and downstream waterways. Alterations to river flows could potentially change downstream stream erosion and change downstream geomorphologic characteristics. However, the frequency and duration of high flow events resulting from this action are expected to be reduced as compared to existing conditions with current operations. Therefore, downstream erosion would not be anticipated to increase. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, Environmental Commitments Common to All Action Alternatives, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant.

This impact would be the same as Impact Geo-9 (CP1) and would be less than significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-10 (CP4): Substantial Soil Erosion or Loss of Topsoil Due to Construction CP4 involves replenishing spawning gravel in the Upper Sacramento River between Keswick Dam and Red Bluff diversion Dam. Implementation of these activities could potentially contribute to soil erosion or loss of topsoil from clearing, grading, and grubbing activities required while constructing roadways to access the new spawning gravel sites. In addition, soil erosion could also potentially occur at sites where clearing and grubbing of the river bank would be required to allow the gravel to be placed on the river bank for recruitment. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, Environmental Commitments Common to All Action Alternatives, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-11 (CP4): Alteration of Fluvial Geomorphology Under implementation of CP4, measures would be taken to restore riparian, floodplain, and side channel habitat at Reading Island, which lies along the Sacramento River just north of Cottonwood Creek in Shasta County. Implementation of CP4 would involve breaching the levee separating Anderson Creek Slough from the Sacramento River. Breaching of the levee would ideally allow Anderson Creek Slough, which previously captured a portion of the Sacramento River flow and functioned as a side channel habitat to reestablish connectivity at flows greater than 4,000 to 6,000 cfs. The reestablished side channel could potentially experience changes in fluvial geomorphology that could result in channelized or unstable braided streams depending on the gradient of the channel. However, restoration of habitat through planting of native vegetation would stabilize channel banks. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with CP4.

Impact Geo-12 (CP4): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP4 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Under implementation of CP1, there would be a potential reduction in high flow events. Therefore, increases in Sacramento River flow would be limited and affects to reservoirs and rivers in the extended study area would be attenuated and dissipated by the large number of these water bodies, as well as by flood bypasses in the extended study area. This impact would be less than significant.

This impact would be similar to Impact Geo-9 (CP1) and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CVP/SWP Service Areas This section describes impacts to the CVP/SWP service areas within the extended study area associated with CP4.

Impact Geo-13 (CP4): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP4 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Changes in water operations in the CVP/SWP service areas could potentially result in small changes in flow in the American and Feather rivers, as a result of operations at Folsom Dam and Oroville Dam. However, changes in flow affecting these reservoirs and rivers in the extended study area would be within the normal range of conditions and would not be expected to result in an increase in channel erosion or meander migration. This impact would be less than significant.

This impact would be the same as Impact Geo-9 (CP1) and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CP5 – 18.5-Foot Dam Raise, Combination Plan

This section describes impacts associated with CP5, which includes raising Shasta Dam 18.5 feet. This alternative also includes (1) implementing environmental restoration features along the lower reaches of major tributaries to Shasta Lake, (2) constructing shoreline fish habitat around Shasta Lake, and (3) constructing additional and/or improved recreation features at various locations around Shasta Lake to increase the value of the recreational experience. The dam raise would increase the reservoir's full pool elevation by 20.5 feet to about 1,090 feet above msl, and enlarge total storage space by 634,000 acre-feet.

Shasta Lake and Vicinity This section describes impacts to the Shasta Lake portion of the primary study area for CP5.

Impact Geo-1 (CP5): Exposure of Structures and People to Geologic Hazards Resulting from Seismic Conditions, Slope Instability, and Volcanic Eruption Implementing CP5 has the potential to increase the exposure of structures and people to geologic hazards similar to CP1. For the same reasons as apply to CP1, impacts resulting from seismic conditions would be less than significant for CP5.

Like CP3, under CP5, the pool level increase would inundate 173 acres of mapped slope instability hazards. Relocation of infrastructure is proposed to occur in the vicinity of about 232 acres of mapped slope instability hazards. For the same reasons as apply to CP1, impacts resulting from slope instability hazards would be less than significant for CP5.

