# 17. Faults and Seismicity

## 17.1 Introduction

This chapter describes the faults and seismicity setting for the Extended, Secondary, and Primary study areas. Descriptions and maps of these three study areas are provided in Chapter 1 Introduction.

The regulatory setting for faults and seismicity is presented in Chapter 4 Environmental Compliance and Permit Summary.

This chapter focuses primarily on the Primary Study Area. Potential impacts in the Secondary and Extended study areas were evaluated and discussed qualitatively. Potential local and regional impacts from constructing, operating, and maintaining the alternatives were described and compared to applicable significance thresholds. Mitigation measures are provided for identified potentially significant impacts, where appropriate.

## 17.2 Environmental Setting/Affected Environment

### 17.2.1 Introduction

#### *17.2.1.1 Fault Activity Classification*

The California Geological Survey (CGS) categorizes faults[1] in California based on the age of last displacement, as defined below (Jennings and Bryant, 2010):

- Historic faults have ruptured during historic time (approximately the last 200 years) and are associated with either a recorded earthquake with surface rupture, measurable surface displacement along a fault in the absence of notable earthquakes (e.g., aseismic creep), or displaced survey lines.
- Holocene age faults have ruptured within the past 11,000 years, as demonstrated by geomorphic or stratigraphic evidence of displacement of Holocene deposits or geomorphic features.
- Late Quaternary age faults have ruptured within approximately the last 700,000 years, as demonstrated by geologic and geomorphic evidence of displacement of Late Quaternary deposits or geomorphic features. This category may include younger faults that lack deposits by which to differentiate younger displacements.
- Quaternary age faults show evidence of surface rupture younger than approximately 1.6 million years ago, including faults that displace undifferentiated Plio-Pleistocene age deposits.
- Pre-Quaternary age faults lack recognized evidence of Quaternary displacement or show evidence of no displacement during Quaternary time. Also included in this category are known faults for which detailed studies have not determined fault activity, and those faults identified only in preliminary mapping (Jennings, 1999).

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[1]Fractures in the earth's crust along which the rocks on one side have shifted relative to those on the other side are called faults. The total amount of displacement along a fault may be a few inches or many miles if it has accumulated over millions of years. Faults are more likely to have future earthquakes if they have had more recent earthquakes along them, have had greater total displacement, and are favorably oriented to relieve accumulating tectonic stresses.

The classification of "active" is applied to historic and Holocene age faults; "potentially active" is applied to Quaternary and late Quaternary age faults; and "inactive" is applied to pre-Quaternary age faults. These classifications were developed by the CGS and were adopted by the Alquist Priolo Act (1972) to help delineate Special Studies Zones where detailed geologic investigations are required prior to development. These classifications are not meant to imply that inactive fault traces will not rupture, only that they have not been shown to have ruptured for some time and the probability of fault rupture is low.

The CGS includes only faults that displace the surface as well as near-surface concealed faults in its fault activity map and in the above definitions (Jennings and Bryant, 2010). However, blind faults that terminate several kilometers below the surface also pose a hazard. Blind faults with evidence of having ruptured and deformed surfaces or deposits of a certain age should also be included as active, potentially active, or inactive according to the age of deformation when considering ground-shaking hazard. The Alquist Priolo Special Studies Zones are limited to areas with the potential for surface rupture and do not include blind faults.

The California Department of Water Resources, Division of Safety of Dams (DSOD) published the "Fault Activity Guidelines" (Fraser, 2001) that uses more stringent criteria on fault activity classification than CGS. Its publication defines an active fault as having ruptured within the last 35,000 years. A conditionally active fault is defined as having ruptured in the Quaternary, but its displacement history during the last 35,000 years is unknown. Fault inactivity is demonstrated by a confidently located fault trace that is consistently overlain by unbroken geologic materials older than 35,000 years. Faults that have no indication of Quaternary activity are presumed to be inactive, except in regions of sparse Quaternary cover. Some faults that are associated with historical seismicity but do not show geologic evidence of Late Quaternary faulting may also be considered as active or conditionally active seismic sources.

Table 17-1 compares the difference in fault activity classifications between CGS and DSOD. For this chapter, the more stringent fault activity classification set forth by DSOD is used.

**Table 17-1**
**Comparison of Fault Activity Classification between the California Geological Survey and Division of Safety of Dams**

| Period | Epoch | Years Before Present | Fault Activity Classification | |
|---|---|---|---|---|
| | | | CGS | DSOD |
| Quaternary | Holocene | 0 to 11,700 years | **Active** (Up to 11,700 years) | **Active** (Up to 35,000 years) |
| | Pleistocene | 11,700 to 1.6 million years | **Potentially active** (Up to 1.6 million years) | **Conditionally active** (Up to 1.6 million years) |
| Pre-Quaternary | | | **Inactive** (Greater than 1.6 million years | **Inactive** (Greater than 1.6 million years |

Notes:

CGS = California Geological Survey
DSOD = Division of Safety of Dams

### *17.2.1.2 Earthquake Magnitude and Intensity Measurement*

Earthquake magnitude is a quantitative measure of the strength and energy release of an earthquake, as determined by the seismographic or geologic observations. Several magnitude scales have been developed by seismologists. The original was the Richter magnitude, also known as "local magnitude

($M_L$)," which is a function of the wave amplitude recorded by a seismograph. This scale was developed for specific circumstances for earthquakes in Southern California recorded by a specific type of seismograph but was adapted to use elsewhere. With appropriate distance corrections for a given amplitude, the magnitude value is constant regardless of location and provides an effective means of earthquake size comparison.

The most commonly used scale is the moment magnitude ($M_w$) scale. Moment magnitude is determined from seismic moment, which is a function of physical properties of the fault rupture, specifically the area of fault rupture, the displacement across the fault, and shear strength of the faulted rock. It is a more uniform measure of the strength of an earthquake because it is independent of the distance and site conditions of recording stations. An earthquake's magnitude is expressed in whole numbers and decimals (e.g., $M_w$ 6.8).

Earthquake intensity is a qualitative measure of the effects a given earthquake has on people, structures, loose objects, and the ground at a specific location. Earthquake intensity is typically measured using the Modified Mercalli intensity scale. The most commonly used adaptation covers the range of intensities from "I" (not felt except by very few, favorably situated), to "XII" (total damage, lines of sight disturbed, and objects thrown into the air).

Although an earthquake has only one magnitude, it can have many intensities. Intensity at a given site is a function of earthquake magnitude, increasing as magnitude increases; distance from the causative fault, decreasing as distance increases; and underlying site geology, generally increasing in areas with weak, unconsolidated materials (CGS, 2002). Table 17-2 presents an approximate relationship between magnitude and maximum expected intensity close to the epicenter.

**Table 17-2**
**Comparison of Richter Magnitude and Modified Mercalli Intensity**

| Richter Magnitude | Expected Modified Mercalli Maximum Intensity (at epicenter) | |
|---|---|---|
| | Intensity | Observations and Effects |
| 2 | I – II | Usually detected only by instruments |
| 3 | III | Felt indoors |
| 4 | IV – V | Felt by most people; slight damage |
| 5 | VI – VII | Felt by all; many frightened and run outdoors; damage minor to moderate |
| 6 | VII – VIII | Everybody runs outdoors; damage moderate to major |
| 7 | IX – X | Major damage |
| 8+ | X – XII | Total and major damage |

Source: Richter, 1958.

### *17.2.1.3 Earthquake Processes and Effects*

The surface of the earth is broken into numerous tectonic plates that move relative to one another, building up stress that causes deformation. The brittle upper crust of the earth responds to these stresses by fracturing, with the relative movement accommodated by displacement along faults that are concentrated near the plate boundary. Friction across fault surfaces commonly prevents the rocks on either side from sliding smoothly. Rather, the two sides remain stuck at the fault, while the deformation or strain produced by the tectonic stress is stored as elastic strain energy within the rocks. When the stress exceeds the strength of the rock at the fault, the fault slips or ruptures, and the rocks on either side slide past each other and spring back to a relaxed position. The stored energy is then released partly as heat and partly as seismic waves; the sudden release of energy generates an earthquake.

A primary effect of earthquakes is ground shaking produced by the passage of seismic waves through the ground. Ground shaking is responsible for most of the damage caused by large earthquakes. The extent of damage to structures is related to the type and quality of construction, and foundation materials. Building codes have been periodically revised to account for our current understanding of how earthquake shaking can damage buildings.

Earthquake-generating, or coseismic, fault ruptures originate at depths from a few to many miles below the ground surface. In smaller earthquakes, the fault displacement is generally confined to the subsurface, but in larger earthquakes (usually greater than about $M_w$ 6.5), the fault may rupture all the way to the surface, producing displacements of natural and man-made features that overlie the fault. Such "surface rupture" displacements can be from a few inches to tens of feet.

Earthquake ground shaking has the potential to trigger secondary effects that can pose a hazard to people and structures. Liquefaction is the loss of strength of unconsolidated sediments due to seismic forces. Liquefaction generally occurs when seismically induced ground shaking causes pore water pressure to increase to a point equal to the weight of the overlying soil and rock above the water table. Liquefaction can cause the failure of building foundations and other facilities because of the reduction of foundation bearing strength.

Earthquake-triggered landslides are another secondary effect of ground shaking. Earthquake-triggered landsliding is dependent, among other things, on underlying geology, slope, and ground saturation. Earthquake shaking and surface fault rupture can generate disturbance in water bodies as well. Tsunamis, or seismic sea waves, are commonly produced when a fault ruptures the sea floor and displaces the water above the fault. Tsunamis can travel across entire oceans. Seiches develop when passing seismic waves induce standing waves in enclosed water bodies, such as lakes and reservoirs.

Further information on earthquake effects is included in the discussion of the study areas.

#### *17.2.1.4 Earthquakes in California*

Earthquakes are detected every day in California by sensitive seismographs that record the very small vibrations of the earth. Each year, 100 to 150 earthquakes occur in the state that are big enough to be felt, but few of these cause damage. Earthquakes large enough to cause moderate damage to structures in the vicinity of the epicenter – those of $M_w$ 5 or larger – occur three or four times a year (CGS, 2003).

On an average of once every 2 or 3 years, a moderate earthquake ($M_w$ 6 to 6.9) strikes somewhere in the state. An earthquake of this size, such as the Northridge (Southern California) earthquake of January 17, 1994 ($M_w$ 6.7) or the Coalinga (central California) earthquake of May 2, 1983 ($M_w$ 6.5) is capable of causing major damage if the epicenter is near a densely populated area (CGS, 2003).

Major earthquakes ($M_w$ 7 to 7.9) occur in California approximately every 10 years. Two recent major earthquakes, the Landers (San Bernardino County) earthquake of June 28, 1992 ($M_w$ 7.3) and the Hector Mine (San Bernardino County) earthquake of October 16, 1999 ($M_w$ 7.1) caused extensive surface fault rupture but relatively little damage because they occurred in lightly populated areas of the Mojave Desert. Earthquakes of similar size such as the $M_w$ 6.9 Loma Prieta (Santa Cruz County) earthquake of October 17, 1989, can cause extensive damage over large areas when they occur in densely populated regions. The two largest crustal earthquakes in California, the Fort Tejon (Kern County) earthquake of

1857 and the San Francisco earthquake of 1906, were similar in magnitude ($M_w$ 7.9 and $M_w$ 7.8, respectively) and resulted from movement along the San Andreas fault. Earthquakes of this size ($M_w$ 7.7 to 7.9) can cause more extensive damage over a larger area than the $M_w$ 7.1 to 7.4 earthquakes that have stricken California in recent decades (CGS, 2003).

Great earthquakes ($M_w$ 8 and larger) have not occurred in California in historic time, but a great ($M_w$ 9) earthquake occurred January 26, 1700 on the Cascadia subduction zone, which extends north from Cape Mendocino to British Columbia. An earthquake of this size is similar to the 2004 $M_w$ 9.2 Sumatra-Andaman earthquake that generated a tsunami that killed 230,000 people. An $M_w$ 9 megathrust earthquake on the Cascadia subduction zone is capable of producing extensive damage over a very broad region (CGS, 2003).

