DRAFT

North of the Delta
Offstream Storage Investigation

Progress Report

Appendix O: Phase 1 Fault and Seismic Hazards Investigation

July 2000

Integrated
Storage
Investigations

CALFED
BAY-DELTA
PROGRAM

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Appendix O: Phase 1 Fault and Seismic Hazards Investigation

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California Department of Water Resources

July 2000

Integrated
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Summary

This report presents the results of the Phase I Fault and Seismic Hazards Investigation of the proposed Red Bank, Thomes-Newville, Sites, and Colusa Project reservoir areas. The purpose of this report is to compile and summarize the information available to date regarding fault and seismic hazards along the west side of the Sacramento Valley. The scope includes a review of previous work, a compilation of damsite and fault mapping previously completed by the Department of Water Resources and other agencies, and an estimation of preliminary seismic and ground breakage risks from known faults.

This is the first in a series of reports discussing faulting and seismicity for the offstream storage project alternatives being investigated by DWR. It is to be used for regional planning studies. Information was obtained from published documents; no fieldwork was performed. The report describes regional geology, faulting, and geologic structures and includes a brief geologic description of project damsites and a regional earthquake history. Also included are preliminary estimates of risks associated with the maximum credible earthquake, reservoir induced seismicity, random earthquakes, liquefaction, landscaping, and surface rupture hazards.

Phase II will be published at a later date and will include the results of field investigations in progress, aerial photography and radar analyses, drilling and trenching of faults and lineaments, detailed geologic mapping, consultant reports, and final seismic and fault hazard evaluations of the proposed alternative projects. The Phase II report will contain information suitable for final design activities.

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Introduction

The study area includes the proposed reservoir areas of the Red Bank, Thomes-Newville, Sites, and Colusa Projects along the west side of the Sacramento Valley between Maxwell and Red Bluff. The four projects shown on Figure 1 are being evaluated for offstream storage opportunities using water from the Sacramento River and its tributaries. Surplus water would be diverted into the reservoirs during periods of surplus flows and released when needed.

Faults and earthquakes affect dams in several different ways. Active faults in the foundation may displace elements of the dam either by slow creep or by sudden movement during earthquakes. Seepage and piping may be induced, resulting in failure of the dam. Shaking during an earthquake may also cause fracturing of the dam, or may cause the dam to slide, settle, liquefy, or separate from its foundation. In some cases, earthquake shaking and landsliding into the reservoir may cause wave action (seiches - the oscillation of a lake in large, slow waves), erosion of the dam face, and overtopping.

Dams in earthquake prone areas generally require a more conservative embankment section and foundation treatment. A more conservative embankment section may include more freeboard, better or thicker filters and drains to reduce pore pressure, thicker impervious cores of piping-resistant material, rockfill toes for slope support, and flatter slopes. New criteria developed by the Department of Water Resources' Division of Safety of Dams require that the outlet works and spillway must be capable of evacuating 10 percent of the maximum water depth within 10 days. This modification is designed to increase safety should the dam be compromised during an earthquake. Design details of embankment type dams can make an enormous difference in whether they are inherently safe from earthquake damages (Sherard, et al., 1963).

Foundation work may include additional stripping, removal of all soil and weathered rock material, and cleaning and dental work to include excavation of faulted material, deeper cutoff trenches, and concrete fill in weak areas. This type of foundation work will prevent loose soil from liquefying and moving out from underneath the dam and from causing cracking, sliding or actual horizontal displacement of the dam.

Proposed Projects

Four projects are being considered. From north to south, they are the Red Bank, Thomes-Newville, Sites, and Colusa Projects. Each one has a number of storage capacity options.

The Red Bank Project, located about 15 miles west of Red Bluff, was first identified in Bulletin 3, the California Water Plan (DWR 1957). It consists of two dams: Dippingvat on south fork Cottonwood Creek and Schoenfield on Red Bank Creek. Excess flows from the South Fork would be diverted through a series of conveyance facilities into the larger Schoenfield Reservoir. Total storage capacity is 358,700 acre-feet. A fault and seismic investigation was completed by DWR in 1991.

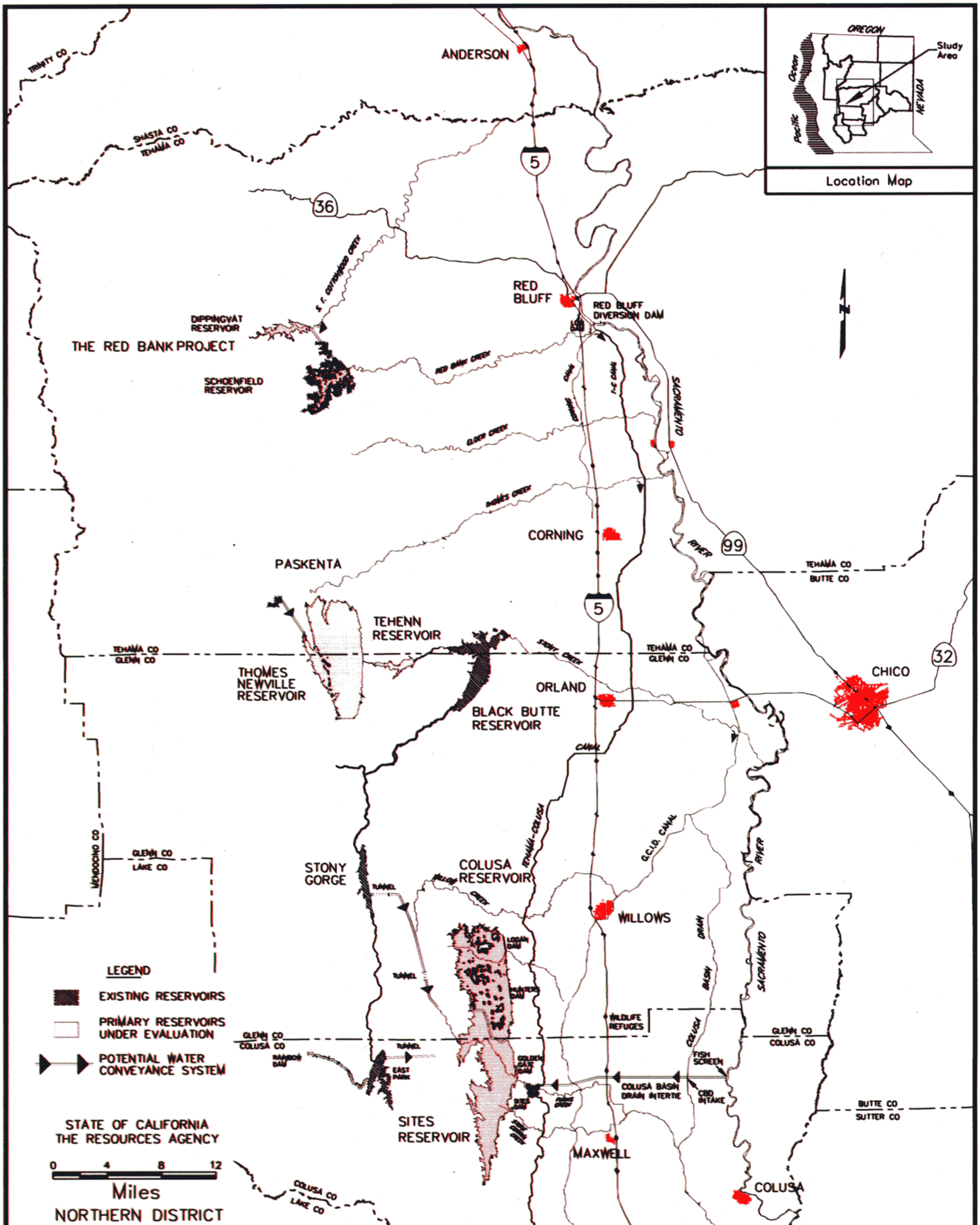


Figure 1. Location Map of Proposed Offstream Storage Projects.

The Thomes-Newville Project, located about 20 miles west of Corning, would provide instream storage for north fork and main stem Stony Creek, and offstream storage for the Sacramento River. Facilities include Newville and Tehenn reservoirs on the north fork, a diversion facility from Thomes Creek to Newville, a two-way conveyance facility between Tehenn and the existing Black Butte Reservoir on Stony Creek, and a two-way canal between the Tehama-Colusa Canal and Black Butte Reservoir. The canal would bring in Sacramento River water. Two storage capacities, a 1.84 million acre-foot smaller facility and a 3.08 maf larger facility, are being considered. Earth Sciences Associates completed a fault and seismic investigation for DWR in 1980.

The Sites and Colusa Projects, located about 10 miles west of Maxwell, would provide offstream storage for the Sacramento River. Water would be conveyed via the Tehama Colusa Canal, Glenn-Colusa Canal, and/or a new cross-valley canal. There are three alternative sizes being considered: a 1.2 maf smaller Sites, a 1.9 maf larger Sites, and a 3.3 maf Colusa Reservoir. The smaller and larger Sites would have a Sites Dam on Stone Corral Creek, Golden Gate Dam on Funks Creek, and up to 12 saddle dams around the reservoir rim.

The Colusa facility would extend the larger Sites into the northern "Colusa Cell." Additional facilities include Hunters Dam on Hunters Creek, Logan Dam on Logan Creek, and about five saddle dams along the north rim of the reservoir. The smaller Sites was investigated by the U.S. Bureau of Reclamation (1969), but their study did not include the larger Sites or Colusa. Golden Gate Dam has several possible axial alignments: an upstream straight alignment, a downstream curved alignment, and a downstream straight alignment.

Purpose and Scope

The study purpose is to identify the potential for tectonic activity along the west side of the Sacramento Valley and to determine fault and seismic hazards affecting the feasibility of the proposed projects.

The work has been divided into two phases. Phase I includes a literature survey and discussion of faulting and seismicity based on available knowledge. Phase I will guide the implementation of Phase II, which will include fieldwork such as mapping, trenching, and drilling. The purpose of Phase II is to conduct field investigations to determine the extent and activity level of faulting within the project area and to develop seismic design parameters for project features. The Phase II report will be published under separate cover at a later date.

The Phase I scope includes the following tasks:

- Review previous work. This includes a literature and Internet search of pertinent information relating to dams and fault and seismic hazards.
- Conduct literature searches and compile known fault zones near the reservoir areas. Determine "not-significant," "potential," and "significant" sources of seismic activity. Compile estimated seismic and ground breakage risks from these sources.
- From published information determine the presence of faults in dam foundations. Compile any existing subsurface exploration statistics to determine extent of fracturing and date of last activity.

- Compile a preliminary earthquake map from DWR's Earthquake Engineering Section epicenter data set.
- Work with the U.S. Geological Survey to produce an analysis of the Red Bluff Microseismic Network data.
- Provide a summary, conclusions, and recommendations section to guide implementation of Phase II.

Seismic parameters were investigated for all four projects. The recent work done at the Red Bank and Thomes-Newville Projects, and the older work done at the Sites and Colusa Projects were compiled from a variety of sources and presented in Attachment A to this report.

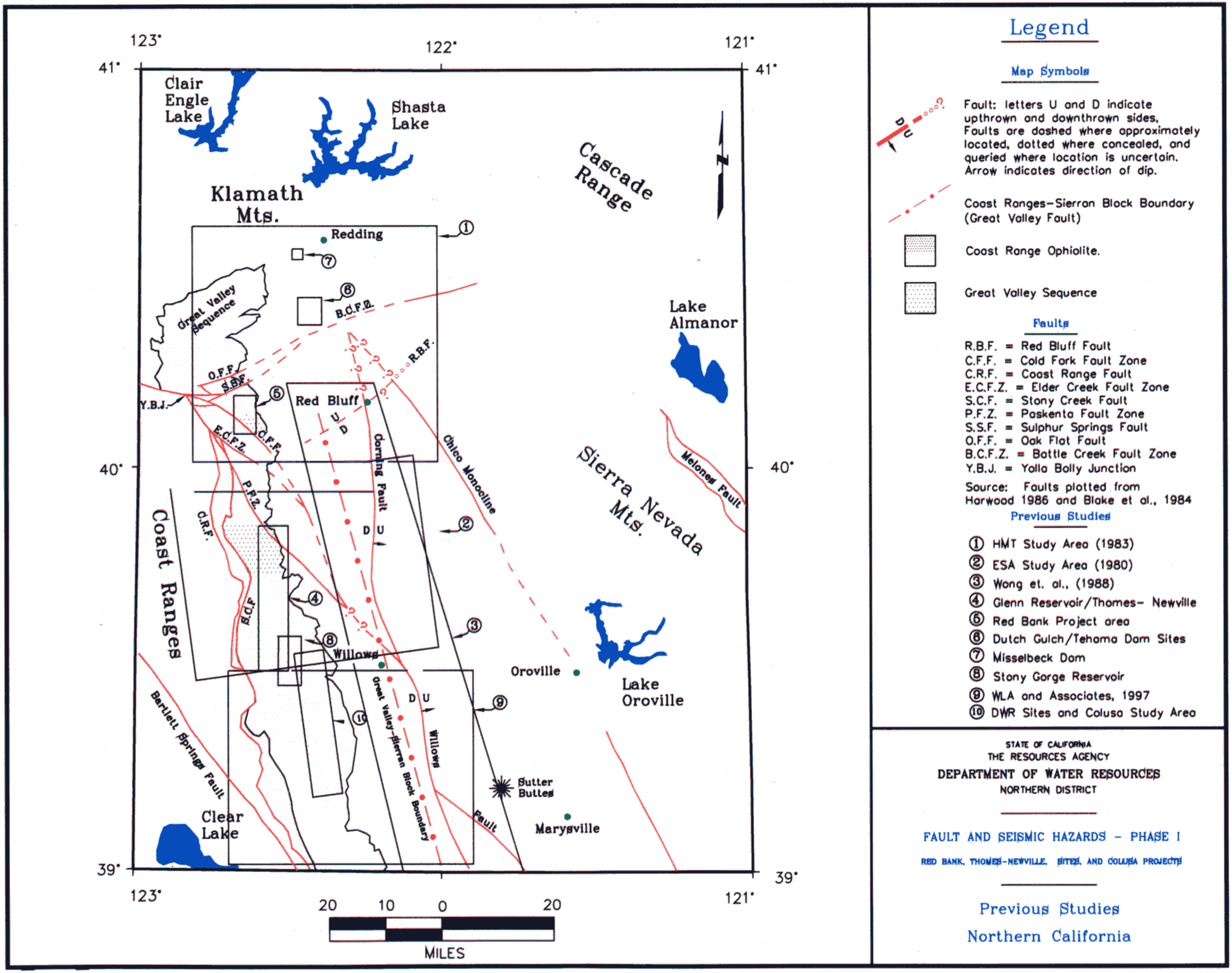
As required by the State of California, Department of Conservation, Division of Mines and Geology (1997), this preliminary fault and seismic investigation was prepared and reviewed by Certified Engineering Geologists.

Previous Investigations

A large amount of work has been done on fault and seismic hazards along the west side of the Sacramento Valley. Figure 2 shows the location of geologic mapping by various workers. Most of this mapping is 10 to 20 years old. Recent advances in our knowledge of the tectonic framework have greatly increased our understanding of the potential for large earthquakes in the area. Pertinent investigations include:

- Brown and Rich, 1961. USGS personnel mapped the geology of the Lodoga 15-minute quadrangle.
- USBR, 1969. USBR conducted a fault investigation of the Sites project. Faults were mapped in the foundation areas of Sites and Golden Gate Dam sites and within the reservoir areas.
- DWR, 1978. A preliminary fault and seismic study of the Glenn Reservoir Complex concluded that there was no evidence of Quaternary fault activity near the proposed reservoir. Seismic activity suggested that faults were active to the west. DWR assigned an MCE of local magnitude (M_L) 7 to the entire west side based on two 1892 Winters-Vacaville earthquakes that occurred 70 miles to the south. The earthquake magnitude was based on a "floating" event and not on any particular fault.
- Earth Science Associates, 1980. ESA conducted this study for DWR's Glenn Reservoir Complex and concluded the following: surface fault activities on all faults in the area are older than 30,000 years, all the transverse faults are pre-Quaternary in age and do not present offset hazards, the probability of reservoir-induced seismicity is low, and that movement occurred on the Stony Creek fault between 30,000 and 130,000 years ago.
- DWR, 1980. A field study of apparent movement on the Stony Creek fault suggests that the movement was caused by landsliding and not faulting.

FIGURE 2



123°
122°
121°
41°
40°
39°
Clair Engle Lake
Shasta Lake
Klamath Mts.
Cascade Range
Redding
Lake Almanor
Great Valley Sequence
B.C.F.Z.
R.B.F.
O.F.F.
S.S.F.
Y.B.J.
Red Bluff
E.C.F.Z.
C.F.F.
Corning Fault
Chico Monocline
Sierra Nevada Mts.
Melones Fault
P.F.Z.
C.R.F.
Coast Ranges
S.C.F.
Willows
Oroville
Lake Oroville
Great Valley-Sierran Block Boundary
Willows Fault
Sutter Buttes
Marysville
Bartlett Springs Fault
Clear Lake
20
10
0
20
MILES
Legend
Map Symbols
Fault: letters U and D indicate upthrown and downthrown sides. Faults are dashed where approximately located, dotted where concealed, and queried where location is uncertain. Arrow indicates direction of dip.
Coast Ranges-Sierran Block Boundary (Great Valley Fault)
Coast Range Ophiolite.
Great Valley Sequence
Faults
R.B.F. = Red Bluff Fault
C.F.F. = Cold Fork Fault Zone
C.R.F. = Coast Range Fault
E.C.F.Z. = Elder Creek Fault Zone
S.C.F. = Stony Creek Fault
P.F.Z. = Paskenta Fault Zone
S.S.F. = Sulphur Springs Fault
O.F.F. = Oak Flat Fault
B.C.F.Z. = Battle Creek Fault Zone
Y.B.J. = Yolla Bolly Junction
Source: Faults plotted from Harwood 1986 and Blake et al., 1984
Previous Studies
① HMT Study Area (1983)
② ESA Study Area (1980)
③ Wong et. al., (1988)
④ Glenn Reservoir/Thomes- Newville
⑤ Red Bank Project area
⑥ Dutch Gulch/Tehama Dam Sites
⑦ Misselbeck Dam
⑧ Stony Gorge Reservoir
⑨ WLA and Associates, 1997
⑩ DWR Sites and Colusa Study Area
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
FAULT AND SEISMIC HAZARDS – PHASE I
RED BANK, THOMES-NEWVILLE, SITES, AND COLUSA PROJECTS
Previous Studies
Northern California

- USBR, 1981. The Stony Creek fault was assessed based on a seismic hazard reevaluation of Stony Gorge Dam, a few miles southwest of the Thomes-Newville Project. The USBR agreed with ESA on the seismic potential of local and regional faults, but felt that the trenching along the Stony Creek fault was inconclusive due to the unverified terrace ages. The USBR assigned a MCE of 6 to a regional event with an epicentral distance of about 5 miles and a focal depth of about 6 miles.
- DWR, 1980, Appendix A of the Thomes-Newville final report. This report included a summary of findings to date. It also included a resolution of the discrepancies regarding recent activity along the Stony Creek fault by concluding that last movement occurred more than 130,000 years ago. The maximum probable horizontal ground acceleration was estimated to be 0.55 gravity.
- Harlan, Miller, and Tait, 1983. The fault and seismic potential of the U.S. Army Corps of Engineers' Cottonwood Creek Project was considered. This project is about 10 miles northeast of the Red Bank Project. Their study included a detailed mapping of Quaternary geology within a 20-mile radius of the proposed dams and a summary of seismic parameters for the project. HMT concluded that no recognizable surface faulting has occurred in the last 125,000 years and surface faulting is not a concern. Reservoir-induced seismicity (RIS) risks were also assumed to be low. A review of the HMT report was used to determine the Cottonwood Creek Project maximum expected peak horizontal ground acceleration (0.5g) and velocity (30 cm\second) for the three most probable seismic sources.
- Walter, 1986. A study of intermediate focus earthquakes in the Weaverville to Red Bluff area further defines the extent of the subducted Gorda plate and Cascadia subduction. The earthquakes also open up the possibility that a magnitude (M) 8+ could occur directly under the Red Bank Project.
- Wong, Ely, and Kollmann, 1988. This study defined the Coast Ranges-Sierra Nevada Block Zone as a fundamental tectonic boundary capable of moderate to major earthquakes. This zone is a complex region of active compressional tectonics extending along the western margin of the greater Central Valley from Coalinga to Red Bluff. It is probably responsible for the two 1892 Winters (M_L6-7) and the 1983 Coalinga (M_L 6.7) earthquakes. The potential for large earthquakes exists along the entire boundary, but the low level of seismicity prevented a definitive characterization of the northern region.
- DWR, 1991. Based on accelerations experienced from the Coalinga aftershocks, DWR estimates a 0.55g peak acceleration for the Red Bank Project.
- Unruh and Moores, 1992. A study of the southwest Sacramento Valley defines the relation between surface deformation and earthquake potential from presently active, blind-thrusting activity associated with the CRSNBZ.