For the same reasons as apply to CP1, impacts resulting from hazards associated with volcanic eruptions would be less than significant for CP5. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-2 (CP5): Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats Like CP3, under CP5 stream channel equilibrium and geomorphology would be affected by an increase in full pool level. Inundation of lower gradient streams draining to Shasta Lake could result in long-term changes to channel equilibrium by changing the sediment transport capacity of the stream channels between 1,070 and 1,090 feet of elevation.

Based on a GIS-generated stream network, the total stream length inundated as a result of CP5 would be the same as for CP3, about 36.5 miles (see Figure 4-10). This value equates to about 1.3 percent of the total length of the streams in watersheds that are directly adjacent and contributory to Shasta Lake. Of the 36.5 miles inundated, about 12.1 miles are streams with a gradient less than 7 percent. This impact would be significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-3 (CP5): Lost or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region Implementing CP5 has the same potential as CP1 to diminish the availability in the region of cement, concrete sand, and aggregate. For the same reasons that apply to CP1, this impact would be significant and unavoidable for CP5. Mitigation for this impact is not available.

Impact Geo-4 (CP5): Lost or Diminished Soil Biomass Productivity Like CP3, under CP5 soil productivity would be lost due to periodic inundation caused by increasing the full pool elevation and by construction including relocation of infrastructure. The acreages of these losses would be the same as those reported for CP3.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-5 (CP5): Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes Under CP5, the area of shoreline that would be inundated would be the same as the area reported under CP3, about 2,498 acres. Substantial soil erosion and loss of topsoil would result. The previous descriptions of the time steps and associated volumes of soil lost due to shoreline processes under CP3 also apply to CP5.

This impact would be significant and unavoidable. Mitigation for this impact is not available.

Impact Geo-6 (CP5): Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes Alternative CP5 is similar to Alternative CP3 with respect to its potential to cause substantial soil erosion or loss of topsoil due to upland processes. The area disturbed by construction activities under CP5 is roughly the same as the area disturbed under CP3, about 3,340 acres. Of this area, approximately 3,128 acres are assigned a hazard rating of severe. For the same reasons as apply to CP1, this impact would be less than significant for CP5. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-7 (CP5): 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 Subsidence Alternative CP5 is similar to Alternative CP1 with respect to its potential to cause or be effected by subsidence. For the same reasons as apply to CP1, this impact would be less than significant for CP5. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-8 (CP5): Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste Alternative CP5 is similar to Alternative CP1 with respect to its potential to cause or be effected by failure of septic tanks or alternative wastewater disposal systems due to soils that are unsuited to land application of waste. For the same reasons as apply to CP1, this impact would be less than significant for CP5. Mitigation for this impact is not needed, and thus not proposed.

Upper Sacramento River (Shasta Dam to Red Bluff) This section describes impacts to the upper Sacramento River portion of the primary study area associated with CP5.

Impact Geo-9 (CP5): Potential Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP5 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. However, by altering storage and operations at Shasta Lake as compared to the No-Action Alternative and existing condition, this alternative would change the maximum pool elevation and seasonal pool elevations at Shasta Lake and the flow regime in the Sacramento River and potentially several other reservoirs and downstream waterways. Alterations to river flows could potentially change downstream stream erosion and change downstream geomorphologic characteristics. However, the frequency and duration of high flow events resulting from this action are expected to be reduced as compared to existing conditions with current operations. Therefore, downstream erosion would not be anticipated to increase. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, Environmental Commitments Common to All Action Alternatives, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant.

Because Shasta Dam and Reservoir operations would be the same for CP3 and CP5, this impact would be the same as Impact Geo-9 (CP3) and would be less than significant. Mitigation for this impact is proposed in Section 4.3.5.

