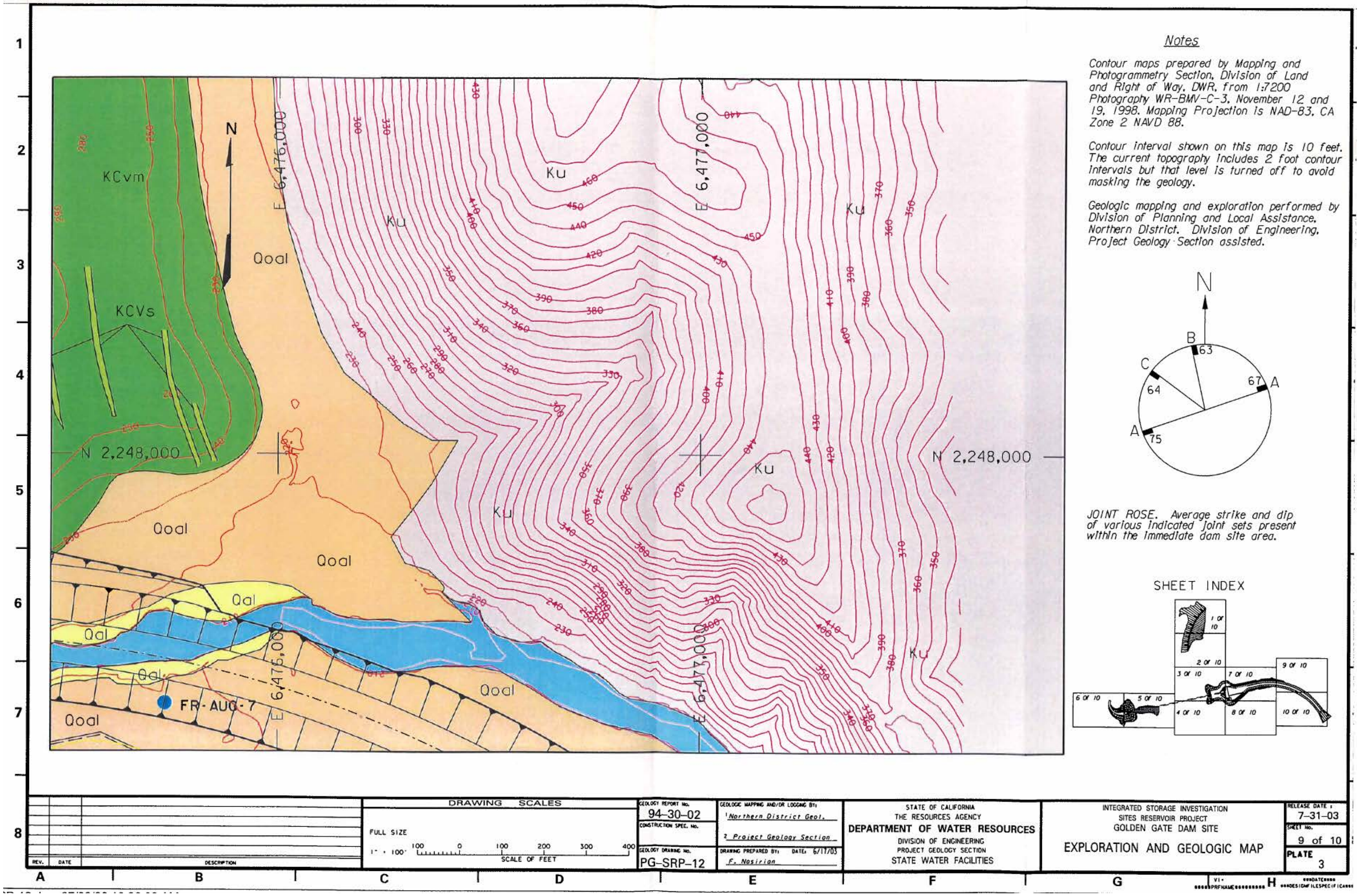


Notes

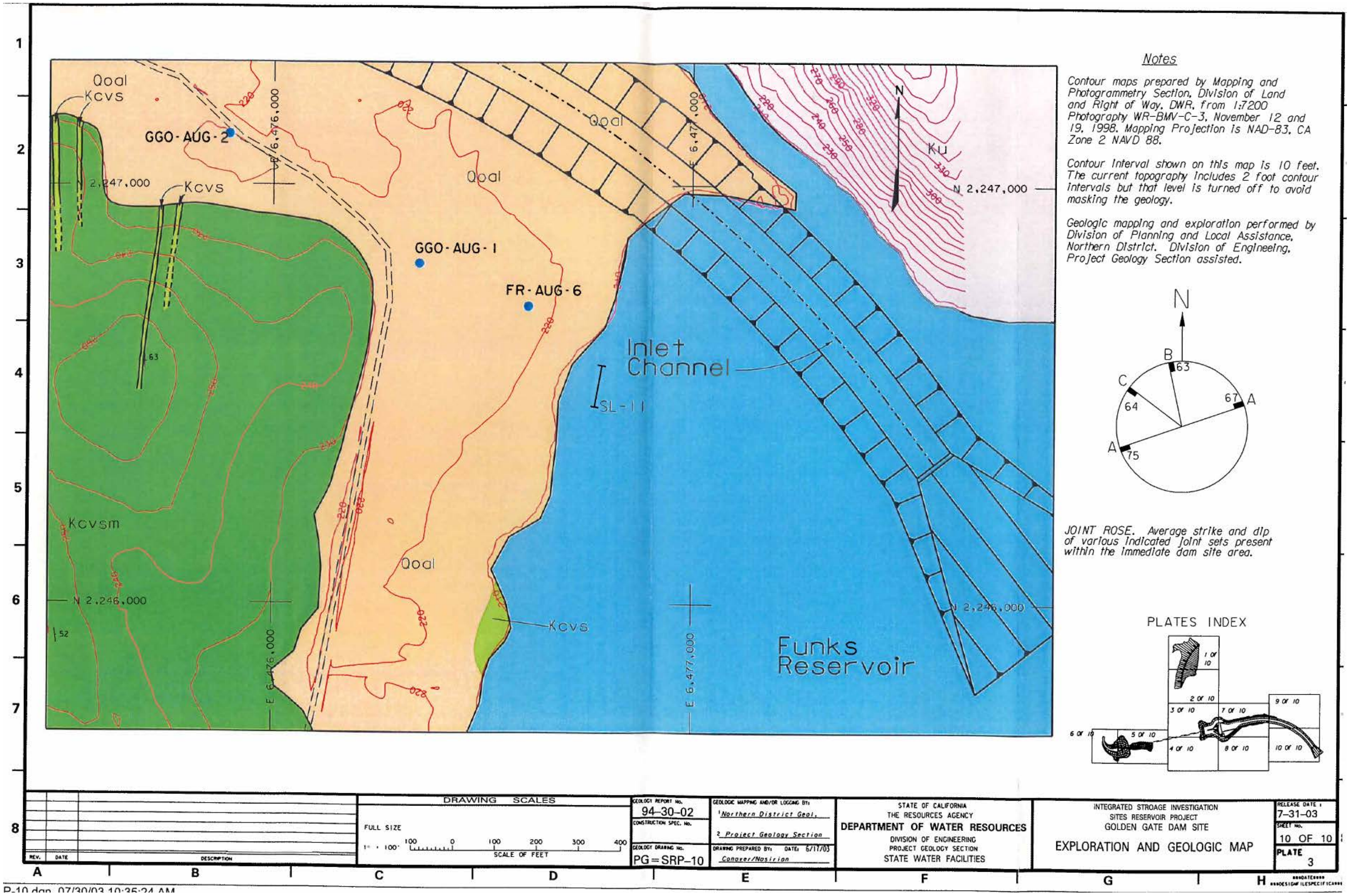
Contour maps prepared by Mapping and Photogrammetry Section, Division of Land and Right of Way, DWR, from 1:7200 Photography WR-BMV-C-3, November 12 and 19, 1998. Mapping Projection is NAD-83, CA Zone 2 NAVD 88.

Contour interval shown on this map is 10 feet. The current topography includes 2 foot contour intervals but that level is turned off to avoid masking the geology.

Geologic mapping and exploration performed by Division of Planning and Local Assistance, Northern District. Division of Engineering, Project Geology Section assisted.

JOINT ROSE. Average strike and dip of various indicated joint sets present within the immediate dam site area.

Figure B.2-20. Golden Gate Dam Site – Exploration and Geologic Map (Sheet 7)



Notes

Contour maps prepared by Mapping and Photogrammetry Section, Division of Land and Right of Way, DWR, from 1:7200 Photography WR-BMV-C-3, November 12 and 19, 1998. Mapping Projection is NAD-83, CA Zone 2 NAVD 88.

Contour Interval shown on this map is 10 feet. The current topography includes 2 foot contour intervals but that level is turned off to avoid masking the geology.

Geologic mapping and exploration performed by Division of Planning and Local Assistance, Northern District. Division of Engineeing, Project Geology Section assisted.

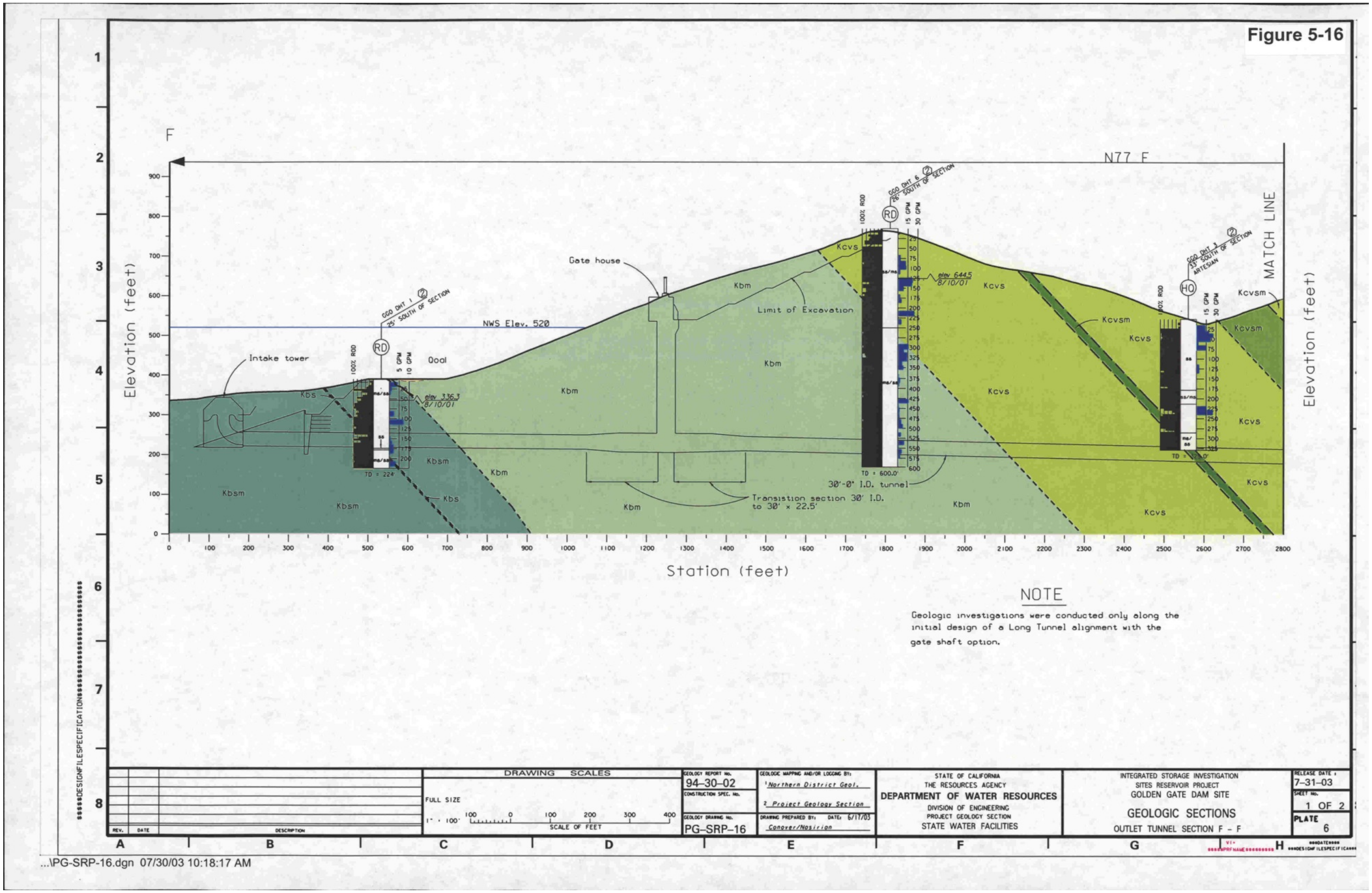
GEOLOGY REPORT No. 94-30-02
CONSTRUCTION SPEC. No.
GEOLOGY DRAWING No. PG=SRP-10
GEOLOGIC MAPPING AND/OR LOGGING BY: 1 Northern District Geol. 2 Project Geology Section
DRAWING PREPARED BY: Conover/Nasirian DATE: 6/17/03

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF ENGINEERING
PROJECT GEOLOGY SECTION
STATE WATER FACILITIES

INTEGRATED STROAGE INVESTIGATION
SITES RESERVOIR PROJECT
GOLDEN GATE DAM SITE
EXPLORATION AND GEOLOGIC MAP

RELEASE DATE: 7-31-03
SHEET No. 10 OF 10
PLATE 3

Figure B.2-21. Golden Gate Dam Site – Exploration and Geologic Map (Sheet 8)



NOTE

Geologic investigations were conducted only along the initial design of a Long Tunnel alignment with the gate shaft option.