- California Department of Transportation, 1996. Publication of a technical report and deterministic seismic hazard map for California was based on MCEs.
- Department of Conservation, Division of Mines and Geology and U. S. Geological Survey, 1996. As part of the Working Group on Northern California Earthquake Potential, both agencies published a database on the sources for earthquakes larger than M6.
- William Lettis and Associates, 1997. The consultant published a seismotectonic evaluation of Monticello, Stony Gorge, and East Park Dams for USBR.

Methods of Investigation

The following activities were conducted for Phase I of this study, which evaluates and summarizes existing information but does not include any new field investigations:

- Literature and Internet reviews and searches were incorporated into a preliminary review of available fault, seismic, and tectonic interpretation data.
- Seismic data from USGS, CDMG, and DWR were collected and integrated into maps. Seismic data in the Red Bank Project region were collected and analyzed by USGS (Attachment A).
- Information on local and regional faulting was summarized. Faults that have the potential of affecting the proposed structures were evaluated.
- Geologic maps, fault maps, and cross-section drawings were prepared using existing data. Both regional and localized geologic mapping were compiled.
- Preliminary conclusions regarding fault and seismic safety design requirements were developed. Recommendations for further work are presented.
- A final report with plates, tables, and figures was prepared summarizing the investigation.

Phase II will include the following:

- Detailed fault mapping of foundation areas for the proposed structures. Most of the mapping will be for the Sites and Colusa Projects, since DWR has already done detailed mapping of the Thomes-Newville and Red Bank Projects.
- Detailed fault mapping of the Salt Lake fault. The Salt Lake fault extends over 40 miles and is one of the larger features of concern.
- Conducting regional photographic analyses along the western foothills of the Sacramento Valley. Stereo-aerial photographs will be viewed to identify lineaments for further field investigation. Low-sun-angle photography and side-looking radar analyses will also be incorporated into Phase II.

- Mapping Quaternary stream terraces to determine age and deformational history.
- Topographic and total station surveying to determine Quaternary to Holocene deformation.
- Analyzing earthquake information to determine potential seismic sources, peak accelerations, attenuation relations, directivity effects, response spectra, time histories, and ground motion parameters for dam stability evaluations.
- Diamond core drilling in the foundation of proposed structures. The drill holes will intersect faults at depth to evaluate fault activity, fracturing, foundation material strength, and permeability.
- Trenching across faults and suspected faults. This will determine fault locations and widths, and provide evidence and age of recent movement.
- Preparing a report with the results of the study.

Definition of Terms

The following includes a brief discussion of some of the terms that are used in this report.

Richter Magnitude - M, is a measure of the strain energy released by an earthquake. It is derived by studying the seismographic record. It is expressed in Arabic numerals and is a single number for an earthquake that does not relate to such factors such as damage or distance from the epicenter. The concept was introduced by C.F. Richter, who first applied it to Southern California earthquakes. The magnitude scale is logarithmic, to the base 10, of the amplitude, in microns, of the largest trace deflection that would be observed on a standard torsion seismograph, at a distance of 100 kilometers from the epicenter. The difference in terms of the total energy released between successive magnitudes such as an M1 and an M2, and between an M7 and an M8 is about 30 times greater. There are several variants to the scale, including:

local magnitude - M_L.

surface magnitude - $M_{S,}$ based on the amplitude of the surface waves.

moment magnitude - $M_{W,}$ that takes into account all the seismic waves present, which is now the most widely used, The M_W can also be estimated using the length or surface area of a fault plane. The calculated M_W may be used to define potential earthquake magnitudes from active faults with a limited seismic record.

Maximum credible earthquake - MCE, the largest possible earthquake that could reasonably be expected to occur in a given area on a given fault. The MCE is based on historic quakes, location of faults in the vicinity, and the general tectonic framework of the region. The MCE is generally somewhat larger than the calculated M_W since it is prudent to assume that more than one fault segment may move at one time.

Design Earthquake - the potential magnitude for which the dam should be designed to withstand during its lifetime. The MCE is chosen as the Design Earthquake for large structures and for areas where structural failure would have dire consequences.

Peak ground acceleration - PGA, and

Peak horizontal ground acceleration - PHGA, are the highest acceleration measured during a seismic event. The PGA and the PHGA for a particular site can also be calculated based on (1) the distance from the presumed hypocenter and (2) various attenuation models.

Reservoir-Induced Seismicity - RIS, is seismicity induced by the filling of large and deep reservoirs .

Earthquake intensity is a rating of the effects of an earthquake on man and his environment. It varies with distance from the epicenter, the type of ground, and the type of damage that occurs. Scales that have been used include:

Rossi-Forel with a scale from 1 to 10.

Mercalli, and the **Modified Mercalli** - MM, with the latter the most common. The MM scale ranges from Roman Numerals I to XII, with I not felt and XII nearly total destruction.

Summary and Conclusions

There are a number of types of earthquakes that need to be considered to evaluate earthquake risk. These are random earthquakes not associated with any known faults, MCEs calculated for active faults, and RIS. There are also earthquake-related hazards such as liquefaction, subsidence, and surface rupture that need to be considered.

Random Earthquakes

Random earthquakes occur with no correlation to known geologic structures, either mapped on the surface or detected by subsurface geophysical methods. Many of the background seismic events fit this definition. A conservative magnitude is selected by evaluating the earthquake history for the period of record. Several M5 and above earthquakes have occurred in the Sacramento Valley. An M5.4 with numerous strong aftershocks occurred recently in the Redding area. An M5.7 occurred in the eastern foothills near Oroville in 1975. In the 1880s two M5 earthquakes occurred near Red Bluff. The random earthquake selected for the westside Sacramento Valley projects is an M6.5 occurring anywhere within the project areas, including directly under the damsites. This is larger than historic random earthquakes and is believed to be conservative.

Maximum Credible Earthquake

Table 1 shows the design parameters selected for the four projects. These parameters are believed to be conservative.

Table 1. Draft Preliminary Design Parameters for the Proposed Projects*

Project	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Sites and Colusa	7	0	10	0.7	26	0.32
Thomes-Newville	7	0	10	0.7	26	0.32
Red Bank	8.3	0	35	0.72	28.5	0.42

* Note: Preliminary design parameters are subject to change as new information becomes available.

DWR (1978), in the West Sacramento Valley Fault and Seismicity Study, Glenn Complex, Colusa Reservoir, and Berryessa Enlargement, summarized what was known at that time about the Design Earthquake for these four projects. After considering the following faults - San Andreas, Hayward-Rodgers Creek-Healdsburg-Maacama, Green Valley-Cedar Roughs, Cordelia-Wragg Canyon, and Winters-Vacaville, the Foothills fault system, and RIS - they concluded that the MCE for the Glenn Reservoir Complex is a RIS earthquake of M6 resulting in 0.29g acceleration. A “Winters” type earthquake of M7 at a distance of 25 miles was also considered, resulting in a 0.14g acceleration. They did not consider the possibility that such a quake could be centered at depth directly underneath the dam. For this study we selected an M7 occurring directly under Newville Dam at a depth of about 6 miles as the Design Earthquake for the Thomes-Newville Project. WLA believes this magnitude to be conservative, based on the short length of the underlying thrust fault (Jeff Unruh, personal communication). However, they also believe that the closest approach may be closer than 6 miles.

ESA (1980), in their *Seismic and Fault Activity Study, Proposed Glenn Reservoir Complex*, assigned an MCE of M6.5 to RIS and to the Stony Creek fault. Both types of earthquakes could potentially occur in the reservoir area.

The Anderson Consulting Group (1997), in their *Preliminary Design Report for the Funks Creek Project,* adopted two MCEs occurring directly under the Funks Creek Dam site (Golden Gate Dam site of the Sites Project). One is based on an M_L6.5 occurring at a depth of 5 km, with a calculated PGA of 0.60, and the second is based on an M_L7 occurring at a depth of 10 km with a PGA of 0.46. The PGAs were based on an average derived from four mathematical attenuation models. WLA believes that even stronger ground shaking may occur at Sites, up-dip of a thrust fault rupture.

The Colusa Reservoir was assigned a similar RIS of M6, resulting in 0.29g and a Winters-type quake of M7 at an epicentral distance of 15 miles, resulting in an acceleration of 0.23g. They also did not consider the possibility that such an earthquake could be centered directly at depth underneath the dams. For this study we selected an M7 earthquake occurring directly under the reservoir at a depth of 6 miles on the Great Valley fault for both Sites and Colusa Reservoirs as the Design Earthquake. Selection of a Design Earthquake that occurs directly under the dams is conservative and justified by the fact that only limited information is available; and an earthquake can occur along a wide zone of faulting and surface deformation. Peak horizontal ground acceleration for such an event is estimated to be about 0.70g, the period about 0.32 seconds, and the duration about 26 seconds.

A conservative estimate of the MCE for the Red Bank Project would be a Gorda plate earthquake of M8.3 occurring directly underneath a project damsite at a depth of 20 to 25 miles (35 to 40 km).

Reservoir-Induced Seismicity

RIS is believed to be a consideration for all of the proposed reservoirs because of the large volume of water and a depth that could exceed 300 feet. An M6.5 earthquake occurring directly under a damsite at a depth of about 6 miles is believed to be a conservative estimate of this type of event. This is based on numerous RIS events ranging from M5 to M6.5 that have been documented worldwide. The RIS event is smaller than other potential earthquakes related to the Great Valley fault or Gorda plate subduction that could occur at the damsites, and therefore is not considered to be the source of the Design Earthquake.

Liquefaction, Landsliding, and Surface Rupture

Liquefaction should not be a problem at the foundation of the proposed structures since the recommended construction would include the removal of all alluvium and colluvium from the dam footprints. The construction material will be processed and designed to have a negligible liquefaction potential.

Numerous small landslides occur in the Dippingvat, Sites, and Colusa reservoir areas. Most of these slides are shallow and small. A few slides occur in the Schoenfield, and Newville reservoir area. Landslides occur on the abutments of Sites and Colusa, but all of the landslide materials will be removed prior to construction. We do not consider the landsliding to be a serious concern at any of the proposed project sites.

Faults occur in the foundation areas of most of the proposed structures. Most of these are small transverse faults oriented roughly perpendicular to the regional structure. These faults are generally short and the amount of displacement small. The faults have been considered to be pre-Pliocene in age. However, if they are more recent, the amount of displacement that would be expected during an earthquake is expected to be less than one foot based on the total length of these features. Limited movement in the foundation can be accommodated by using conservative dam designs. DSOD requires that these faults be considered potentially active until evidence becomes available to the contrary.

WLA (1997) considered the Salt Lake fault to be inactive based on lack of Quaternary surface deformation. However, for the purpose of this investigation, the fault will be considered potentially active and subject to possible surface movement until further evidence of inactivity becomes available.

Field work during this study suggests that the fault is a zone of folded, faulted, and sheared rock that may be wider than the actual mapped trace. Gas seeps and salt springs occur within this zone. The zone is also a structural discontinuity between the middle Cretaceous sedimentary rocks found at the damsites and Lower Cretaceous rocks found farther to the west. One of the numerous shears associated with this zone appears to cross the foundation of the Sites Dam site. It is possibly a continuation or splay of the Salt Lake fault, as mapped by Brown and Rich (1961).

Recommendations

We recommend that the dam design for any of the four proposed projects be conservative and that elements of the Phase II Fault and Seismic Hazards Investigation be instigated. The seismic risks at these projects are not that well known. The following are a number of conservative design considerations that can be implemented. This is not meant to be a state-of-the-art discussion, but a brief list of design factors that can be implemented to reduce the risk of dam failure.

All of the major dams of the four projects are tall, nearly 300 feet. Other things being equal, the higher the dam and the deeper the water, the greater the hazard of RIS, foundation shear failure, abutment slides, large slides into the reservoir, embankment cracking and concentrated leaks, and crest settlement and overtopping (Sherard 1966). These failure modes are most prevalent during earthquakes.

The first consideration in dam design is foundation preparation. It is recommended that all soil, alluvium, colluvium, and terrace deposits be removed from the dam footprint, and that the dam be founded entirely on rocks of the Great Valley sequence (GVS). The reason for this is the potential for the alluvial materials in the foundations to fail by shear or liquefaction during an earthquake. This requires the removal of large quantities of these unconsolidated materials, particularly at Golden Gate Dam. Here terrace deposits are about 20 feet thick and cover much of the channel section.

Landslides also occur at some of the damsites. These should be removed. Most of the removed alluvial, colluvial, and landslide material can be used within the random fill part of the dam. Fault breccia and gouges should be excavated as deep as is reasonable and backfilled with concrete.

Dam design should include most of the following conservative design considerations:

- Protection from overtopping, including extra freeboard and a well-protected downstream face. Earthquake-produced landslides and seiches are capable of overtopping the dam and causing erosion on the downstream face and possible failure of the dam. A thick blanket of large riprap provides protection from this type of event.
- Excellent internal drainage, including both horizontal and vertical drains for moisture and leakage control to prevent piping and liquefaction.
- Excellent zoning with wide transition and filter zones to aid in the sealing of earthquake- or fault-induced fractures. The zones should extend all the way

to the top of the dam. The filter zones should be well graded with a mix of fine sand to gravel sizes. The finer transition material should also have an appreciable percentage of gravel to seal fractures and prevent piping. This may require processing the natural construction material deposits by sieving and washing. The strongest foundation material should be placed on the downstream toe where it will reduce the potential for embankment slumping.

- Gentler embankment slopes to increase stability, since the steeper slopes are generally more susceptible to failure. All materials should have high compactive effort to 95 percent relative compaction or more.
- Core containing plastic soils for high cohesion and minimal erosion. The core should not contain zones with clean sand or silt. For inorganic clays, the leakage resistance is probably strongly dependent on the Atterberg limits - the higher the plasticity index, and the higher the position above the A-line, the higher the leakage resistance. A coarse component of gravel would help to seal any cracks developed during an earthquake.
- Outlet facilities capable of releasing a large part of the reservoir in a short time. This would allow the rapid drawdown of the reservoir in case the dam is damaged during an earthquake. DSOD requires outlet facilities capable of evacuating 10 percent of the maximum reservoir height in ten days. Spillways should also be oversized in case of landslide-generated waves, reduced-reservoir capacity from large landslides, and seiches.
- Use of ungated, open spillways on stable rock instead of gated spillways, tunnels, or glory holes. Damage during earthquakes may make gated spillways inoperable. Tunnels or glory holes may become blocked, offset, or collapsed and would be difficult to repair during emergency conditions.

Investigation of the Salt Lake fault should be continued and expanded to determine whether this feature is active. More work needs to be done to determine whether a lineament crossing the Sites Dam site is a continuation of faulting along the Salt Lake fault. This would include trenching across possible fault traces, seismic refraction, low-angle radar imaging, and others. These activities would be carried out in Phase II.

Dynamic analysis of proposed dam designs are needed. The essential elements of such analyses are as follows: (1) an analysis of the static stresses developed in individual elements of the embankment before an earthquake; (2) the use of a dynamic finite element analysis procedure, with strain-dependent properties to allow for the nonlinear stress-strain characteristics of the embankment and foundation soils, which would determine the dynamic stresses developed in individual elements of the embankment; (3) the use of cyclic loading triaxial compression test data to determine the response of the soil elements in the dam to the induced stresses; and (4) consideration of progressive failure effects by determining the redistribution of dynamic stresses after liquefaction of 5 percent strain has developed in any soil element (Seed, in DWR 1974).

Low level, low-sun-angle aerial photography analysis and side-looking radar should be done in addition to Landsat and stereo aerial photo analyses.

Detailed laboratory testing of construction and foundation materials should be done. Compaction and remolded triaxial shear tests should be done on core materials. Relative density or compaction, in the absence of any other data, is perhaps the single most important item to be used in judging a soil's dynamic stability.

Regional Geology

The proposed projects are in the western foothills along the edge of the Sacramento Valley. The rocks underlying the damsites are part of the Great Valley geologic province, which is mostly sandstone, mudstone, and conglomerate of the Cretaceous GVS.

Geomorphic Provinces

The Great Valley geologic province is bound on the west by the Coast Ranges province, to the north by the Klamath Mountains province, to the northeast by the Cascade Range province, and to the east by the Sierra Nevada province. The location of the various geologic provinces in Northern California is shown in Figure 3. Figure 4 shows the North American geologic time scale.

Great Valley Province

The projects lie along the western edge of the Great Valley province, a 400-mile-long by 60-mile-wide sedimentary basin positioned between the Sierra Nevada, Klamath Mountains, Cascade Range, and Coast Ranges.

Along the west side of the Sacramento Valley, rocks of the Great Valley province include Upper Jurassic to Cretaceous marine sedimentary rocks of the GVS, fluvial deposits of the Tertiary Tehama, Quaternary Red Bluff, Riverbank, and Modesto formations, and Recent alluvium.

Rocks of the GVS form an asymmetric south-plunging syncline, with a steeply dipping western limb and a gently dipping eastern limb. The west side has eroded to form a series of northwest-trending, east-dipping ridges of sandstone and conglomerate separated by valleys underlain by siltstone and mudstone. Water gaps in the sandstone and conglomerate ridges form the damsites for all four proposed projects.