Impact Geo-10 (CP5): Substantial Soil Erosion or Loss of Topsoil Due to Construction   CP5 involves replenishing spawning gravel in the Upper Sacramento River between Keswick Dam and Red Bluff Diversion Dam. Implementation of these activities could potentially contribute to soil erosion or loss of topsoil from clearing, grading, and grubbing activities required while constructing roadways to access the new spawning gravel sites. In addition, soil erosion could also potentially occur at sites where clearing and grubbing of the river bank would be required to allow the gravel to be placed on the river bank for recruitment. An Erosion and Sediment Control Plan would be implemented, as described in Chapter 2, Environmental Commitments Common to All Action Alternatives, to control any short-term and long-term erosion and sedimentation effects of construction activities. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Impact Geo-11 (CP5): Alteration of Fluvial Geomorphology   Under implementation of CP5, measures would be taken to restore riparian, floodplain, and side channel habitat at Reading Island, which lies along the Sacramento River just north of Cottonwood Creek in Shasta County. Implementation of CP5 would involve breaching the levee separating Anderson Creek Slough from the Sacramento River. Breaching the levee would ideally allow Anderson Creek Slough, which previously captured a portion of the Sacramento River flow and functioned as a side channel habitat, to reestablish connectivity at flows greater than 4,000 to 6,000 cfs. The reestablished side channel could potentially experience changes in fluvial geomorphology that could result in channelized or unstable braided streams, depending on the gradient of the channel. However, restoration of habitat through planting of native vegetation would stabilize channel banks. This impact would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

Lower Sacramento River and Delta This section describes impacts to the lower Sacramento River and Delta portions of the extended study area associated with CP5.

Impact Geo-12 (CP5): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP5 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Under implementation of CP1, there would be a potential reduction in high flow events. Therefore, increases in Sacramento River flow would be limited and affects to reservoirs and rivers in the extended study area would be attenuated and dissipated by the large number of these water bodies, as well as by flood bypasses in the extended study area. This impact would be less than significant.

Because Shasta Dam and Reservoir operations would be the same for CP3 and CP5, this impact would be the same as Impact Geo-9 (CP3) and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

CVP/SWP Service Areas This section describes impacts to the CVP/SWP service areas within the extended study area associated with CP5.

Impact Geo-13 (CP5): Substantial Increase in Channel Erosion and Meander Migration It is not anticipated that implementation of CP5 would lead to increased channel erosion and meander migration as compared to the No-Action Alternative and existing conditions. Changes in water operations in the CVP/SWP service areas could potentially result in small changes in flow in the American and Feather rivers, as a result of operations at Folsom Dam and Oroville Dam. However, changes in flow affecting these reservoirs and rivers in the extended study area would be within the normal range of conditions and would not be expected to result in an increase in channel erosion or meander migration. This impact would be less than significant.

Because Shasta Dam and Reservoir operations would be the same for CP3 and CP5, this impact would be the same as Impact Geo-9 (CP3) and would be less than significant. Mitigation for this impact is not needed, and thus not proposed.

4.3.5 Mitigation Measures

This section discusses mitigation measures for each significant impact described in the environmental consequences section, as presented in Table 4-13.

Table 4-13. Summary of Mitigation Measures for Geology, Geomorphology, Minerals, and Soils

Impact		No-Action Alternative	CP1	CP2	CP3	CP4	CP5
Impact Geo-1: Exposure of Structures and People to Geologic Hazards Resulting from Seismic Conditions, Slope Instability, and Volcanic Eruptions	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-2: Alteration of Fluvial Geomorphology and Hydrology of Aquatic Habitats	LOS before Mitigation	NI	S	S	S	S	S
	Mitigation Measure	None required.	Mitigation Measure Geo-2: Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-3: Loss or Diminished Availability of Known Mineral Resources That Would Be of Future Value to the Region	LOS before Mitigation	NI	SU	SU	SU	SU	SU
	Mitigation Measure	None required.	None available.				
	LOS after Mitigation	NI	SU	SU	SU	SU	SU
Impact Geo-4: Lost or Diminished Soil Biomass Productivity	LOS before Mitigation	NI	SU	SU	SU	SU	SU
	Mitigation Measure	None required	None available.				
	LOS after Mitigation	NI	SU	SU	SU	SU	SU
Impact Geo-5: Substantial Soil Erosion or Loss of Topsoil Due to Shoreline Processes	LOS before Mitigation	NI	SU	SU	SU	PS	SU
	Mitigation Measure	None required	None available				
	LOS after Mitigation	NI	SU	SU	SU	SU	SU

Table 4-13. Summary of Mitigation Measures for Geology, Geomorphology, Minerals, and Soils (contd.)