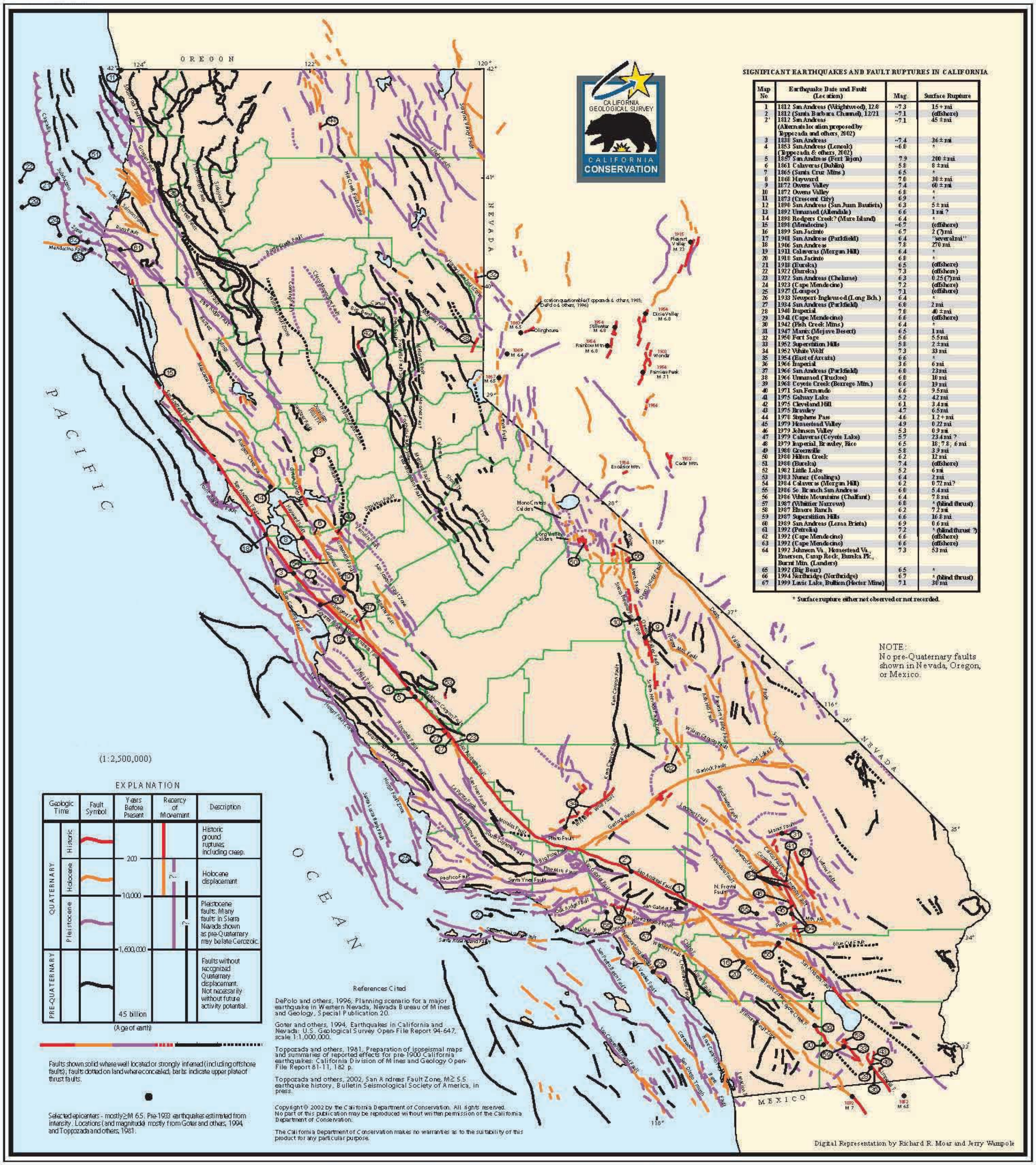
### 17.2.2 Extended Study Area

The modern tectonic setting of California is dominated by the transform plate boundary contact between the Pacific and North American plates south of the Mendocino triple junction. The Pacific Plate moves north-northwest at a rate of about 2 inches per year relative to the North American Plate (DeMets et al., 1994). Initially, since about 148 Ma, this boundary was a convergent boundary with the Farallon Plate subducting beneath the North American Plate until, beginning about 17 to 29 Ma, the Farallon Plate was consumed and the plate boundary changed from an east-dipping subduction zone to a dextral transform margin (Atwater and Stock, 1998). Remnants of the Farallon Plate still exist as the Gorda and Juan de Fuca plates that are subducting under the Pacific Northwest, north of Cape Mendocino, at the Cascadia subduction zone.

The right-lateral, northwest-striking San Andreas fault system in the study area consists of the San Andreas fault and a series of sub-parallel right-lateral faults, including the Bartlett Springs and Maacama faults (Figures 17-1 and 17-2). This system accommodates about 75 to 80 percent of the total relative motion between the Pacific Plate and stable North America. East of the Coast Ranges, the Great Valley and the adjacent Sierra Nevada form a relatively stable crustal block, the Sierran microplate, the western edge of which is coincident with the western margin of the Great Valley (Hill et al., 1991). This region is referred to as the Coast Ranges-Sierran Block (CRSB) boundary zone (Wong and Ely, 1983; Wong et al., 1988), where compressional deformation occurs (Unruh and Moores, 1992; Unruh and Lettis, 1998). High slip-rate faults associated with the San Andreas fault system lie to the west of this boundary zone. The California faults outside the San Andreas fault system generally have much lower rates of movement, and correspondingly longer times between significant earthquakes.

### 17.2.3 Secondary Study Area

Earthquakes are a regional phenomenon. Earthquakes within the Secondary Study Area could have potential effects on Sites Reservoir Project (Project) features within the Primary Study Area. Although this discussion addresses faults and seismicity within the Secondary Study Area, their location relative to the Primary Study Area has been included.




| Map No | Earthquake Date and Fault (Location) | Mag. | Surface Rupture |
|---|---|---|---|
| 1 | 1812 San Andreas (Wrightwood), 12/8 | ~7.3 | 15+ mi |
| 2 | 1812 (Santa Barbara Channel), 12/21 | ~7.1 | (offshore) |
| 2' | 1812 San Andreas (Alternate location proposed by Toppozada and others, 2002) | ~7.1 | 45 ± mi |
| 3 | 1838 San Andreas | ~7.4 | 36 ± mi |
| 4 | 1853 San Andreas (Lonoak) (Toppozada & others, 2002) | ~6.0 | * |
| 5 | 1857 San Andreas (Fort Tejon) | 7.9 | 200 ± mi |
| 6 | 1861 Calaveras (Dublin) | 5.8 | 8 ± mi |
| 7 | 1865 (Santa Cruz Mtns.) | 6.5 | * |
| 8 | 1868 Hayward | 7.0 | 30 ± mi |
| 9 | 1872 Owens Valley | 7.4 | 60 ± mi |
| 10 | 1872 Owens Valley | 6.8 | * |
| 11 | 1873 (Crescent City) | 6.9 | * |
| 12 | 1890 San Andreas (San Juan Bautista) | 6.3 | 5 ± mi |
| 13 | 1892 Unnamed (Allendale) | 6.6 | 1 mi ? |
| 14 | 1898 Rodgers Creek? (Mare Island) | 6.4 | * |
| 15 | 1898 (Mendocino) | ~6.7 | (offshore) |
| 16 | 1899 San Jacinto | 6.7 | 2 (?) mi |
| 17 | 1901 San Andreas (Parkfield) | 6.4 | "several mi" |
| 18 | 1906 San Andreas | 7.8 | 270 mi |
| 19 | 1911 Calaveras (Morgan Hill) | 6.4 | * |
| 20 | 1918 San Jacinto | 6.8 | * |
| 21 | 1918 (Eureka) | 6.5 | (offshore) |
| 22 | 1922 (Eureka) | 7.3 | (offshore) |
| 23 | 1922 San Andreas (Cholame) | 6.3 | 0.25 (?) mi |
| 24 | 1923 (Cape Mendocino) | 7.2 | (offshore) |
| 25 | 1927 (Lompoc) | 7.1 | (offshore) |
| 26 | 1933 Newport-Inglewood (Long Bch.) | 6.4 | * |
| 27 | 1934 San Andreas (Parkfield) | 6.0 | 2 mi |
| 28 | 1940 Imperial | 7.0 | 40 ± mi |
| 29 | 1941 (Cape Mendocino) | 6.6 | (offshore) |
| 30 | 1942 (Fish Creek Mtns.) | 6.4 | * |
| 31 | 1947 Manix (Mojave Desert) | 6.5 | 1 mi |
| 32 | 1950 Fort Sage | 5.6 | 5.5 mi |
| 33 | 1952 Superstition Hills | 5.8 | 2 ± mi |
| 34 | 1952 White Wolf | 7.3 | 33 mi |
| 35 | 1954 (East of Arcata) | 6.6 | * |
| 36 | 1966 Imperial | 3.6 | 6 mi |
| 37 | 1966 San Andreas (Parkfield) | 6.0 | 23 mi |
| 38 | 1966 Unnamed (Truckee) | 6.0 | 10 mi |
| 39 | 1968 Coyote Creek (Borrego Mtn.) | 6.6 | 19 mi |
| 40 | 1971 San Fernando | 6.6 | 9.5 mi |
| 41 | 1975 Galway Lake | 5.2 | 4.2 mi |
| 42 | 1975 Cleveland Hill | 6.1 | 3.4 mi |
| 43 | 1975 Brawley | 4.7 | 6.5 mi |
| 44 | 1978 Stephens Pass | 4.6 | 1.2+ mi |
| 45 | 1979 Homestead Valley | 4.9 | 0.22 mi |
| 46 | 1979 Johnson Valley | 5.3 | 0.9 mi |
| 47 | 1979 Calaveras (Coyote Lake) | 5.7 | 23.4 mi ? |
| 48 | 1979 Imperial, Brawley, Rico | 6.5 | 18; 7.8; .6 mi |
| 49 | 1980 Greenville | 5.8 | 3.9 mi |
| 50 | 1980 Hilton Creek | 6.2 | 12 mi |
| 51 | 1980 (Eureka) | 7.4 | (offshore) |
| 52 | 1982 Little Lake | 5.2 | 6 mi |
| 53 | 1983 Nunez (Coalinga) | 6.4 | 2 mi |
| 54 | 1984 Calaveras (Morgan Hill) | 6.2 | 0.72 mi? |
| 55 | 1986 So. Branch San Andreas | 6.0 | 5.4 mi |
| 56 | 1986 White Mountains (Chalfant) | 6.4 | 7.8 mi |
| 57 | 1987 (Whittier Narrows) | 6.0 | * (blind thrust) |
| 58 | 1987 Elmore Ranch | 6.2 | 7.2 mi |
| 59 | 1987 Superstition Hills | 6.6 | 16.8 mi |
| 60 | 1989 San Andreas (Loma Prieta) | 6.9 | 0.6 mi |
| 61 | 1992 (Petrolia) | 7.2 | * (blind thrust ?) |
| 62 | 1992 (Cape Mendocino) | 6.6 | (offshore) |
| 63 | 1992 (Cape Mendocino) | 6.6 | (offshore) |
| 64 | 1992 Johnson Va., Homestead Va., Emerson, Camp Rock, Eureka Pk., Burnt Mtn. (Landers) | 7.3 | 53 mi |
| 65 | 1992 (Big Bear) | 6.5 | * |
| 66 | 1994 Northridge (Northridge) | 6.7 | * (blind thrust) |
| 67 | 1999 Lavic Lake, Bullion (Hector Mine) | 7.1 | 30 mi |

Compiled by Charles W. Jennings and George J. Saucedo
1999 (Revised 2002, Tousson Toppozada and David Branum)