The basement of the GVS is believed to be basaltic ocean floor consisting of flows, dikes, gabbroic plutonic rocks, and serpentinites and is commonly referred to as the Coast Ranges ophiolite. The ophiolite is middle Jurassic in age and is believed to be the oceanic basement of a forearc basin. Most of the ophiolite is fragmented and stratigraphically thin. The contact with the overlying sedimentary rocks is believed to be depositional in some places but faulted by the Stony Creek fault in other areas.

The GVS formed from sediments deposited within a submarine fan in the forearc basin environment along the continental edge. Sources of the sediments were the Klamath Mountains and the Sierra Nevada to the north and east. Limited lateral extent and the grading of one unit into another are characteristic of this type of depositional environment.

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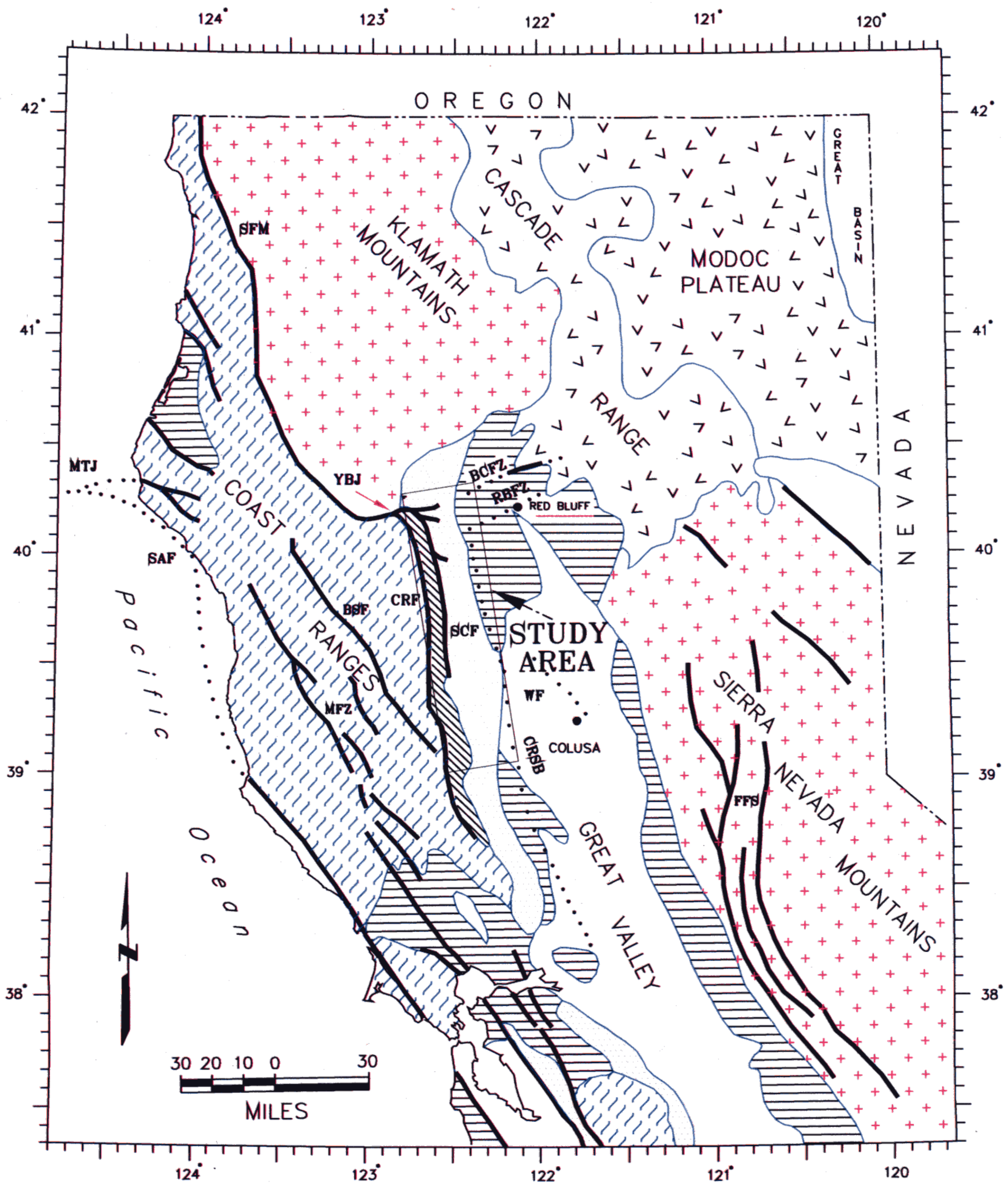
NORTHERN CALIFORNIA



LEGEND

GEOLOGIC UNITS

- Quaternary Sedimentary Deposits
- Quaternary and Tertiary Volcanic Rocks of the Cascade Range and Modoc Plateau.
- Tertiary Sedimentary Deposits
- Upper Jurassic/Cretaceous Sedimentary Rocks of the Great Valley
- Upper Jurassic/Cretaceous Sedimentary Rocks of the Coast Ranges
- Upper Jurassic to Cretaceous Mafic to Ultramafic Rocks
- Mesozoic – Paleozoic Metamorphic and Granitic Rocks of the Klamath and Sierra Nevada Mountains.
- Geologic Contact
- Fault– Dotted where Concealed

FAULTS

SAF	San Andreas Fault
CRF	Coast Range Fault
SFM	South Fork Mountain Fault
SCF	Stony Creek Fault
BCFZ	Battle Creek Fault Zone
MFZ	Maacama Fault Zone
FFS	Foothills Fault System
YBJ	Yolla Bolly Junction
RBFS	Red Bluff Fault Zone
CRSB	Coast Range–Sierran Block Boundary
WF	Willows Fault
MTJ	Mendocino Triple Junction
BSF	Bartlett Springs Fault

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

FAULT AND SEISMIC HAZARDS – PHASE I
RED BANK, THOMES–NEWVILLE, SITES, AND COLUSA PROJECTS

Regional Geologic Map

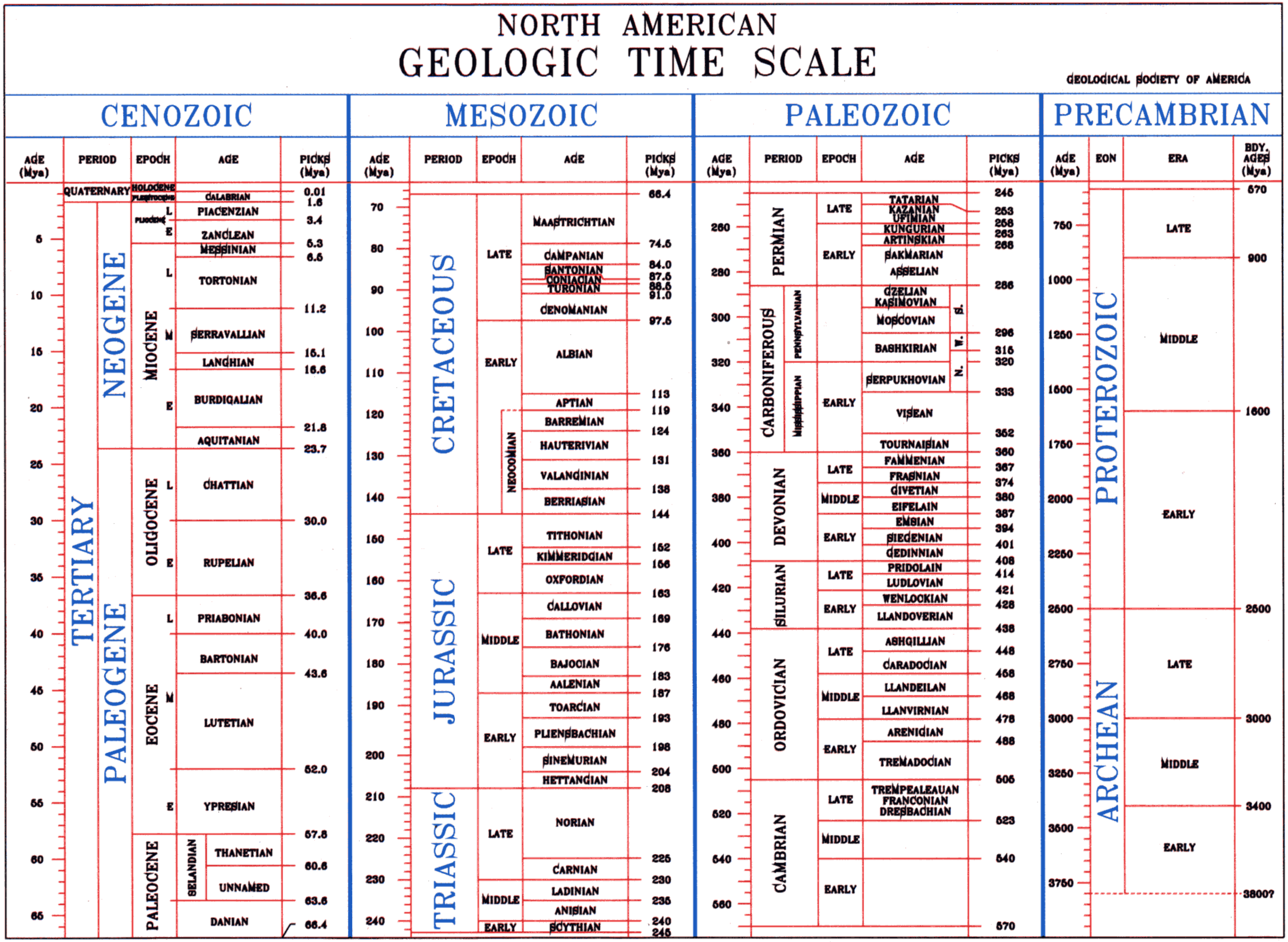


Figure 4. North American Geologic Time Scale.

The mudstones of the GVS are typically dark gray to black. Generally the mudstones are thinly laminated and have closely spaced and pervasive joints. When fresh, the mudstones are hard, but exposed units weather and slake readily. Mudstones generally underlay the valleys because of the minimal resistance to weathering and erosion.

The sandstones are light green to gray. They are considered to be graywackes in some places because of the percentage of fine-grained interstitial material. Sandstone beds range from thinly laminated to massive. In many places the sandstones are interlayered with beds of conglomerates, siltstones, and mudstones. Massive sandstones are indurated with widely spaced joints, forming the backbone of most ridges.

The conglomerates are closely associated with the massive sandstones and consist of lenticular and discontinuous beds varying in thickness from a few feet to over 100 feet. Conglomerate clasts range in size from pebbles to boulders and are composed primarily of chert, volcanic rocks, granitic rocks, and sandstones set in a matrix of cemented sand and clay. The conglomerates are similar to the sandstones in hardness and jointing.

Tertiary and Quaternary fluvial sedimentary deposits unconformably overlie the GVS. The Pliocene Tehama formation is the oldest. It is derived from erosion of the Coast Ranges and Klamath Mountains and consists of pale green to tan, semiconsolidated silt, clay, sand, and gravel. The Nomlaki tuff member occurs near the bottom of the Tehama and has been age-dated at about 3.3 million years. The Nomlaki is a slightly pink to gray dacitic pumice and lapilli tuff outcropping as a single massive bed about 30 feet thick. Along the western margin of the valley the Tehama is generally thin, discontinuous, and deeply weathered.

The Quaternary Red Bluff formation consists of reddish poorly sorted gravel with thin interbeds of reddish clay. The Red Bluff is a broad erosional surface, or pediment, of low relief formed on the Tehama formation between 0.45 and 1 million years ago. Thickness varies up to about 30 feet. The pediment is an excellent datum to assess Pleistocene deformation because of its original widespread occurrence and low relief. Red Bluff outcrops occur just east of the damsites.

Recent alluvium is a loose sedimentary deposit of clay, silt, sand, gravel, and boulders. Deposits include landslides, colluvium, stream channel deposits, floodplain deposits, and stream terraces. Quaternary alluvium is the major source of construction materials. Colluvium, or slope wash, consisting mostly of soil and rock, occurs at the face and base of a hill. Landslide deposits are similar but more defined and generally deeper. Landslides occur along the reservoir rim but are generally small, shallow debris slides or debris flows. These deposits may be incorporated as random fill in dam construction.

Stream channel deposits generally consist of sand and gravel. Construction material uses include concrete aggregate, filters, and drains. Floodplain deposits are finer grained and consist of clay and silt. Floodplain deposits may be used for the impervious core and for random fill.

The stream terraces form flat benches adjacent to and above the active stream channel. Up to nine different stream terrace levels have been identified. Terrace deposits consist of several to ten feet of clay, silt, and sand overlying a basal layer of coarser alluvium containing sand, gravel, cobbles, and boulders. Four terrace levels have been given formational names by the USGS (Helley and Harwood 1985): the Upper Modesto, Lower Modesto, Upper Riverbank, and Lower Riverbank, ranging in age from 10,000 to several hundred thousand years old.

Terraces are valuable for evaluating the age and activity of faults that trend across them. A number of investigators have applied soil-stratigraphic, relative, and absolute age dating techniques, together with geomorphic analysis, to date and correlate terrace deposits. Evidence of faulting across the terrace deposits constrains the time of last movement.

Coast Ranges Province

The Coast Ranges are located just west of the reservoir projects. The Coast Ranges are underlaid by a collection of accretionary wedges of the Mesozoic-Cenozoic Franciscan complex, a Cenozoic forearc basin consisting of marine sedimentary deposits. The Franciscan increases in age and metamorphic grade inland and consists of a mixture of marine sedimentary, igneous, and metamorphic rocks ranging in age from Jurassic to Tertiary. The assemblage of graywacke, metagraywacke, shale, chert, schist, limestone, mafic and ultramafic metamorphic and igneous rocks is pervasively deformed by folds, faults, and zones of extensive shearing. The Coast Ranges fault, the Coast Ranges ophiolite, and the Stony Creek fault separate the Coast Ranges from the Great Valley province to the east.

Klamath Mountains Province

Rocks of the Klamath Mountains province occur northwest of the Great Valley province, about 10 miles from the Red Bank Project. The province is about 70 miles wide and extends northward into Oregon. Geologically it is similar to the Sierra Nevada, ranging in age from Paleozoic to Jurassic. It consists of several well-defined mountain ranges, including the Trinity, Marble, Scott, and Salmon Mountains. These mountains comprise a series of arcuate metamorphic terranes of different age and stratigraphy separated by major faults. Large bodies of intrusive rocks, such as the Shasta Bally Batholith, occur in the province.

The variety of terranes and structural features can be related to pre-Cretaceous subduction. The faults between the terranes are probably old subduction zones where two crustal plates converged, and the terranes are melanges or fragments of individual plates.

Cascade Range Province

The Cascade Range is a long sequence of volcanoes and volcanic rocks stretching from about Mt. Lassen to Alaska. Rocks of the Cascades vary in age from Eocene to Recent and consist of ash, tuffs, flows, mudflows, breccias, agglomerates, dikes, and sills. Along with the igneous rocks are associated volcanically derived sedimentary rocks.

The Cascade Range is a volcanic arc, a product of subduction of the Gorda and Juan de Fuca plates beneath the North American plate. The migration of the

Mendocino triple junction northward along the coast results in the gradual extinction of volcanic activity to the south. Intermediate- to deep-focus earthquakes from Red Bluff north have been correlated to the subduction of the Gorda plate (Cockerham 1984; Walter 1986).

Sierra Nevada Province

The Sierra Nevada are about 400 miles long, extending from Southern California to just south of Lassen to the north. The Sierra Nevada are diverse in composition and age, but consist mostly of igneous and metamorphic rocks.

The mountains are complex, with structural deformation dating back 300 million years. Like the Klamath Mountains, both the lithology and structures are related to subduction and accretion of a variety of different terranes. About 10 mya in the early Pliocene time period, the compressional tectonic regime was replaced by an extensional regime (associated with tectonics in the Basin and Range provinces) that continues to the present. The west-northwest-directed extension is responsible for the uplift and tilting of the Sierra Nevada and the seismicity along the Chico monocline.

Regional Plate Tectonic Setting

Plate tectonics have played a major role in the geologic development of California. From the late Jurassic to mid-Tertiary peiods, the eastern Pacific lithosphere (Farallon plate) was subducted beneath the western margin of the North American continental plate. This resulted in the coeval formation of an arc-trench system that included an accretionary prism, a forearc basin, and a magmatic arc. The Franciscan complex, the GVS, and the Klamath Mountains-Sierra Nevada represent these terrains.

Throughout the Cretaceous time period, sediments from the magmatic arc were deposited by submarine currents in the forearc basin. These sediments now make up the GVS on which the proposed dams would be founded. At the same time, sediments and volcanic rocks, now the Franciscan complex, were scraped from the subducting ocean floor and accumulated as an accretionary wedge seaward of the GVS. As subduction ceased during the late Tertiary period, uplift became more rapid, and the transition to a strike-slip regime of the San Andreas fault system began in Southern California. Figure 5 is a cross-sectional drawing showing the California area during the middle Cretaceous period.