Impact		No-Action Alternative	CP1	CP2	CP3	CP4	CP5
Impact Geo-6: Substantial Soil Erosion or Loss of Topsoil Due to Upland Processes	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-7: 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 Subsidence	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-8: Failure of Septic Tanks or Alternative Wastewater Disposal Systems Due to Soils that are Unsuited to Land Application of Waste	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-9: Substantial Increase in Channel Erosion and Meander Migration	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	Mitigation Measure Geo-9: Implement Channel Sensitive Water Release Schedules.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS

Table 4-13. Summary of Mitigation Measures for Geology, Geomorphology, Minerals, and Soils (contd.)

Impact		No-Action Alternative	CP1	CP2	CP3	CP4	CP5
Impact Geo-10: Substantial Soil Erosion or Loss of Topsoil Due to Construction	LOS before Mitigation	NI	NI	NI	NI	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	NI	NI	NI	LTS	LTS
Impact Geo-11: Alteration of Fluvial Geomorphology	LOS before Mitigation	NI	NI	NI	NI	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	NI	NI	NI	LTS	LTS
Impact Geo-12: Substantial Increase in Channel Erosion and Meander Migration (Lower Sacramento River and Delta)	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS
Impact Geo-13: Substantial Increase in Channel Erosion and Meander Migration (CVP/SWP Service Areas)	LOS before Mitigation	NI	LTS	LTS	LTS	LTS	LTS
	Mitigation Measure	None required.	None needed; thus, none proposed.				
	LOS after Mitigation	NI	LTS	LTS	LTS	LTS	LTS

Key:
CVP = Central Valley Project
LOS = level of significance
LTS = less than significant
NI = No Impact
PS = potentially significant
S = significant
SU = significant and unavoidable
SWP = State Water Project

No-Action Alternative

No mitigation measures are required for this alternative.

CP1 – 6.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply

The following section describes the mitigation measures associated with potential impacts of CP1.

Mitigation Measure Geo-2 (CP1): Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact The loss of 18.5 miles of intermittent and perennial streams (including 6.2 miles of streams with a gradient less than 7 percent) will be mitigated by compensating for the impact by replacing or providing substitute resources or environments. Compensation will be accomplished by restoring and enhancing the aquatic functions of existing, degraded aquatic habitats in or near the Shasta Lake and vicinity area. Examples of techniques that may be used include channel and bank stabilization, channel redirection, channel reconstruction, culvert replacement and elimination of barriers to fish passage, and enhancement of habitat physical structure (e.g., placement of woody debris, rocks). The nature and extent of the restoration and enhancement activities will be based on an assessment of the ecological functions that are lost as a consequence of implementing this alternative. Implementation of this mitigation measure would render the impact less than significant.

Mitigation Measure Geo-9 (CP1): Implement Channel-Sensitive Water Release Schedules Dam operators will establish water release schedules that would maintain flow levels equal to or similar to current operating conditions. Under a sound water release regime, single event flows would remain at levels similar to the existing condition, although the frequency and duration of these flows could increase. This potential increase in frequency and duration would not be considered significant provided that single event flow levels do not exceed current operating conditions. Implementation of this mitigation measure would reduce the impact to a less than significant level.

Mitigation Measure Geo-9 (CP1) would reduce the impact of potential channel erosion and meander migration to a level of less than significant.