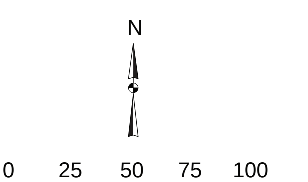
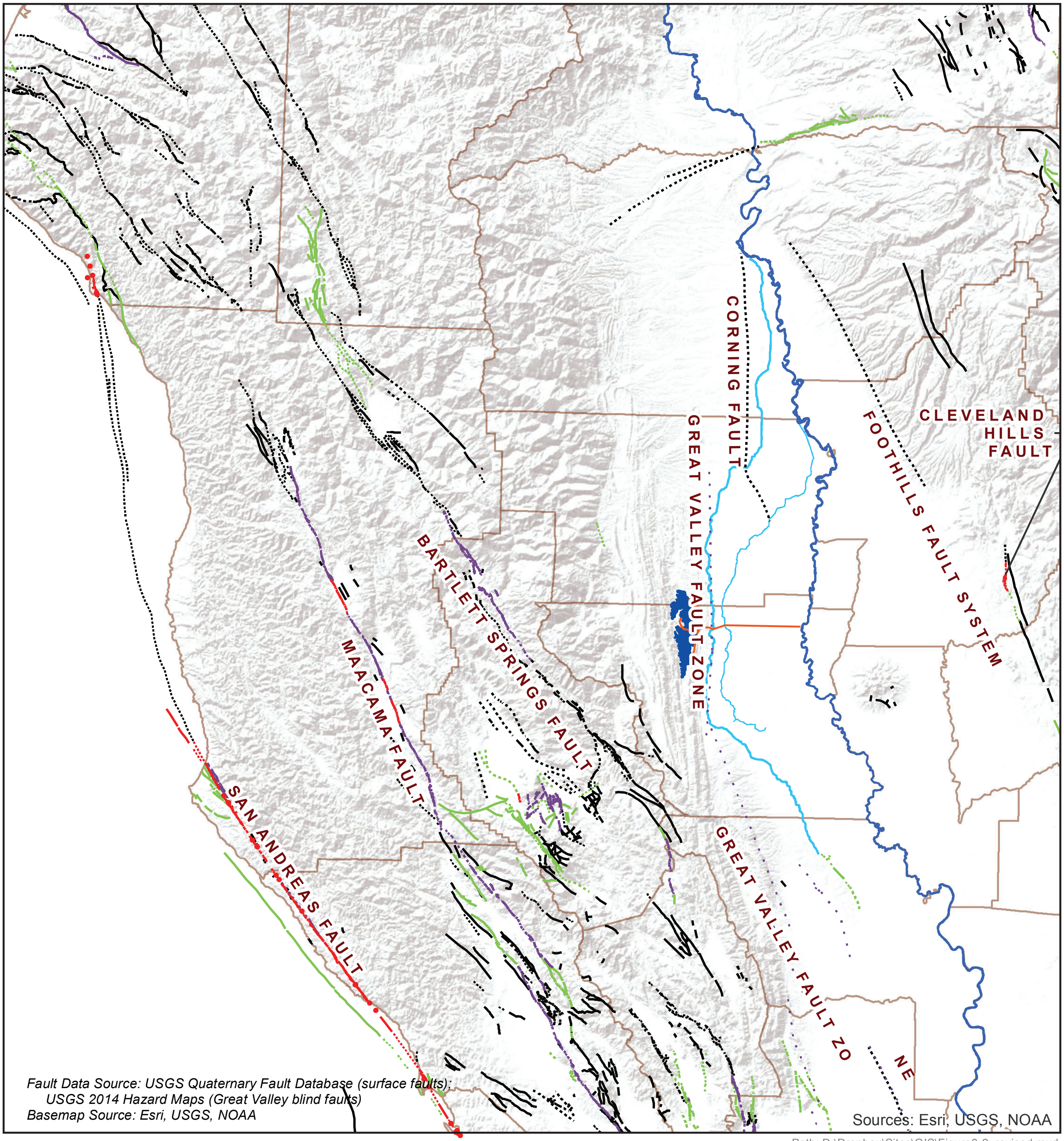



**FIGURE 17-1**
**Simplified Fault Activity in California**
*Sites Reservoir Project EIR/EIS*

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**Legend**

**QuaternaryFaults**

- Historic Displacement (Last 200 Years)
- Holocene Displacement (Last 11,000 Years)
- Late Quaternary Displacement (Last 750,000 years)
- Undivided Quaternary Displacement (Last 1,600,000 Years)
- Sites/Delevan Overhead Power Line
- Rivers
- Sites Reservoir
- Canal
- County Boundary

0 5 10 20 30 40 50 Miles

N

**FIGURE 17-2**
**Regional Faults**
*Sites Reservoir Project EIR/EIS*

Table 17-3 lists the locations of active faults and potentially active faults significant to the Secondary Study Area due to proximity, activity status, date of most recent motion, and maximum magnitude (Mmax).[2] Figure 17-2 shows the active and potentially active faults within the Secondary Study Area that could affect the operation of the Project.

**Table 17-3**
**Regional Faults in the Secondary Study Area**

| Fault | Fault Type | Recency of Movement | Fault Classification | Mmax ($M_w$) | Closest Distance from proposed Sites Reservoir (mi) |
|---|---|---|---|---|---|
| San Andreas | Strike Slip | Holocene | Active | ~8.0 | 71 |
| Maacama | Strike Slip | Holocene | Active | 7.5 | 46 |
| Bartlett Springs | Strike Slip | Holocene | Active | 7.3 | 21 |
| Collayomi | Strike Slip | Late Quaternary | Conditionally Active | 6.5 | 36 |
| Cross Spring | Normal | Late Quaternary to Quaternary | Conditionally Active | 6.5 | 21 |
| Resort | Normal/Oblique | Quaternary | Conditionally Active | 6.7 | 12 |
| Coast Range | Normal or Thrust | Late Pliocene | Not Active | Not characterized | 12 |
| Green Valley | Thrust | Pre-Late Quaternary | Not Active | Not characterized | 8 |
| Stony Creek | Thrust | Pre-Quaternary | Not Active | Not characterized | 12 |
| Great Valley/CRSB | Blind Thrust | Holocene | Active | 6.8 | 4 |
| Paskenta | Normal | Late Pliocene | Not Active | Not characterized | 23 |
| Corning | Reverse | Late Quaternary | Active | 6.7 | 18 |
| Willows | Reverse | Quaternary | Conditionally Active | 6.7 | 15 |
| Foothills Fault System | Normal/Oblique | Holocene | Active | 6.5 | |
| Cascadia Subduction Zone | Megathrust | Holocene | Active | ~9 | ~100 |
| Cascadia Subduction Zone | Slab | Holocene | Active | 7.5 | ~50 |

Notes:

CRSB = Coast Ranges-Sierran Block
mi = miles
Mmax = maximum magnitude
$M_w$ = moment magnitude

The pre-Quaternary Green Valley thrust fault should not be confused with the Holocene Green Valley strike-slip fault

Sources: William Lettis & Associates, 2002; Working Group for California Earthquake Probabilities (WGCEP), 2008; Field et al., 2013.

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[2] The Mmax is the strongest earthquake that is likely to be generated along a fault. It is based on historical data or calculated from empirical relationships between magnitude and fault geometry (surface rupture length or rupture area), which are all related to the physical size of fault rupture and displacement across a fault.

### *17.2.3.1 Seismotectonic Setting*

The right-lateral San Andreas fault system forms the boundary between the North American and Pacific plates. The San Andreas fault, the principal element of the San Andreas fault system, extends from Cape Mendocino to the Salton Sea. This 700-mile-long network of faults is generally believed to be segmented such that the entire fault does not rupture in a single earthquake (WGCEP, 2008). The closest section to the Project area is the North Coast section. The San Andreas fault has experienced significant activity during historical time, most recently during the 1989 Loma Prieta Earthquake ($M_w$ 6.9), which resulted in widespread damage throughout the Bay Area. Prior to that, the rupture of the northernmost San Andreas fault from near San Juan Bautista to the triple junction in Cape Mendocino, a length of 296 miles, produced the 1906 San Francisco earthquake (estimated at $M_w$ 7.9).

Several right-lateral strike-slip faults of the San Andreas fault system, including the high-slip-rate Maacama fault and the Bartlett Springs fault, are sub-parallel and east of the San Andreas fault. Both faults have been active in Holocene time. The Maacama fault is the northern extension of the Hayward-Rodgers Creek fault zone and slips at a comparable rate of about .5 inch per year. Some of the slip on the Maacama fault is released gradually as aseismic creep, but the fault also produces earthquakes up to $M_w$ 7.5 (WGCEP, 2008; Field et al., 2013; URS Corporation [URS], 2013). The Bartlett Springs fault, east of the Maacama fault, slips at about .25 inch per year. Recent analyses suggest that it may be linked to the Hunting Creek, Berryessa, and Green Valley strike-slip faults, allowing longer ruptures than previously recognized. It too may have earthquakes up to about $M_w$ 7.4 (Lienkaemper, 2010, 2012). The CGS has published several Alquist-Priolo maps along both of these faults.

A number of smaller active and conditionally active faults occur within the Coast Ranges around the Bartlett Springs and Maacama faults, including Collayomi, Cross Spring, and Resort faults. These faults have activity levels at least 10 times lower than those of the San Andreas, Maacama, and Bartlett Springs faults, and earthquakes on them are likely to be in the $M_w$ 6 rather than $M_w$ 7 range. Farther east, several inactive faults (Coast Range Fault, Green Valley Thrust, Stony Creek Thrust) occur at or near the contact between the Franciscan Formation and the Great Valley Sequence. Movement along these fault planes is generally attributed to eastward compression of the Coast Range and slippage along bedding planes. These three faults are considered not active (William Lettis & Associates, 1997; 2002).

The Great Valley fault zone is a series of low-angle blind thrust faults located along the west side of the Sacramento and San Joaquin valleys. The fault planes dip west under the Coast Ranges, projecting at low angles up toward the Great Valley. It is a primary structure of the CRSB boundary zone. It underlies the Primary Study Area, approximately 4 to 7 miles below the surface, and extends east of the site, projecting toward but not reaching the surface. The Great Valley fault zone is not a single through going fault but includes multiple small segments that likely rupture independently, producing moderate to large earthquakes (~$M_w$ 6.5 to 7). The segment of the Great Valley fault zone nearest to the Primary Study Area is active and may produce earthquakes up to $M_w$ 6.8. Historically, seismic activity has occurred along the Great Valley fault zone in the Sacramento Valley, notably the 1889 Antioch earthquake ($M_w$ 6) and the 1892 Winters earthquake ($M_w$ 6+). In addition, a swarm of small earthquakes ($M_w$ 3.6 to $M_w$ 4.0) occurred in the region of Maxwell and Williams in late 1943 that are believed to have originated along the Great Valley fault zone.

The Corning Fault is a blind reverse fault located west of the Sacramento River and east of the Primary Study Area and extending from Red Bluff southward into Glenn County (Figure 17-2). The fault trace is not visible on the surface. Based on evidence of uplifting and folding of the late Pleistocene Modesto

Formation across the trace of the fault, the Corning fault is considered active. The Corning fault may be linked with the Willows fault that extends southward through the Sacramento Valley to near Stockton (Harwood and Helley, 1987; William Lettis & Associates, 2002) and passes about 15 miles east of the Project site. The CGS considers the Willows fault to be pre-Quaternary, but it is associated with seismicity and is, therefore, potentially active (Wong, 1992).

The Foothills fault system is located east of the Sacramento Valley at the edge of the Sierra foothills, and comprises a suite of Mesozoic reverse faults, some of which have been reactivated in the late Cenozoic, including some in the Quaternary, as normal or normal-oblique-slip faults (LaForge and Ake, 1999; Page and Sawyer, 2001). The fault system is complex and discontinuous, with most faults being less than 15 miles long, suggesting that earthquakes on the faults will be moderate, no larger than $M_w$ 6.5. The faults have very low activity rates. The Cleveland Hills Fault is a normal fault within the Foothills fault system located south of Lake Oroville. In 1975, several earthquakes occurred along the fault; the greatest event was $M_L$ 5.7. The earthquakes are believed to have been triggered by the presence of Lake Oroville. Surface rupturing along the fault line occurred for several miles.

The Cascadia subduction zone is the boundary between the subducting Pacific Plate and the North American Plate. Its closest occurrence to the Primary Study Area is approximately 150 miles west-northwest offshore of Northern California, north of Cape Mendocino. The zone extends north offshore of Oregon, Washington, and southern Canada. Geological investigations (Atwater et al., 1995; Nelson et al., 1995), geophysical modeling (Fluck et al., 1997; Hyndman and Wang, 1995), and historical tsunami records from Japan (Satake et al., 1996) provide the basis for the current scientific consensus that the Cascadia subduction zone has the potential to generate earthquakes that may rupture the entire 700-mile length of the plate boundary, with seismic events exceeding $M_w$ 9. Smaller earthquakes, rupturing only a portion of the plate boundary, may also occur. The most recent great earthquake is inferred to have taken place in January 1700, based on tree ring evidence and Japanese tsunami records. Paleoseismic data indicate that earthquakes of this size may occur every 500 to 530 years, on average. Sediment cores obtained off the coast suggest that smaller events (~$M_w$ 8), rupturing only Northern California or southern Oregon, may occur more frequently (Goldfinger et al., 2012). A still smaller earthquake, the 1992 Cape Mendocino earthquake ($M_w$ 7.2), is the most recent earthquake to occur on the Cascadia subduction zone. The Cascadia subduction zone also produces large (~$M_w$ 7) earthquakes within the subducting plate, which can occur as deep as 50 miles below the surface.

Figure 17-3 shows the locations of earthquakes within the Secondary Study Area. The majority of the historical seismic activity is associated with movement along the Bartlett Springs and Maacama faults west of the Primary Study Area. The concentration of seismicity to the northwest is associated with the Mendocino triple junction. Earthquake hazards are greater there because that region is part of the Cascadia subduction zone. A cluster of minor to moderate seismic events in the Oroville area is associated with the Cleveland Hill Fault. Additional minor seismicity occurs throughout the Secondary Study Area, and is generally attributed to compressional forces between the Coast Range geomorphic province and the Great Valley geomorphic province.

#### *17.2.3.2 Seismic Ground Shaking*

The CGS produced an Earthquake Shaking Potential for California Map (CGS, 2008). The map indicates that seismic shaking potential in the Secondary Study Area ranges from low to high, with the highest potentials existing along the San Andreas fault and other faults in the Coast Range and Southern California.