Since the late Tertiary period, the Mendocino triple junction has been migrating northward along the coastline, leaving the San Andreas transform fault in its wake. In a rigid plate model, one consequence of the northward migration of the triple junction is that the North American plate slides off the Gorda plate, leaving in its wake a void that is filled by upwelling asthenosphere, often referred to as a “slabless window” or “slab gap.” Seismic refraction-reflection profiles indicate partial melt and/or metamorphic fluids at the base of the crust or in the upper mantle south of the Gorda plate (Beaudoin, et al., 1997). Other supporting evidence for a slabless window includes gravity and magnetic data, teleseismic P-wave delay studies, shear-wave velocities, and changes in volcanism. The slabless

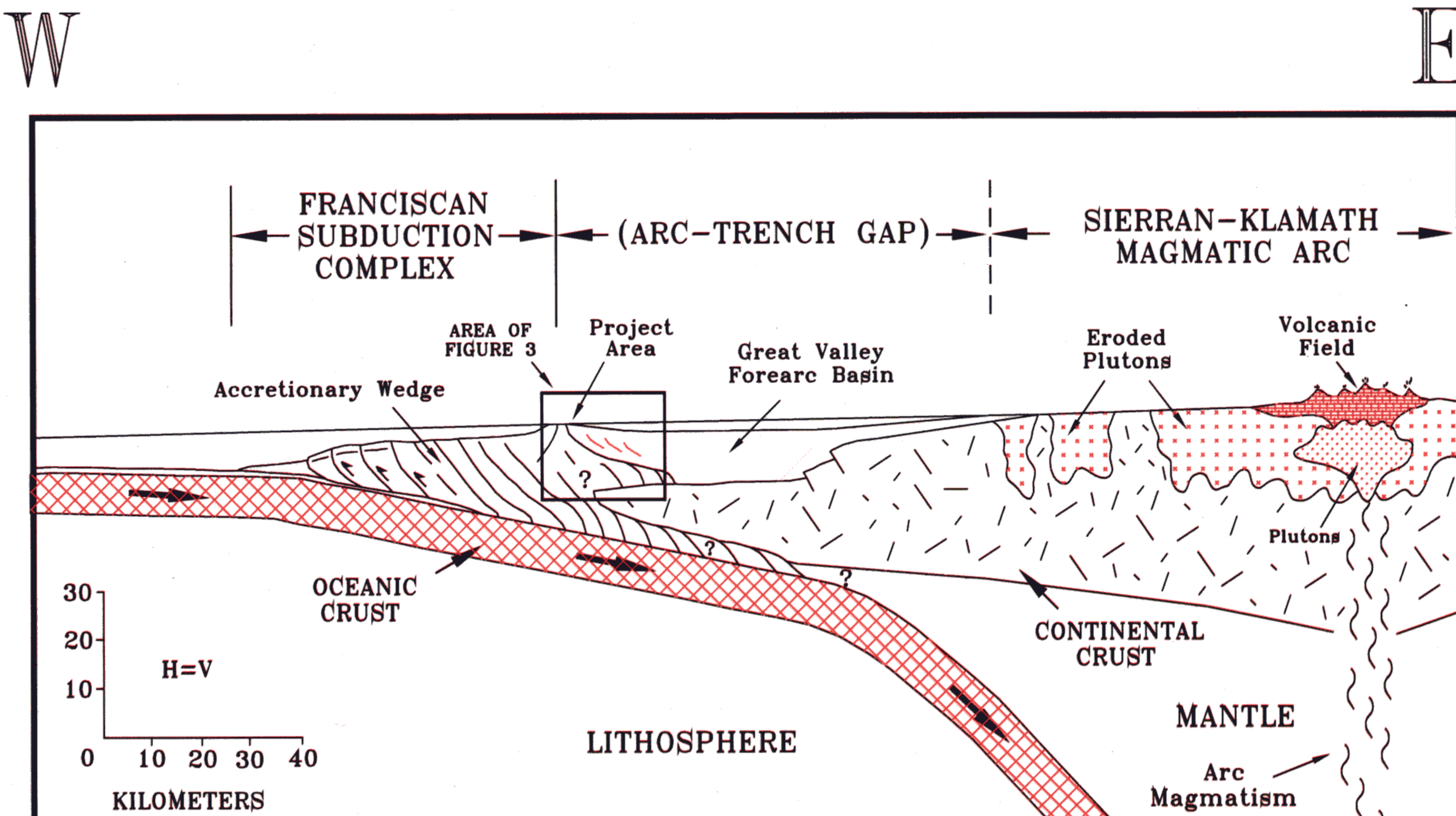


FIGURE 5. Schematic profile of subduction system across northern California during the late Mesozoic, (modified from Dickinson and Seeley, 1979).

window is probably the reason for the region's volcanic and geothermal activity, such as the Geysers, Mt. Konocti, and Clear Lake volcanics.

Subduction of oceanic lithosphere still occurs north of Cape Mendocino above the Mendocino triple junction among the Pacific, North American, and Gorda plates. Here the Gorda plate is moving under the North American continental plate in a northeast direction at an average rate estimated at about 3.5 cm per year, as evidenced by the 150-mile-long zone of intermediate focus earthquakes dipping eastward below the North American plate.

As described by Atwater (1970), the Juan de Fuca and Gorda plates are remnants of the larger Farallon plate. The Pacific plate is on the opposite side of the spreading center, several hundred miles off the coast. Subduction of the Farallon plate here has caused most of the deformation from the Cretaceous period to the present. As the San Andreas fault zone evolved, the triple junction migrated slowly northward. During this period, the Great Valley experienced several episodes of uplift and subsidence, until the early Miocene when the valley emerged from the sea and was subjected to fluvial erosion and deposition (Harwood 1984). At the same time, volcanic eruptions were occurring along the northern Sierra Nevada, damming streams and filling narrow valleys.

Extensional forces from backarc spreading reached their peak during this period. These forces are responsible for the upward tilting of the Sierra Nevada and the large expansion of the Great Basin to the east during the Tertiary.

Strong evidence suggests that as the Mendocino triple junction migrated northward, structures in the valley began to show compressive deformation and faulting in a similar progressive pattern (Harwood 1984). This is evident from the age of faulting, folding, and volcanic activity ranging from 2.5 mya near Sutter Buttes to 0.5 mya near the Battle Creek fault. Figure 6 shows the current position of the plates.

The stress regime in the Sacramento Valley is a result of its position between the right lateral transform tectonism of the San Andreas fault to the west and the crustal extension of the Basin and Range provinces to the east. The direction of stress may vary but, in general, the direction of maximum compression is northeast-southwest.

Evidence of this stress regime is a series of northwest trending folds and faults along the western Sacramento Valley. The faults dip steeply east, with reverse and minor left-lateral movement. In the north and northeastern valley, the structural trend shifts, and structures are oriented in an east to northeast direction. The faults typically dip steeply to the south with normal offset and a minor right-lateral component.

The relationship among the Coast Ranges, Great Valley, and Sierra Nevada is explained by the process of tectonic wedging. In this process, the Franciscan rocks of the Coast Ranges were metamorphosed to blueschist grade in a subduction zone and then were thrust upward and eastward as a wedge onto the Klamath-Sierra Nevada basement. As it moved, the wedge progressively peeled up and carried before it, in imbricate fashion, a slab of Coast Ranges ophiolite and several slabs of the GVS. This thrusting greatly shortened the original distance across the basin in which the GVS was deposited (Wentworth, et al., 1984).

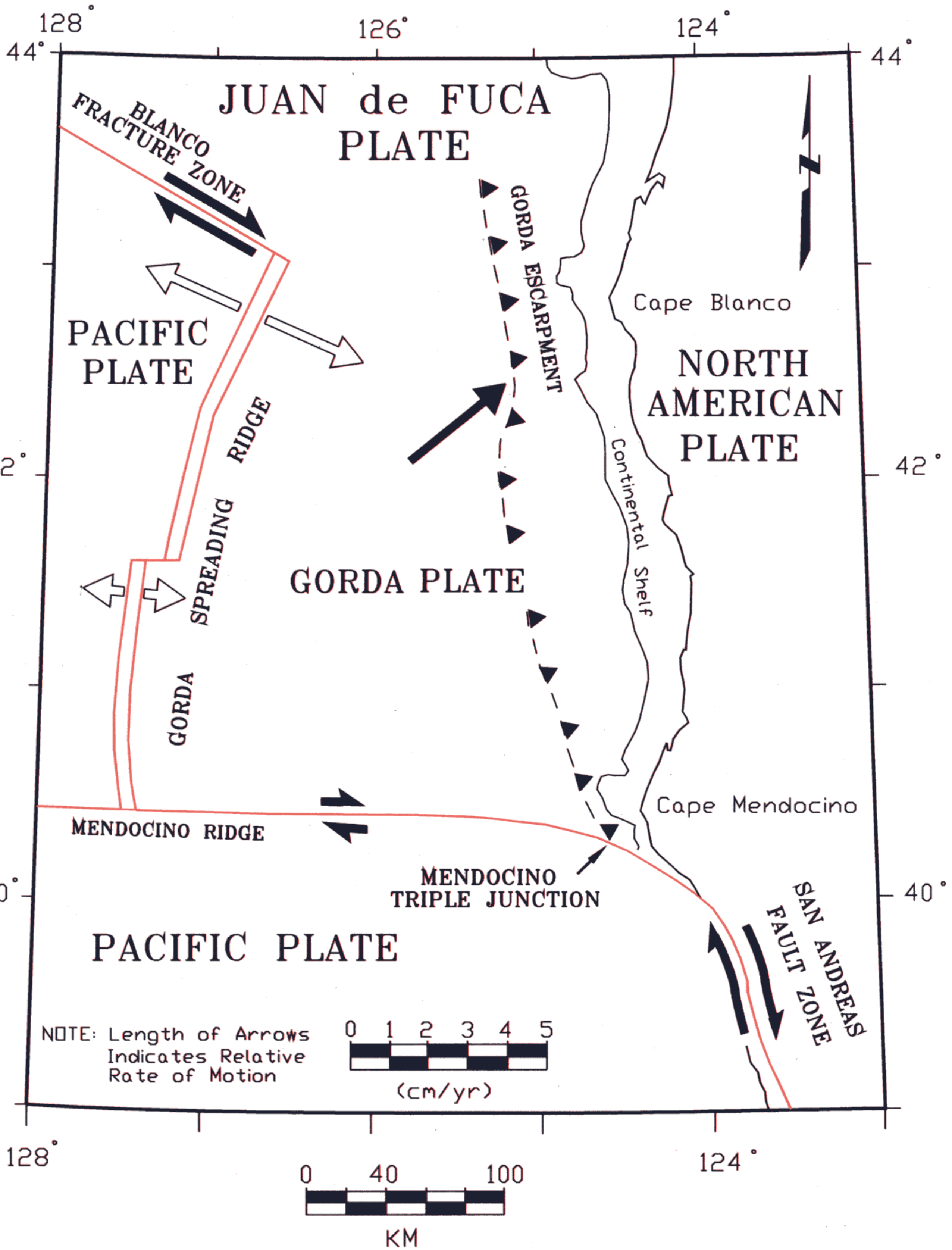


FIGURE 6. Mendocino Triple Junction and Plate Boundaries

Recent studies indicate that folding and faulting along the west side of the Sacramento Valley are active and represent the shallow expression of deeper thrusting. Evidence also suggests that this seismically active zone, called the Coast Ranges-Sierra Nevada block boundary or the Great Valley fault, extends the full length of the greater Central Valley.

Local Seismotectonic Setting

The project area lies near the boundaries of three tectonic stress provinces (Zoback and Zoback 1989). Stress provinces are areas affected by the same stress regime, resulting in roughly similar faulting.

The San Andreas transform stress province is characterized by NW-SE tension and NE-SW compression. The province extends along the northern Coast Ranges, as far east as the central part of the Great Valley, and as far north as Cape Mendocino.

The Cordilleran stress province encompasses the eastern part of the Great Valley, the Sierra Nevada, and the Basin and Range to the east. The province is characterized by WNW-ENE-trending minimum principal stress (extension).

The Pacific Northwest stress province extends northward from the general area of Red Bluff. The province is characterized by roughly east-west compression resulting from the underthrusting of the Gorda plate beneath the North American plate. Both strike-slip and thrust faulting have occurred here.

San Andreas Transform Stress Province

The Red Bank, Thomes-Newville, Sites, and Colusa Projects all lie along the eastern edge of the San Andreas transform stress province. The stress is caused by right lateral movement between the Pacific and North American plates, estimated to be about 37 to 41 millimeters per year. Most of this motion occurs along three major right-lateral strike-slip fault systems. These are the San Andreas to the west, the Maacama, and the Bartlett Springs fault systems. The amount of movement decreases from the west to the east, with about 75 percent of the motion accommodated along these three faults in the northern Coast Ranges, and the remainder in the Great Valley and the Sierra Nevada to the east. The 2 to 5 mm component of plate motion perpendicular to the plate boundary is probably accommodated primarily by thrust and reverse faulting along the Great Valley margin (Great Valley fault).

In this general area, WLA (1997) divides the stress province into the northern Coast Ranges and the CRSNBZ seismotectonic provinces.

The eastern extents of the northern Coast Ranges seismotectonic province include, from south to north: the Green Valley, Cordelia, Hunting Creek, and Bartlett Springs faults. WLA (1997) believes these faults to represent the easternmost extent of major strike-slip faulting in the northern Coast Ranges. The Bartlett Springs fault lies about 18 miles southwest of the town of Sites and 25 miles southwest of Newville.

The CRSNBZ seismotectonic province lies east of the northern Coast Ranges. The eastern extent of the province lies along the Willows and Corning faults near the center of the Sacramento Valley. The province is a complex region of contractional deformation characterized by uplift, folding, and thrust faulting. Quaternary deformation is present in places such as the Dunnigan Hills, Rumsey Hills, and the Corning domes. Compressive deformation along the CRSNBZ is also responsible for the uplift and tilting of the east-dipping strata of the GVS. Patterns of historical seismicity and microearthquakes show that the thrust faults are active (Wong, et. al., 1988; Unruh and Moores 1992; and WLA 1997).

Cordillera Extensional Stress Province

The eastern Great Valley and the Sierra Nevada physiographic provinces lie within the Cordillera extensional stress province (Zoback and Zoback 1989). This province is characterized by WNW-ENE trending tensile stress. Both normal and strike-slip faulting are common. The tensile stresses in this province have caused such features as the Chico monocline, the westward tilting of the Sierra Nevada, and the Basin and Range features to the east.

Pacific Northwest Stress Province

The southern extent of this province is in the general area of Cape Mendocino, and includes the Klamath Mountains and most of the Cascade Range. Both strike-slip and thrust faulting are common. The state of stress is probably mostly related to underthrusting of the Gorda plate under the North American plate. The Red Bank Project is on the boundary between this stress province and the San Andreas transform stress province.

Regional Faulting And Structures

In general, south of Red Bluff, regional faults strike to the northwest, roughly parallel to the San Andreas fault. Fault plane solutions for the Sacramento Valley and Coast Ranges in this area are variable and do not show consistent right-lateral movement. Faulting along the CRSNBZ also have a large component of east-west thrusting.

North of Red Bluff, faults strike to the east and northeast, roughly parallel to the Gorda plate subduction direction. The following discussion of faulting includes only those faults that may affect the proposed west side projects, either from seismic events or ground breakage.

Numerous smaller faults strike perpendicular to the regional faults and the regional structural trend. These are called cross, tear, or transverse faults. Most of the damsites and saddle damsites have these faults in the foundation area. They are believed to be late Cretaceous in age, and none of these faults have shown any evidence, to date, of Quaternary movement.

The faults represent weaknesses in the foundation where present. Typically the faults need to be excavated deeper than the rest of the foundation, then filled with concrete. Faults also are seepage corridors and require more grout. Because of the inherent weakness of faults, landslides are also common along fault surface traces.

Gorda Plate-Cascadia Subduction Zone

The Pacific Northwest coast from the Mendocino triple junction northward to Alaska is a subduction zone where the Gorda plate to the south and the Farallon plate to the north are descending beneath the North American plate. The Cascade Range is a continental volcanic arc resulting from the collision zone and the melting of the downgoing plate. Worldwide, these subduction zones are marked by seismicity to include large or great (M>7.5) earthquakes having thrusting focal mechanisms. South of the Mendocino triple junction, the San Andreas right lateral transform fault mechanism is operational.

The Cape Mendocino area exhibits intense activity, as expected in a zone where three plates join. Most of the larger magnitude seismicity appears to be associated with the Mendocino fracture zone, San Andreas fault, and other related faults. The triple junction is too far away from the proposed projects to affect the designs and specifications.

Cockerham (1984) presented seismic data suggesting the subduction of a 180-km-long slab of the Gorda plate beneath Cape Mendocino. The slab would extend eastward to the vicinity of Red Bluff. The plate dips about 10 degrees for a length of 120 km to depths of 30 to 35 km, then steepens to 25 degrees and plunges to depths of 60 km.

Most of the world's strongest earthquakes occur along active subduction zones. Recent examples include the M8.3, 1964 Alaskan earthquake and the M8.1, 1985 Mexican earthquake. These are the result of locking in the zone of contact between the descending and overriding plates, with a longer period of locking resulting in a larger release of energy during an earthquake. However, not all subduction zones produce great earthquakes; and the differences between those generating great earthquakes, and those that do not, appear to be systematic. There have been no large-thrust earthquakes in the subduction zone in historical times. Explanations for this include the cessation of subduction, aseismic convergence, and locking, which is most likely based on similarities with other subduction zones in other parts of the world that have experienced great historical earthquakes.

These similarities include the lack of an active backarc basin, an absence of seismicity at depths greater than 100 km, the presence of a shallow, sediment-choked trench, a shallow-dipping Benioff zone, smooth topography of the subducted slab, and seismic quiescence over a significant time span. In addition, an empirical relationship between convergence rate, age of subducted crust, and maximum earthquake magnitude for major subduction zones suggests that the Cascadia subduction zone may be strongly locked and capable of producing great earthquakes (USBR 1986).

CDMG (1996, Web site) assumes that large earthquakes occur every few hundred to 1,000 years as inferred from paleoseismic information. The entire zone was modeled as a combination of an M9 occurring along the entire length from California to Washington about every 500 years and an M8.3 rupture along the California portion of the zone about every 335 years.

The Gorda plate extends underneath the continental plate as shown in Figure 7. In a zone that extends from about Weaverville to Red Bluff, several earthquakes have had focal depths between 45 and 55 km. Walter (1986) and Cockerham

(1984) have associated these events with the southeastern edge of the underthrusting Gorda plate. Further east, several events 50 to 80 km deep are grouped along a northwestern trend. It is theorized that these deeper events could be related to isolated failures within the same plate (HMT 1983).

American Indian stories tell of a quake in this general area in 1700, and major quakes normally come every 300 to 500 years, hence the prediction of the Big One by 2200. "It's going to be bigger than the San Francisco earthquake, bigger than 1906," Stephen Walter of USGS said (Ralph Jennings in Record Searchlight article on Shasta Shaker).

A major earthquake related to Gorda plate subduction is a concern for the Red Bank Project. This is because the edge of the plate is directly underneath the project or somewhat to the south at depth. Walter (1986) described the seismic characteristics of Gorda plate subduction, including shallow earthquakes to the west and increasing depth of focii to the east. Recently USGS outlined the possibility of an M8+ occurring near the Red Bank Project at an approximate depth of 35 to 55 km or about 25 to 35 miles.

San Andreas Fault System

The San Andreas fault extends almost the entire length of the state. In Northern California, the system consists of three subparallel right lateral strike- slip faults, the San Andreas, Maacama, and Bartlett Springs faults. The total width of the system is about 100 km. Freymuller and Segall (1997) used Global Positioning System measurements along all three faults over a period of four years to determine a relative motion of 3.9 centimeters between the North American plate and the Pacific plate. They further divide the slip rate to 2 cm for the San Andreas, 1.2 to 1.5 cm for Maacama, and 0.7 to 0.9 cm for Bartlett Springs.

San Andreas Fault

The San Andreas fault lies about 80 miles west of the project area. HMT (1983) assigned the following seismic parameters to the Corps' Cottonwood Creek project: an M8.3 resulting in a peak horizontal ground acceleration of 0.07g, a peak ground velocity of 12 cm per second, and a duration of five seconds. CDMG (1996) assigned an M7.6 and a recurrence interval of 210 years to the north coast segment of the great San Francisco earthquake of 1906.

Maacama Fault

The Maacama is generally considered a splinter fault of the San Andreas and part of the Hayward fault subsystem. No major historical earthquakes have been associated with this fault, although it has a sizable creep rate of about 7 mm per year near Ukiah (USGS 1996), but most of the fault must be locked according to Freymueller and Segall (1997).

Seismic refraction-reflection profiles from the Mendocino triple junction seismic experiment (Beaudoin, et al., 1997) across the Coast Ranges show breaks in these reflections correlate to this Maacama fault and the Bartlett Springs fault, suggesting that these faults extend at least to the mantle.