In wet years, CP1 would decrease potential channel erosion and meander migration compared to the existing condition, because of the dam's ability to store more water than is currently possible. Greater storage capacity would provide dam operators more flexibility in timing and amount of water that would be released during wet years, decreasing the need for large releases when the dam is at or near capacity. This impact would be less than significant after implementation of channel-sensitive water release schedules.

CP2 – 12.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply

The following section describes the mitigation measures associated with potential impacts of CP2.

Mitigation Measure Geo-2 (CP2): Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact The loss of 25.5 miles of intermittent and perennial streams (including 8.2 miles of streams with a gradient less than 7 percent) will be mitigated by compensating for the impact by replacing or providing substitute resources or environments. Compensation will be accomplished by restoring and enhancing the aquatic functions of existing, degraded aquatic habitats in or near the Shasta Lake and vicinity area. Examples of techniques that may be used include channel and bank stabilization, channel redirection, channel reconstruction, culvert replacement and elimination of barriers to fish passage, and enhancement of habitat physical structure (e.g., placement of woody debris, rocks). The nature and extent of the restoration and enhancement activities will be based on an assessment of the ecological functions that are lost as a consequence of implementing this alternative. Implementation of this mitigation measure would render the impact less than significant.

Mitigation Measure Geo-9 (CP2): Implement Channel-Sensitive Water Release Schedules This mitigation measure is identical to Mitigation Measure Geo-9 (CP1).

Implementation of Mitigation Measure Geo-9 (CP2) would reduce the stream channel erosion and meander migration impact associated with CP2 to a less than significant level.

In wet years, CP2 would decrease potential channel erosion and meander migration compared to the existing condition, because of the dam's ability to retain more water than is currently possible. Greater storage capacity would provide dam operators more flexibility in the timing and amount of water that would be released during wet years, decreasing the need for large releases when the dam is at or near capacity. This impact would be less than significant after implementation of channel-sensitive water release schedules.

CP3 – 18.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply

The following section describes the mitigation measures associated with potential impacts of CP3.

Mitigation Measure Geo-2 (CP3): Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact The loss of 36.5 miles of intermittent and perennial streams (including 12.1 miles of streams with a gradient less than 7 percent) will be mitigated by compensating for the impact by replacing or providing substitute resources or environments. Compensation will be accomplished by restoring and enhancing the aquatic functions of existing, degraded aquatic habitats in or near the Shasta Lake and vicinity area. Examples of techniques that may be used include channel and bank stabilization, channel redirection, channel reconstruction, culvert replacement and elimination of barriers to fish passage, and enhancement of habitat physical structure (e.g., placement of woody debris, rocks). The nature and extent of the restoration and enhancement activities will be based on an assessment of the ecological functions that are lost as a consequence of implementing this alternative. Implementation of this mitigation measure would render the impact less than significant.

Mitigation Measure Geo-9 (CP3): Implement Channel-Sensitive Water Release Schedules This mitigation measure is identical to Mitigation Measure Geo-9 (CP1).

Implementation of Mitigation Measure Geo-9 (C3) would reduce the stream channel erosion and meander migration impact associated with CP3 to a less than significant level.

In wet years, CP3 would decrease potential channel erosion and meander migration compared to the existing condition, because of the dam's ability to retain more water than is currently possible. More retention capacity would provide dam operators more flexibility in the timing and amount of water that would be released during wet years, decreasing the need for large releases when the dam is at or near capacity. This impact would be less than significant after implementation of channel-sensitive water release schedules.

CP4 – 18.5-Foot Dam Raise, Anadromous Fish Focus With Water Supply Reliability

The following section describes the mitigation measures associated with potential impacts of CP4.

Mitigation Measure Geo-2 (CP4): Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact This mitigation measure is identical to Mitigation Measure Geo-2 (CP3). Implementation of this mitigation measure would reduce the impact to a less than significant level.

Mitigation Measure Geo-9 (CP4): Implement Channel-Sensitive Water Release Schedules This mitigation measure is identical to Mitigation Measure Geo-9 (CP1).