Figure B.2-22. Golden Gate Dam Site – Geologic Sections – Outlet Tunnel Section F-F (Sheet 1)

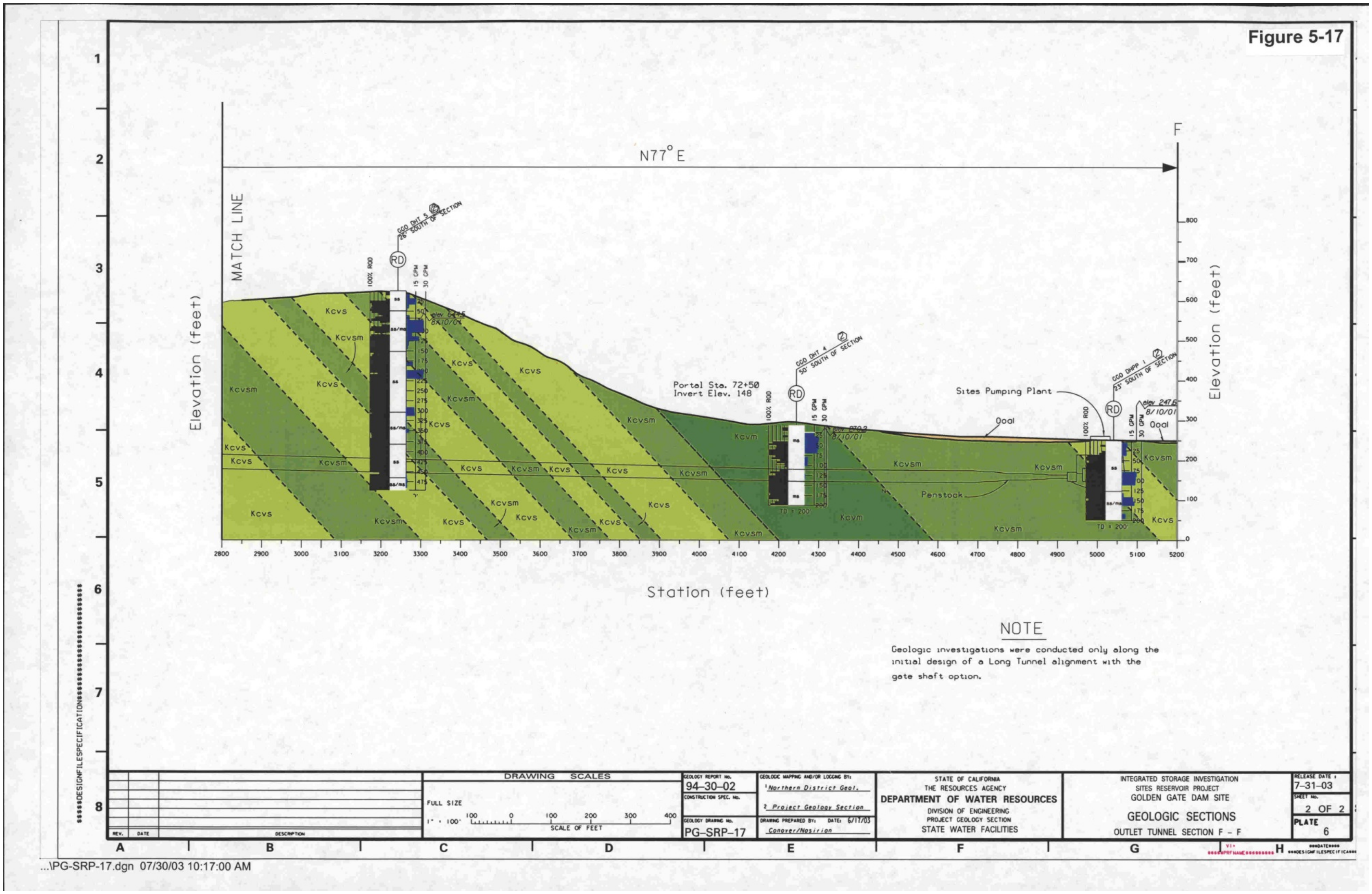


Figure B.2-23. Golden Gate Dam Site – Geologic Sections – Outlet Tunnel Section F-F (Sheet 2)

Sandstone with interbedded mudstone of the Cortina Formation (Kcvsm) would comprise the foundation.

The strike of the bedding is generally north-south, with a dip of approximately 50 degrees East. The sandstone and interbedded mudstone are anticipated to be fresh and hard at invert, and should provide excellent bearing capacity for the support of the structures. The older alluvium (Qoal) and recent alluvium (Qal) along the alignment for the approach channel range in depth from as shallow as 6 feet at the eastern end of Funks Reservoir to approximately 35 feet at the western end. The soils are primarily lean clay and silt, with some gravel interbeds. These soils may be erodible; therefore, the channel would likely require some type of protection.

Only one exploration borehole was drilled at the SPGP site. The rock is approximately 90 percent sandstone (Kcvs), with some minor mudstone interbeds. The sandstone is mostly hard and strong, and slightly fractured to massive. The hardness and strength, along with the excellent RQD values for the sandstone, indicate that blasting would be required below a depth of approximately 50 feet. Depth to groundwater is approximately 13 feet.

Auger holes were advanced to the top of bedrock along the straight alignment for the approach channel. The current design would encounter approximately 35 to 50 feet of interbedded sandstone and mudstone (Kcvsm). Seismic velocities generated from seismic lines SL-10 and SL-11, in the vicinity of the approach channel, ranged between 8,000 and 9,000 feet per second (fps). Some blasting in the lower 5 to 15 feet of the excavation may be required in the harder, fresh sandstone.

Fault GG-3 trends (approximately North 30 degrees East) diagonally across the approach channel approximately 450 feet west of the pumping plant site (Figure B.2-18). Fault trenches excavated by WLA indicate that the “GG-3 fault is a narrow (less than 2 feet wide), sub-vertical bedrock shear zone” (WLA 2002). GG-3 may act as a groundwater barrier in the bedrock exposed in the approach channel.

Permanent cuts in the alluvial soils should be stable, at slopes with a ratio of 2 horizontal to 1 vertical (2H:1V), or possibly at 1.5H:1V slopes, on further investigation and testing. Weathered bedrock slopes should be stable at 1H:1V, and fresh rock slopes at 0.5H:1V along the approach channel. Groundwater would be encountered in the excavation for the approach channel at a depth of approximately 25 feet or higher; therefore, dewatering would be required. Clearing would be minimal at the pumping plant and along the approach channel, because the only vegetation is light grasses and scattered pockets of riparian growth in the Funks Creek channel.

Conveyance Measures

Preliminary design of conveyance facilities for the NODOS/Sites Reservoir Project includes the 13.5-mile Delevan Pipeline from the Sacramento River Pumping/Generating Plant (SRPGP) to Holthouse Reservoir. The pipeline alignment was characterized using a number of auger borings, with SPT, and seismic refraction surveys. Geologic soil units traversed by the proposed conveyance alignment include, from east to west, Sacramento River channel deposits, Modesto Formation, Basin Deposits, Riverbank Formation, Tehama Formation, and Red Bluff Formation. Soils types encountered range from lean clay to poorly graded sand. Cretaceous-age mudstone of the Cortina Formation was encountered at relatively shallow depths (16 feet) in the westernmost

2 miles of the conveyance alignment. The mudstone was generally decomposed to intensely weathered between 16 and 52 feet, and is considered rippable to that depth. All of the soil units may be excavated using common methods (Figures Figure B.2-24 through Figure B.2-26).

Along this 13-mile alignment, groundwater was encountered at relatively shallow depths in all of the auger holes, ranging from 5.5 to 9 feet below the surface. The shallow groundwater depths indicate that dewatering would be required for excavation of most of the conveyance alignment. Temporary slopes for the pipeline excavation in saturated soils should be no steeper than 1.5H:1V, but may require laying back to 2H:1V if instability is a problem.

Seismicity

General

This section describes faulting and seismicity for the features under consideration for the proposed NODOS/Sites Reservoir Project. Information is summarized from *Project Geology Report No. 94-30-02* (DWR DOE 2003c) and *Geologic Feasibility Report, Sites Reservoir Project, Appendix to Engineering Feasibility Report* (DWR DOE 2008b). *Project Geology Report No. 94-30-02*, in turn, provided a general summary of the detailed fault and seismic hazard reports prepared by the Division of Planning and Local Assistance, Northern District, Geology Section, and by WLA. Discussions include findings from the 1999 Phase I, Fault and Seismic Hazards Investigation by Northern District, and the Seismotectonic Evaluation, Phase II Fault and Seismic Hazards Investigations conducted by WLA for the NODOS/Sites Reservoir Project. The study also included data from previous mapping and studies conducted by the USGS and Reclamation. The aforementioned detailed geologic reports are referenced at the end of this report.

Analysis of faulting and seismicity data for the two main dam sites (Sites and Golden Gate), the saddle dam sites, and all other project facilities show that displacement along Quaternary-age faults in the reservoir site could be activated by regional seismic sources such as the San Andreas or Great Valley faults.

Faulting

Faults that might have an effect on the proposed reservoir and structures can be categorized into regional and NODOS/Sites Reservoir Project site faults. Regional faults, such as the San Andreas fault, Cascadia Subduction Zone, and the Great Valley fault (also known as the Coast Ranges–Sierran Block Boundary Zone) are considered active seismic sources for earthquakes that could affect the project area.

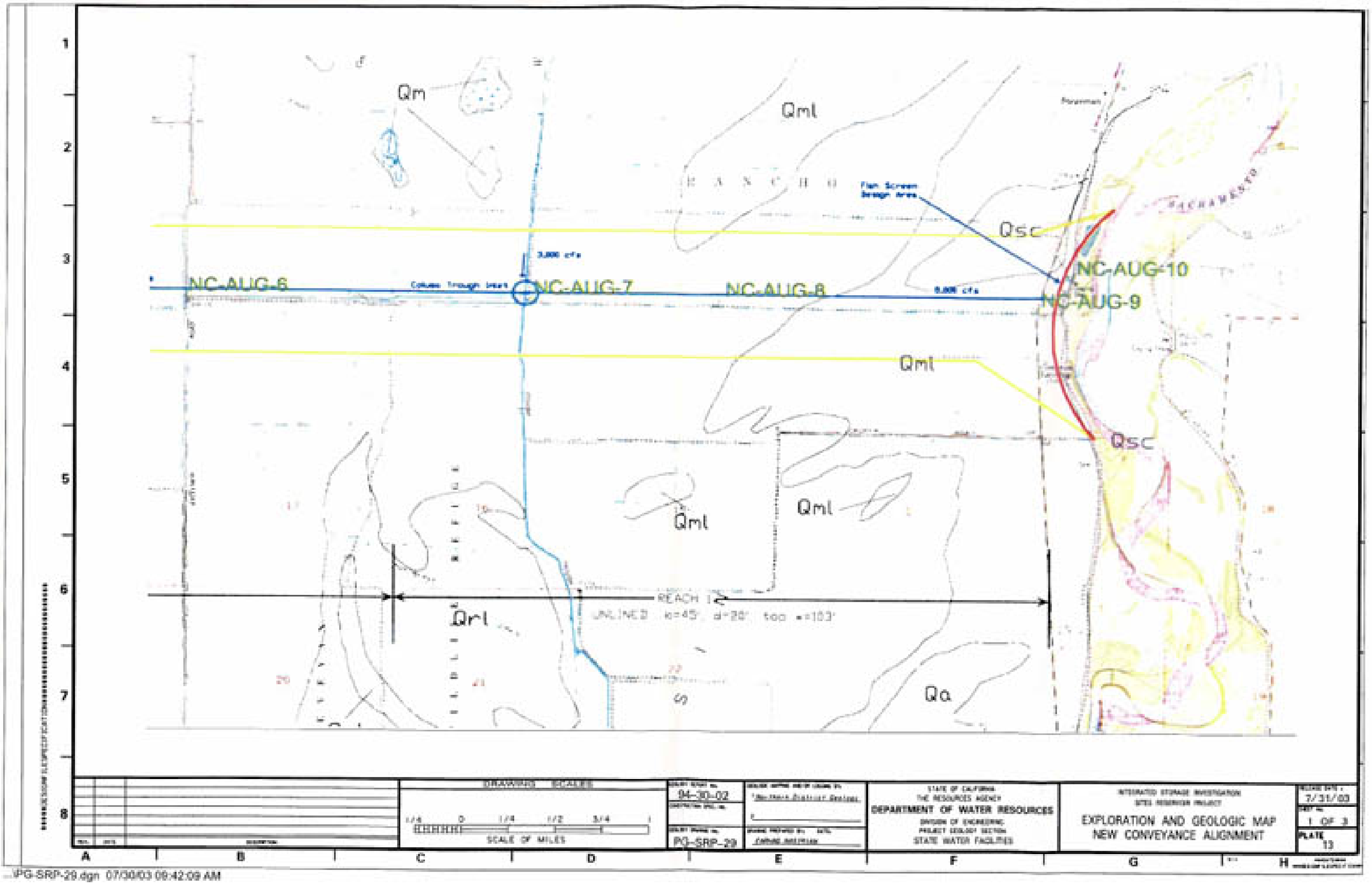


Figure B.2-24. Exploration and Geologic Map – New Conveyance Alignment (Sheet 1)