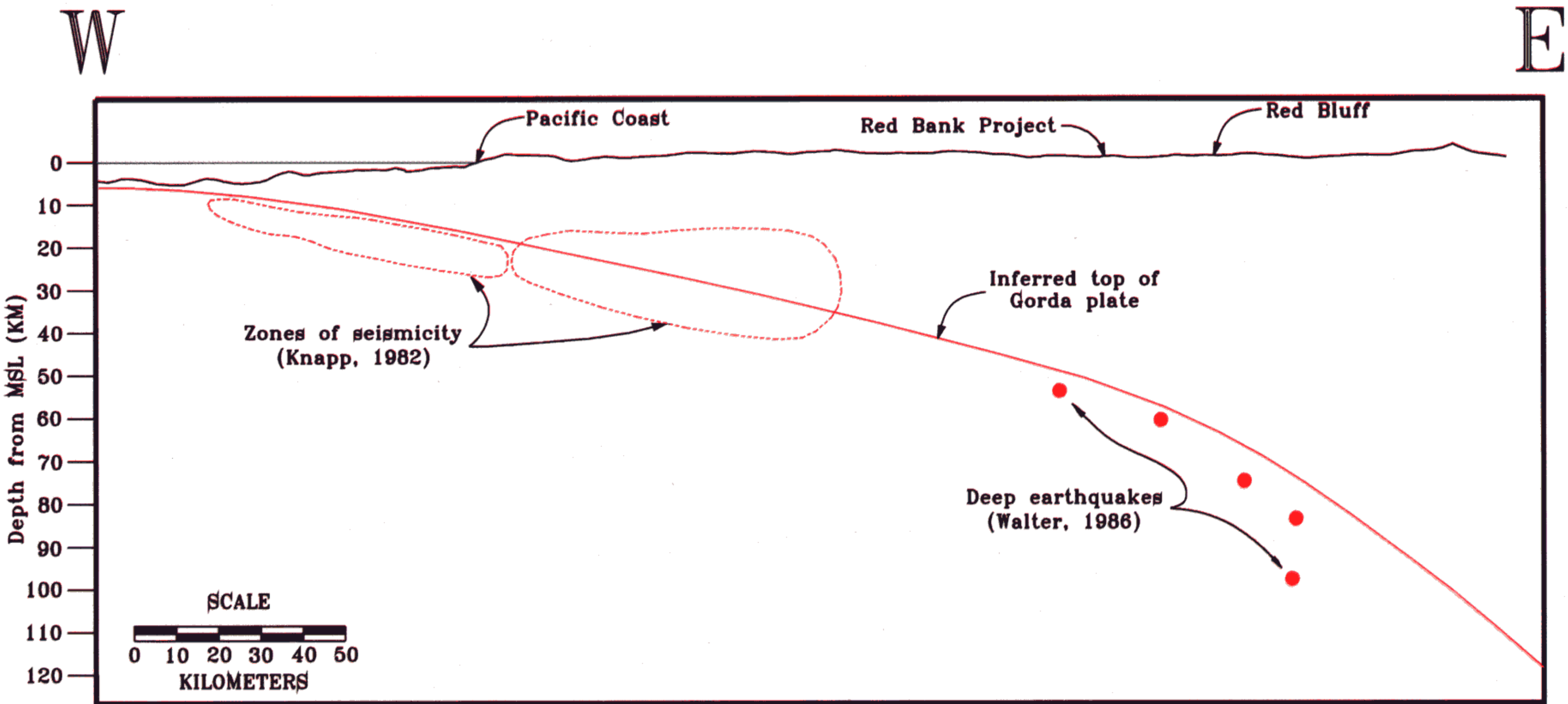


Figure 7. East–west cross–section at the latitude of the Red Bank Project showing the inferred top of the Gorda plate.

Bartlett Springs Fault

The Bartlett Springs fault is believed to be a northward extension of the Green Valley fault. No historic major earthquakes have occurred on the Bartlett Springs fault, but creep rates of about 8 mm per year on the Calaveras fault suggest that this may continue to the north. USGS (1996) assigned an M_W of 7.1, a slip rate of 6 mm per year, and an effective recurrence time of 230 years to this fault.

As stated previously, seismic refraction-reflection profiles from the Mendocino triple junction seismic experiment (Beaudoin, et al., 1997) across the Coast Ranges show breaks in these reflections correlate to the Maacama fault and this Bartlett Springs fault, suggesting that these faults extend at least to the mantle.

Coast Ranges-Sierra Nevada Block Boundary

Recent work by numerous researchers indicates an active tectonic boundary between the Sierra Nevada basement and the Coast Ranges lies buried beneath the entire western edge of the greater Central Valley from Bakersfield to Red Bluff. This system of faults is generally referred to as the Great Valley thrust fault system or the Great Valley fault.

Activity along this complex zone is characterized by both reverse and thrust faulting, and is considered to be the source of the two 1892 Winters-Vacaville earthquakes (M_L 6-7), and the 1983 Coalinga earthquake (M_L6.7). Many small to moderate earthquakes have also occurred along the full length of the boundary. These include an M5.8 in 1866 and an M5.9 in 1881 west of Modesto, and an M6 in 1889 near Antioch. The deeper faulting manifests itself on the surface as the deformation of younger deposits. The anticlines at Corning and Dunnigan Hills are thought to be shallow expressions of deeper thrusting along this boundary (Wentworth and Zoback 1990).

Since no definitive surface faulting exists, the analysis of microseismic data becomes an important tool to define the extent and seismic potential. Wong, et al. (1988), believes that an M_L 7 earthquake could possibly occur anywhere along the boundary. WLA considers this too conservative, with an M6.5 to M6.75 more likely.

The Working Group on Northern California Earthquake Potential and other workers have divided the Great Valley fault into about 14 segments that act, and are independent of each other. The segments of interest to this study are designated GV01, with the source centered at the Sites anticline, and GV02 outside the project area to the south, centered on the Cortina thrust (USGS 1996).

It is not clear whether there are additional segments to the north of GV01. Luce (1993), in his masters thesis, outlined nine segments from the Battle Creek fault zone on the north, to Coalinga on the south. Caltrans also assumes that the boundary zone extends north to the Battle Creek fault zone, and this seems the most logical.

The idea of “characteristic earthquakes” is that major faults tend to rupture along discrete segments rather than along their entire length (Schwartz and Coppersmith 1984). Segmentation of the fault is based on bends, stepovers, and truncations of major structural features associated with faulting. Based on experience with the Coalinga earthquake, this segmentation distinctly limits the extent of ruptures and the magnitude of the tremors. Figure 8 shows this segmentation. GV01 has been assigned an Mw of 6.7 with a recurrence interval of 8,300 years and a slip rate of 0.1 mm per year. GV02 has an Mw of 6.4 with a recurrence interval of 6,000 years and a slip rate of 0.1 mm per year (USGS 1996). These moment magnitudes do not include the possibility that more than one segment may rupture at once. The USGS also assigns a slip rate of 1.5 mm per year to all segments except for GV01 and 02, to which they assign a slip rate of 0.1 mm. This increases the recurrence interval from about 500 years to about 8,000 years.

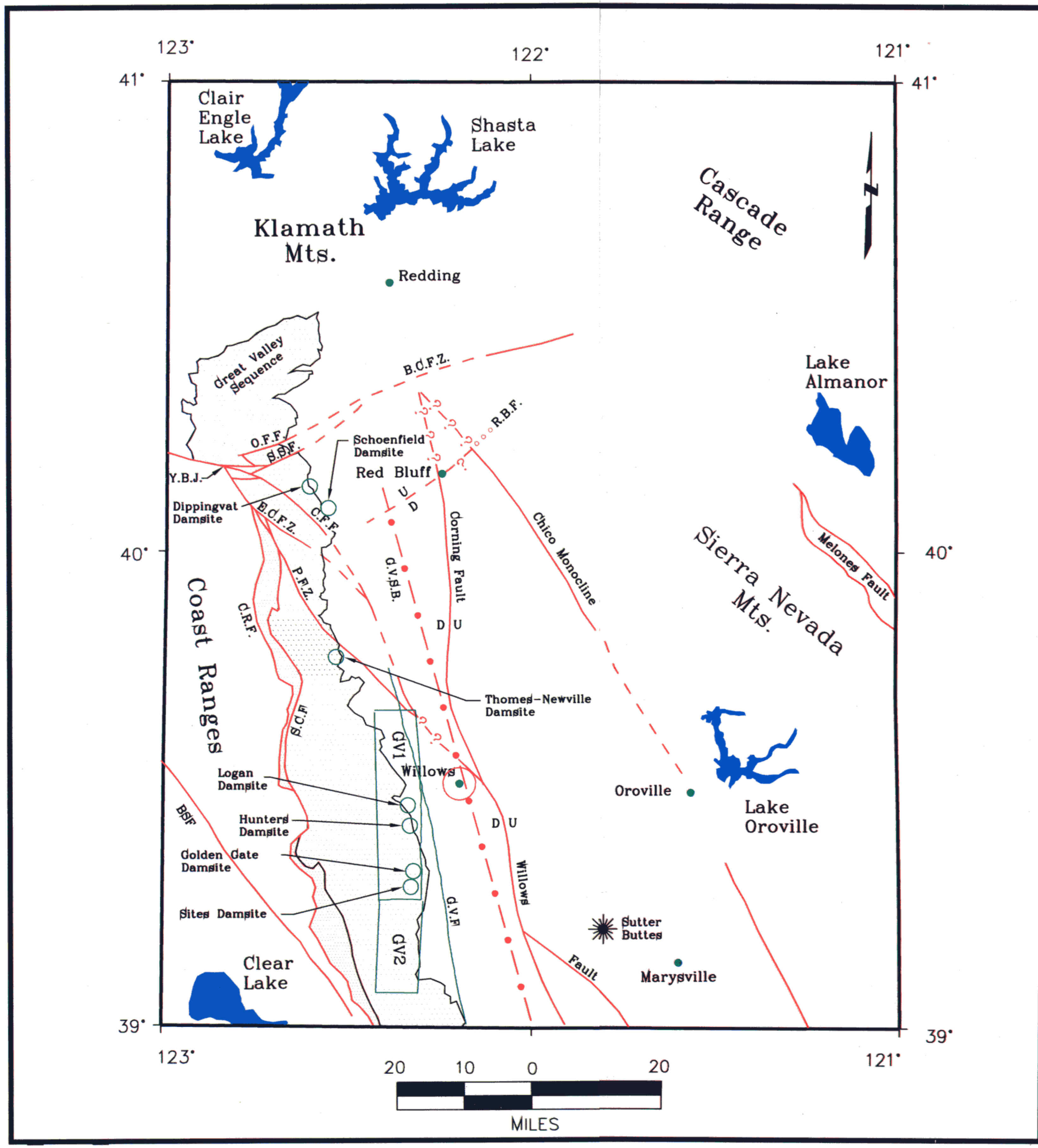
Earthquakes along this zone could potentially affect all of the proposed projects. Figure 8 shows the distance between the proposed structures and a potential earthquake. The worst case scenario is that an earthquake may occur directly underneath the damsite at depths ranging from 5 to 15 km, with the dam on the upthrown block of a thrust fault, resulting in directivity effects. Accelerations and consequent damages are generally much higher on the upthrown side.

Salt Lake Fault, Sites Anticline, and Fruto Syncline

The Sites anticline is associated with the adjacent Fruto syncline that extends a distance of about 45 miles from an area near the town of Sites to near the town of Newville to the north. The anticline is a tight fold with steeply dipping and locally overturned strata on both limbs. Based on analyses of seismic reflection data, WLA (1997) interprets the anticline as a fault-propagation fold developed above one or more blind-thrust faults. The faults are truncated by a subhorizontal detachment at a depth of about 3 miles.

The Salt Lake fault is a high-angle thrust fault that developed adjacent to the axis of the doubly plunging Sites anticline (DWR 1978). Salt water springs, gas seeps, and possible sag ponds along the fault trace are suggestive of recent fault activity. In several locations, however, the fault is concealed by an unbroken Pliocene Tehama formation, suggesting that the latest movement occurred prior to this time.

Based on the work done by the WLA and the Working Group on Northern California Earthquake Potential in 1996, it is probable that the Salt Lake fault, the Sites anticline, and the Fruto syncline are features related to the Great Valley fault. The fault trends within one mile of most of the Thomes- Newville, Sites, and Colusa Project damsites, and possibly crosses the upstream edge of the Sites Dam site. The Sites anticline (Kirby 1943) and the Fruto syncline (Chuber 1961) are flexures extending in the northwest direction from the general area of Sites about 40 miles north to Newville, and possibly as far as Paskenta. It was generally believed that the folds and attendant faulting (Salt Lake fault and numerous transverse faults) in the middle Cretaceous sediments were formed as a result of east-west compression prior to Pliocene (Tehama formation) deposition (Chuber 1961). It is now, however, considered possible that deformation along this zone may be an active process, caused by deep thrusting along the CRSNBZ (see section on the Coast Ranges-Sierra Nevada block boundary).



Legend

Map Symbols

Fault: letters U and D indicate upthrown and downthrown sides. Faults are dashed where approximately located, dotted where concealed, and queried where location is uncertain. Arrow indicates direction of dip.

Coast Ranges–Sierran Block Boundary

Coast Range Ophiolite.

Great Valley Sequence

Faults

R.B.F. = Red Bluff Fault
C.F.F. = Cold Fork Fault Zone
C.R.F. = Coast Range Fault
E.C.F.Z. = Elder Creek Fault Zone
S.C.F. = Stony Creek Fault
P.F.Z. = Paskenta Fault Zone
S.S.F. = Sulphur Springs Fault
O.F.F. = Oak Flat Fault
B.C.F.Z. = Battle Creek Fault Zone
Y.B.J. = Yolla Bolly Junction
G.V.S.B.= Great Valley–Sierran Block Bdy
B.S.F. = Bartlett Springs Fault

Source: Faults plotted from Harwood 1986 and Blake et al., 1984

Damsite Locations

G.V.F. = Great Valley Fault

GVI — Downdip extent of hypothetical ruptures along the Great Valley Fault.

GV1 – Fault segment

Source: USGS 1996

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

FAULT AND SEISMIC HAZARDS – PHASE I

RED BANK, THOMES–NEWVILLE, SITES, AND COLUSA PROJECTS

Great Valley Fault

Field inspections during this investigation along the trace of these three features suggest that the zone is more complex, with numerous smaller folds, faults, and shears along a wide area of deformation. Hints of this complexity can be seen along creek exposures on Sites, Funks, and Logan Creeks.

There also appears to be a bedding, dip, and strike discontinuity between the middle and early Cretaceous sedimentary rocks. Exposures are poor and more work needs to be done in the area to determine the true character of this zone.

WLA (1997) surveyed three geomorphic fluvial terrace profiles across the Sites anticline. They found no evidence for systematic uplift or tilting evident on surfaces dating back to the last 30,000 years. The Sites anticline also lacks the pronounced geomorphic expression similar to Dunnigan Hills and Rumsey Hills, two actively growing anticlines in the southwestern Sacramento Valley.

WLA also performed aerial and field reconnaissance of the Salt Lake fault. They observed undeformed colluvium draping the escarpment and fault traces at numerous locations. Terraces crossed by the fault appear to be undeformed. For these reasons, WLA concluded that the fault is not active.

Coast Ranges Fault

This fault is the structural contact between the Franciscan complex to the west and the Coast Ranges ophiolite to the east. In general, the fault is within 10 miles of the proposed damsites. The fault generally dips steeply. It is one of the longer faults in the State, extending from south of Colusa Reservoir to near the Oregon border. The fault may have originated in the Cretaceous period as a result of east-dipping subduction and subsequently accommodated crustal attenuation. However, there is little agreement about the fault's current activity and recent displacement history.

At the surface, it appears to be a high-angle, west-side-up reverse fault. However, recent research suggests that it probably has, over time, moved under compression, extension, and right lateral strike-slip (Jayko 1987; Wentworth, et al., 1984; Platt 1986; Krueger and Jones 1989).

Phipps and Unruh (1992) believe the fault to have been a subduction fault that has locally been reactivated as a thrust and, possibly, a normal fault. They also believe the fault to be allocthonous, that is, separated from its deep-seated roots. The fault has been cut and folded by later thrusts and by strike-slip faults.

This fault is generally considered a Mesozoic and early Tertiary feature. A part of the fault northwest of Lake Berryessa shows evidence of Quaternary displacement. It is uncertain whether the Coast Ranges fault is active. Near the Red Bank Project, HMT (1983) found no evidence of movement since the deposition of the Nomlaki 3.3 mya. WLA (1997) also found no evidence for late Quaternary activity.

Stony Creek Fault

The Stony Creek fault is east of and runs parallel to the Coast Ranges fault. It is also the contact that separates the Coast Ranges ophiolite from the GVS to the east. This contact is believed to be both depositional and faulted, showing both normal and reverse movement. In most places, the fault is near-vertical. This fault is only of concern because of its proximity to the proposed structures.

Past investigations (ESA 1980; DWR 1982; USBR 1981) studying movement along this fault have been inconclusive. Evidence from these studies suggests that at least some of the segments have been inactive for at least the last 130,000 years and, most likely, the last 250,000 years. WLA (1997) concluded that the fault is not active.

Outcrops of the fault trace along roadcuts near Grindstone Creek indicate that the contact is sharp and well defined, suggesting that not much movement has occurred. The USGS (1996) does not consider it a potential source of M6+ earthquakes.

Corning and Willows Faults

The Corning fault is not expressed at the surface but is based on well data and the overlying deformation, including the Corning domes and the Greenwood anticline. Pleistocene deformation and the association of microearthquakes suggest that the fault may be an active steeply east-dipping reverse fault (Wong, et al., 1988). Near its southern end, the Corning fault is interpreted to trend NW-SE and either splay off from or terminate against the Willows fault (Harwood and Helley 1987). The closest approach of the Willows fault to any of the damsites is 12 miles from the Sites Dam site.

The Willows fault appears to be a steeply dipping reverse fault with the east side up. It is probably the most extensive fault within the valley and appears to be a major tectonic boundary dividing the Sacramento Valley into two late-Cenozoic structural provinces. North of Willows, the fault changes to a northwest strike and appears to splay into the Paskenta, Cold Fork and Elder Creek faults (Wong, et al., 1988).

Northern Transverse or Tear Faults, and Other Minor Faults

From south to north there are a number of minor faults, some of which are transverse to the regional structure. These include the Paskenta, Black Butte, Elder Creek, Cold Fork, Sulphur Spring, and Oak Flat faults.

The faults near the Red Bank Project are believed to be tear faults associated with subduction and the westward rotation of the Klamath Mountains. Wentworth and Zoback (1984) believe that the faults break the GVS but do not root in the deeper basement rocks.

The Paskenta fault consists of a number of subparallel faults that trend west-northwest. To the east, the fault disappears under the Pliocene Tehama formation, suggesting that the last movement occurred prior to that time (DWR 1978).

The Elder Creek fault zone originates west of the Red Bank Project, then strikes southeast, branching out to form a series of bifurcating fault segments. Displacement is largely left-lateral strike-slip (Bailey and Jones 1973) with GVS rocks displaced tens of miles west. Harwood and Helley (1987) projected the Willows fault to the south and the Cold Fork fault to the north into the Elder Creek fault zone. There has been no evidence of Quaternary movement documented for this fault zone but the Willows fault has recent seismic activity associated with it.