Implementation of Mitigation Measure Geo-9 (CP4) would reduce the stream channel erosion and meander migration impact associated with CP4 to a less than significant level. Mitigation Measure Geo-9 (CP4) would also provide mitigation for the less than significant impacts Geo-10 (CP4), and Geo-11 (CP4).

In wet years, CP4 would decrease potential channel erosion and meander migration compared to the existing condition, because of the dam's ability to retain more water than is currently possible. More retention capacity would provide dam operators more flexibility in the timing and amount of water that would be released during wet years, decreasing the need for large releases when the dam is at or near capacity. This impact would be less than significant after implementation of channel-sensitive water release schedules.

CP5 – 18.5-Foot Dam Raise, Combination Plan

The following section describes the mitigation measures associated with potential impacts of CP5.

Mitigation Measure Geo-2 (CP5): Replace Lost Ecological Functions of Aquatic Habitats By Restoring Existing Degraded Aquatic Habitats in the Vicinity of the Impact This mitigation measure is identical to Mitigation Measure Geo-2 (CP3). Implementation of this mitigation measure would reduce the impact to a less than significant level.

Mitigation Measure Geo-9 (CP5): Implement Channel-Sensitive Water Release Schedules This mitigation measure is identical to Mitigation Measure Geo-9 (CP1).

Implementation of Mitigation Measure Geo-9 (CP5) would reduce the stream channel erosion and meander migration impact associated with CP5 to a less than significant level. Mitigation Measure Geo-9 (CP5) would also provide mitigation for the less than significant impacts Geo-10 (CP5), and Geo-11 (CP5).

In wet years, CP5 would decrease potential channel erosion and meander migration compared to the existing condition, because of the dam's ability to retain more water than is currently possible. More retention capacity would provide dam operators more flexibility in the timing and amount of water that would be released during wet years, decreasing the need for large releases when the dam is at or near capacity. This impact would be less than significant after implementation of channel-sensitive water release schedules.

4.3.6 Cumulative Effects

Chapter 3, "Considerations for Describing the Affected Environment and environmental Consequences" discusses overall cumulative impacts of the project alternatives, including the relationship to CALFED Programmatic Cumulative Impacts Analysis, qualitative and quantitative assessment, past and future actions in the study area, and significance criteria.

This section provides an analysis of overall cumulative impacts of the project alternatives with other past, present, and reasonably foreseeable future projects producing related impacts. For both the primary and extended study areas, a number of factors could substantially affect geology, soils and erosion, mineral resources, and geomorphology as an outcome of present and future actions. These actions may result in either a beneficial or adverse impact for the study areas. However, there is a high level of uncertainty regarding potential effects of the reasonably foreseeable future actions. Therefore, geology, soils and erosion, mineral resources, and geomorphology are expected to remain in similar conditions to existing conditions with the exception of potential effects associated with future climate change as described below.

The effects of climate change on operations at Shasta Lake could potentially result in changes to downstream geomorphology. As described in the Climate Change Projection Appendix, climate change could result in higher reservoir releases in the future due to an increase in winter and early spring inflow into the lake from high intensity storm events. The change in reservoir releases could be necessary to manage for flood events resulting from these potentially larger storms. The potential increase in releases from the reservoir could lead to long-term changes in downstream channel equilibrium.

The effects of increased monthly inflow into Shasta Lake in winter and early spring could also potentially result in changes to stream channel equilibrium and geomorphology upstream from the lake and at the point where the streams meet the lake.

CP1 – 6.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply Reliability

As discussed in Section 4.3.4 above, CP1 could result in (1) several localized project-level impacts related to exposure of structures and people to geologic hazards (less than significant), (2) alteration of fluvial geomorphology and hydrology of aquatic habitats (significant but mitigable), (3) soil erosion from shoreline processes (significant and unavoidable), (4) soil erosion from upland processes (less than significant), (5) location of project features on unstable geologic or soil units (less than significant), and (6) the suitability of soils for wastewater disposal systems (less than significant). As with many types of geologic impacts, these project-level impacts are localized and would not contribute to any cumulative impacts.