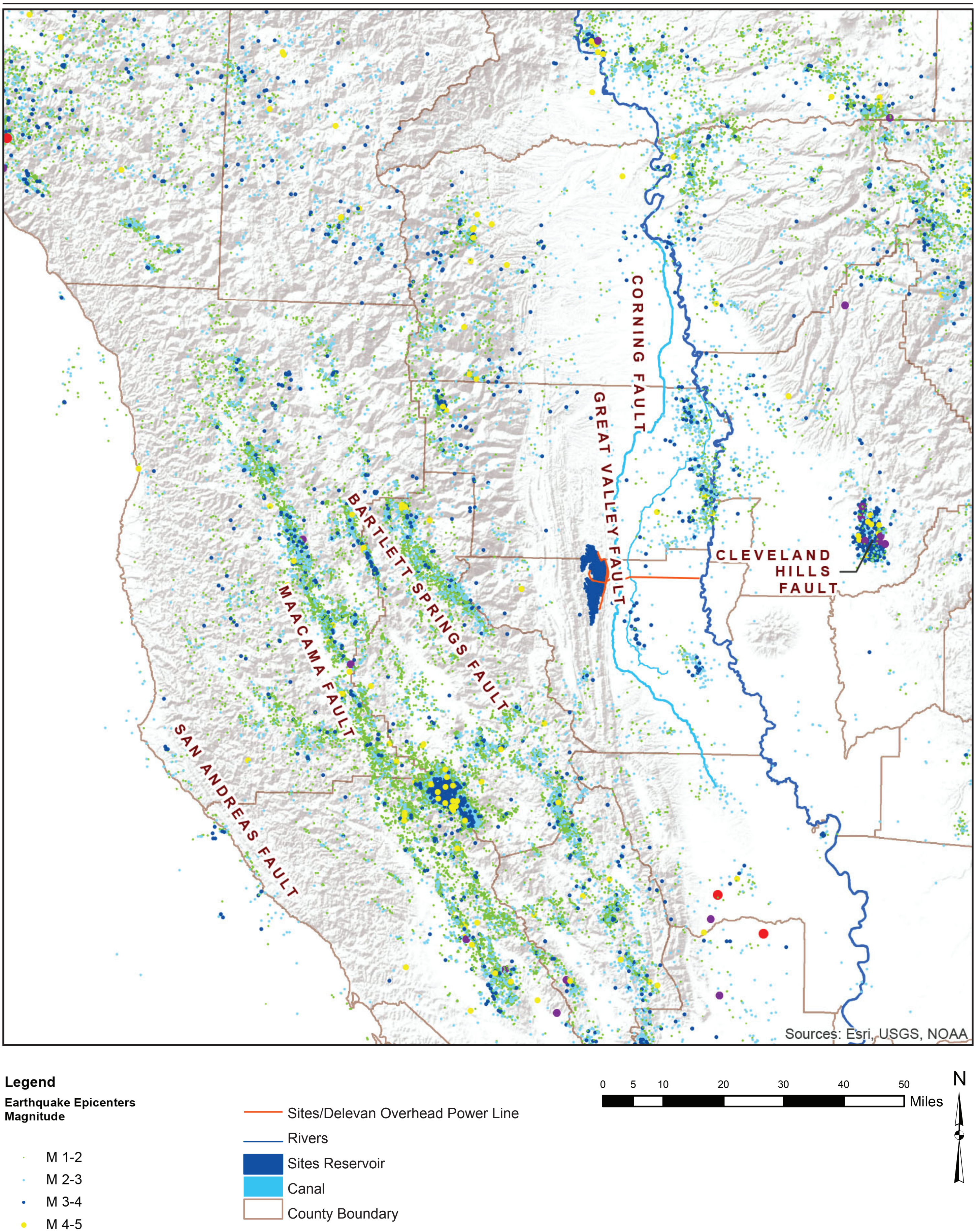



**FIGURE 17-3**
**Regional Seismicity**
*Sites Reservoir Project EIR/EIS*

This pattern is also reflected in the maps of earthquake participation rates developed in the most recent Uniform California Earthquake Rupture Forecast (UCERF3), which highlights the high rates of participation for faults within the San Andreas fault system, moderate rates along the CRSB boundary zone, and low rates within the Sacramento Valley.

#### *17.2.3.3 Liquefaction*

The U.S. Geological Survey (USGS) has produced numerous maps of areas within the Secondary Study Area showing liquefaction potential (USGS, 1996a). Many areas, such as artificial fill adjacent to the San Francisco Bay, have a high liquefaction potential.

#### *17.2.3.4 Landslides*

The CGS has produced numerous maps showing landslide features and delineating potential slope-stability problem areas (CGS, 2011a). Many areas within the Secondary Study Area have high landslide susceptibility (CGS, 2011b).

#### *17.2.3.5 Reservoir-triggered Seismicity*

Reservoir-triggered seismicity (RTS) is a phenomenon in which earthquakes are triggered by the filling of a reservoir or by water-level changes during reservoir operation. The phenomenon was reported as early as the 1940s following the impoundment of Lake Mead. Shortly after Lake Mead reached its maximum elevation in 1936, numerous earthquakes, up to $M_L$ 5, began occurring around the reservoir. In the first 10 years after the reservoir was filled, more than 6000 earthquakes were recorded within 10 miles of Hoover Dam where none had been recorded in the previous 15 years (Rogers, 2010; Carder, 1945). Earthquake frequency correlated somewhat with changing reservoir levels. Since 1966, seismicity levels around Lake Mead are no different from in the surrounding area.

Since the Lake Mead observations, RTS has been identified at dam sites all over the world, and it is recognized as a potential hazard for large dams. Accordingly, numerous efforts have been made to understand the mechanisms of RTS and identify the factors that contribute to it to assess the likelihood of occurrence after impoundment of a reservoir. RTS has been documented at over 100 reservoirs in the world, with dozens more questionably associated (Gupta, 2002; Woodward-Clyde Federal Services, 1996). However, this is a small number compared to the 11,000 "large" dams in the world. Some of the most well-known cases are at Koyna Dam in India, Aswan Dam in Egypt, Kariba Dam in Zambia, Hsinfengiang Dam in China, and Kremasta Dam in Greece. Only four RTS events have been larger than $M_w$ 6; the largest was an $M_w$ 6.3 event in 1967 triggered by the Koyna Dam reservoir. Within the Secondary Study Area, several reservoirs, including Shasta Lake, Lake Oroville, Lake Berryessa, and Del Valle Reservoir have been suspected of creating RTS (Wong and Strandberg, 1996). The area around the 525-foot-deep Shasta Lake, at the northern end of the Sacramento Valley, experienced an increase in seismicity following the initiation of filling in 1944. Some studies concluded there was no RTS (Hawkins et al., 1986), but others accept it as a case (William Lettis & Associates, 2002; MWH, 2013). Shasta Lake was recently reevaluated to assess the probability of RTS (Knudsen et al., 2009). Knudsen et al. (2009) found that although the seismicity near the reservoir is still equivocal with respect to RTS, a probabilistic assessment indicates that there is a 54 percent conditional probability that Shasta Lake could generate RTS based on its site characteristics.

No elevated seismicity was observed at Lake Oroville following initial impoundment, but 7 years later, in 1975, following reservoir drawdown, a series of earthquakes occurred, culminating in an M 5.7 earthquake on the Cleveland Hills fault, a normal fault. Seismicity rates decreased following the aftershock sequence. Lake Berryessa, impounded by Monticello Dam, is located in the Coast Ranges and experienced RTS in the years immediately following filling. It is considered a questionable case of RTS (Wong and Strandberg, 1996). Del Valle Reservoir, in the Livermore Valley, a relatively shallow (207 feet) reservoir impounded in 1969, generated a swarm of earthquakes near the reservoir in 1980 and 1986, following rapid and large inflows of water into the reservoir and has been accepted as a case of RTS (Knudsen et al., 2009). The largest event in the triggered swarms was $M_L$ 4.0.

RTS is discussed in more detail in Section 17.2.4.7.

## 17.2.4 Primary Study Area

### *17.2.4.1 Methodology*

William Lettis & Associates (2002) completed a Phase II Fault and Seismic Hazards Investigation for the NODOS Integrated Storage Investigations The report focused on the area around the proposed Sites Reservoir, particularly the proposed dam sites, and is the primary source of information presented for the Primary Study Area in this chapter.

### *17.2.4.2 Surface Fault Rupture Potential*

No faults of known Holocene age occur within the Primary Study Area. The Great Valley fault zone, which underlies the study area, is known to have ruptured in the Holocene farther to the south, but Holocene displacement of the segment in the Primary Study Area is uncertain. No Alquist-Priolo Act maps have been published for areas within the Primary Study Area.

The Phase II Fault and Seismic Hazards Investigation for the NODOS Integrated Storage Investigations (William Lettis & Associates, 2002) identified several faults in proximity to the proposed Sites Reservoir and the Sites and Golden Gate dam sites (Table 17-4).

**Table 17-4**
**Faults in Proximity to the Proposed Sites Reservoir and Sites and Golden Gate Dam sites**

| Fault | Fault Length | Sense of Displacement | Fault Separation (horizontal) | Fault Separation (vertical) | Fault Zone Width (in trench) | Nearest Distance to Golden Gate Dam site | Nearest Distance to Sites Dam site | Time of Last Movement[a] |
|---|---|---|---|---|---|---|---|---|
| GG-1 | 1.1 miles | Right-lateral | 246 ±82 feet | Unknown | 2 feet | < 0.5 mile | 3.1 miles | Holocene deposits unfaulted |
| GG-2[b] | 3.7 miles | Right-lateral | 1,312 ±196/-98 feet | Unknown | 2 feet | < 0.5 mile | 1.7 miles | Holocene deposits unfaulted |
| GG-3 | 3.0 miles | Right-lateral | 1,574 ±65 feet | Unknown | 2 feet | < 0.5 mile | 0.4 mile | Early Holocene deposits unfaulted |
| S-2[c] | 2.4 miles | Right-lateral | 558 ±164/-180 feet | None | 3 feet | 2.2 miles | < 0.5 mile | Early Holocene deposits unfaulted |
| S-3 | Unknown | Thrust (east side up) | Unknown | Unknown | 6 feet | 600 feet | 0.9 mile | Older than, and offset by, Faults S-2, GG-3 |
| Salt Lake Thrust Fault | > 7 miles | Thrust (east side up) | Unknown | > 10 feet | 2 feet | 1.7 miles | 0.9 mile | Pleistocene gravels offset |

[a]Youngest faulted or oldest deposits that cross the fault are given.

[b]Fault GG-2 would be located within the footprint of the Golden Gate Dam proposed for the 1.8-MAF reservoir.

[c]Fault S-2 would be located within the footprint of the Sites Dam proposed for the 1.8-MAF reservoir.

Source: William Lettis & Associates, 2002.

The Funks and Bear Valley segments of the Great Valley fault zone underlie both dam sites at a depth of 4 to 7 miles but do not reach the surface. Displacement on the Great Valley fault zone manifests at the surface by folding of the overlying rocks and the presence of secondary surface faults that move to accommodate the deformation. Because the fault is blind and located well below the surface, the potential for primary surface rupture on the Great Valley fault is minimal.

Two major sets of surface faults were also recognized:

1. Northeast-striking high-angle faults cut obliquely across the north-striking bedrock units, and consistently displace stratigraphic contacts in a right-lateral sense. Specific examples of these structures include the informally named GG-1, GG-2, GG-3 and S-2 faults, all of which pass directly through the proposed Sites and Golden Gate dam sites or are located near them (Figure 17-4).

2. North-striking faults are generally parallel to bedding (Figure 17-4). The most laterally continuous example of these structures is the Salt Lake thrust fault, which is parallel to, and east of, the axis of the Sites anticline.[3] The Salt Lake thrust fault is at least 12 miles long, reaching the surface 1 to 2 miles west of the proposed dam sites. The fault dips down to the east, under the dam sites at a depth of about 1 to 2 miles. The surface trace of the fault passes through the site of proposed saddle dam SSD-2.

The northeast-striking GG-1, GG-2, GG-3, and S-2 faults are tear faults accommodating differential deformation of the rocks overlying different sections of the Great Valley thrust fault. Movement along these faults probably occurs as triggered displacement during moderate to large magnitude earthquakes on the underlying Great Valley fault zone, but is not likely to act as an independent seismic source. William Lettis & Associates (2002) concluded that 3 to 8 inches of triggered slip could occur along the northeast-striking GG-1, GG-2, GG-3, and S-2 faults. Fault GG-2 is located within the footprint of the proposed Golden Gate Dam, which would impound the 1.8-MAF Sites Reservoir. Fault S-2 is located within the footprint of the Sites Dam for the 1.8-MAF Sites Reservoir. All four faults would be located outside the footprint of the proposed for the Alternative A 1.3-MAF reservoir (Figures 17-5 and 17-6).