The Cold Fork fault is about 6 miles north of the Elder Creek fault zone and is similar in form, trend, and displacement. The fault consists of numerous splays that trend northwest, crossing both the Sulphur Spring and Oak Flat faults. There is no evidence of Quaternary displacement along this fault.

The Sulphur Spring fault is a few miles north of the Dippingvat Dam site. It trends from the Stony Creek fault northeast about 10 miles to the contact point between the GVS and the Tehama formation. Movement is right lateral, with significant displacement of both the GVS and the basal Tehama units. Bailey and Jones mapped several thousand feet of offset in the Nomlaki tuff (3.3 million years old). HMT excavated several trenches across traces of the fault and concluded that movement along the fault ceased by more than 100,000 years ago, but more likely 1.2 mya.

The Oak Flat fault is about 2 miles north of, and parallel to the Sulphur Spring fault. It is also about the same length and shows right lateral movement, but does not displace the Pliocene Tehama. This suggests that the last movement was older than 3.3 mya.

Battle Creek Fault Zone

This fault zone consists of a number of parallel faults that end near the town of Cottonwood to the west and extend northeast about 22 miles toward Mt. Lassen. The fault is associated with an east-west trending zone of seismicity and folding (Inks Creek fold system), separating the Sacramento Valley proper from the Redding basin.

Movement is predominantly normal with the south side down, but with a smaller component of right lateral strike-slip (Helley, et al., 1981). Interpretation of deep seismic lines (HMT 1984) indicates vertical basement displacements of about 150 feet near the west end to 1,300 feet on the east. The fault is Quaternary in age, but it is not known whether it is active. The age of latest displacement increases toward the east with the most recent movement believed to be greater than 0.42 mya (Harwood and Helley 1987).

Foothills Fault System

Located about 50 miles to the east of the project along the western flank of the Sierra Nevada, the Foothills fault system is believed to be a low activity fault with a slip rate of less than 0.1 mm per year. An M5.7 occurred on this fault zone (Cleveland Hills fault) near Oroville in 1974. An MCE of 6.5 was assigned by Caltrans in 1996 to this fault; an earthquake of this magnitude should have minimal effects on the proposed structures.

This system is composed of generally minor and younger normal displacement faults superimposed on a wider zone of older high-angle reverse faults.

Mt. Lassen and Related Earthquakes

Seismicity is associated with Mt. Lassen volcanic activity, including earthquakes associated with eruptive activity, aftershocks, and swarms. The largest earthquakes are in the M5-6 range with intensities of MM VII. These earthquakes are too far away to affect the designs of the project dams.

Other Regional Structures

Other regional structures besides faults include folds and joints. Regional folds generally trend in the same northwest direction as the regional faults. Some of the folds, such as Corning and Dunnigan Hills, are probably the surface expression of deeper movements along faults. Regional folds are consistent with a compressive stress regime oriented about N75E.

The largest structure is the synclinal fold of the Sacramento Valley. On the west side, the Cretaceous mudstone, sandstone, and conglomerate dip moderately to steeply east and strike northwest. On the east side, similar beds dip to the west and strike in about the same direction.

The Chico monocline occurs along the east side of the valley between Chico and Red Bluff. Along the east side, beds dip shallowly to the west, but at the axis of the monocline, the beds dip more steeply toward the center of the valley. The axis is also displaced by numerous faults trending parallel to the axial plane.

Jointing is pervasive in the GVS but is generally not present in rocks younger than the Cretaceous. The Cretaceous mudstones are generally the most jointed. Jointing sets in three directions, and spacings from less than an inch to about a foot are common. The joint directions are perpendicular to each other with one set parallel to the bedding and the other two sets perpendicular to the bedding and to each other. The pervasive jointing causes the exposed mudstone outcrops to slake readily.

The Cretaceous sandstones and conglomerates vary in joint spacing depending mostly on the thickness of the individual beds. Joint directions are similar to the mudstones. The massive units have joint spacings ranging from a few feet to several tens of feet or more.

Seismicity

The seismicity of the western Sacramento Valley foothills has been recorded by a number of different agencies over the last 100 years. These agencies include the University of California, Berkeley, the California Department of Conservation, USGS, and DWR. The accuracy in the measurements of the epicenters, focii, and magnitude has improved over the years as more instruments with greater sensitivity and accuracy have been installed. The older data were recorded with instruments located several hundred miles away. Consequently, the plotted locations of seismic events may be off by tens of miles.

Earthquakes as small as M1 and M2 have been recorded in the project area since the installation of the Northern California Seismic Network beginning in 1975 (Attachment A). The appendix includes an analysis of earthquake activity to date. DWR, in 1991, as part of the Red Bank Project, worked with USGS to install four additional seismic stations in the area. Accuracy in the plotting of epicenters with the data from these stations can be within several miles for relatively small earthquakes occurring close by. USGS provided DWR with an analysis of the data recorded to date by the network.

According to USGS, the number of earthquakes recorded by the network is typically three or less and often zero per month.

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Historical Earthquakes

Historical seismic activity for the last 200 years or so in the central and northern part of the Sacramento Valley has been low to moderate compared to other areas of California. Events in Northern California larger than M6 have occurred in the San Francisco Bay region, near Eureka, north of Tahoe, and in the Vacaville-Winters area. Events larger than M7 occurred in Eureka in 1923 and 1992, and in the San Francisco area in 1868, 1906, and 1989.

Major fault zones known to be seismically active near the project area include the Foothills fault system, the Chico monocline, the blind thrusts of the Great Valley fault, the Willows and Corning faults, the Bartlett Springs, Maacama, and San Andreas faults, and the Cascadia subduction zone.

The Winters-Vacaville earthquakes of April 19-21, 1892, are the two earthquakes with the most significant impact on the design of the proposed projects, particularly Thomes-Newville, Sites, and Colusa. This is because the proposed dams and structures are overlying the same Great Valley fault (Coast Ranges-Sierra Nevada block boundary) that is believed to have been the cause of the earthquakes. This zone is believed to extend the entire length of the greater Central Valley. A similar temblor (M6.7) to the Winters-Vacaville earthquakes occurred in 1983, causing considerable damage in the Coalinga area.

The two major Winters-Vacaville temblors and numerous aftershocks produced widespread damage throughout much of Solano, Yolo, and Napa Counties. The towns of Winters, Vacaville, and Dixon suffered massive destruction with intensities reaching MM IX and estimated magnitudes between six and seven (DWR 1978).

On January 7, 1881, an estimated M5 occurred east of Red Bluff at the edge of the Cascade Range. On June 6, 1884, an estimated M5 occurred near or north of Red Bluff. One wall cracked. An M4.5 occurred in the Willows area on July 24, 1903, with some cracking and falling plaster. An MM VI event occurred on April 16, 1904, south of Redding. An M5.7 occurred northeast of Chico on February 8, 1940, and an M4.6 near Chico in 1966. Both of these were probably associated with the Chico monocline. An M4.7 event occurred on April 29, 1968, near Willows (Wong 1988).

On August 1, 1975 an M5.7 occurred near Oroville on the Cleveland Hills fault. This quake renewed interest in the Foothills fault system and speculations about RIS related to Lake Oroville.

Several earthquakes have occurred fairly recently near Redding, Chico, Cottonwood, and Willows. A series of earthquakes, including an M5.2 that occurred in November 1998, struck the Redding area over a period of months. Historic earthquakes of M6+ have occurred both in the valley and in the Coast Ranges to the west.

Earthquake Design Criteria

The MCE measure is used because the likelihood of such earthquakes occurring is great enough, and the probability of certain faults being active and their recurrence rates are not known for most faults. The MCE implicitly takes into account such factors. The resultant ground motions from MCE are the most appropriate consideration for critical structures and for public safety because they are considered to be conservative.

Hazards relating to earthquakes include surface rupture, soil liquefaction, and shaking. Generally, ground shaking is the predominant source of earthquake damage, resulting in 90 percent or more of the damage; but in areas with liquefaction potential, damage can increase commensurately. Surface rupture generally results in less than 5 percent of the damage. Neither surface ruptures nor liquefaction is considered to be a likely cause of damage to the proposed projects.

The magnitude or local magnitude of an earthquake is defined as the logarithm to the base 10 of the amplitude, in microns, of the largest trace deflection observed on a standard torsion seismograph at a distance of 100 km from the epicenter. The moment magnitude is a newer concept calculated from modern seismographs, taking into account all the seismic waves; or it can be estimated based on the rupture area (M_W=4.07+0.98log(lw)). This estimated value is used when historic earthquakes or potential earthquakes lacking instrument data are evaluated.

CDMG (1996) published a probabilistic seismic hazard map showing peak horizontal ground acceleration on uniform soft-rock sites. The values have a 10 percent probability of exceedance in 50 years. Acceleration at 10 percent in 50 years ranges from about 0.1 to over 1g. The map shows that the damsites lie in a zone with a 50-year recurrence interval of between 0.1 and 0.3 g. CDMG also developed a map showing areas that are thought to have experienced an intensity of MM VII or greater between 1800 and 1996. This includes most of the north coastal area but is somewhat west of the proposed damsites.

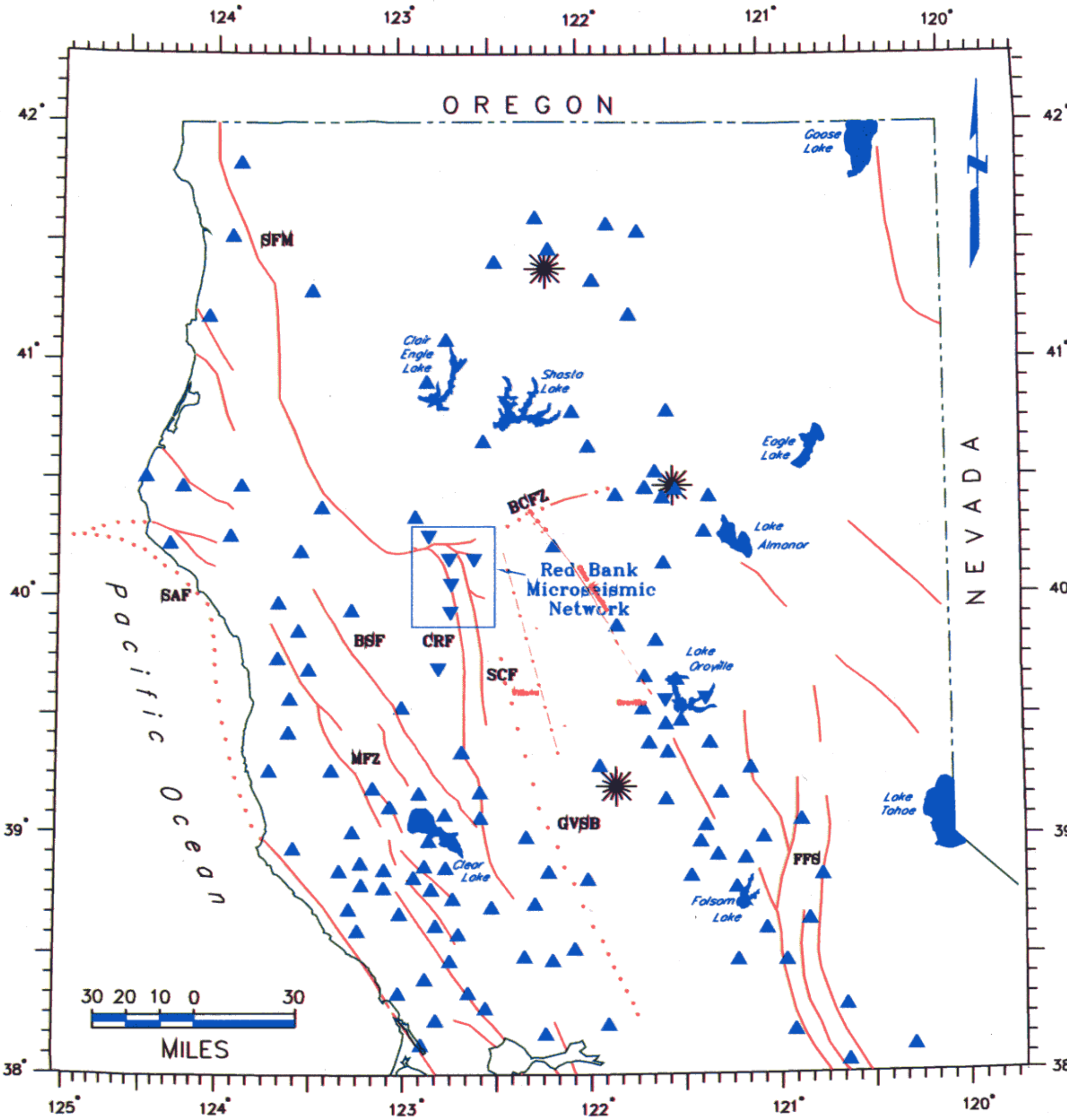
Seismic Stations and Microseismic Networks

Figure 9 shows the seismic stations in Northern California. The majority of stations are clustered around preexisting reservoirs such as Lake Shasta, Lake Oroville, Stony Gorge Reservoir, and Clear Lake.

Figure 10 shows the epicenter data for the north-central part of the Sacramento Valley. Sources of data include DWR (1900-1949, M_L>3), U.C. Berkeley (1950-1970, M_L>3), and USGS (1970 to present, M_L>1). Earthquakes of M_L>4 are fairly rare, averaging about one per year. Smaller quakes between M1-3 are more common, averaging two to three per month.

Figure 10 shows earthquakes from one of several seismic networks that have operated intermittently. These include the survey's main network, the Shasta Dam network, and the DWR network. The data shows the date, time, location, hypocentral depth, maximum intensity, and local magnitude of each earthquake. Accuracy of location and magnitude is dependent on the density and geometry of the seismic stations existing at the time of the event.

A microseismic network was installed in 1991 and is maintained by USGS as part of the Red Bank Project investigation to fill in the gap between Stony Gorge Reservoir and Lake Shasta. The purpose was to monitor and analyze microearthquakes to assist in defining hidden faults along the Coast Ranges-Sierra Nevada block boundary and to determine whether this zone extended this far to the north. The network consists of five additional stations in the Red Bank area



Legend

Map Symbols

Fault: Faults are dashed where approximate, and dotted where concealed

USGS Seismic Stations

DWR Seismic Stations

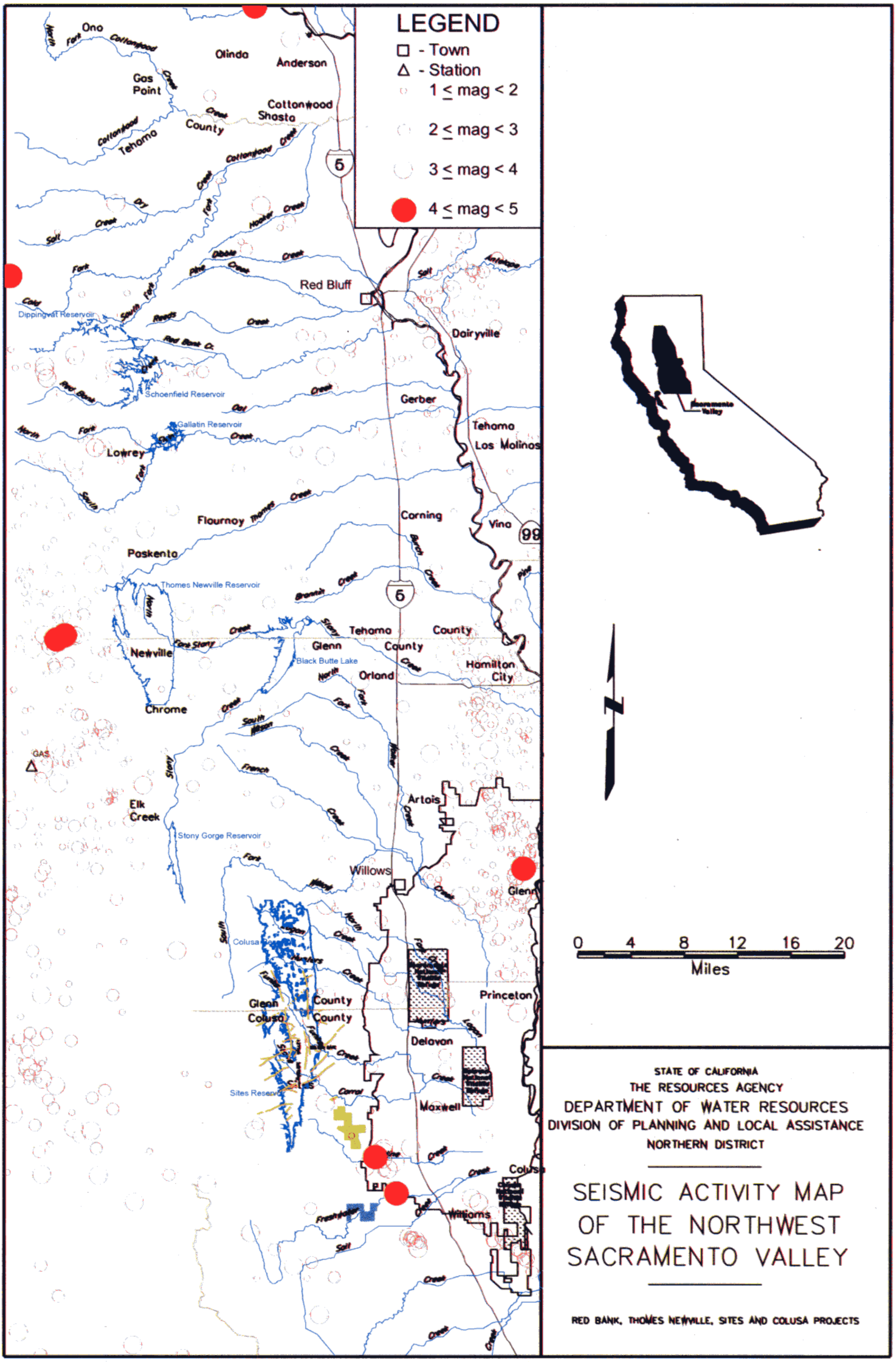
Volcano

Faults

SAF = San Andreas Fault
CRF = Coast Range Fault
SCF = Stony Creek Fault
FFS =Foothills Fault System
MFZ = Maacama Fault Zone
BCFZ = Battle Creek Fault Zone
SFM = South Fork Mountain Fault
GVSB = Great Valley Sierran Block Boundary
BSF = Bartlett Springs Fault

Figure 9. Location of Seismic Stations in N. California

FIGURE 10



N: geo\projects\SitesDam\seismic\activity.dwg that are shown on Figure 10. DWR receives their reports quarterly and enters the information into an appropriate database. A summary of the data is in Attachment A.

USBR installed a 10-station microseismic network in the Shasta-Trinity area in 1982. The network has provided hypocenter information on magnitudes as low as 0.2. Two older stations operated by U.C. Berkeley are at Whiskeytown Dam and at Mineral near Mt. Lassen.

Northern California Earthquake Potential

There are a number of different methodologies for estimating earthquake ground motion parameters. These include: simple prescribed parameter values, selection of a design strong-motion record, probabilistic seismic hazard analysis, and deterministic seismic hazard analysis. The latter two types were done for this study.