Also discussed in Section 4.3.4 above, CP1 could result in regional impacts related to a diminished availability of cement, concrete sand, and aggregate and a loss of soil productivity. When taken together with reasonable foreseeable future projects in the region, CP1 could contribute to significant cumulative impacts related to these mineral and soil biomass resources. Mitigation is not available for either of these impacts; therefore, these cumulative impacts would be considered significant and unavoidable.

As stated previously, effects of climate change on operations at Shasta Lake could include a higher frequency of high flow events, potentially resulting in changes to geomorphology. While implementation of CP1 could potentially diminish these effects through additional storage capacity of the reservoir available after construction, it is not expected to result in long-term changes to channel equilibrium downstream from Shasta Dam. In addition, potential impacts associated with channel meander and erosion under CP1 would be less than significant in the Shasta Lake and vicinity portion of the study area, the upper Sacramento River (Shasta Dam to Red Bluff) portion of the primary study area, and in the extended study area. When added to the anticipated effects of climate change, raising Shasta Dam would not have a significant cumulative effect.

CP2 – 12.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply Reliability

As discussed in Section 4.3.4 above, CP2 could result in (1) several localized project-level impacts related to exposure of structures and people to geologic hazards (less than significant), (2) alteration of fluvial geomorphology and hydrology of aquatic habitats (significant but mitigable), (3) soil erosion from shoreline processes (significant and unavoidable), (4) soil erosion from upland processes (less than significant), (5) location of project features on unstable geologic or soil units (less than significant), and (6) the suitability of soils for wastewater disposal systems (less than significant). As with many types of geologic impacts, these project-level impacts are localized and would not contribute to any cumulative impacts.

Also discussed in Section 4.3.4 above, CP2 could result in regional impacts related to a diminished availability of cement, concrete sand, and aggregate and a loss of soil productivity. When taken together with reasonable foreseeable future projects in the region, therefore, CP2 could contribute to significant cumulative impacts related to these mineral and soil biomass resources. Mitigation is not available for either of these impacts; therefore, these cumulative impacts would be considered significant and unavoidable.

As stated previously, effects of climate change on operations at Shasta Lake could include a higher frequency of high flow events, potentially resulting in changes to geomorphology. While implementation of CP2 could potentially diminish these effects through additional storage capacity of the reservoir available after construction, it is not expected to result in long-term changes to channel equilibrium downstream from Shasta Dam. In addition, potential impacts associated with channel meander and erosion under CP2 would be less than significant in the Shasta Lake and vicinity portion of the study area, the upper Sacramento River (Shasta Dam to Red Bluff) portion of the primary study area, and in the extended study area. When added to the anticipated effects of climate change, raising Shasta Dam would not have a significant cumulative effect.

CP3 – 18.5-Foot Dam Raise, Anadromous Fish Survival and Water Supply

As discussed in Section 4.3.4 above, CP3 could result in (1) several localized project-level impacts related to exposure of structures and people to geologic hazards (less than significant), (2) alteration of fluvial geomorphology and hydrology of aquatic habitats (significant but mitigable), (3) soil erosion from shoreline processes (significant and unavoidable), (4) soil erosion from upland processes (less than significant), (5) location of project features on unstable geologic or soil units (less than significant), and (6) the suitability of soils for wastewater disposal systems (less than significant). As with many types of geologic impacts, these project-level impacts are localized and would not contribute to any cumulative impacts.

Also discussed in Section 4.3.4 above, CP3 could result in regional impacts related to a diminished availability of cement, concrete sand, and aggregate and a loss of soil productivity. When taken together with reasonable foreseeable future projects in the region, therefore, CP3 could contribute to significant cumulative impacts related to these mineral and soil biomass resources. Mitigation is not available for either of these impacts; therefore, these cumulative impacts would be considered significant and unavoidable.