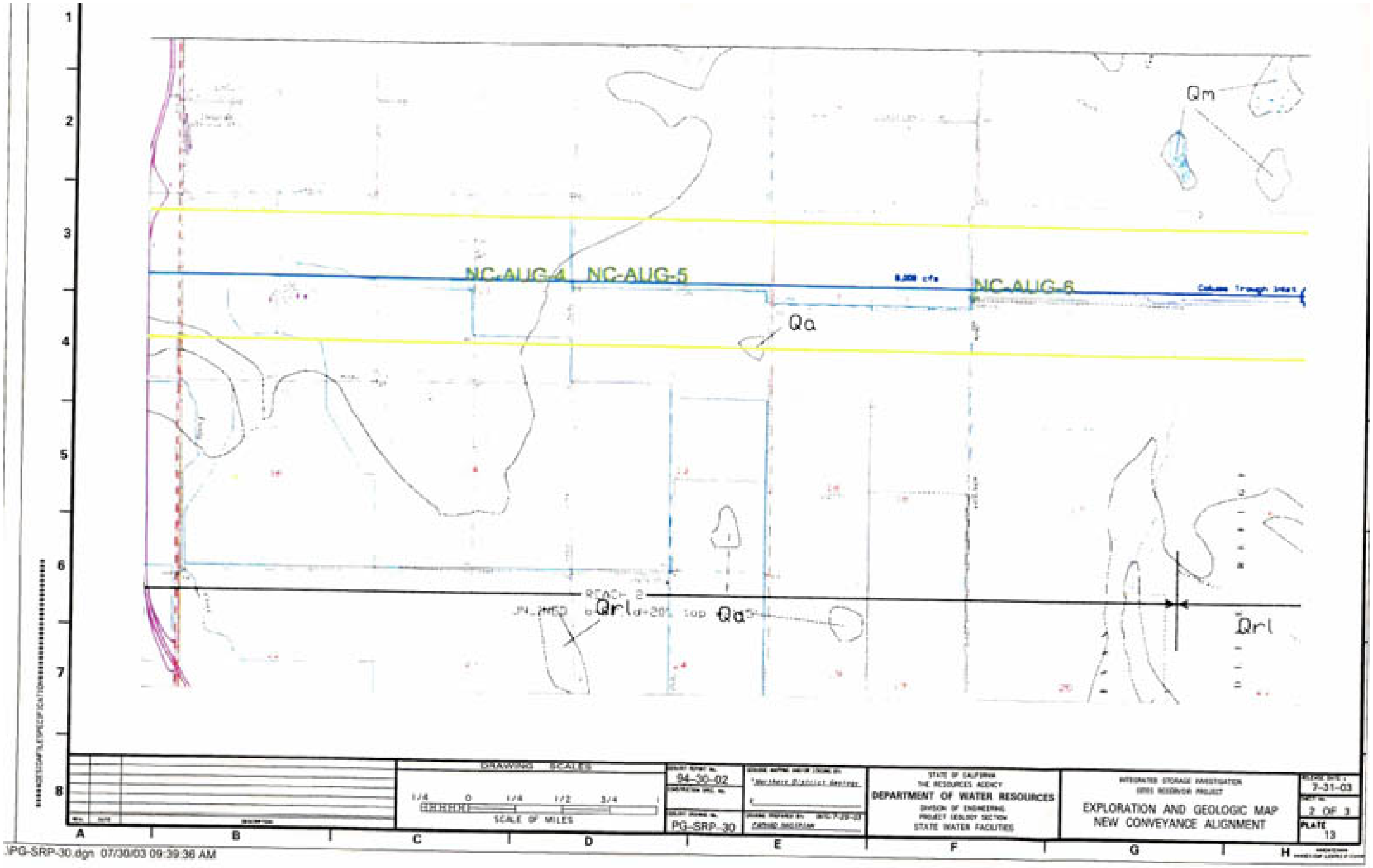


Figure B.2-25. Exploration and Geologic Map – New Conveyance Alignment (Sheet 2)

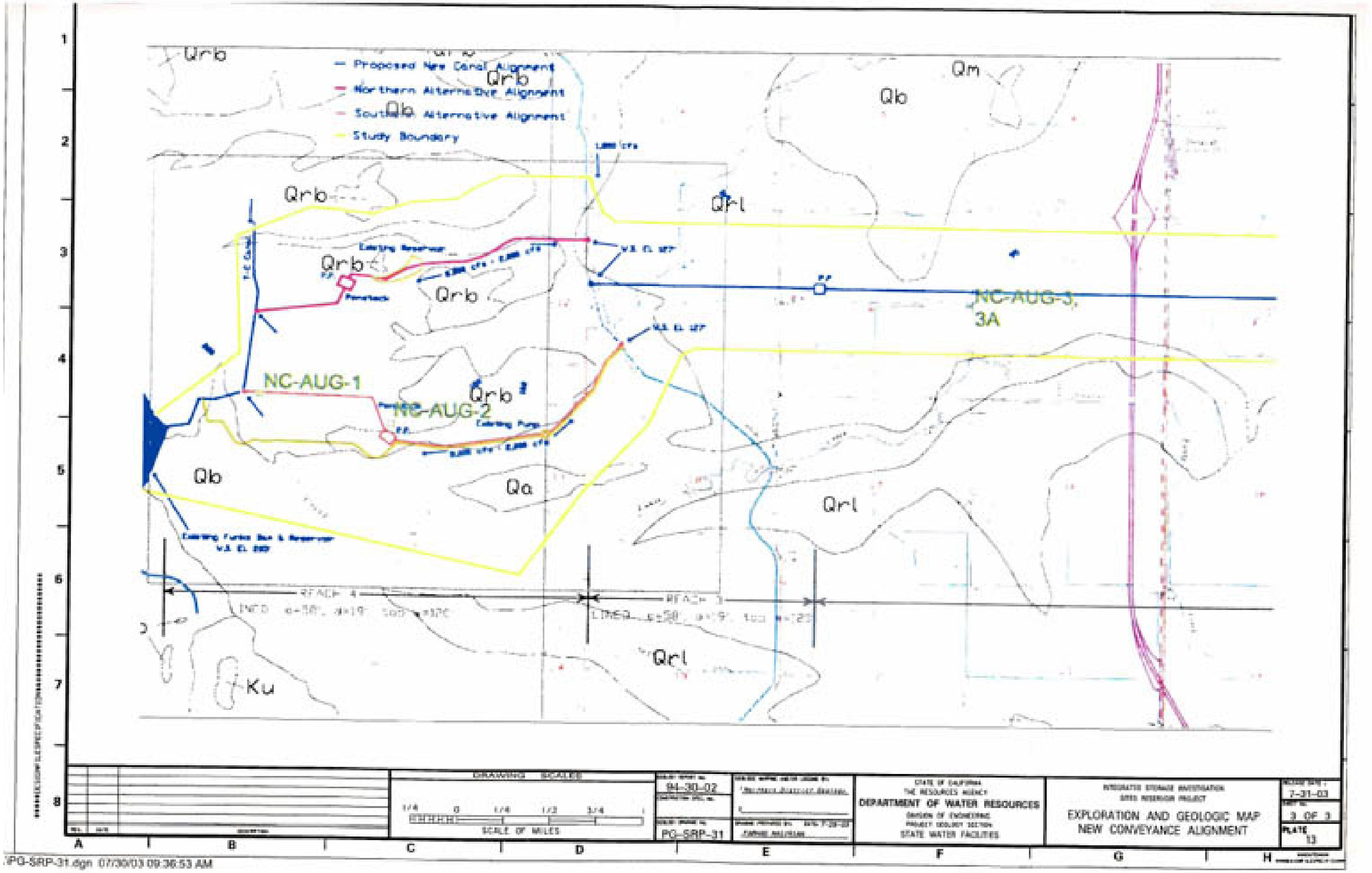


Figure B.2-26. Exploration and Geologic Map – New Conveyance Alignment (Sheet 3)

The Great Valley fault zone is a series of low-angle blind-thrust faults along the western 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. The fault zone is a primary structure of the Coast Ranges–Sierra Nevada block 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 (~ moment magnitude [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-Vacaville earthquakes (M_w 6+). In addition, a swarm of small earthquakes (M_w 3.6 to Mw 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.

Six faults have been mapped within the Sites Reservoir boundaries that could have a noteworthy impact on one or more of the proposed structures (Figure B.2-27 and Figure B.2-28). Two sets of surface faults have been mapped in the vicinity of the dam sites. The first set is characterized as northeast-striking, high-angle faults that obliquely cut the north-striking bedrock units, and consistently displace stratigraphic contacts in a right-lateral strike-slip sense. This fault set includes the informally named S-2, GG-1, GG-2, and GG 3 faults, which traverse through or near the proposed Sites and Golden Gate Dam sites. The second set of faults, characterized as north-striking structures that are generally parallel to bedding, include the east-dipping Salt Lake thrust and S-3 faults. The Salt Lake thrust fault lies within approximately 1 mile of both the Sites and Golden Gate Dam sites, while the S-3 fault has been mapped as passing through the inlet/outlet tunnel immediately west of the pumping plant site. WLA believes that the westward-dipping Funks segment of the Great Valley fault underlies the surface faults and ramps up to and intercepting the Salt Lake thrust fault (Figure B.2-29). Faults S-2, GG-1, GG-2, and GG-3 are interpreted as tear faults associated with the Funks segment southern structural boundary.

Exploration trenches have shown that surface rupture may occur along the Salt Lake fault during earthquakes on the Funks segment of the Great Valley fault. The Funks segment is considered the most likely seismic source for the project. Studies concluded that approximately 4.5 to 16 inches of reverse displacement might occur during a single surface-rupturing event. Paleoseismic data support only minor movement along the northeast-striking dextral or tear faults GG-1, GG-2, GG-3, and S-2. Analyzing the paleoseismic data with an assumed 3.3 feet of slip and a maximum magnitude earthquake (M_w 6.6) along the Funks Segment, and using three different fault movement models, WLA concluded that displacement along the tear faults would not exceed 8 inches, and is likely be lower (approximately 2.4 to 4 inches).

Seismicity History and Potential

Moderate to strong earthquakes have been reported in Northern California since the mid-1800s. Some of the more prominent events that probably shook the NODOS/Sites Reservoir Project area include the following: magnitude (M) 6.2 1898 Sonoma County; M 6.5 1898 Mendocino County; M 6.6 1954 Arcata; M 5.7 1940 Chico; M 6 1889 Antioch; three M 5.5 to M 6.4 1892 Winters-Vacaville earthquakes; and the M 7.8 1906 San Francisco earthquake on the San Andreas fault zone. The Winters-Vacaville earthquakes of 1892 are of the most importance to this study, because they have been associated with a blind, west-dipping segment of the Great Valley fault (Figures Figure B.2-30 through Figure B.2-33).

No faults of known Holocene age occurred in the anticipated construction 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 in the Primary Study Area.

The Phase II Fault and Seismic Hazards Investigation for the NODOS Integrated Storage Investigations (WLA 2002) identified several faults in proximity to the proposed Sites Reservoir and the Sites and Golden Gate dam sites (Table B.2-1). Two major sets of surface faults were recognized:

1. The Funks and Bear Valley segments of the Great Valley fault zone. The Great Valley fault zone underlies both dam sites at a depth of 4 to 7 miles, but does not reach the surface.
2. Northeast-striking high-angle faults that obliquely cut 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 near them (Figure B.2-28).
3. North-striking faults that are generally parallel to bedding (Figure B.2-28). 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[1]. 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 2.

Displacement on the Great Valley fault zone is manifested 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 itself is minimal.

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, and they likely do not act as independent seismic sources. WLA (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.