The Salt Lake thrust fault is a backthrust fault, splaying upward from the Great Valley fault zone. The fault likely ruptures as triggered slip during an earthquake on the underlying Great Valley fault and is not an independent source of earthquakes. Trench investigations across the trace of the Salt Lake thrust fault indicated that at least one, and probably three or more, surface ruptures have occurred in the past 30,000 to 70,000 years. If rupture events have a regular recurrence, then the trench evidence indicates that at least one surface rupturing event probably has occurred in the past 35,000 years, and thus the fault would be considered active by DSOD criteria (William Lettis & Associates, 2002). Faulted sediments exposed in trenches excavated across the fault suggest that a maximum of 16 inches of triggered slip could occur on the Salt Lake fault during an earthquake on the Great Valley fault below.

#### *17.2.4.3 Seismic Ground Shaking*

The proposed dam would be under the jurisdiction of the California Department of Water Resources, Division of Safety of Dams (DSOD). For engineering analysis, DSOD requires a deterministic seismic hazard analysis (DSHA). A DSHA yields estimates of the level of ground shaking due to an earthquake occurring on identified faults. The most significant fault for the Primary Study Area is the underlying Great Valley fault zone. William Lettis & Associates (2002) performed a DSHA for the Bear Valley

[3] An anticline is a fold with strata sloping downward on both sides from a common crest.

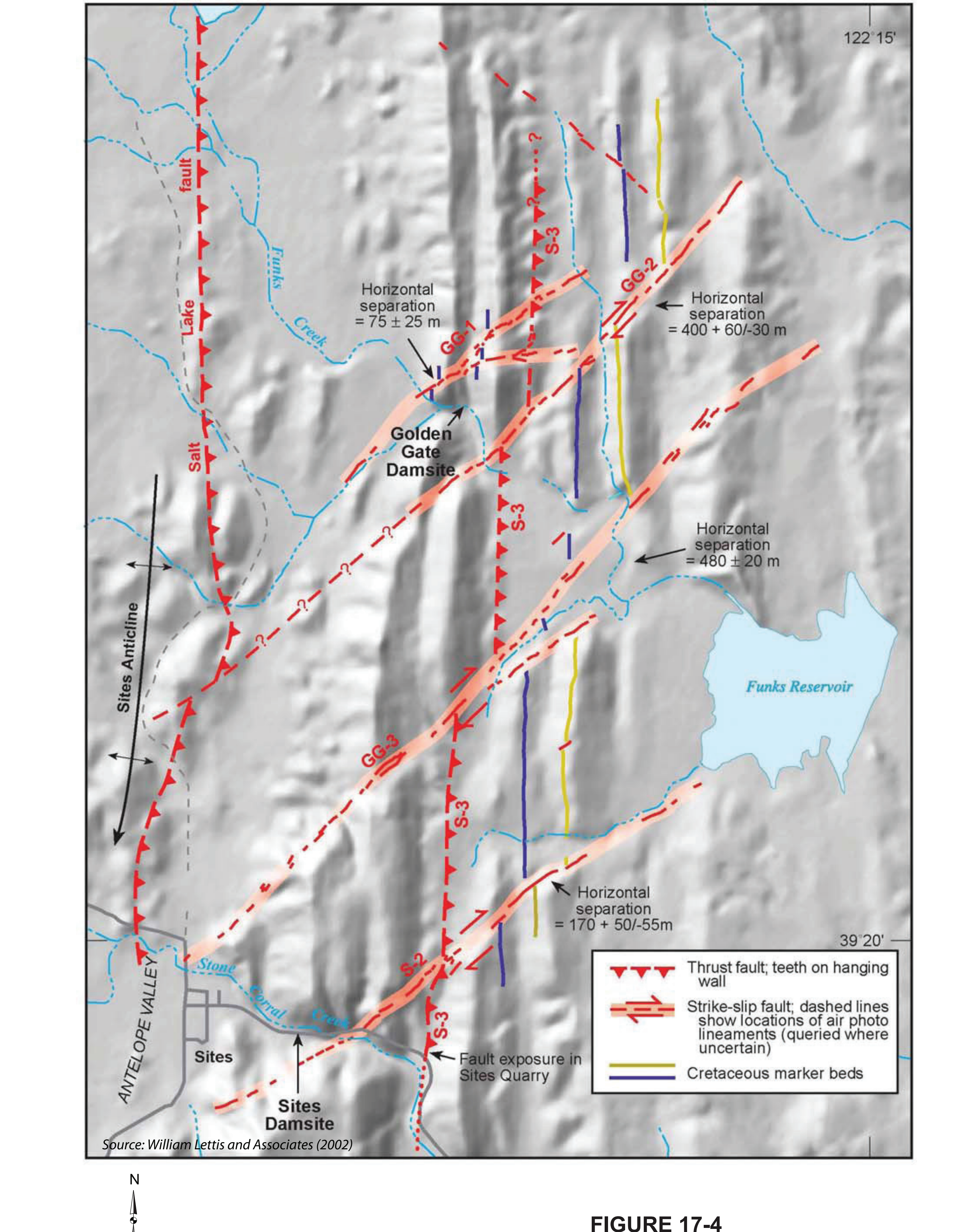
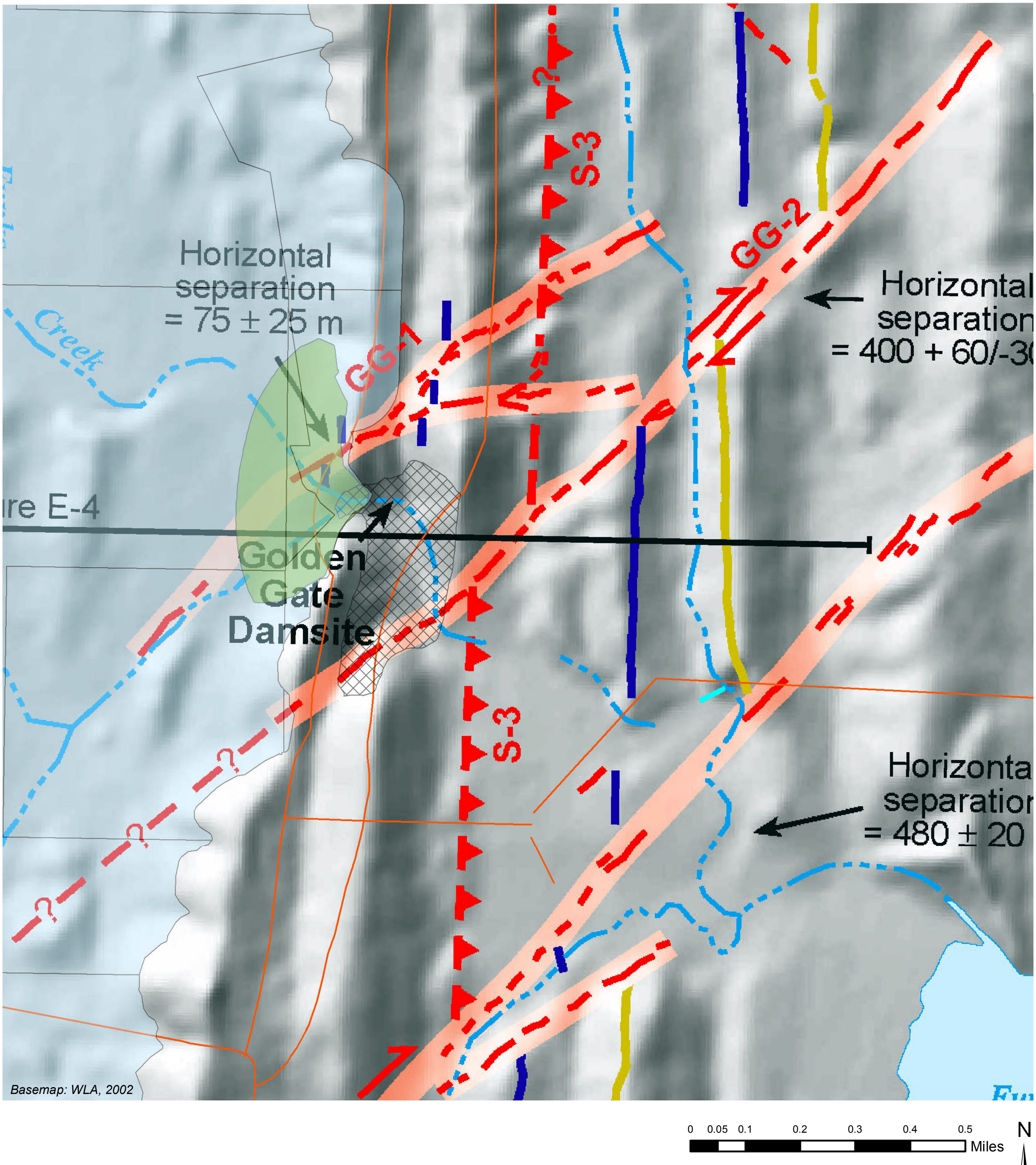



**FIGURE 17-4**
**Faults in the Vicinity of Project Dam Sites**
*Sites Reservoir Project EIR/EIS*




**Legend**

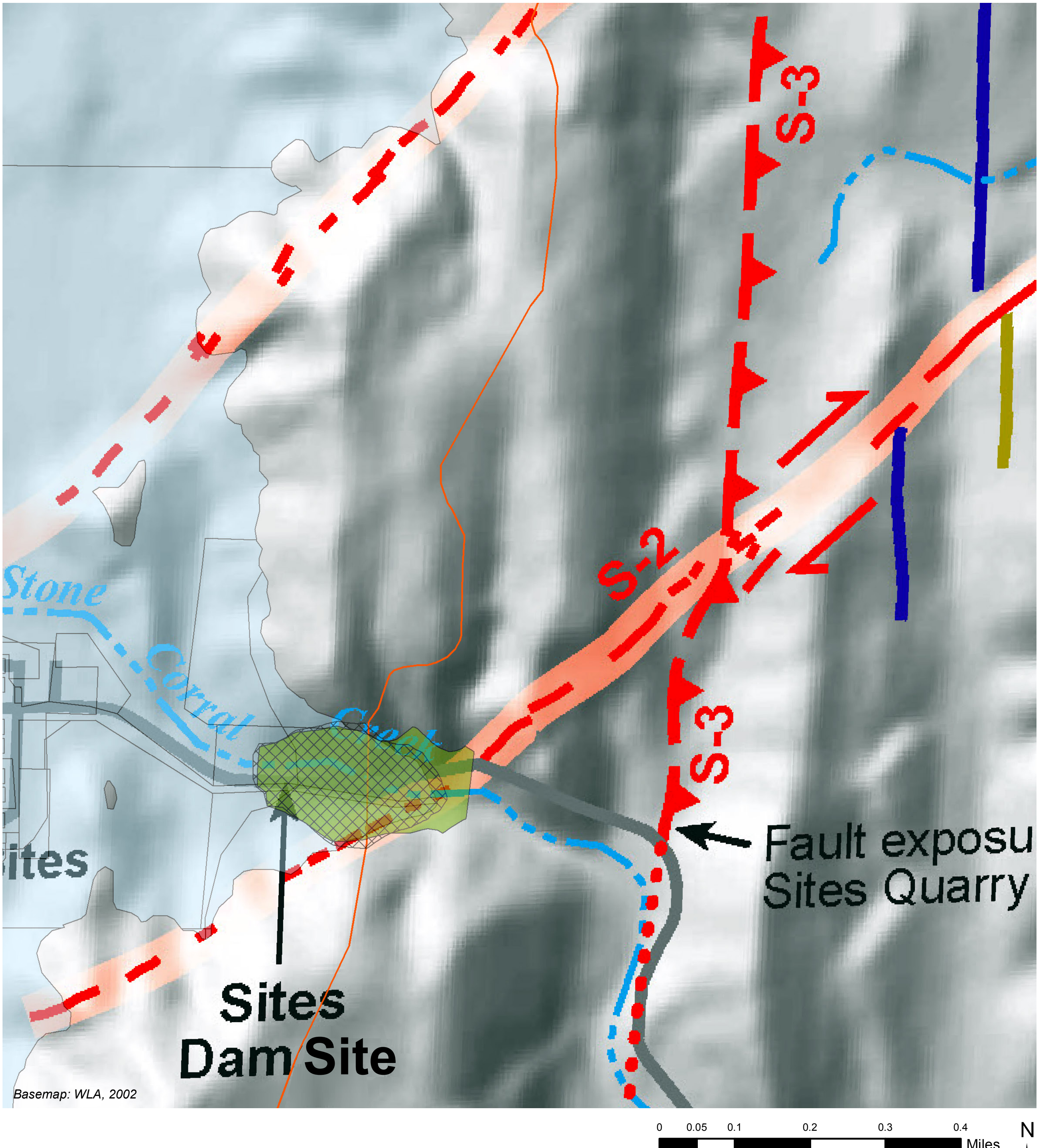
**Golden Gate Dam Footprint**

MAF 1.8

MAF 1.27

**Alternative A Sites Reservoir Footprint**

**FIGURE 17-5**
**Faults near Golden Gate Dam Site**
*Sites Reservoir Project EIR/EIS*




**Legend**

**Golden Gate Dam Footprint**

MAF 1.8

MAF 1.27

**Alternative A Sites Reservoir Footprint**

**FIGURE 17-6**
**Faults near Sites Dam Site**
*Sites Reservoir Project EIR/EIS*

segment of the Great Valley fault zone. This segment, as mapped by William Lettis & Associates (2002) based on surface and subsurface geologic data, is 14 miles long, dips about 21° to the west, and is located at a depth of about 4 to 5 miles beneath the Sites Dam site. The fault rupture would extend from a depth of about 9 miles along the fault plane for a distance of about 14 miles up dip. A fault rupture of this size would produce a likely maximum earthquake of $M_W$ 6.8. The USGS national seismic hazard model (Field et al., 2013) uses a somewhat different geometry for the Great Valley fault zone, with a longer (27 miles), narrower (6 miles), and more gently dipping fault, which yields a similar earthquake magnitude. This geometry is based on considering the entire 27-mile section of fault to have similar rupture behavior, based on similar geomorphic expression at the surface. However, William Lettis & Associates (2002) concluded that, based on their assessment of subsurface data, the fault has discontinuities that limit single earthquake ruptures to smaller sections of the fault. The historical record of earthquakes along other sections of the Great Valley fault zone, which include the 1983 $M_L$ 6.7 Coalinga earthquake, the 1985 $M_L$ 5.8 Kettleman Hills earthquake, and the 1892 $M_L$ ~6.5 Winters-Vacaville earthquake, suggest that the fault generates moderate-sized earthquakes along short rupture segments rather than large earthquakes with ruptures that extend tens of miles. The shorter segment proposed by William Lettis and Associates (2002) was adopted for use in a DSHA.