As stated previously, effects of climate change on operations at Shasta Lake could include a higher frequency of high flow events, potentially resulting in changes to geomorphology. While implementation of CP3 could potentially diminish these effects through additional storage capacity of the reservoir available after construction, it is not expected to result in long-term changes to channel equilibrium downstream from Shasta Dam. In addition, potential impacts associated with channel meander and erosion under CP3 would be less than significant in the Shasta Lake and vicinity portion of the study area, the upper Sacramento River (Shasta Dam to Red Bluff) portion of the primary study area, and in the extended study area. When added to the anticipated effects of climate change, raising Shasta Dam would not have a significant cumulative effect.

CP4 – 18.5-Foot Dam Raise, Anadromous Fish Focus With Water Supply Reliability

As discussed in Section 4.3.4 above, CP4 could result in (1) several localized project-level impacts related to exposure of structures and people to geologic hazards (less than significant), (2) alteration of fluvial geomorphology and hydrology of aquatic habitats (significant but mitigable), (3) soil erosion from shoreline processes (significant and unavoidable), (4) soil erosion from upland processes (less than significant), (5) location of project features on unstable geologic or soil units (less than significant), and (6) the suitability of soils for wastewater disposal systems (less than significant). As with many types of geologic impacts, these project-level impacts are localized and would not contribute to any cumulative impacts.

Also discussed in Section 4.3.4 above, CP4 could result in regional impacts related to a diminished availability of cement, concrete sand, and aggregate and a loss of soil productivity. When taken together with reasonable foreseeable future projects in the region, therefore, CP4 could contribute to significant cumulative impacts related to these mineral and soil biomass resources. Mitigation is not available for either of these impacts; therefore, these cumulative impacts would be considered significant and unavoidable.

As stated previously, effects of climate change on operations at Shasta Lake could include a higher frequency of high flow events, potentially resulting in changes to geomorphology. While implementation of CP4 could potentially diminish these effects through additional storage capacity of the reservoir available after construction, it is not expected to result in long-term changes to channel equilibrium downstream from Shasta Dam. In addition, potential impacts associated with channel meander and erosion under CP4 would be less than significant in the Shasta Lake and vicinity portion of the study area, the upper Sacramento River (Shasta Dam to Red Bluff) portion of the primary study area, and in the extended study area. When added to the anticipated effects of climate change, raising Shasta Dam would not have a significant cumulative effect.

CP5 – 18.5-Foot Dam Raise, Combination Plan

As discussed in Section 4.3.4 above, CP5 could result in several localized project-level impacts related to exposure of structures and people to geologic hazards (less than significant), alteration of fluvial geomorphology and hydrology of aquatic habitats (significant but mitigable), soil erosion from shoreline processes (significant and unavoidable), soil erosion from upland processes (less than significant), location of project features on unstable geologic or soil units (less than significant), and the suitability of soils for wastewater disposal systems (less than significant). As with many types of geologic impacts, these project-level impacts are localized and would not contribute to any cumulative impacts.

Also discussed in Section 4.3.4 above, CP5 could result in regional impacts related to a diminished availability of cement, concrete sand, and aggregate and a loss of soil productivity. When taken together with reasonable foreseeable future projects in the region, therefore, CP5 could contribute to significant cumulative impacts related to these mineral and soil biomass resources. Mitigation if not available for either of these impacts; therefore these cumulative impacts would be considered significant and unavoidable.

As stated previously, effects of climate change on operations at Shasta Lake could include a higher frequency of high flow events, potentially resulting in changes to geomorphology. While implementation of CP5 could potentially diminish these effects through additional storage capacity of the reservoir available after construction, it is not expected to result in long-term changes to channel equilibrium downstream from Shasta Dam. In addition, potential impacts associated with channel meander and erosion under CP5 would be less than significant in the Shasta Lake and vicinity portion of the study area, the upper Sacramento River (Shasta Dam to Red Bluff) portion of the primary study area, and in the extended study area. When added to the anticipated effects of climate change, raising Shasta Dam would not have a significant cumulative effect.

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