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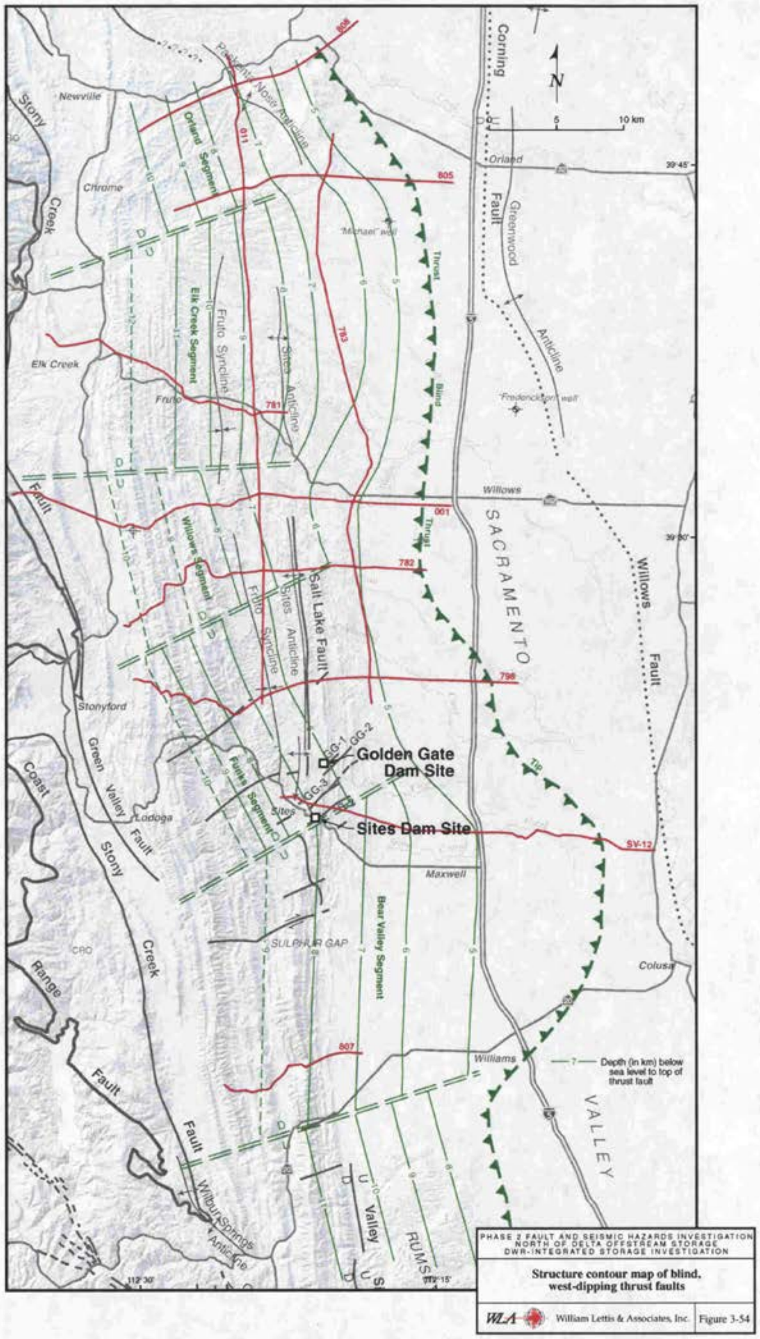
[1] An anticline is a fold with strata sloping downward on both sides from a common crest.

Figure 5-3



PHASE 2 FAULT AND SEISMIC HAZARDS INVESTIGATION
NORTH OF DELTA OFFSTREAM STORAGE
DWR-INTEGRATED STORAGE INVESTIGATION

Structure contour map of blind, west-dipping thrust faults

WLA William Lettis & Associates, Inc. | Figure 3-54

Figure B.2-27. Structure Contour Map of Blind West-Dipping Thrust Faults

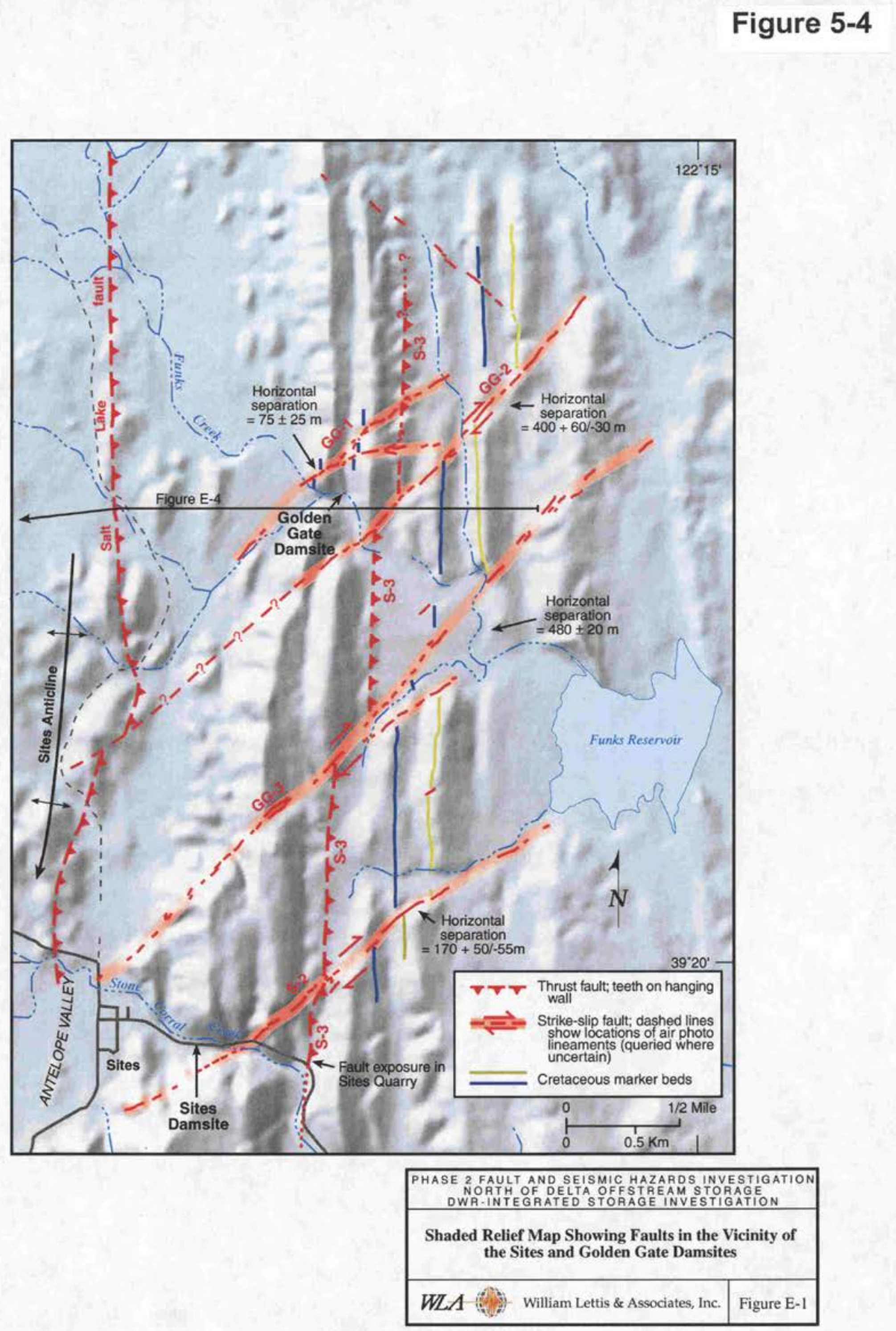


Figure B.2-28. Shaded Relief Map Showing Faults in the Vicinity of the Sites and Golden Gate Dam Sites

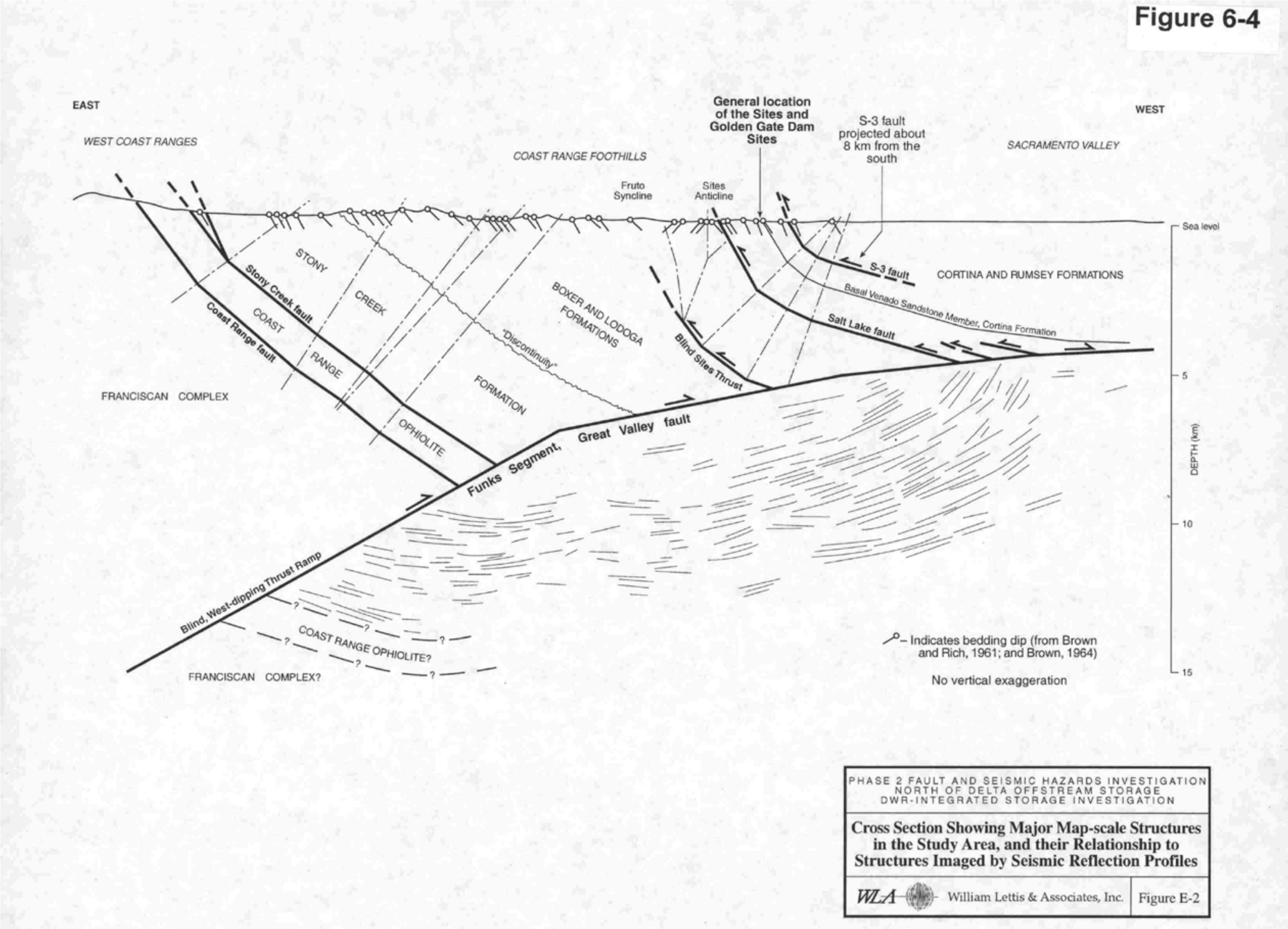


Figure B.2-29. Cross Section Showing Major Map Scale Structures in the Study Area Reflection Profiles