An updated DSHA was performed using the Next Generation of Attenuation – West2 (NGA-W2) ground motion models, which are the most current ground motions models for active tectonic regions. The DSHA was calculated for a firm rock site condition (time-averaged shear wave velocity in the top 30 meters [100 feet], or $V_s30$, of 760 meters per second [m/sec]). The Bear Valley segment was modeled with a $M_W$ 6.8, a rupture distance of 4.8 miles, a Joyner-Boore distance of 0 mile, reverse faulting, and with the site located in the hanging wall of the fault. For the Great Valley fault zone (Bear Valley segment), the DSHA yields median ground motions characterized by a peak horizontal ground acceleration (PGA) of 0.52 g and the 84th percentile ground motions with a PGA of 0.95 g (where g equals the standard acceleration due to gravity). The median 0.2 second and 1.0 second spectral acceleration (SA) values are 1.17 g and 0.29 g, respectively; the 84th percentile 0.2 second and 1.0 second SA values are 2.25 g and 0.60 g, respectively (Figure 17-7).

In accordance with the DSOD dam consequence-hazard matrix (Fraser and Howard, 2002), the statistical level of design earthquake ground motions for dam analysis depends on the consequence classification of a dam and on the slip rate of the controlling fault(s). The consequence classification is a function of the dam's total class weight, which depends on the dam and reservoir sizes and the hazard associated with the dam. The DSOD consequence-hazard matrix is shown on Figure 17-8. The matrix shows that for extreme consequence dams, the statistical level of ground motion to be used for dam analysis is the 84th percentile level, unless the controlling fault can be assigned to the low slip rate category (i.e., the slip rate is less than 0.1 millimeter per year [mm/yr]). The Great Valley faults in the Primary Study Area have a moderate slip rate according to UCERF3 geologic slip rate data (slip rate of 0.1 mm/yr). For high consequence dams, the matrix allows motions in the 50th to 84th percentile range if the slip rate is moderate or low. For final design, the total class weight and the statistical levels of the ground motions will need to be determined.

The 2014 version of the USGS National Seismic Hazard Maps, which is the basis for the U.S. building code, the International Building Code, estimate probabilistic ground motions for the U.S. for a range of annual exceedance frequencies at several structural periods (Petersen et al., 2015). The maps are calculated for firm rock or a National Earthquake Hazards Reduction Program B/C site class (VS30 of 760 m/sec). Although not required by DSOD, a probabilistic seismic hazard analysis is useful to

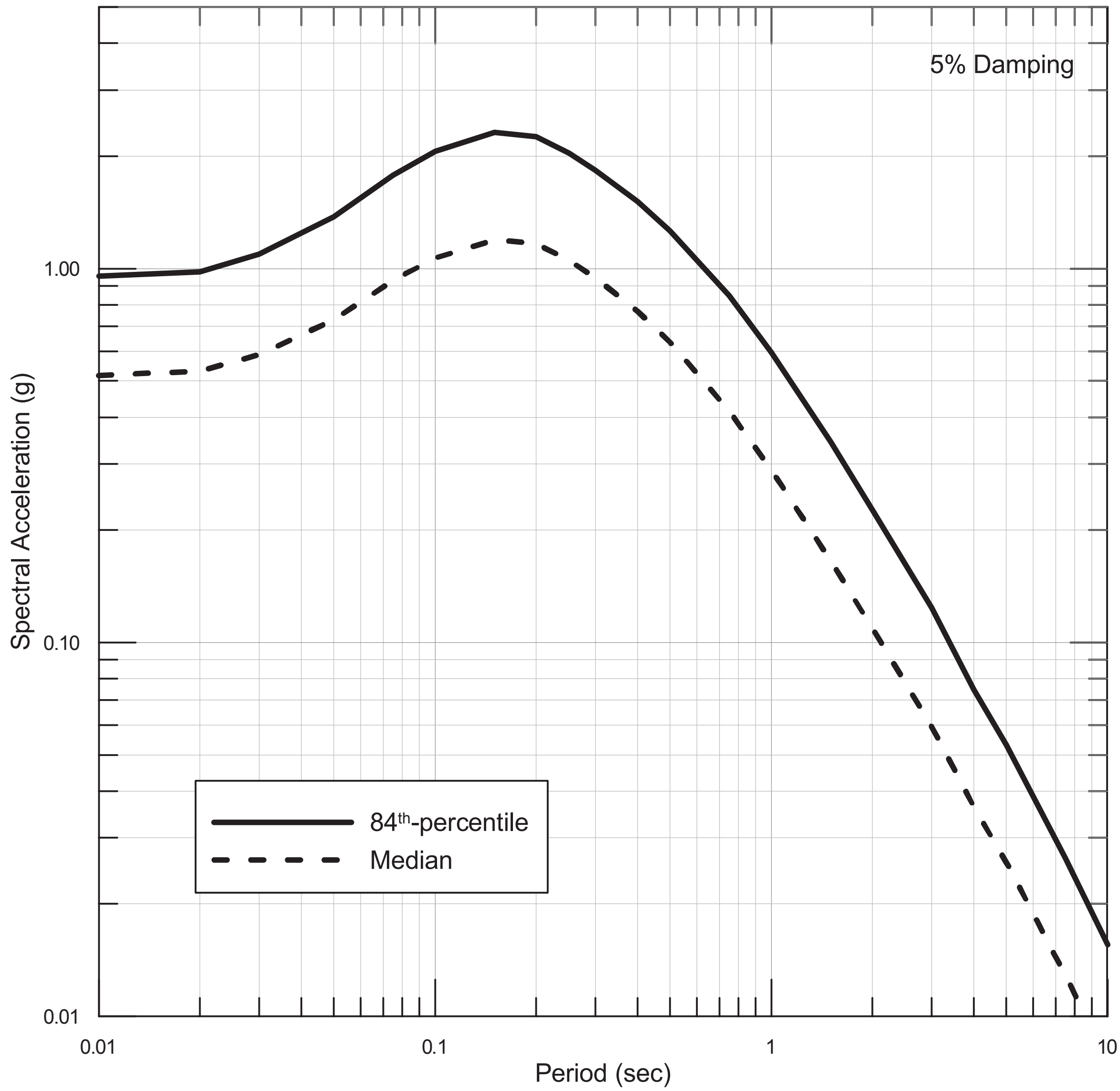



**FIGURE 17-7**
**Median and 84th Percentile Deterministic Response Spectra**
*Sites Reservoir Project EIR/EIS*

| | **Very High Slip Rate** 9 or greater mm/yr | **High Slip Rate** 8.9 to1.1 mm/yr | **Moderate Slip Rate** 1.0 to 0.1 mm/yr | **Low Slip Rate** less than 0.1 mm/yr |
|---|---|---|---|---|
| **Extreme Consequence** Total Class Weight 31-36 | $84^{th}$ | $84^{th}$ | $84^{th}$ | $50^{th}$ to $84^{th}$ |
| **High Consequence** Total Class Weight 19-30 | $84^{th}$ | $84^{th}$ | $50^{th}$ to $84^{th}$ | $50^{th}$ to 84th |
| **Moderate Consequence** Total Class Weight 7-18 | $84^{th}$ | $50^{th}$ to $84^{th}$ | $50^{th}$ to $84^{th}$ | $50^{th}$ |
| **Low Consequence** Total Class Weight 0-6 | $50^{th}$ | $50^{th}$ | $50^{th}$ | $50^{th}$ |

Source: Fraser and Howard (2002)

**FIGURE 17-8**
**DSOD Consequence-hazard Matrix**

*Sites Reservoir Project EIR/EIS*

determine the approximate return period of the deterministic values and provide an estimate of the conservatism in the range of statistical levels of the ground motions (i.e. median and 84th percentiles). At the Primary Study Area for a probability of exceedance of 10 percent in 50 years (475-year return period), the USGS calculates a PGA of 0.20 g. This indicates that over the next 50 years there is a 10 percent chance that the site will be subjected to ground shaking in excess of a PGA of 0.20g due to one or more earthquakes in the region. At 0.2 second SA and 1.0 second SA, the USGS calculates 0.45 g and 0.16 g, respectively. For a 2 percent chance in 50 years (2,475-year return period), the USGS calculates PGA, 0.2 second SA and 1.0 second SA of 0.39 g, 0.89 g, and 0.31 g, respectively. The DSHA median and 84th percentile deterministic PGA values of 0.52 g and 0.95 g would have return periods of about 5,800 years and 45,000 years, respectively.

These ground motion values represent the seismic hazard that can be expected in a site underlain by firm rock. The Primary Study Area is located on sedimentary bedrock of the Great Valley Sequence (western portion) and recent alluvial deposits (eastern portion). For design purposes, the DSHA should be conducted incorporating site-specific information for the local seismic sources and site conditions with a robust characterization of uncertainties.

#### *17.2.4.4 Seismic-related Ground Failure including Liquefaction*

The potential for liquefaction depends on the duration and intensity of earthquake shaking, particle size distribution of the soil, density of the soil, and elevation of the groundwater. Areas that are at risk because of the effects of liquefaction typically have a high groundwater table and underlying loose to medium-dense granular sediments, particularly younger alluvium and artificial fill.

The Sites and Golden Gate dam sites are underlain by marine sandstones and shales of the Jurassic-Cretaceous Great Valley Group. The sandstone and shale deposits have been incised by streams flowing eastward into the Sacramento Valley and are locally overlain by Quaternary alluvial deposits, generally bedded silts, sands, and gravels. Quaternary landslide deposits and colluvium are also present in the Primary Study Area.

Liquefaction potential is low in the western portion of the Primary Study Area because the soils are well-drained (i.e., low groundwater table) and Quaternary deposits overlying bedrock are thin. Liquefaction potential in the eastern portion is moderate due to the higher groundwater table and greater soil depth. Project features located in this area include the Holthouse Reservoir Complex, the TRR and its associated facilities, the Delevan Pipeline, the Delevan Pipeline Intake/Discharge Facilities, and the Sites/Delevan Overhead Power Line.

#### *17.2.4.5 Landslides*

Slope failures, commonly referred to as landslides, include many phenomena that involve the downslope displacement and movement of material, either triggered by static (i.e., gravity) or dynamic (i.e., earthquake) forces. Rock slopes exposed to either air or water can undergo rockfalls, rockslides, or rock avalanches; soil slopes experience shallow soil slides, rapid debris flows, and/or deep-seated rotational slides.

Landslide potential is low in the eastern portion of the Primary Study Area where the land profile is relatively flat. Landslide potential increases in the western upland portion where steeper slopes occur. Small to medium landslides have been observed on steep slopes within and adjacent to the proposed Sites Reservoir, particularly along the western side of Logan Ridge (eastern shoreline of proposed Sites

Reservoir). These landslides occur in the Boxer Formation, which is composed primarily of mudstone. Small isolated rockslides have been observed within and adjacent to the proposed Sites and Golden Gate dam sites. These rockslides occur in the Venado Sandstone member of the Cortina Formation.