Probabilistic Seismic Hazard Analysis

This type of analysis is site-specific. According to CDMG (1997, Web site), this includes the following:

- Compiling a database of potentially damaging earthquake sources, including known active faults and historic seismic source zones, activity rates, and distances from project sites. This should include a comparison with published slip rates. Differences in slip rates should be documented and the reasons for them explained.
- Using published maximum moment magnitudes for earthquake sources, or estimates that are justified, well documented, and based on published procedures.
- Using published curves for attenuation of peak ground acceleration with distance from the earthquake source as a function of earthquake magnitude and travel path.
- Evaluating likely effects of site-specific response characteristics from soft soils, topography, and near-source effects.
- Characterizing the ground motion in terms of peak ground acceleration with a 10 percent probability of exceedance in 50 years, taking into account historical seismicity, available paleoseismic data, the slip rate of active faults, and site-specific resonance characteristics.

A probabilistic seismic hazard working group on Northern California earthquake potential was convened in 1994 as part of the USGS National Earthquake Hazards Reduction Program. The working group was composed of many scientists from academia, government, and private industry, including CDMG (1996) and USGS (1996). The task of the working group was to create a map and database of active faults, both surficial and buried. The database contains 62 potential Northern California sources, including fault segments and areal-distributed zones. Factors considered include broadly-based plate tectonics, geologic slip rates, geodetic strain rates, and microseismicity. The hazard maps form the basis for the ground motion design maps of the 1997 edition of the *National Hazard Reduction Program Recommended Provisions for Seismic Regulations for New Buildings*. Maps and databases developed by the working group are on CDMG's Web site (see References).

Because of the brief historical record of earthquakes, a standard methodology was used, based on the empirical relationships between fundamental earthquake parameters (USGS 1996), including the following:

- Fault segmentation or determination of source length (l) - The fault rupture length is generally related to the size of the earthquake.
- Fault down-dip width (w) - Dip width is generally assumed to be 12 km in Northern California, except where more accurate data from microearthquakes or other sources are available.
- Historical values of magnitude (M_W) - Historical values were used where available: otherwise the empirical relation of the moment to rupture area M_W=4.07+0.98log(lw)(km^2) was used.
- Average coseismic slip (d) - Historical values were used when available; otherwise the relationship between seismic moment and moment magnitude was used to determine d.
- Long-term slip rate (r) - Only minimum values on a few faults are available for this measurement. The values are provided in ranges that are a measure of the reliability.
- Recurrence time (t) - Historic values were used when possible, otherwise the empirical relation t=d/r was used, where d is the average coseismic slip and r is the slip rate.

CDMG (1996) published a *Probabilistic Seismic Hazard Map (10 percent probability in 50 years) of Peak Horizontal Ground Acceleration in Uniform Soft-Rock Site Conditions.* This is shown on the CDMG Web site. The map shows that the project damsites fall within the 0.1 to 0.3g zone. It is important to note, however, that a 50-year recurrence interval is too small for such a large and important structure as a large dam, since the consequences of failure are too large. For these structures, a deterministic approach is generally adopted.

Deterministic Seismic Hazard Analysis

Deterministic evaluation (CDMG Web site) of seismic hazards includes the following:

- Evaluating potentially damaging earthquake sources and deterministic selection of one or more suitable "controlling" sources and seismic events. The magnitude for any fault should be the maximum value that is specific to the seismic source. Maximum earthquakes may be assessed by estimating rupture dimensions of the fault.
- Using published curves for the effects of seismic travel paths using the shortest distance from the sources to the sites.
- Evaluating the effects of site-specific response characteristics on either site acceleration or cyclic shear stresses within the soils of interest.

Caltrans published a deterministic map in 1996 based on the MCE and accompanying text detailing the latest understanding of earthquake science and earthquake engineering. The work was apparently done independently of USGS and CDMG work. Also, the potential for an M8+ on the Gorda plate-Cascadia subduction zone was not considered. This probably affected the predicted peak horizontal acceleration for the Red Bank Project, but not the Thomes-Newville, Sites, and Colusa Projects.

DSOD uses a deterministic approach. This method includes setting an MCE for the project and determining the peak acceleration based on the horizontal distance, the predominant period for the maximum acceleration, and the bracketed duration of the shaking.

Table 2 shows the published information regarding peak horizontal acceleration, MCE, and acceleration probabilities for each of the project damsites. This is based on the Caltrans California Seismic Hazard Map 1996 which shows major active faults and contours of expected peak acceleration. Also shown is the M_W earthquake based on the Great Valley fault system segmentation model (CDMG 1996). The last column is the 10 percent probability in 50 years that the peak horizontal acceleration will equal or exceed the predicted value on soft-rock site conditions (CDMG 1996).

Table 2. Published Seismic Criteria for Project Damsites Source: CDMG 1996, Caltrans 1996

Damsite	Creek	Peak Acceleration Caltrans 1996 (g)	M_W CDMG 1996	10% in 50 years CDMG 1996 (g)
Dippingvat	S.F. Cottonwood	0.4-0.5	6.7	0.1-0.2
Schoenfield	Red Bank	0.4-0.5	6.7	0.1-0.2
Newville	N.F. Stony	0.6+	6.7	0.1-0.2
Grindstone	Grindstone	0.4-0.5	6.7	0.2-0.3
Logan	Logan	0.4-0.5	6.7	0.1-0.2
Hunters	Hunters	0.4-0.5	6.7	0.1-0.2
Golden Gate	Funks	0.5-0.6	6.7	0.2-0.3
Sites	Stone Corral	0.5-0.6	6.7	0.2-0.3

Caution should be used in applying these criteria to dam designs. The highest peak acceleration shown on the Caltrans map is 0.6g. This is a realistic value for most instances. However, surprisingly high peak accelerations exceeding 1g have been recorded in several instances during recent earthquakes such as San Fernando and Northridge. Caltrans does not imply that the 0.6 is the maximum possible, but rather to indicate the least controversial upper level of peak acceleration known to occur.

USBR (1986) published a seismotectonic study of the northernmost part of California for its project features. The seismographs show a variety of fault plane solutions from 1983-84 network data but mostly strike-slip faulting from north-south compression or east-west extension. Whether extension or compression is the causative stress in the Shasta area cannot be determined from the current information. There is also no evidence in the seismic patterns to determine the orientation of the fault planes. Clusters, however, do identify localized zones where stress is being released. The seismicity does not appear to correspond with faults or geologic structures mapped on the surface.

Reservoir-Induced Seismicity

Increased earthquake activity has been associated with the filling of a number of reservoirs. From a total of 64 cases of possible RIS reported worldwide prior to 1983, 45 were classified as actual cases (HMT 1983).

The magnitude of RIS is a function of the location, depth, and size of a reservoir, and seismic activity in the area. The two main RIS triggering mechanisms appear to be the increased stress from loading the reservoir area, and the increased pore pressure from seepage. Both of these factors relate directly to reservoir height and volume, with height probably being more important than volume. Data indicate that RIS is most common in reservoirs greater than 300 feet in height in regions that are seismically active.

RIS is believed to be a consideration for all of the proposed reservoirs because of the large volume of water and depths that could exceed 300 feet. An M6.5 earthquake occurring directly under a damsite at a depth of about 6 miles is believed to be a conservative estimate of this type of event. This is based on numerous RIS events ranging from M5 to M6.5 that have been documented worldwide.

The RIS event is smaller than other potential earthquakes related to the Great Valley fault or Gorda plate subduction that could occur at the damsites, and therefore are not considered to be the source of the Design Earthquake.

Project Design Earthquakes

Project Design Earthquakes are based on the deterministic approach and the occurrence of an MCE. Design Earthquakes are based on a number of factors, including the occurrence of historic earthquakes and concern for public safety as described in previous sections. The earthquakes were selected to present a conservative estimate of the MCE.

Red Bank Design Earthquake

Three types of earthquakes were considered for the Red Bank Project. The first is an M6.5 RIS event occurring at a depth of 10 km directly under the dam. The second is a Great Valley fault rupture, in this case, of several segments resulting in an M7 event directly under the dam at a depth of 10 to 12 km. The third is a Gorda plate event of M8.3 at a depth of 35 km directly underneath the dam. Table 3 shows the design parameters developed from these events using graphs by Seed and Idriss (EERI 1982). The Gorda plate event has the highest peak acceleration and the longest duration and is considered the Design Earthquake for the Red Bank Project. Because of the deep source area of 35 km, the depth was used as a distance to determine the attenuated acceleration, duration, and period. It should also be noted that the chances that a Gorda plate earthquake would occur directly under the project are extremely remote.

Table 3. Draft Preliminary Design Parameters for the Red Bank Project

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.69	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Gorda Plate	8.3	0	35	0.72	28.5	0.42

* Note: Preliminary design parameters are subject to change as new information becomes available. These parameters are believed to be conservative.

Thomes-Newville Design Earthquake

Three types of earthquakes were considered for the Thomes-Newville project. The first is an M6.5 RIS event occurring at a depth of 10 km directly under the dam. The second is a Great Valley fault rupture, in this case, of several segments resulting in an M7 event directly under the dam at a depth of 10 to 12 km. WLA (1997) believes the M7 is very conservative, but that the earthquake could nucleate at a shallower depth, possibly 6 km. The third event is an M6.5 on the Stony Creek fault (ESA 1983). A Gorda plate event was not considered because it is believed that the southern edge of the plate boundary is postulated to be near Red Bluff. The Coast Ranges and Stony Creek faults are generally not considered active, although some moderately deep earthquakes may be associated with them. The Bartlett Springs fault is active but is about 40 km to the west, too far away to be the Design Earthquake. The Great Valley fault encompasses a wide zone of deformation and is considered to be active because of the Winters-Vacaville earthquakes of 1892. The conservative scenario is that an M7 could occur directly under the proposed dam.

Table 4 shows the design parameters for the Thomes-Newville project. The M7 Great Valley fault earthquake has the highest acceleration and the longest duration and is therefore considered the Design Earthquake. The Seed and Idriss (EERI 1982) curves, using a distance of zero, were used to estimate the acceleration, duration, and period.

Table 4. Draft Preliminary Design Parameters for the Thomes-Newville Project

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.69	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Bartlett Springs	7.1	40	10	0.17	23.5	0.32
Stony Creek Fault	6.5	6	10	0.28	19	0.28

* Note: Preliminary Design parameters are subject to change, as new information becomes available. These parameters are believed to be conservative.

Sites and Colusa Projects Design Earthquake

Three types of earthquakes were considered for the Sites and Colusa Projects. The first is a RIS of M6.5 occurring at a depth of 10 km. The second is an M7.1 occurring on the Bartlett Springs fault at a distance of 40 km. The third is a Great Valley fault multiple-segment rupture with an M7 occurring at a depth of 10 km. Table 5 summarizes the design parameters. The M7 Great Valley fault event is considered to be the design earthquake. WLA (1997) considers the M7 to be very conservative, but the site-source distance may be somewhat less. Directivity effects may be significant in estimating ground motions.

Table 5. Draft Preliminary Design Parameters for the Sites and Colusa Projects

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.40	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Stony Creek Fault	6.5	16	10	-	-	-
Bartlett Springs	7.1	32	10	-	-	-

* Note: Preliminary Design parameters are subject to change as new information becomes available. These parameters are believed to be conservative.

Damsite Geology And Surface Rupture Hazards

CDMG (1996) published guidelines for evaluating the hazards of surface fault ruptures. The guidelines include a suggested report outline on faults, the types of exploration methods, and a comprehensive list of references. The study of the potential hazards of surface fault ruptures is based partially on the concepts of recency and recurrence, with the more recent the faulting and the higher the recurrence interval, the greater the probability for future faulting.

This Phase I report is a summary of past investigations and does not include any current field investigations. Phase II will include detailed mapping, trenching, drilling, and stereo aerial photo, side-looking radar, and low-sun-angle photography analyses. The Red Bank Project was initially investigated by DWR (1991) between 1989 and 1991. The Thomes-Newville Project was investigated between 1980 and 1983 by DWR (1980) and ESA (1980). USBR investigated the Sites Project between 1969 and the mid-1980s. No damsite geology has been done for the Colusa Cell Project.

Red Bank Project

The Red Bank Project was initially envisioned as a number of earthfill structures. Advances in the use of roller compacted concrete (RCC) created renewed interest in the project (DWR 1987). The faulting and seismicity was investigated in detail by DWR (1991) and a summary is provided here. Figure 11 shows the damsite foundation areas, simplified geology, and faulting in the Red Bank area. Two small diversion structures, Bluedoor and Lanyan, are not discussed in the text.

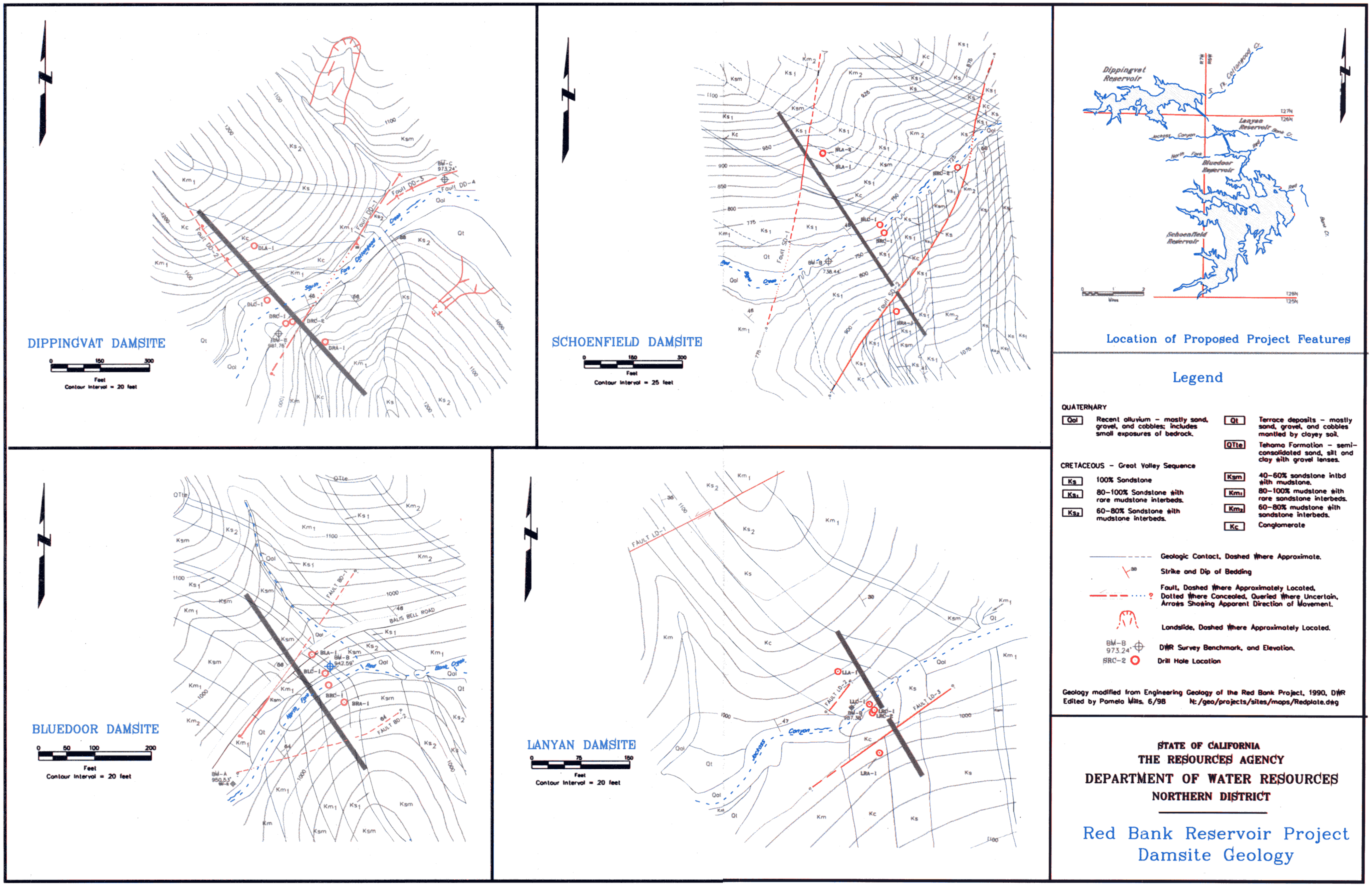
Dippingvat Dam Site

Dippingvat is in a narrow gorge on South Fork Cottonwood Creek. The proposed dam is a 256-foot-high RCC structure impounding 104,000 acre-feet. The damsite is on Upper Cretaceous (Turonian) conglomerate (39 percent), sandstone (6 percent), and mudstone (55 percent). The beds dip downstream 45 to 65 degrees and strike northwest.

Quaternary and Recent deposits include minimal stream channel deposits averaging about 2 feet thick and colluvial soil along the base of the abutments averaging from about 5 to a maximum of 15 feet. Terrace deposits are found both upstream and downstream of the axis.

Three faults are exposed in the foundation. All were intersected during drilling. Associated with the faults were narrow zones of gouge and sheared mudstone. Fault DD-1 bears diagonally (N25W) across the channel at the dam axis. The fault can be traced at least 700 feet, with an apparent horizontal offset of 75 to 100 feet, and a width of 3 feet. Fault DD-2 trends N40W and offsets a conglomerate bed on the left abutment. It is poorly exposed but drilling intersected a number of narrow shears, each less than a foot wide, which may be associated with this fault. Fault DD-3 is about 300 feet downstream of the axis. This fault is a zone of fracturing with minimal offset. The faults do not cross datable Quaternary deposits. DWR (1991) concluded that the faults were pre-Quaternary in age and would not create a seismic or surface rupture hazard.

Figure 11


DIPPINGVAT DAMSITE
0 150 300
Feet
Contour Interval = 20 feet
SCHOENFIELD DAMSITE
0 150 300
Feet
Contour Interval = 25 feet
BLUEDOOR DAMSITE
0 50 100 200
Feet
Contour Interval = 20 feet
LANYAN DAMSITE
0 75 150
Feet
Contour Interval = 20 feet
Dippingvat Reservoir
Lanyan Reservoir
Bluedoor Reservoir
Schoenfield Reservoir
Location of Proposed Project Features
Legend
QUATERNARY
Qal Recent alluvium - mostly sand, gravel, and cobbles; includes small exposures of bedrock.
Qt Terrace deposits - mostly sand, gravel, and cobbles mantled by clayey soil.
QTte Tehama Formation - semi-consolidated sand, silt and clay with gravel lenses.
CRETACEOUS - Great Valley Sequence
Ks 100% Sandstone
Ks1 80-100% Sandstone with rare mudstone interbeds.
Ks2 60-80% Sandstone with mudstone interbeds.
Ksm 40-60% sandstone intbd with mudstone.
Km1 80-100% mudstone with rare sandstone interbeds.
Km2 60-80% mudstone with sandstone interbeds.
Kc Conglomerate
Geologic Contact, Dashed Where Approximate.
Strike and Dip of Bedding
Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, Arrows Showing Apparent Direction of Movement.
Landslide, Dashed Where Approximately Located.
BM-B 973.24' DWR Survey Benchmark, and Elevation.
SRC-2 Drill Hole Location
Geology modified from Engineering Geology of the Red Bank Project, 1990, DWR
Edited by Pamela Mills, 6/98 N:/geo/projects/sites/maps/Redplate.dwg
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
Red Bank Reservoir Project
Damsite Geology

Schoenfield Dam Site

The Schoenfield Dam site is in a narrow and steep gorge on Red Bank Creek. The proposed dam would be a 300-foot-high RCC structure. The dam foundation consists of Upper Cretaceous (Turonian) sandstone (82 percent), mudstone (14 percent), and minor conglomerate (4 percent), with the bedding thickness varying from less than one inch to tens of feet. The beds trend northwest and dip about 60 degrees to the east.