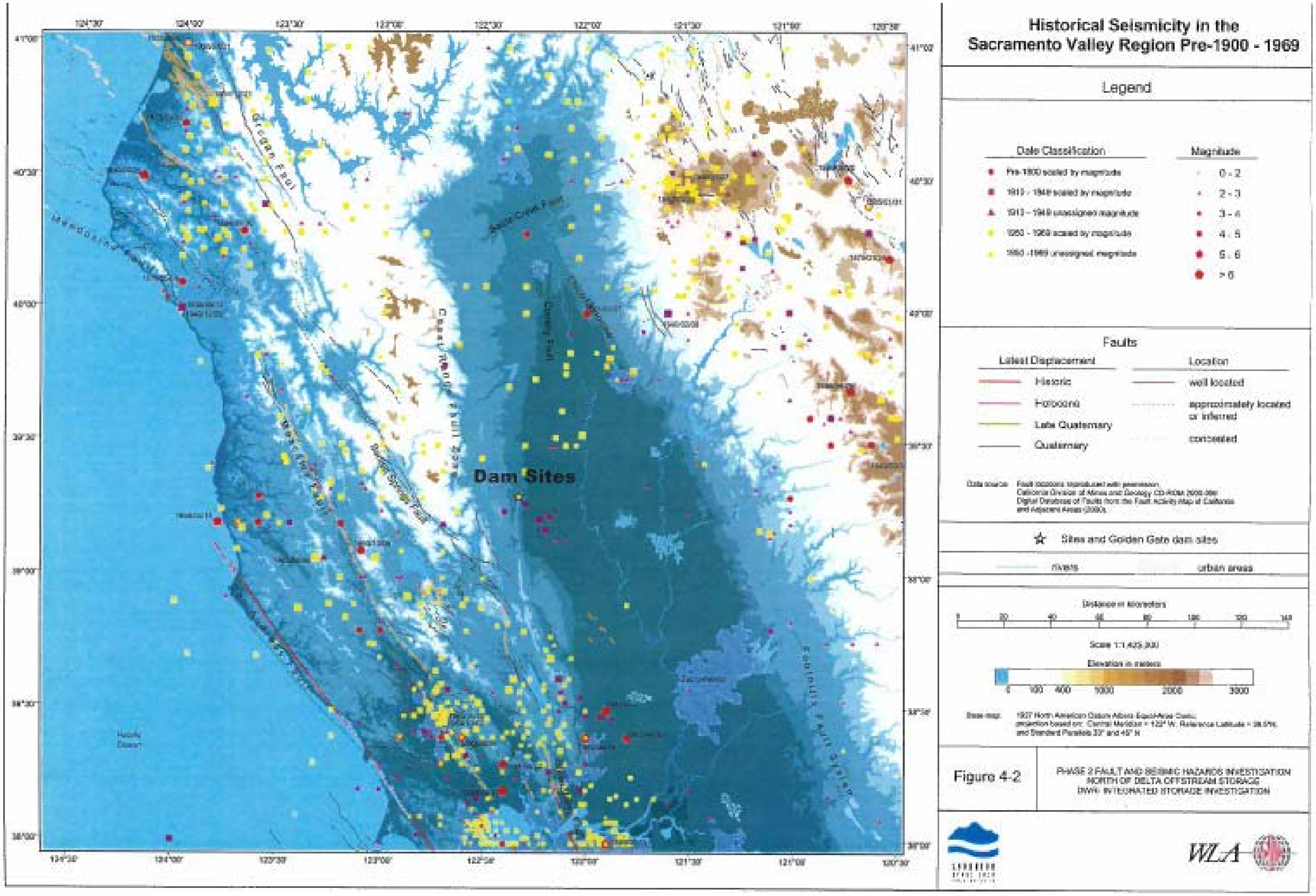


Figure B.2-30. Historical Seismicity in the Sacramento Valley Region, Pre-1900 – 1969

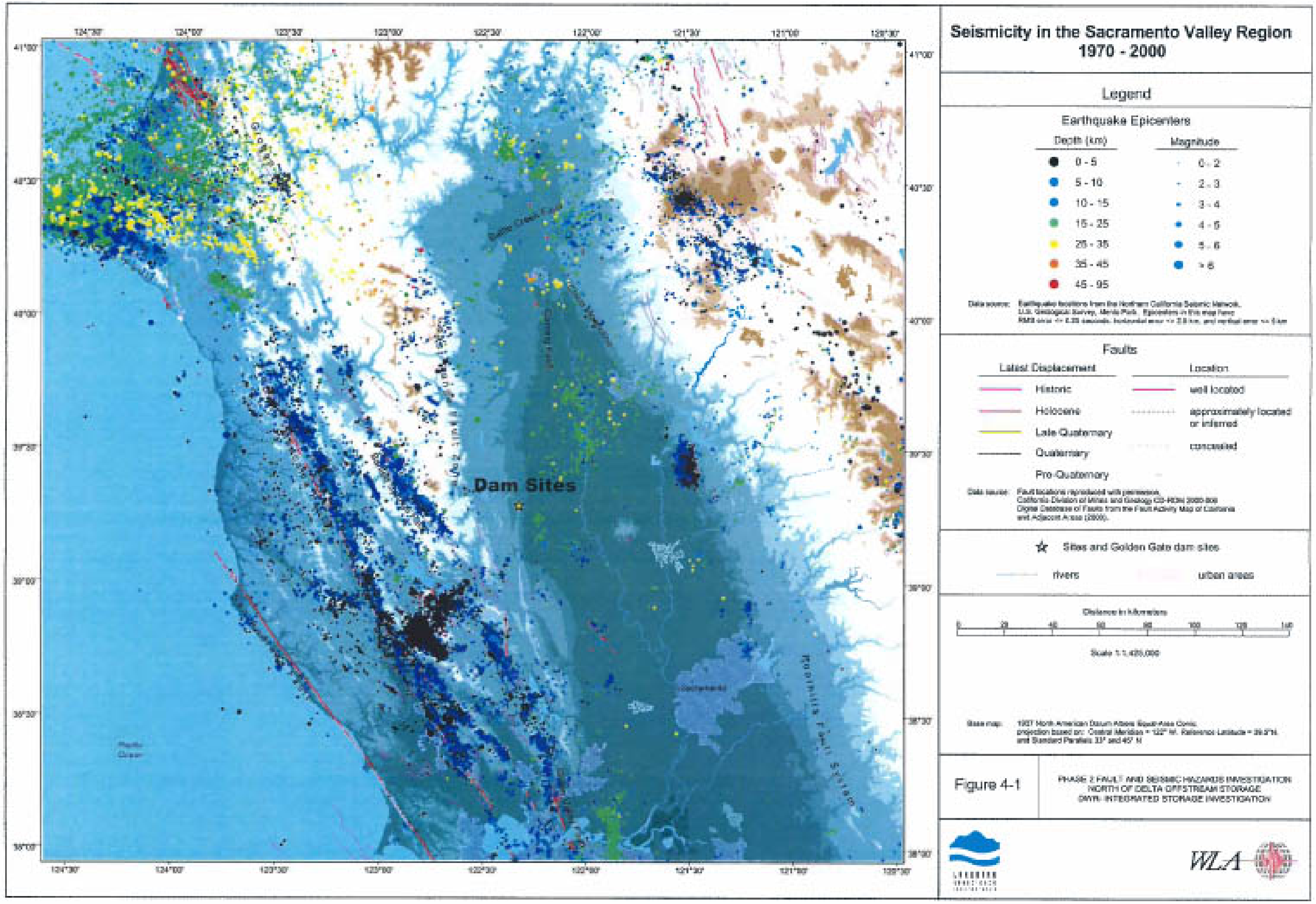


Figure B.2-31. Seismicity in the Sacramento Valley Region, 1970 – 2000

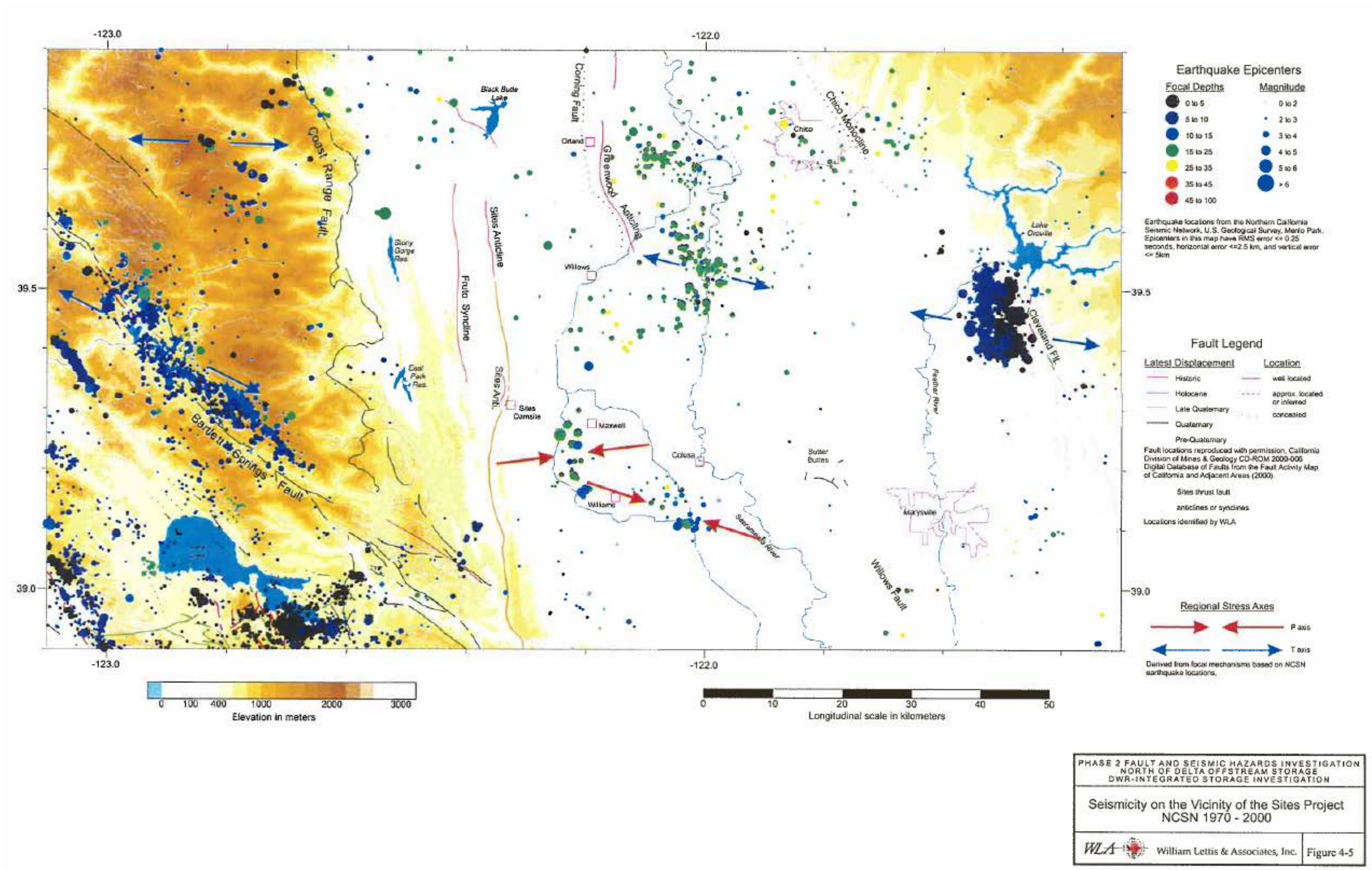
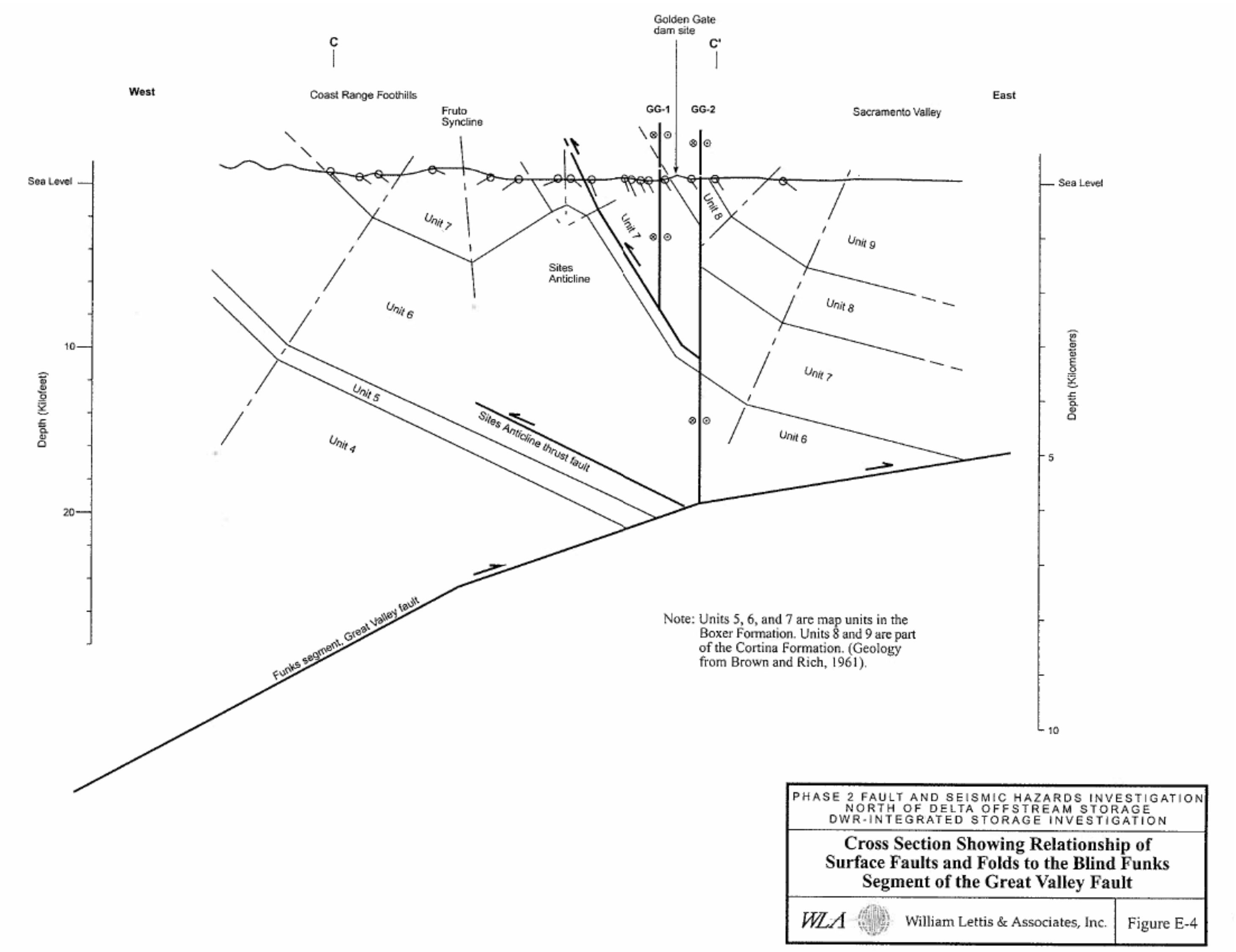


Figure B.2-32. Seismicity in the Vicinity of the NODOS/Sites Reservoir Project – Northern California Seismic Network, 1970 – 2000



Note: Units 5, 6, and 7 are map units in the Boxer Formation. Units 8 and 9 are part of the Cortina Formation. (Geology from Brown and Rich, 1961).