### 17.2.4.6 Seiches and Tsunamis

Earthquake-induced seiches (wave oscillations in an enclosed or semi-enclosed body of water) can be excited in natural lakes and reservoirs. An analysis of seismically induced seiches in Lake Tahoe, for example, indicated that a $M_w$ 7 earthquake on a fault traversing the lake could induce a tsunami followed by a seiche with waves 10 to 30 feet high (Ichinose et al., 2000). An earthquake on a fault outside the basin induced wave heights of only about 2 feet. Seiches can be triggered by distant earthquakes. The 1964 $M_w$ 9.2 Alaska earthquake induced seiches as far away as Australia (McGarr and Vorhis, 1968). The seiches were induced in bodies of water with a wide range of sizes and depth. In the United States, the highest density of seiches due to the 1964 earthquake occurred in the southeastern United States near the Gulf of Mexico. Notably, numerous seiches were induced by that earthquake in California's Great Valley. The maximum wave height recorded in that event was 3 inches. McGarr and Vorhis (1968) concluded that the occurrence of seiches is related to the period of seismic surface waves, the thickness of low-rigidity sediments, and the presence of major tectonic features such as thrust faults, basins, and domes. Development of seiches and their wave height depend strongly on the shape of the basin containing the water body.

The Primary Study Area is not located within a coastal area, and no faults are likely to produce significant surface offset underlie the proposed reservoirs. Therefore, the hazard due to tsunamis (seismic sea waves) is negligible.

The existing Funks Reservoir is considered too small to produce a significant seiche.

### 17.2.4.7 Reservoir-triggered Seismicity

As described in Section 17.2.3.5, RTS occurs when water level changes in a reservoir trigger earthquakes. RTS may occur immediately following the filling of a reservoir as “initial seismicity” or “rapid response”; or, RTS can begin or continue many years later as “protracted seismicity” or “delayed response” (Talwani, 1997; Simpson et al., 1988). Two mechanisms have been proposed to account for the different types of triggered seismicity: 1) The added load from the weight of the water can change the stress on local faults, leading to failure; and 2) a change in pore pressure, either from reservoir water penetrating the underlying rock or from compaction of pore space, can weaken a fault and move it to slip and generate an earthquake (Simpson, et al., 1988). The relatively slow diffusion pore pressure changes in response to water migrating through the rock to a depth at which earthquakes nucleate may account for the delay seen in protracted or delayed response seismicity. Pore pressure diffusion is considered the more dominant trigger mechanism.

Numerous studies have investigated the relationship between dam, reservoir, and site conditions, and the development of RTS. Conditions that affect RTS include water depth, reservoir size, the regional state of stress, the underlying geology, and the presence of active faults (Wong and Strandberg, 1996). RTS occurs in regions that contain faults and that are in a near-critical state of tectonic stress, so that the relatively small additional stresses added by the reservoir are sufficient to push a fault to failure (Talwani, 1997). Thus, the reservoir does not cause or “induce” seismicity; rather, it triggers the release of accumulated strain that already exists due to tectonic forces.

The exact mechanism by which RTS occurs is not well understood so its occurrence cannot be calculated. Assessments of RTS likelihood have been empirical, based on looking at occurrences of RTS and comparing the conditions of reservoirs that have experienced RTS and those that have not to infer the conditions under which it is most likely (Baecher and Keeney, 1982; MWH, 2013; Wong and Strandberg, 1996; Knudsen et al., 2009). Analyses of RTS have shown that it is most correlated with reservoir depth and volume, and to a lesser extent with state of stress and local geology (Baecher and Keeney, 1982; MWH, 2013). RTS is more prevalent in larger, deeper reservoirs (greater than ~300 feet). For this reason, the U.S. Committee on Large Dams recommends that investigations of RTS be undertaken for all reservoirs deeper than 80 meters (~262 feet). However, it can also occur in shallower reservoirs (Assumpção et al., 2002). Qui (2012) reports that RTS has been documented in 0.05 percent of dams less than 50 meters high, 0.93 percent of dams 50 to 100 meters high, 6.46 percent of dams 100 to 150 meters high, and 17.11 percent of dams more than 150 meters high. The likelihood for RTS in shallow reservoirs is low.

RTS is also dependent on underlying rock type, being moderately more common in sedimentary rock than in igneous or metamorphic rock. However, the majority of RTS occurring in sedimentary rock is in carbonate, not clastic rock (Qui, 2012). Carbonate rock can have high permeability, which allows more rapid migration of water through pore space and may facilitate the pore pressure changes that trigger RTS. Fractured rock of any kind is also susceptible to RTS because fractures can lead to high permeability.

RTS is more common in extensional and strike-slip than in compressional tectonic environments. The change in elastic stress due to the reservoir water load is likely to increase the normal stress on the thrust faults and decrease the probability of failure, whereas it can make an extensional fault, like that at Lake Oroville, more likely to slip.

The Primary Study Area is in a state of compressional stress and contains an active reverse fault, along with secondary strike-slip faults. The geology of the area comprises clastic sedimentary rock, primarily fine- to medium-grained, with relatively low permeability. The compressional state of stress and the presence of folding may contribute to decreasing the permeability of the rock. Lake Berryessa and San Luis Reservoir in California are in similar environments. Lake Berryessa, which is 85 meters (279 feet) deep, is a questionable case of RTS; San Luis Reservoir is an accepted case. San Luis Reservoir is 104 meters deep and is underlain by more variable geology than the Primary Study Area, including coarse sedimentary rock and volcanic rock. Outside of California, Lake Benmore, a 315-foot-deep reservoir in New Zealand, experienced RTS following impoundment (Packer et al., 1979). It is also in a compressional environment and underlain by coarse clastic sedimentary rock. Del Valle Reservoir in Livermore is in a transpressional environment, with both strike-slip and thrust faults present, and it has likely generated RTS.

The only existing reservoir within the Primary Study Area is Funks Reservoir. Depth of the water in the reservoir is the most important factor in RTS. Funks Reservoir, with a normal operating depth at the dam of 36 feet, is too shallow to create RTS, nor has any been observed.

# 17.3 Environmental Impacts/Environmental Consequences

## 17.3.1 Evaluation Criteria and Significance Thresholds

Significance criteria represent the thresholds that were used to identify whether an impact would be potentially significant. Appendix G of the *CEQA Guidelines* suggests the following evaluation criteria for faults and seismicity:

*Would the Project:*

- Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
  - 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?
- Inundation by seiche, tsunami, or mudflow?

The evaluation criteria used for this impact analysis represent a combination of the Appendix G criteria and professional judgment that considers current regulations, standards, and/or consultation with agencies, knowledge of the area, and the context and intensity of the environmental effects, as required pursuant to the National Environmental Policy Act. For the purposes of this analysis, an alternative would result in a potentially significant impact if it would result in any of the following:

- Exposure of people or structures to fault rupture, seismic ground shaking, seismic-related ground failure, liquefaction, or landslides.
- Inundation by seiches or tsunamis.
- RTS (increased seismicity due to the presence of a new reservoir or re-operation of existing reservoirs).

## 17.3.2 Impact Assessment Assumptions and Methodology

Combinations of Project facilities were used to create Alternatives A, B, C, $C_1$, and D. In all resource chapters, the Authority and the Bureau of Reclamation described the potential impacts associated with the construction, operation, and maintenance of each of the Project facilities for each of the five action alternatives. Some Project features/facilities and operations (e.g., reservoir size, overhead power line alignments, provision of water for local uses) differ by alternative, and are evaluated in detail within each of the resource areas chapters. As such, the Authority has evaluated all potential impacts for each feature individually, and may choose to select or combine individual features as determined necessary.

Impacts associated with the construction, operation, and maintenance for Alternative $C_1$ would be the same as Alternative C and are therefore not discussed separately below.

#### 17.3.2.1 Assumptions

The following assumptions were made regarding Project-related construction, operation, and maintenance impacts on existing seismic hazards and impacts on the Project from those seismic hazards:

- Direct Project-related construction, operation, and maintenance activities would occur in the Primary Study Area.
- Direct Project-related operational effects would occur in the Secondary Study Area.
- The only direct Project-related construction activity that would occur in the Secondary Study Area is the installation of two additional pumps into existing bays at the Red Bluff Pumping Plant.
- The only direct Project-related maintenance activity that would occur in the Secondary Study Area is the sediment removal and disposal at the two intake locations (i.e., GCID Main Canal Intake and Red Bluff Pumping Plant).
- No direct Project-related construction or maintenance activities would occur in the Extended Study Area.
- Direct Project-related operational effects that would occur in the Extended Study Area are related to San Luis Reservoir operation; increased reliability of water supply to agricultural, municipal, and industrial water users; and the provision of an alternate Level 4 wildlife refuge water supply. Indirect effects to the operation of certain facilities that are located in the Extended Study Area, and indirect effects to the consequent water deliveries made by those facilities, would occur as a result of implementing the alternatives.
- The existing bank protection located upstream of the proposed Delevan Pipeline Intake/Discharge Facilities would continue to be maintained and remain functional.
- No additional channel stabilization, grade control measures, or dredging in the Sacramento River at or upstream of the Delevan Pipeline Intake/Discharge Facilities would be required.
- Likely sources of major regional seismicity would be from earthquakes to the west of the Project area in the Coast Range or from a Cascadia subduction zone event (occurrence every 500 to 530 years).
- No undiscovered major faults or seismic sources would have an impact.

#### 17.3.2.2 Methodology

Existing conditions and the future No Project/No Action alternatives were assumed to be similar in the Primary Study Area given the generally rural nature of the area and limited potential for growth and development in Glenn and Colusa counties within the 2030 study period used for this EIR/EIS as further described in Chapter 2 Alternatives Analysis. As a result, within the Primary Study Area, it is anticipated that the No Project/No Action Alternative would not entail material changes in conditions as compared to the existing conditions baseline.

With respect to the Extended and Secondary study areas, the effects of the proposed action alternatives would be primarily related to changes to available water supplies in the Extended and Secondary study areas and the Project's cooperative operations with other existing large reservoirs in the Sacramento watershed, and the resultant potential impacts and benefits to biological resources, land use, recreation, socioeconomic conditions, and other resource areas. The Department of Water Resources has projected future water demands through 2030 conditions that assume the vast majority of CVP and SWP water contractors would use their total contract amounts, and that most senior water rights users also would fully use most of their water rights. This increased demand in addition to the projects currently under construction and those that have received approvals and permits at the time of preparation of the EIR/EIS would constitute the No Project/No Action Condition. As described in Chapter 2 Alternative Analysis, the primary difference in these projected water demands would be in the Sacramento Valley; and as of the time of preparation of this EIR/EIS, the water demands have expanded to the levels projected to be achieved on or before 2030.

Accordingly, existing conditions and the No Project/No Action alternatives are assumed to be the same for this EIR/EIS and as such are referred to as the Existing Conditions/No Project/No Action Condition, which is further discussed in Chapter 2 Alternatives Analysis. With respect to applicable reasonably foreseeable plans, projects, programs and policies that may be implemented in the future but that have not yet been approved, these are included as part of the analysis of cumulative impacts in Chapter 35 Cumulative Impacts.

A combination of data, published reports, and professional experience with initial investigations for the Project were used to evaluate the alternatives for potential impacts due to faults and seismicity.

The impact assessments for the Extended and Secondary study areas primarily relied on data and publications (both printed and web-based) from the CGS and USGS. The Primary Study Area impact assessments primarily relied on the Phase II Fault and Seismic Hazards Investigation for the NODOS Integrated Storage Investigations (William Lettis & Associates, 2002). Professional experience with initial investigations included geological mapping within the Primary Study Area and core-drilling within the footprints of the proposed dam sites.

## 17.3.3 Topics Eliminated from Further Analytical Consideration

No Project facilities or topics that are included in the significance criteria listed above were eliminated from further consideration in this chapter.

## 17.3.4 Impacts Associated with Alternative A

### *17.3.4.1 Extended and Secondary Study Areas – Alternative A*

#### Construction, Operation, and Maintenance Impacts

*Agricultural Water Use, Municipal and Industrial Water Use, Wildlife Refuge Water Use, San Luis Reservoir, Pump Installation at the Red Bluff Pumping Plant, Trinity Lake, Lewiston Lake, Trinity River, Klamath River downstream from the Trinity River, Whiskeytown Lake, Spring Creek, Shasta Lake, Keswick Reservoir, Sacramento River, Clear Creek, Lake Oroville, Thermalito Complex, Feather River, Sutter Bypass, Yolo Bypass, Folsom Lake, Lake Natoma, American River, Sacramento-San Joaquin Delta, Suisun Bay, San Pablo Bay, and San Francisco Bay*

***Impact Seis-1: Exposure of People or Structures to Fault Rupture, Seismic Ground Shaking, Seismic-related Ground Failure, Liquefaction, or Landslides***

With the exception of installing an additional pump at the RBPP, no Project facilities would be constructed, operated, or maintained in the Extended or Secondary study areas. When compared to the Existing Conditions/No Project/No Action Condition, Project facilities would not expose people or structures to fault rupture, seismic ground shaking, seismic-related ground failure, liquefaction, or landslides. Similarly, those seismic events, if they occurred, would not affect Project facilities because most facilities would not be developed within those areas. The installation of a pump within the existing RBPP would not affect and is not expected to be affected by seismic events. There would be **no impact** when compared to the Existing Conditions/No Project/No Action Condition. In addition, the continued operation of San Luis Reservoir, Shasta Lake, Lake Oroville, and Folsom Lake would not cause these seismic events, resulting in **no impact** when compared to the Existing Conditions/No Project/No Action Condition.