PHASE 2 FAULT AND SEISMIC HAZARDS INVESTIGATION
NORTH OF DELTA OFFSTREAM STORAGE
DWR-INTEGRATED STORAGE INVESTIGATION

Cross Section Showing Relationship of Surface Faults and Folds to the Blind Funks Segment of the Great Valley Fault

WLA William Lettis & Associates, Inc. | Figure E-4

Figure B.2-33. Cross Section Showing Relationship of Surface Faults and Folds to the Blind Funks Segment of the Great Valley Fault

Table B.2-1. 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[1]
GG-1	1.1 miles	Right-lateral	246 ± 82 feet	Unknown	2 feet	< 0.5 mile	3.1 miles	Holocene deposits unfaulted
GG-2	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	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

Source: WLA 2002.

Notes:

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

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 suggests that at least one surface rupturing event probably has occurred in the past 35,000 years, and therefore the fault would be considered active by DSOD criteria (WLA 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.

On the basis of a probabilistic seismic hazard map that depicts the peak horizontal ground acceleration (PGA) that would be exceeded at a 10 percent probability in 50 years (Petersen et al. 2014), the values in the Primary Study Area range from 0.15 g to 0.25 g (where *g* equals the standard acceleration due to gravity). This indicates that over the next 50 years, there is a 10 percent chance that one or more earthquakes somewhere in the region, not necessarily on a fault in the Primary Study Area, would cause ground shaking with an acceleration at 15 to 25 percent of that due to gravity. This level of shaking is approximately equivalent to a Modified Mercalli Intensity value of VI-VII (Strong to Very Strong, with Light to Moderate damage) (Atkinson and Kaka 2007; Wald et al. 1999).

The 2014 hazard maps depict the seismic hazard that can be expected in a site underlain by firm rock. The Primary Study Area is on sedimentary bedrock of the Great Valley Sequence (western portion) and recent alluvial deposits (eastern portion). The PGA values reflected in the hazard maps do not account for site amplification of ground shaking due to underlying soil conditions that deviate from firm rock. Hazard values that reflect site conditions can be obtained from a site-specific seismic hazard analysis.

Historically, the Primary Study Area has a low rate of seismicity. Data from the Northern California Seismic Network database indicate that no seismic event greater than M_w 4.5 has occurred since 1970. Sparse data from the historical record show no event greater than M_w 4.5 (WLA 2002). The strike-slip faults of the San Andreas Fault system have activity rates one or two orders-of-magnitude higher than the Great Valley fault zone and other faults in the Sacramento Valley. Ground shaking experienced at the dam sites is therefore more likely to originate from earthquakes in the Secondary Study Area than faults in the Primary Study Area.

Focal depths of earthquakes near the Primary Study Area generally cluster between about 10 and 20 kilometers (km) (6 to 12 miles), with some as shallow as 5 km (3 miles), and a few reaching depths of about 25 km (15 miles). This is somewhat deeper than focal depths for earthquakes originating on the strike-slip faults in the Coast Ranges to the west, and on the normal faults on the eastern side of the Sacramento Valley (WLA 2002).

Seismically Related Ground Failure, including Liquefaction

Liquefaction is the sudden temporary loss of shear strength in saturated, loose to medium–dense granular sediments subjected to ground shaking. 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 foundation failure of buildings and other facilities due to the reduction of foundation bearing strength. 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 at risk due to the effects of liquefaction are typified by 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. These 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. NODOS project features in this area include the Holthouse Reservoir Complex, the Terminal Regulating Reservoir and its associated facilities, the Delevan Pipeline, the Delevan Pipeline Intake/Discharge Facilities, and the Delevan Transmission Line.

The Funks and Bear Valley segments of the Great Valley fault are the closest seismogenic faults to the NODOS project that are considered capable of triggering surface displacement at one or more of the proposed structures. Indirect evidence of late-Quaternary activity along the Funks segment includes the following:

- Paleoseismic trenching studies of the Salt Lake thrust fault have shown that at least one, and probably three or more, surface ruptures have occurred in the past 30,000 to 70,000 years; the Salt Lake thrust fault has been interpreted by WLA as terminating down-dip against the Funks segment of the Great Valley fault.
- Morphometric analysis of regional topography showing evidence of localized late Quaternary uplift coincident with the Sites anticline and Salt Lake thrust fault, both of which are above the Funks segment.
- Morphometric analysis of stream drainages across Coast Range foothills, showing localized fluvial incision and channel morphology consistent with active surface uplift above the Funks segment.

Locally, the northeast-striking tear faults (S-2), GG-1, GG-2, and GG-3 have been interpreted to terminate downward against the Funks segment. It is thought that the tear faults move sympathetically during large-magnitude earthquakes on the Funk segment thrust ramp, and do not behave as independent seismic sources. However, WLA has concluded that the northeast-striking faults may be a source of aftershocks following an earthquake on the Funks or Bear Valley segments of the Great Valley fault. Calculations and seismic reflection data analyses by WLA show that the tear faults would have a maximum rupture depth of 3.1 miles, and maximum earthquake magnitudes of M_w 5.3 to 5.4; the rupture depth for GG-1 was calculated at 1 to 2 miles, based on its short surface trace. Maximum surface displacement along the northeast-striking tear faults were calculated to range from 2.4 to 8 inches. WLA’s ground motion analysis, using methods by Abrahamson and Silva (1997) and Sadigh et al. (1997), accounting for fault rupture directivity, determined that a peak ground acceleration of 0.8 g (acceleration due to gravity) would be generated from a Maximum Credible Earthquake (MCE) of M_w 6.8 on the Bear Valley segment of the Great Valley fault. Analytical results may be slightly less for individual sites and structures in the project area (Figures Figure B.2-34 and Figure B.2-35).

A similar study was not conducted for the Bear Valley segment of the Great Valley fault south of the reservoir site. However, WLA concluded that the Bear Valley segment is active, based on its location in a recognized zone of late-Cenozoic tectonic activity, and between two other active segments of the Great Valley Fault (Funks segment to the north, and the tectonically active Rumsey Hills-Dunnigan Hills region to the south). The Bear Valley segment is considered the controlling seismic source for both major dam sites in the project area, based on comparative earthquake response spectra within a 31-mile radius of the reservoir site. Analyses of surface geologic structures and seismic reflection data indicate that the Bear Valley segment is 14 miles long, 3 to 6 miles deep, strikes north-south, and dips approximately 21º west, has a rupture width of 14 miles, and rupture area of 207 square miles. Further analysis by WLA shows an MCE, or design basis earthquake, magnitude of M_w 6.8, located 4.8 and 4.4 miles, respectively, from the Sites and Golden Gate Dam sites (Figures Figure B.2-32 and Figure B.2-33).

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 Richter magnitude (M_L) 5, began occurring around the reservoir. In the first 10 years following reservoir filling, over 6,000 earthquakes were recorded within 10 miles of Hoover Dam, where none had been recorded in the previous 15 years (Carder 1945; Rogers 2010). Earthquake frequency correlated somewhat with changing reservoir levels. Since 1966, seismicity levels around Lake Mead are no different than 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 put forth to try to understand the mechanisms of RTS, and identify the factors that contribute to it, to assess the likelihood of it occurring following impoundment of a reservoir. RTS has been documented at over 100 reservoirs throughout the world, with dozens more questionably associated (Gupta 2002; WCFS 1996). However, this is a small number compared to the 11,000 “large” dams that exist in the world. Some of the most well-known cases are at Koyna Dam in India, Aswan Dam in Egypt, Kariba Dam in Zambia, Xinfengjiang 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.

RTS may occur immediately following filling of a reservoir, “initial seismicity” or “rapid response,” or it can begin or continue many years later, “protracted seismicity” or “delayed response” (Simpson et al. 1988; Talwani 1997). Two mechanisms have been proposed to account for the different types of triggered seismicity. The added load from the weight of the water can change the stress on local faults, leading to failure; and a change in pore pressure—either from