***Impact Seis-2: Inundation by Seiches or Tsunamis***

Because no Project facilities would be constructed, operated, or maintained in the Extended or Secondary study areas (other than one pump to be installed at the existing RBPP), Project facilities would not be affected by seiches or tsunamis, if they were to occur there, resulting in **no impact** when compared to the Existing Conditions/No Project/No Action Condition. The installation of a pump within the existing RBPP would not affect and is not expected to be affected by a tsunami because the RBPP is not located in a coastal area, and it would not be affected by a seiche because it is not located on a waterbody. The continued operation of San Luis Reservoir would have **no impact** when compared to the Existing Conditions/No Project/No Action Condition, on tsunamis because the reservoir is not located in a coastal area. During the continued operation of San Luis Reservoir, Shasta Lake, Lake Oroville, and Folsom Lake, it is possible that a large earthquake-induced landslide could cause a tsunami on these reservoirs. However, the tsunami would be small to moderate, resulting in a **less-than-significant impact** when compared to the Existing Conditions/No Project/No Action Condition**.**

***Impact Seis-3: Reservoir-triggered Seismicity***

The only examples of suspected RTS associated with existing State and federal reservoirs located within the Extended and Secondary study areas occurred over 35 years ago (San Luis Reservoir, 1969 and Lake Oroville, 1975). Major State and federal reservoirs within the Extended and Secondary study areas (Shasta, Folsom, San Luis, and Oroville) have been operated according to established engineering guidelines since their completion in 1945 (Shasta), 1956 (Folsom), 1967 (San Luis) and 1968 (Oroville) and will continue to operate according to these same guidelines in the future. The continued absence of RTS that has characterized the past 35 to 70 years of operation of these very large reservoirs should be anticipated in the future resulting in **no impact** when compared to the Existing Conditions/No Project/No Action Condition. RTS is generally restricted to the immediate vicinity of the reservoir producing it, so construction of the Project would not affect the likelihood of RTS in the Extended or Secondary study areas. In addition, the addition of one pump to an existing bay at the RBPP would not cause or be affected by RTS because the RBPP is not located near or on a reservoir, resulting in **no impact** when compared to the Existing Conditions/No Project/No Action Condition.

### *17.3.4.2 Primary Study Area – Alternative A*

#### Construction, Operation, and Maintenance Impacts

*All Primary Study Area Project Facilities*

***Impact Seis-1: Exposure of People or Structures to Fault Rupture, Seismic Ground Shaking, Seismic-related Ground Failure, Liquefaction, or Landslides***

The seismic hazard within the Primary Study Area is low to moderate. The Great Valley fault zone is not known to have ruptured in the Holocene, but William Lettis & Associates (2002) inferred it to be active based on DSOD criteria (displacement within the last 35,000 years). The Great Valley fault zone does not reach the surface, and its activity rate is low. Strong seismic ground shaking and seismic-related liquefaction or landslides may be caused by earthquakes on more distant sources than the Great Valley fault zone. Detailed site-specific geologic and foundation investigations are used to develop design criteria to withstand reasonably probable seismic events.

William Lettis & Associates (2002) concluded that no more than 16 inches of displacement would occur on the secondary faults beneath or in proximity to the Project dam sites, with 3 to 8 inches of surface displacement along the northeast-striking GG-1, GG-2, GG-3, and S-2 faults, and 4.5 to 16 inches on the Salt Lake thrust fault. DSOD would require that the design specifications be sufficient to mitigate an impact related to this slip. Therefore, constructing, operating, and maintaining the Project facilities in this area would result in a **less-than-significant impact** when compared to the Existing Conditions/No Project/No Action Condition.

Project construction would involve creating high-angle temporary slopes at dam sites, quarry areas, new roads, recreation areas, and temporary and permanent access roads. Project construction would also include trenching along the Delevan Pipeline. Given that Project design would account for the potential for localized slumping (i.e., landslides or trench wall failure) and liquefaction due to seismic shaking there would be a **less-than-significant impact** when compared to the Existing Conditions/No Project/ No Action Condition.

During Project operation, increased soil moisture and reservoir surface level fluctuations along the shores of Sites Reservoir could exacerbate slope instability (particularly along the eastern shoreline west of Logan Ridge) and increase earthquake-induced landslide potential. Project design would address the potential for such instability such that there would be a **less-than-significant impact** when compared to the Existing Conditions/No Project/No Action Condition.

***Impact Seis-2: Inundation by Seiches or Tsunamis***

The Primary Study Area is not located in a coastal area. Therefore, potentially significant hazards due to earthquake-tsunamis (seismic sea waves) are negligible. It is possible that a large earthquake-induced landslide or seismic ground shaking could cause a tsunami on Sites Reservoir, but the tsunami would be small to moderate and would result in a **less-than-significant impact** when compared to the Existing Conditions/No Project/No Action Condition**.**

***Impact Seis-3: Reservoir-triggered Seismicity***

Alternative A proposes a 1.3-MAF Sites Reservoir, with a maximum depth of approximately 220 feet (67 meters). Reservoirs are classified as deep (263 feet [80 meters]) to very deep (deeper than 492 feet [150 meters]). Sites Reservoir would be classified as a less than deep reservoir. Deep and very deep reservoirs account for the majority of reported examples of RTS (USGS, 1996b).

The Primary Study Area is in a compressional tectonic environment and is underlain by folded, relatively fine-grained clastic sedimentary rock. It is underlain by active thrust faults, the Great Valley fault zone, and the secondary backthrust Salt Lake thrust fault. The elastic stress changes from the reservoir load directly over a thrust fault would reduce the likelihood of fault failure because it increases the normal stress on the fault plane. However, San Luis Reservoir is in a compressional environment, and Del Valle reservoir is in a transpressional environment with both thrust and strike-slip faults present, and both have experienced RTS. The underlying siltstones and sandstones have low permeability as evidenced in boreholes, and that permeability is likely to decrease with depth. Fracture permeability at seismogenic depth is likely decreased in a compressional environment. Overall, the conditions do not favor RTS, and there are few cases of RTS documented in similar conditions globally. Lake Benmore in New Zealand is such a case, but it is deeper (96 meters) than Sites Reservoir. Del Valle reservoir is only 207 feet (63 meters) deep, however, and has experienced RTS.

Given the site conditions and lack of many cases of RTS in comparable conditions globally, the likelihood of RTS occurring at the proposed Sites Reservoir is judged to be low. Although Del Valle Reservoir, of similar depth and situated in a similar setting, represents a likely case of RTS, it is not an expected occurrence. Knudsen et al. (2009) assessed the likelihood of RTS occurring at Del Valle Reservoir, given its setting, and concluded that the conditional probability of RTS at Del Valle is 0.092, indicating that the observed RTS is somewhat anomalous. RTS for a similarly situated reservoir of comparable size, therefore, has a low probability of occurring, and thus the likelihood of RTS occurring at the proposed Sites Reservoir is judged to be low. Although not anticipated to be a concern, the potential for RTS will be monitored as described in Chapter 3 Description of the Sites Reservoir Project Alternatives as part of the Project through the deployment of strong motion instruments at center crests, abutments, and toes of the two primary dams, the Golden Gate Dam and the Sites Reservoir Dam, before, during, and a minimum of 2 years after the reservoir first reaches the maximum normal storage level. In addition, the rate of impoundment will be monitored in conjunction with seismic monitoring and adjusted as needed in the event of increases in seismicity potentially attributable to RTS, and monitoring will continue over the life of the Project such that RTS-related impacts would be a **less-than-significant impact** when compared to the Existing Conditions/No Project/No Action Condition. The smaller Holthouse Reservoir and terminal regulating reservoir (TRR) would be too shallow to create RTS, and would, therefore, result in **no impact** when compared to the Existing Conditions/No Project/No Action Condition.

### 17.3.5 Impacts Associated with Alternative B

#### *17.3.5.1 Extended and Secondary Study Areas – Alternative B*

#### Construction, Operation, and Maintenance Impacts

The impacts associated with Alternative B, as they relate to seismic conditions (**Impact Seis-1**), seiches or tsunamis (**Impact Seis-2**), and RTS (**Impact Seis-3**), would be the same as described for Alternative A for the Extended and Secondary study areas.

#### *17.3.5.2 Primary Study Area – Alternative B*

#### Construction, Operation, and Maintenance Impacts

The impacts associated with Alternative B, as they relate to seismic conditions (**Impact Seis-1**) and seiches or tsunamis (**Impact Seis-2**), would be the same as described for Alternative A for all Primary Study Area Project facilities.

The impacts associated with Alternative B, as they relate to RTS (**Impact Seis-3**), would be the same as described for Alternative A for all Primary Study Area Project facilities, with the exception of Sites Reservoir. Alternative B includes a 1.8-MAF Sites Reservoir, compared to the 1.3-MAF Sites Reservoir evaluated for Alternative A. The potential impacts of the larger reservoir on RTS are discussed below.

*Sites Reservoir Inundation Area*

***Impact Seis-3: Reservoir-triggered Seismicity***

The Alternative B 1.8-MAF Sites Reservoir would have a maximum depth of approximately 260 feet, which is on the threshold of classifying it as a deep reservoir. However, the Alternative B Sites Reservoir would still be classified as a less than deep reservoir. Although deeper than the Alternative A 1.3-MAF Sites Reservoir, the Alternative B Sites Reservoir would still be classified as less than deep. The conditions affecting RTS are, therefore, not markedly different for Alternative B compared to Alternative A, and the likelihood of RTS is still judged to be low. The same design, impoundment approach, and monitoring over the life of the Project would be implemented as part of Alternative B, resulting in a **less-than-significant impact** when compared to the Existing Conditions/No Project/ No Action Condition.

### 17.3.6 Impacts Associated with Alternative C

#### *17.3.6.1 Extended and Secondary Study Areas – Alternative C*

**Construction, Operation, and Maintenance Impacts**

The impacts associated with Alternative C, as they relate to seismic conditions (**Impact Seis-1**), seiches or tsunamis (**Impact Seis-2**), and RTS (**Impact Seis-3**), would be the same as described for Alternative A for the Extended and Secondary study areas.

#### *17.3.6.2 Primary Study Area – Alternative C*

**Construction, Operation, and Maintenance Impacts**

The impacts associated with Alternative C, as they relate to seismic conditions (**Impact Seis-1**) and seiches or tsunamis (**Impact Seis-2**), would be the same as described for Alternative A for all Primary Study Area Project facilities.

The impacts associated with Alternative C, as they relate to RTS (**Impact Seis-3**), would be the same as described for Alternative A for all Primary Study Area Project facilities, with the exception of Sites Reservoir. Alternatives B and C include a 1.8-MAF Sites Reservoir. Therefore, the impacts associated with the Alternative C Sites Reservoir, as related to RTS (**Impact Seis-3**), would be the same as described for Alternative B for Sites Reservoir.

### 17.3.7 Impacts Associated with Alternative D

#### *17.3.7.1 Extended and Secondary Study Areas – Alternative D*

**Construction, Operation, and Maintenance Impacts**

The impacts associated with Alternative D, as they relate to seismic conditions (**Impact Seis-1**), seiches or tsunamis (**Impact Seis-2**), and RTS (**Impact Seis-3**), would be the same as described for Alternative A for the Extended and Secondary study areas.

#### *17.3.7.2 Primary Study Area – Alternative D*

**Construction, Operation, and Maintenance Impacts**

The impacts associated with Alternative D, as they relate to seismic conditions (**Impact Seis-1**), seiches or tsunamis (**Impact Seis-2**), and RTS (**Impact Seis-3**), would be the same as described for Alternative A for all Primary Study Area Project facilities. Although Alternative D would include the construction and operation of the Delevan Overhead Power Line adjacent to State Route 45 that is unique to Alternative D, this facility would not result in additional impacts as they relate to seismic conditions (**Impact Seis-1**), seiches or tsunamis (**Impact Seis-2**), or RTS (**Impact Seis-3**). Therefore, the impacts associated with Alternative D Sites Reservoir and all Project facilities would be the same as Alternative A.

## 17.4 Mitigation Measures

Because no potentially significant impacts were identified, no mitigation is required or recommended. Suitable materials and design considerations would be included as part of Project design to account for anticipated seismic activity including fault rupture, ground shaking, ground failure, and liquefaction in coordination with DSOD. In addition, RTS-related monitoring would also be included in all Project alternatives and is discussed in Chapter 3 Description of the Sites Reservoir Project Alternatives.

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