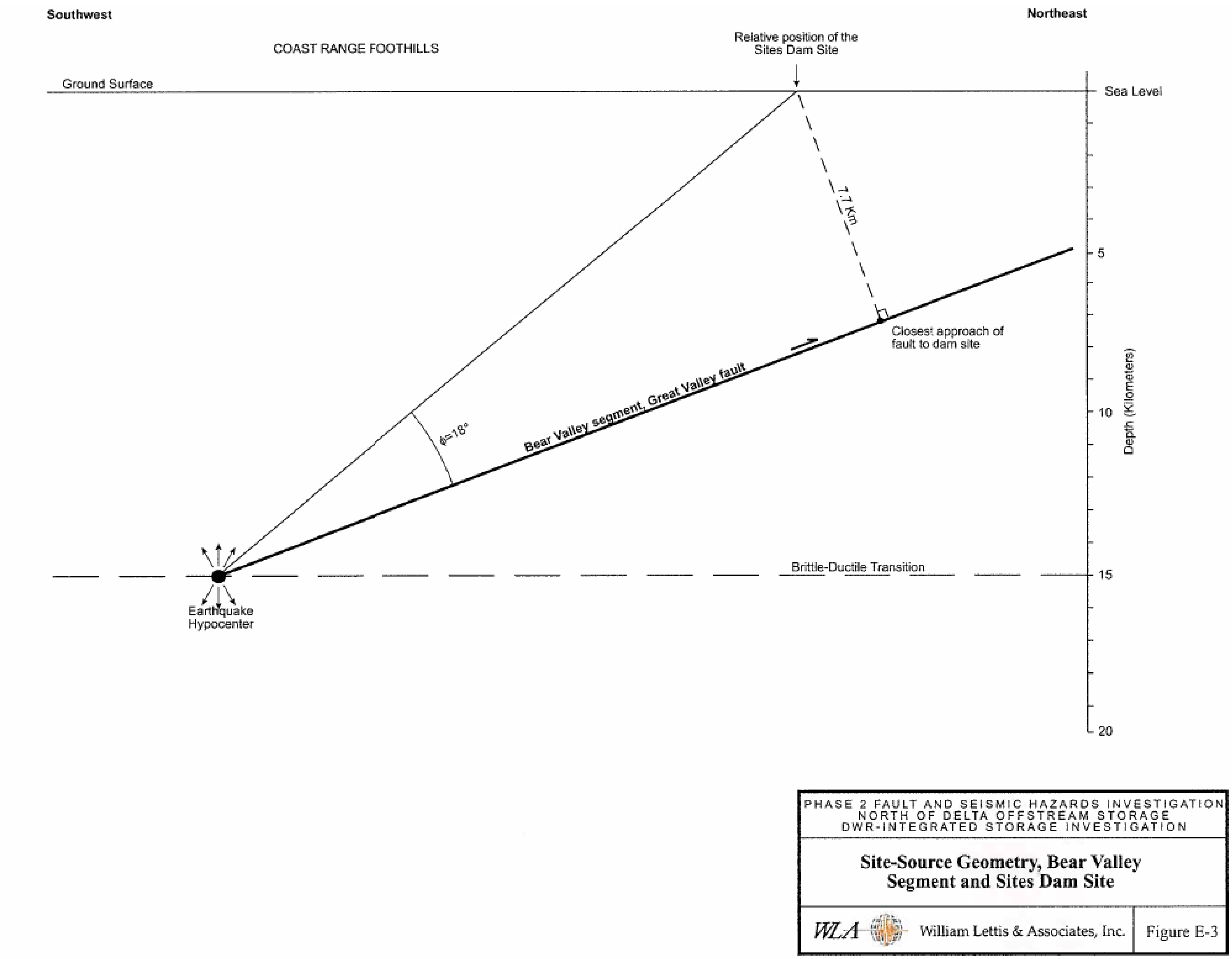


Figure B.2-34. Site-Source Geometry, Bear Valley Segment and Sites Dam Site

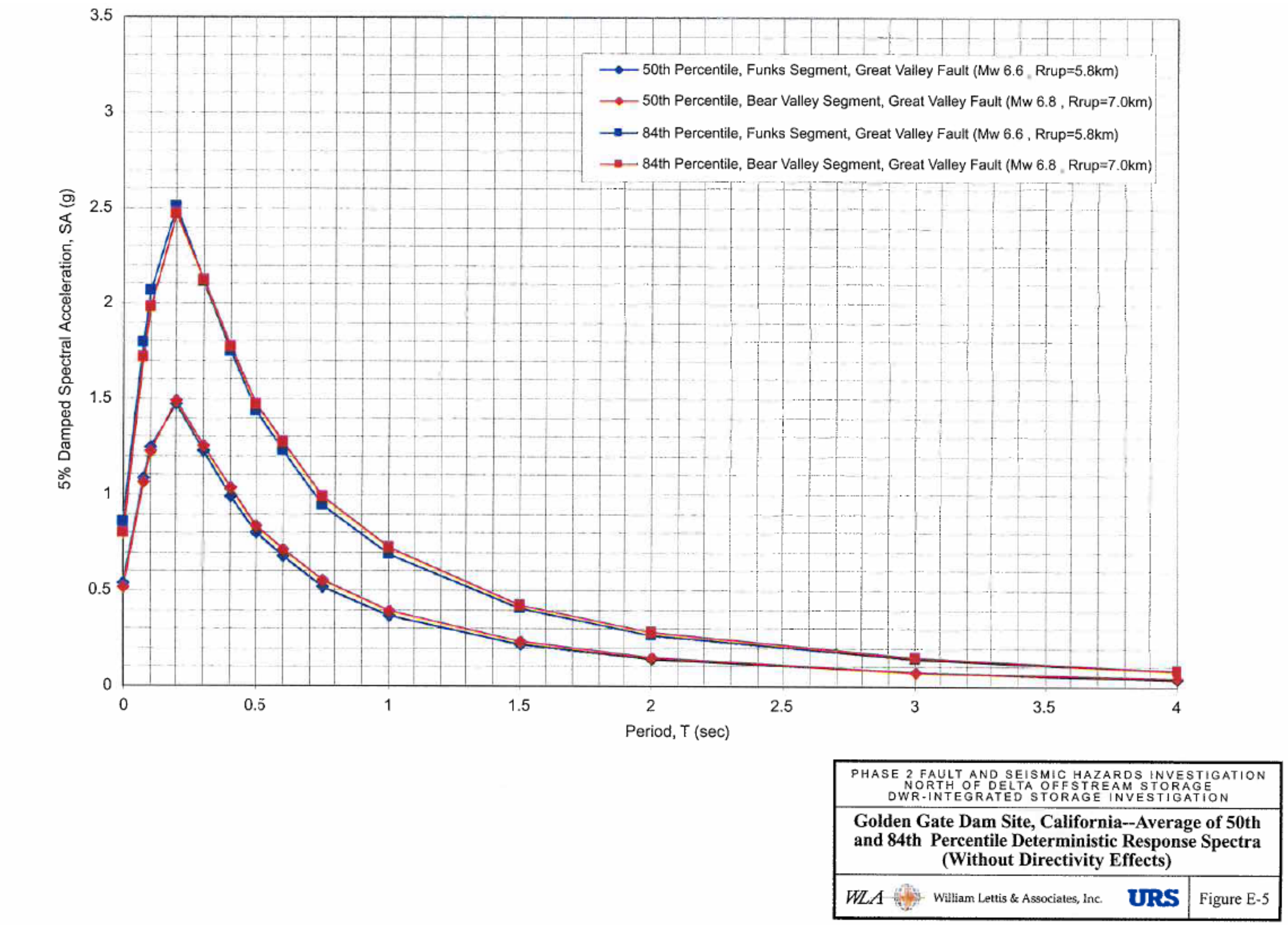


Figure B.2-35. Bear Valley and Funks Segments, California – Average of 50th and 84th Percentile Deterministic Response Spectra (without Directivity Effects) reservoir water penetrating the underlying rock or from compaction of pore space—can weaken a fault, and move it to slip and generate an earthquake (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 (e.g., 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). Therefore, 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 (e.g., Baecher and Keeney 1982; Knudsen et al. 2009; MWH 2013; Wong and Strandberg 1996). 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 (> ~300 feet). For this reason, the United States 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 (Assumpcao 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 over 150 meters. 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 igneous and metamorphic. However, the majority of RTS occurring in sedimentary rocks is in carbonate, not clastic rocks (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 rocks, 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, 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 that the Primary Study Area, including coarse sedimentary rocks and volcanic rocks. Outside of California, Lake Benmore, a 315-foot-deep reservoir in New Zealand, experienced RTS following impoundment (Packer et al. 1979). Lake Benmore is also in a compressional environment and underlain by coarse clastic sedimentary rocks. 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 in the Primary Study Area is Funks Reservoir. Depth of the water in the reservoir is the most important factor in reservoir-induced seismicity. Funks Reservoir, with a normal operating depth at the dam of 36 feet, is too shallow to create reservoir-induced seismicity, and none has been observed.

Construction Materials

Materials Investigations

Construction materials, for use in embankment dams and levee protection, have been investigated in the NODOS/Sites Reservoir Project area since the 1960s. Previous materials investigations have been performed by Reclamation and USACE, and were reviewed as part of the current DWR investigation. Reclamation material investigations in 1964 and 1980 included an evaluation of material sources for the construction of dams at the Sites Reservoir site. The USACE investigations focused on evaluating the suitability of Venado sandstone for use as riverbank protection projects on the Sacramento River. The USACE investigations primarily consisted of sampling and testing Venado sandstone at quarry sites downstream of the proposed Sites Dam, and were not formally documented in a report. In addition, an extensive evaluation of the shear strength properties of the Venado sandstone is presented in a University of California, Berkeley report published by Becker et al. (1972).

Because material requirements for the Sites Reservoir dams constitute a major component of the overall NODOS project, the primary focus of the preliminary materials investigation program was to identify and evaluate materials sources for construction of the proposed dams. The current DWR construction materials investigation program consisted of an assessment of available on-site and off-site material sources, laboratory testing, and an evaluation of the suitability and engineering properties of the available materials. The assessment included a review of published data, field investigations, and material sampling, with materials testing performed at DWR’s Soils and Concrete Laboratory. An evaluation of the engineering properties and suitability of the available materials for construction of the proposed dams is documented in the report *Sites Reservoir Feasibility Study, Materials Investigation, Testing, and Evaluation Program* (DWR DOE 2002c).

Material Sources

General

The construction materials investigation program examined the following materials available in or near the proposed NODOS/Sites Reservoir Project area: alluvial deposits (Recent and older alluvium), and Venado sandstone of the Cortina Formation (fresh and weathered).

Mudstone of the Boxer Formation

These material sources were investigated, tested, and evaluated to examine their suitability for use as the following types of construction materials: impervious core; rockfill and riprap; random fill; filter, drain, and transition; and concrete aggregate.

Impervious Core

A large amount of potential impervious material exists in or near the NODOS/Sites Reservoir Project. Previous studies by Reclamation identified four main areas of alluvial deposits in the reservoir area, encompassing roughly 36 million cubic yards of material.

Figure B.2-36 illustrates the extent of these deposits. Additional impervious materials are in required excavation areas for the appurtenant structures and Funks Reservoir enlargement. These required excavation areas would be used to the maximum extent practicable. Additional quantities of impervious materials are in potential borrow sites within 1 mile of each of the 11 dam sites. Figure B.2-36 illustrates the locations of these potential borrow areas. The impervious materials are suitable for use in the proposed embankment dams and are generally classified as low- to medium-plasticity clays, with lesser amounts of high-plasticity clays, and clayey sands.

Rockfill and Riprap

The best available source of clean rockfill material in the NODOS/Sites Reservoir Project area is fresh Venado sandstone. Sandstone quarry areas have been identified within 1 mile of both the Golden Gate and Sites Dam sites, and are presented in plan view on Figure B.2-24. Sufficient quantities of fresh sandstone for rockfill material can be obtained from these quarries to construct the proposed embankment dams. Future design investigations should also evaluate the advantages and disadvantages of developing one centrally located quarry for both Golden Gate and Sites Dams, instead of developing a quarry for each dam.

Figure B.2-36 also presents a proposed sandstone quarry location for construction of the saddle dams. The haul distance from this proposed quarry is roughly 3 to 4 miles from the saddle dam sites. A potential alternate source of rockfill and riprap material for construction of the saddle dams is a ridge of conglomerate in the reservoir area near Saddle Dam 3 (Figure B.2-36). Although not evaluated as part of the materials investigation program, this potential rockfill source offers a shorter haul distance to the saddle dams (1 to 2 miles). This rockfill source would cause fewer environmental impacts in comparison to the proposed sandstone quarry, because the ridge of conglomerate is in the reservoir area, and the potential sandstone quarry is not. Because the suitability of the conglomerate cannot be confirmed at this time, it was assumed that development of the sandstone quarry would be required for construction of the saddle dams.

Random Materials

It is anticipated that two general types of random materials would be generated during construction, depending on the source of the material. One type of random material would be comprised of predominately weathered sandstone from the Cortina Formation, while the other type would be predominately mudstone from the Boxer Formation. Mudstone from the Boxer Formation would tend to be “soil like” after excavation and compaction operations, because it is a low-strength rock and has a propensity to break down when exposed to air and water. The weathered Cortina Formation would tend to be a dirty rockfill.

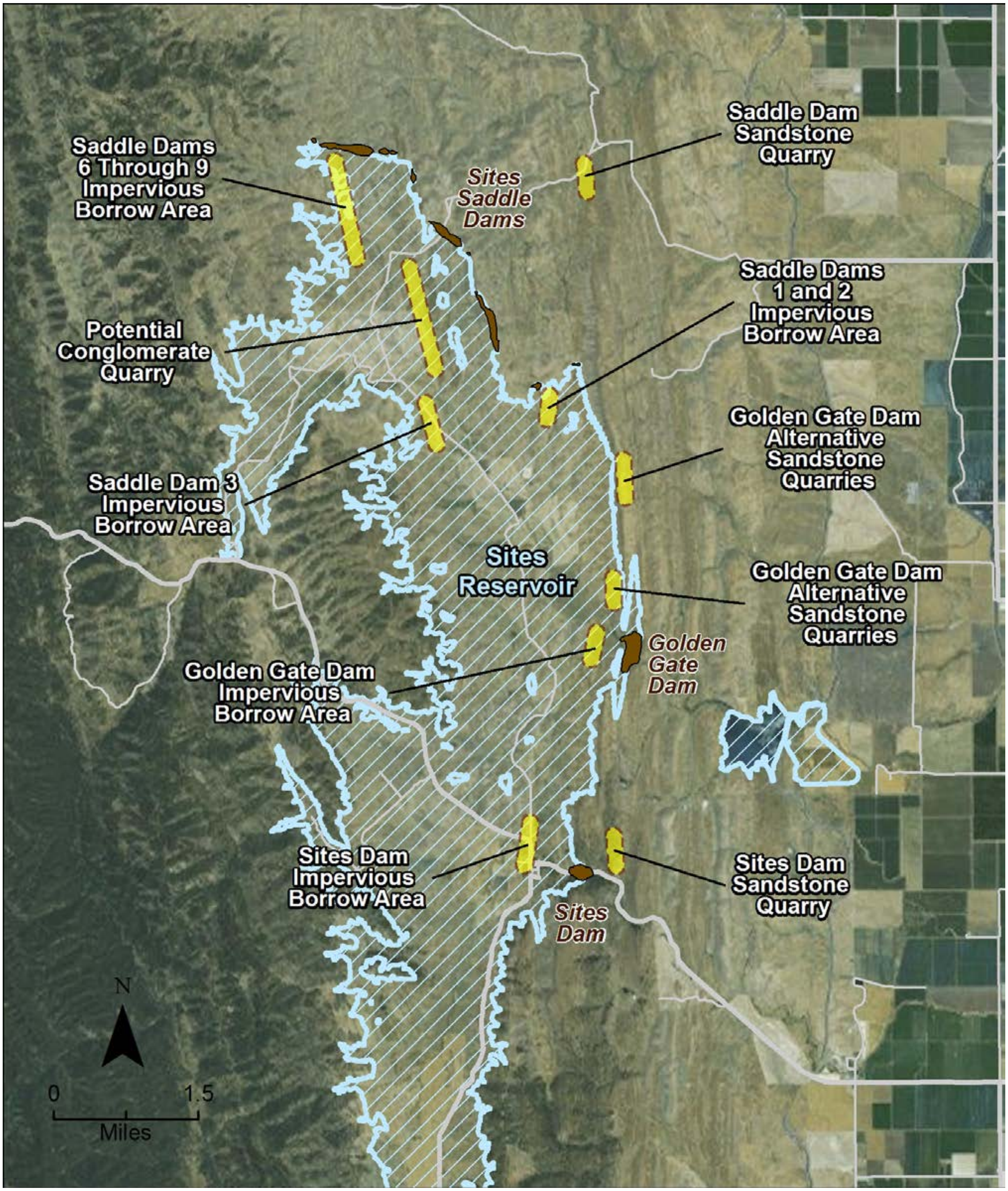


Figure B.2-36. Sites Reservoir – Proposed Impervious Borrow Areas and Quarries

At the Sites Dam and Golden Gate Dam sites, random embankment material would be composed of materials unsuitable for use as clean rockfill. Materials would consist of weathered sandstone, mudstone, slopewash, etc., from excavations for the dam foundations, appurtenant structures, and rockfill quarries. Material from clearing and grubbing operations would not be used in any embankment structure. Random material generated during construction of these dams would have haul distances of less than 1 mile.

Random material would be generated from the Boxer Formation during construction of the saddle dams and designated borrow areas. Random material borrow areas for construction of the saddle dams have not been identified, but would be located in the reservoir area, with haul distances of less than 1 mile. Sufficient quantities are available for construction of the saddle dams. Although the Boxer Formation material would function more as an upstream and downstream shell zone in the saddle dam sections, the term "random" is used for this material zone to be consistent with the terminology used at Sites and Golden Gate Dams.

Filter, Drain, and Transition Materials

Deposits of sand and gravel of sufficient quantity for construction of the Sites Reservoir dams are not available in the project area. Therefore, alternative sources of filter, drain, and transition materials were examined as part of the preliminary materials investigation. Laboratory testing indicated that crushed, fresh Venado sandstone would not be suitable as filter, drain, and transition materials.

Filter, drain, and transition materials for the proposed embankment dams would be imported from the closest off-site sand and gravel deposit. Potential borrow sites for aggregate are shown on Figure B.2-37. Table B.2-2 provides the coordinates for the potential sites. The preferred location is an off-site deposit identified as an old channel on Stony Creek, between Orland and Willows (Figure B.2-38). The channel is approximately 30 to 35 road miles from the project area, and has an estimated material availability of 160 million cubic yards, far exceeding the construction requirement.

Concrete Aggregate

Similar to the approach used for filter, drain, and transition materials, crushed Venado sandstone and off-site sand and gravel deposits were examined as potential sources of concrete aggregate. Preliminary testing performed on crushed samples of Venado sandstone indicates that it marginally meets concrete aggregate suitability criteria. Verification of the suitability of the Venado sandstone for use as concrete aggregate would be the focus of future investigations.

Construction Water

Construction water would be obtained from Funks Creek and Stone Corral Creek. Additional water would be supplied by off-site sources if required.

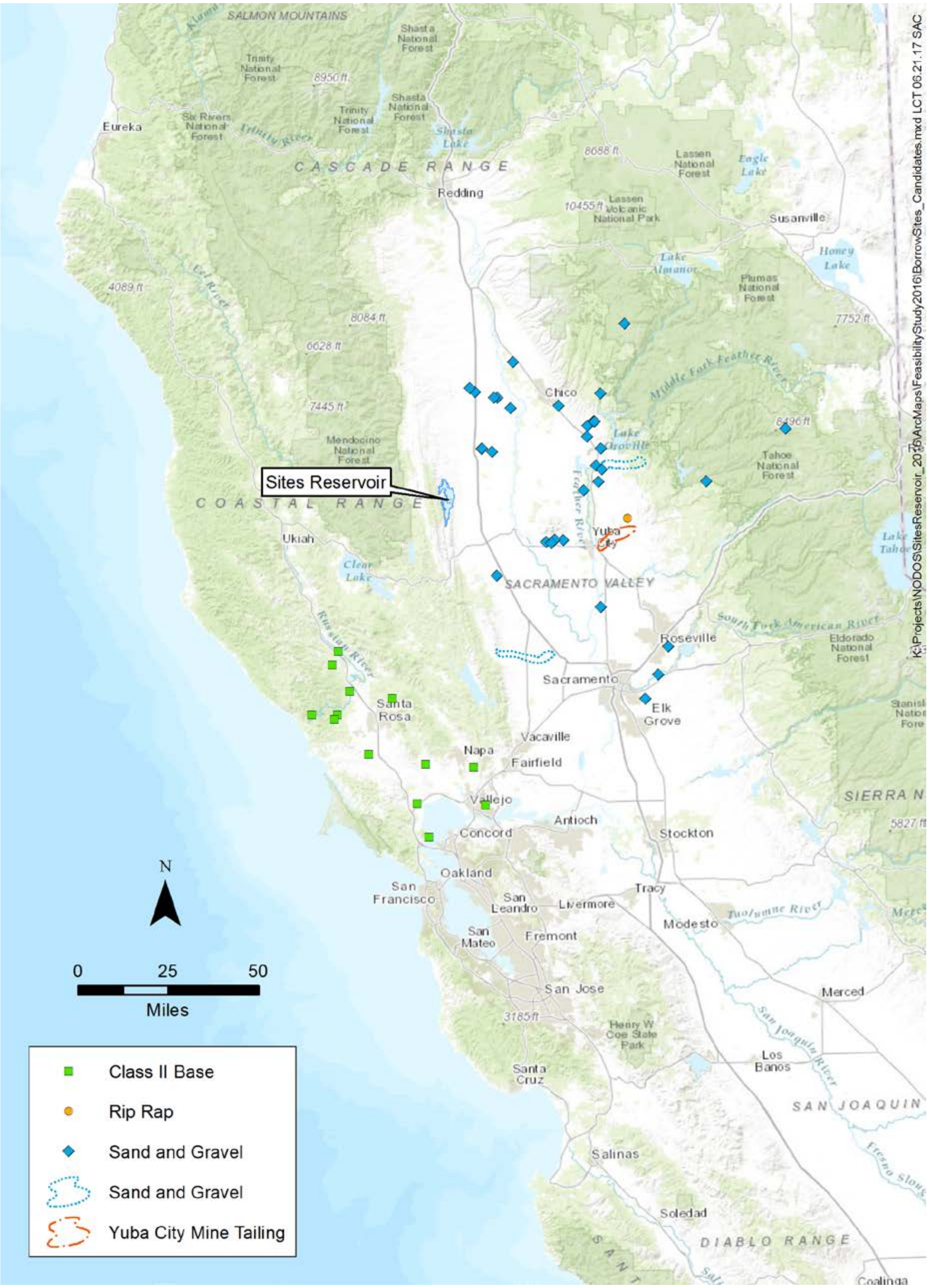


Figure B.2-37. Candidate Borrow Sites

Table B.2-2. Candidate Borrow Site Locations

ID	Latitude	Longitude	Name	Type	County
1	39.025	-122.094	Whiskey Creek Pits	Sand and Gravel	Colusa
2	39.396	-121.01	Rinceton Ranch Pit	Sand and Gravel	Colusa
3	39.742	-122.1	Hamilton City Pit	Sand and Gravel	Glenn
4	39.542	-122.166	Willows Pit	Sand and Gravel	Glenn
5	39.7	-122.017	Hamilton City Pit	Sand and Gravel	Glenn
6	39.536	-122.168	Willow Pit	Sand and Gravel	Glenn
7	39.766	-122.2	Stoney Creek Pit	Sand and Gravel	Glenn
8	39.525	-122.116	Pacheco Pit	Sand and Gravel	Glenn
9	39.742	-122.083	Stoney Creek Pit	Sand and Gravel	Glenn
10	39.78	-122.228	Stoney Creek Pit	Sand and Gravel	Glenn
11	39.167	-121.75	Sutter Buttes Pit	Sand and Gravel	Sutter
12	39.165	-121.839	Myer Quarry	Sand and Gravel	Sutter
13	39.158	-121.813	Sutter Buttes Quarry	Sand and Gravel	Sutter
14	38.897	-121.563	Nicolaus Pit	Sand and Gravel	Sutter
15	39.168	-121.802	Butte Ranch Quarry	Sand and Gravel	Sutter
16	39.646	-121.583	Pentz Pit	Sand and Gravel	Butte
17	39.601	-120.591	Green Rock Quarries	Sand and Gravel	Butte
18	39.585	-121.62	Oroville North Pit	Sand and Gravel	Butte
19	39.45	-121.55	Oroville South Pits	Sand and Gravel	Butte
20	39.755	-121.55	Pine Creek Pit	Sand and Gravel	Butte
21	39.64	-121.583	Pentz Pit	Sand and Gravel	Butte
22	39.708	-121.767	Chico Pit	Sand and Gravel	Butte
23	39.367	-121.645	Gridley Pit	Sand and Gravel	Butte
24	39.467	-121.575	Oroville Pit	Sand and Gravel	Butte
25	39.4	-121.567	Vance Pit	Sand and Gravel	Butte
26	40.033	-121.417	Carr Mine	Sand and Gravel	Butte
27	39.648	-121.585	Gunn Pit	Sand and Gravel	Butte
28	39.626	-121.616	Lucky Seven Pit	Sand and Gravel	Butte
29	39.533	-121.55	Natomas 100 Pit	Sand and Gravel	Butte
30	39.883	-122	Pine Creek Pit	Sand and Gravel	Butte

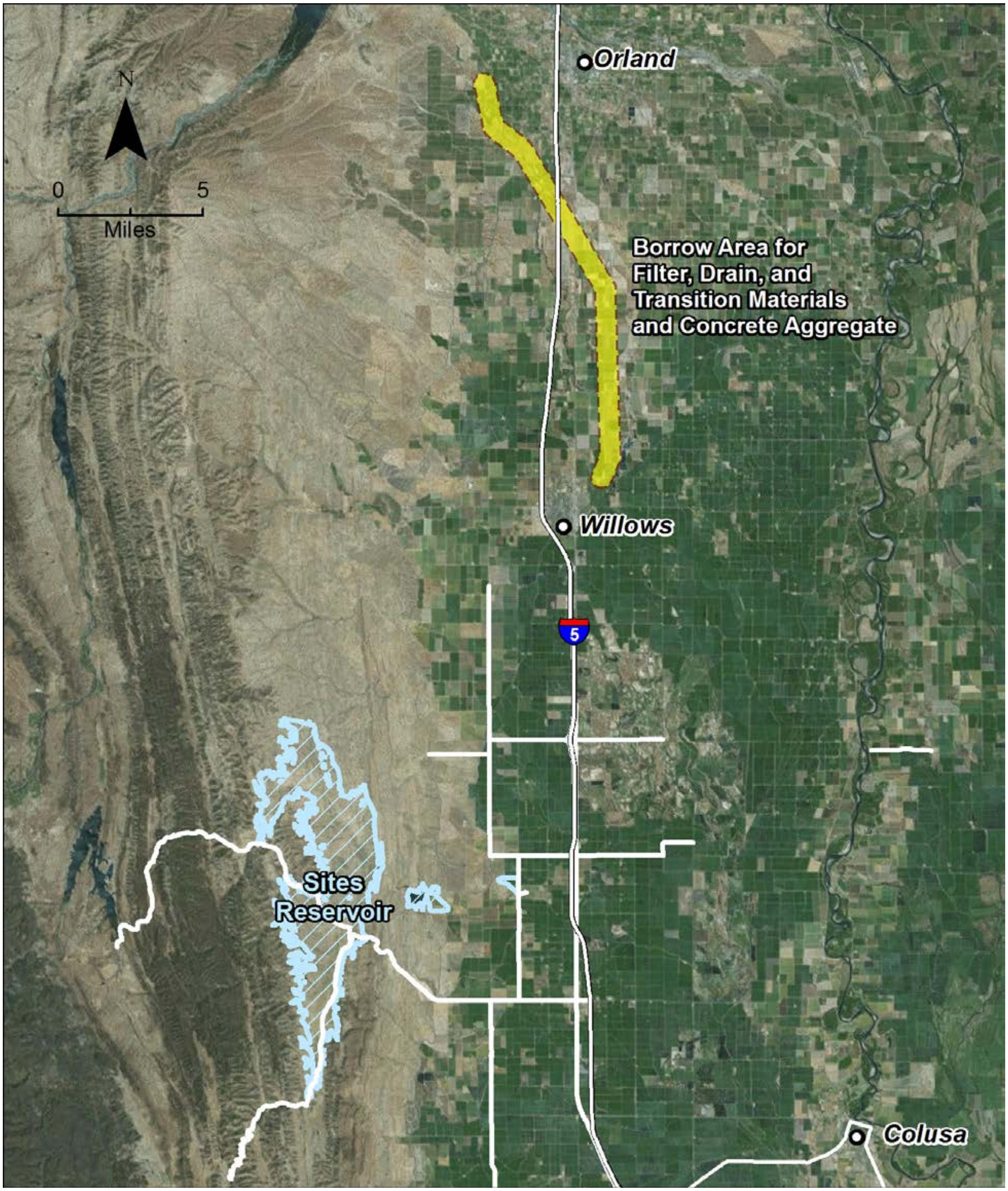


Figure B.2-38. Proposed Borrow Area for Filter, Drain, and Transition Materials, and Concrete Aggregate