Quaternary to Recent deposits consist of minor stream gravel in the channel and some colluvium at the base of the abutments. Terrace deposits 4- to 8-feet thick occur both upstream and downstream of the axis within the foundation area.

There are two mapped faults and several smaller faults that intersect the foundation area. All are transverse faults that are roughly perpendicular to the regional strike of bedding. Fault SD-1 cuts the dam axis at N15E high on the left abutment and has an apparent right lateral offset of 45 feet. The fault is poorly exposed and does not appear to have great lateral extent. A small terrace lies across the fault trace but no trenching was done. SD-2 is more prominent, trends N25E, and cuts through the right abutment. Movement appears to be right-lateral with a displacement of about 75 feet. The fault consists of highly sheared and slickensided fault gouge. The faults do not cross datable Quaternary deposits. DWR (1991) concluded that the faults were pre-Quaternary in age and would not create a seismic or surface rupture hazard.

Thomes-Newville Project

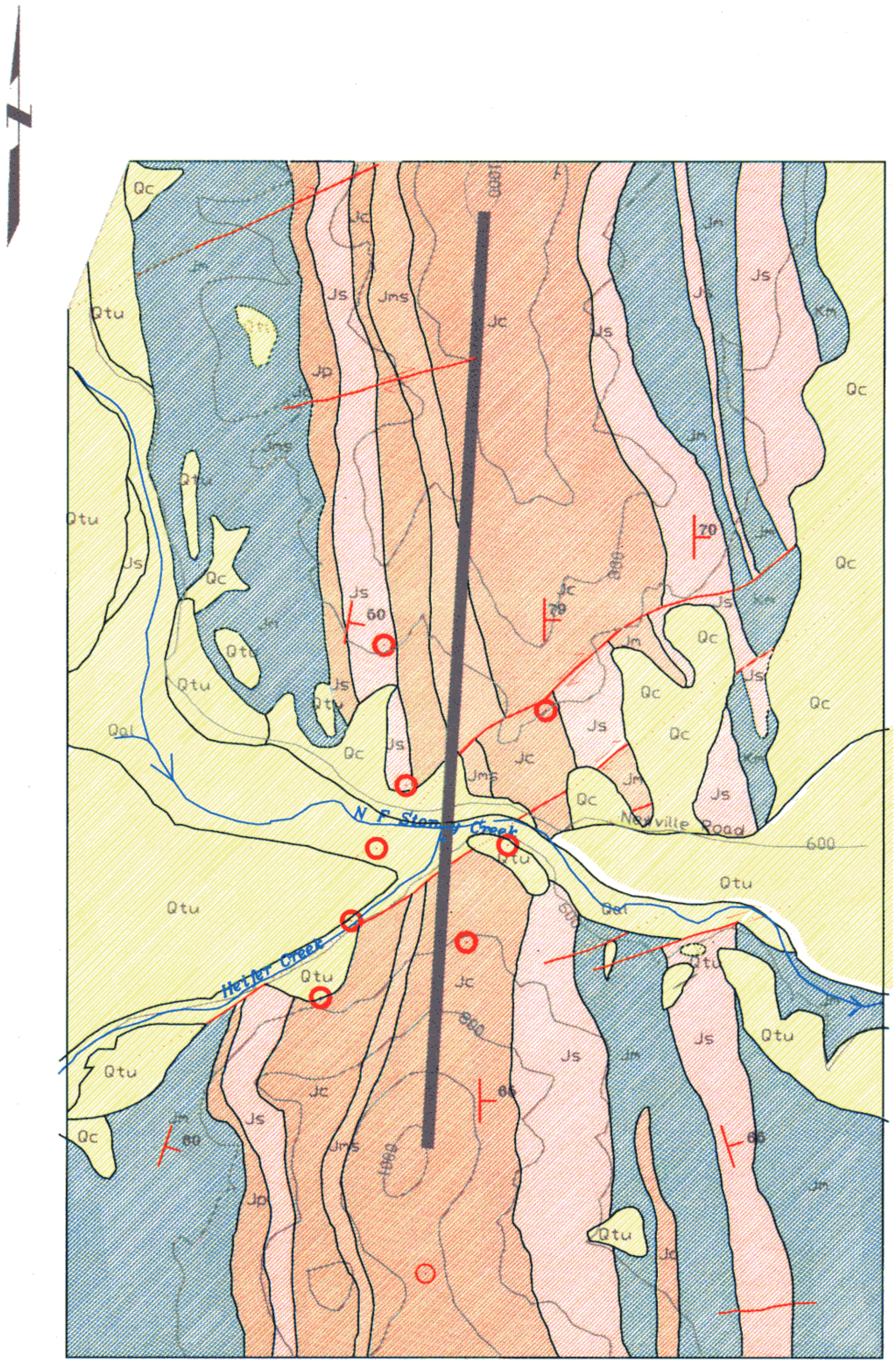
The Thomes-Newville Project consists of a 1.4 to 1.9 maf reservoir created by Newville Dam, a diversion dam on Thomes Creek, conveyance facilities to the reservoir, and Tehenn Reservoir, an afterbay with a pumping-generating plant. Additional facilities would be needed to bring water in from Black Butte Reservoir and the Sacramento River. The plan and geologic conditions were described in detail by DWR (1980).

A fault and seismic investigation was completed by ESA (1980). ESA concluded that none of the numerous well defined, dated, Quaternary terraces in the area show any topographic expression of offset by faulting or deformation by tectonic stresses.

Even the Pliocene Tehama formation that caps the ridges east of the reservoir area shows no signs of tectonic activity. The two critical structures proposed for this project are the Newville Dam and the Burrows Gap Saddle Dam. Figure 12 shows the damsite geology and the locations of faults.

Newville Dam Site

The Newville Dam site is about 20 miles west of Corning on North Fork Stony Creek where the creek crosses Rocky Ridge. The dam would be a 288- to 325-foot-high earth-rockfill structure. The dam would be founded on sandstone, mudstone, and conglomerate of the Jurassic Stony Creek formation and Cretaceous mudstones of the Lodoga formation. The units strike N-S and dip 50 to 80 degrees to the east.

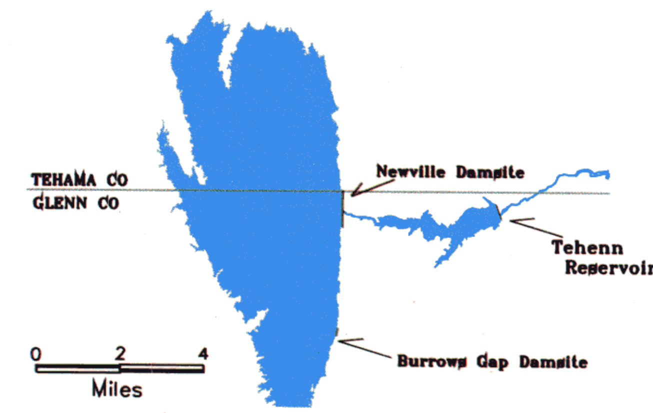


Newville Damsite

0 200 400 600
Feet
Contour Interval = 100 feet

Burrows Gap Damsite

Contour Interval = 20 feet



Location of Proposed Project Features

Legend

Quaternary Deposits

- Qal — Recent alluvium – mostly sand, gravel, and cobbles; includes small exposures of bedrock.
- Qtu — Terrace deposits – mostly sand, gravel, and cobbles mantled by clayey soil.
- Qc — Colluvium

Great Valley Sequence

Lodoga Formation

- Km — Mudstone

Stony Creek Formation

- Jc — Conglomerate with lenses of mudstone.
- Jm — Mudstone
- Jp — Pebbly mudstone grading to conglomerate
- Jms — Interbedded mudstone and sandstone
- Js — Sandstone with few beds of conglomerate and mudstone

- Geologic Contact, Dashed where Approximate
- Strike and Dip of Bedding
- Fault, Dashed where Approximate, Dotted where Concealed Arrows Showing Direction of Movement, Queried where Questionable
- Drill Hole Location
- Dam Axis

Geology from Thomes–Newville and Glenn Reservoir Engineering Feasibility DWR Report, 1990

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Thomes – Newville Reservoir Project

Damsite Geology

Colluvium, alluvium, and terrace deposits cover about 20 percent of the foundation. The colluvium is generally less than 5 feet thick except at the base of the slopes where depths to 15 feet are reached. Gravelly deposits to 5 feet thick cover parts of the stream channel. Terrace deposits are the most abundant, and cover large areas both upstream and downstream of the dam axis. The terraces consist of 5 to 20 feet of sandy clay overlying a silty-to-clayey sand and gravel from 3 to 15 feet thick.

There are five faults crossing the foundation area. These are all roughly parallel, striking N50E across the regional bedding. The faults show apparent right-lateral movement and dip steeply. The faults appear to widen and branch irregularly in the mudstone beds. Diamond core drill holes encountered closely fractured and slickensided rock with numerous mud seams. Caving and sloughing were severe.

Complex fault movement makes the total amount of displacement difficult to determine, but it could be as high as 4,000 feet along the fault parallel to Heifer Creek. ESA (1980) placed four trenches across these features. The faults appeared to be confined to the Jurassic and Cretaceous bedrock and were considered to be pre-Tehama formation in age (3.3 mya). None showed any evidence of Quaternary-to-Recent movement.

The faults range in width from a few feet to over 40 feet and typically consist of highly fractured rock with seams of mylonite. Some faults have been cemented with calcium carbonate.

Burrows Gap Dam Site and Chrome Dike

Only a minimal amount of mapping has been done at these damsites. Burrows Gap Dam site foundation rocks consist mostly of sandstone and conglomerate with mudstone occurring on the upstream and downstream sections. Several NE-trending faults with minimal movement cross the foundation area. Chrome Dike is founded mostly on mudstone and Quaternary deposits. The Stony Creek fault trends just west of the right abutment. No trenching or drilling has been done at either damsite.

Sites Project

The Sites Project would be either a 1.2 maf smaller project or a 1.9 maf larger project about 10 miles west of Maxwell in the Antelope Valley. The project would consist of Sites Dam that would dam Stone Corral Creek, Golden Gate Dam that would dam Funks Creek, and an additional 5 to 12 saddle damsites across low areas along the reservoir rim. USBR has investigated the construction materials (1981) and engineering geology for the Sites Project (1969). Brown and Rich (1961) produced the *Geologic Map of the Lodoga Quadrangle, Glenn and Colusa Counties, California*, which includes the geology of Sites and Golden Gate Dam sites, and the Hunters and Logan Dam sites of the Colusa Project.

General geologic structural trends of bedding, folding and some faulting are N-NW, with most of the cross faults trending NE-SW across the prevailing structural trend.

The Salt Lake fault is a major structural feature that trends within a mile of most of the damsites in the Sites and Colusa Projects and possibly through the Sites Dam site. Most of the fieldwork and aerial photography analyses in Phase II will be directed at this fault.

The fault is a thrust that developed on the eastern limb of the doubly plunging, west-vergent Sites anticline (DWR 1978). Salt water springs, gas seeps, and sag ponds on the fault trace suggest the possibility of recent fault activity. In several locations, however, the fault is concealed by unbroken Pliocene Tehama formation, suggesting that the latest movement occurred prior to this time. Quaternary terrace deposits near and over the fault do not appear to be deformed (WLA 1997).

Preliminary field work and aerial photo analyses for this study suggest that the fault is not a trace, but a zone of subparallel shears, faults, and folding that may be wider than the mapped trace. It is therefore possible that movement has occurred since the Pliocene period on one of the fault traces.

Exposures are generally poor across the Salt Lake fault. Some geologic detail can be seen along Stone Corral and Funks Creeks, but the section is incomplete. Exposures at Stone Corral Creek directly west of the town of Sites shows fractured rock with numerous shears, folding, discontinuities in bedding, and faulting.

At Funks Creek, most of the Cretaceous bedrock is below the thalweg of the creek and not exposed. Some bedrock is exposed along the fault trace mapped by Brown and Rich (1961). Black discoloration, probably caused by seepage of gas and hydrothermal fluids, occurs on a number of these outcrops. Farther to the east, toward the Golden Gate Dam site, numerous shears, dislocations, and highly fractured rock are exposed. Several zones of mylonite also occur. The most probable location of major fault activity occurs along a linear valley directly to the west but has no bedrock exposures. Poor or no exposures occur along the Salt Lake fault where it crosses Logan Creek or Hunter Creek.

Sites Dam Site

Sites Dam site is underlaid by Upper Cretaceous interbedded sandstone, mudstone, and conglomerate of the Cortina formation. Within the reservoir area to the west, Cretaceous Boxer formation beds are folded by the Sites anticline. Beds at the damsite strike NNW and dip 40 to 60 degrees east. The predominant unit in the foundation is massive sandstone and associated thin-bedded sandstone, siltstone, and claystone of the Venado sandstone member.

Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring both above and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation area but may reach depths of 15 feet at the base of the slope. One small landslide occured on the left abutment and a larger slide occured on the right abutment. The larger landslide deposit is probably about 30 feet thick at the base but thinner at the top. It is in the range of 200 feet high and about 75 feet wide at the base. The landslide also covers the trace of fault S2 on the right abutment. Figure 13 shows the geologic map that was developed by

USBR (1969) and modified by DWR (1998) to show an additional fault and several landslides.

Faults at Sites include faults S1 and S2. S2, mapped by Brown and Rich (1961), extends from near the vicinity of the town of Sites, trends northeast through the right abutment, crosses the channel near the dam axis, and then extends downstream on the left abutment. The fault is several miles, possibly up to 5 miles, long. The fault shows apparent right lateral displacement and possible vertical displacement with the north side up.

Fault S1 was not mapped by Brown and Rich (1961) or by USBR (1969). It was mapped by WLA (1997) as a thrust fault. It crosses the left abutment, then the channel near the dam axis, and trends to the southeast across the right abutment. There is a possibility that S1 is a southward extension of the Salt Lake fault, which is shown by Brown and Rich to terminate about 2 miles north of the damsite.

The Salt Lake fault follows the axis of the Sites anticline, a major, doubly plunging, nearly isoclinal anticline on the west side of Logan Ridge. The anticline and the Fruto syncline to the west extend a distance of at least 40 miles and possibly farther.

The Salt Lake fault is a high-angle reverse fault or a thrust fault that developed adjacent to the axis of the anticline (DWR 1978). Salt water springs, gas seeps, and sag ponds occur along the fault trace. In several locations, the fault is concealed by unbroken Pliocene Tehama formation, suggesting that the latest movement occurred prior to deposition of the Tehama formation (3.3 mya) in these areas (USBR 1969).

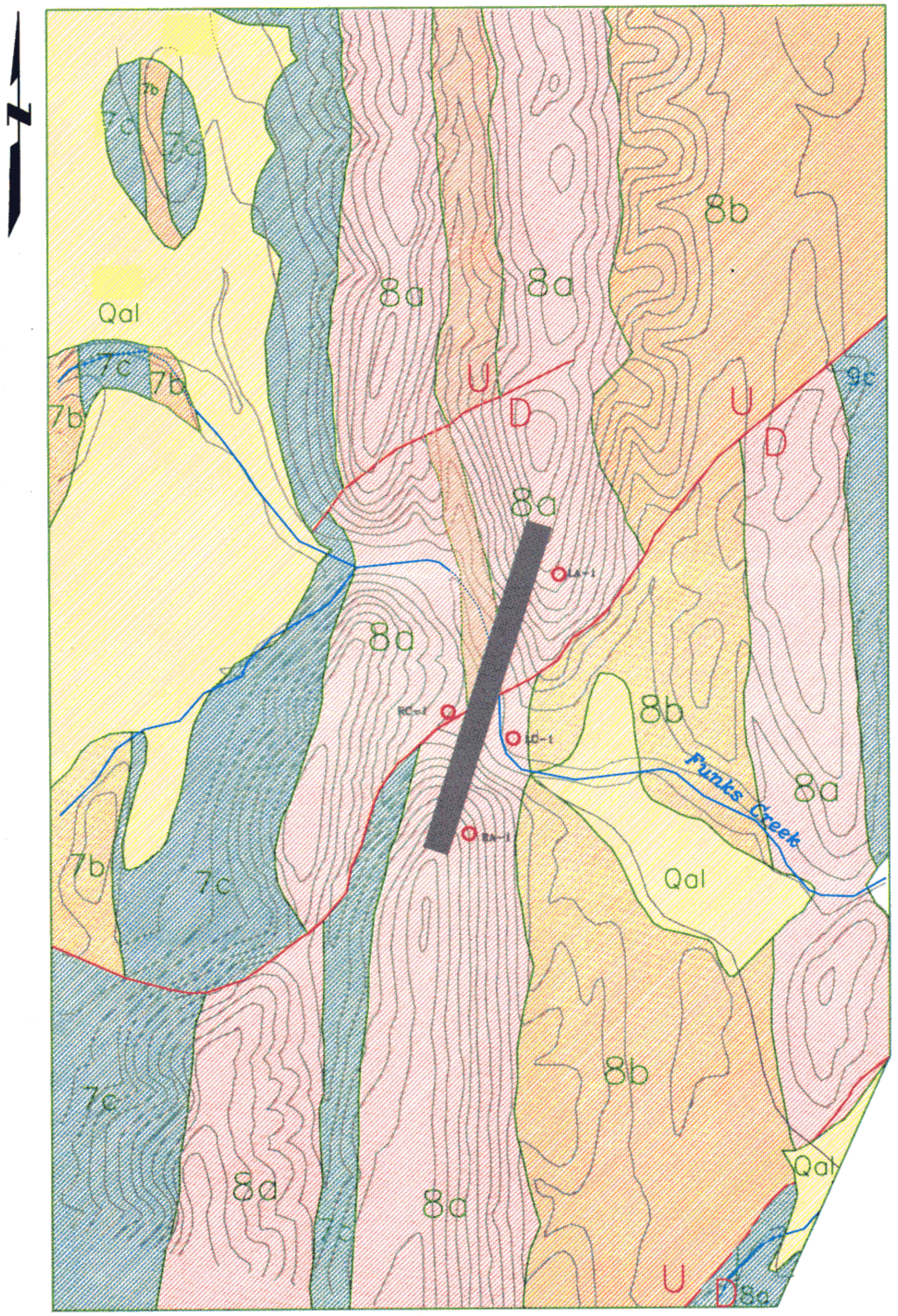
The presence of this possibly active fault in the foundation at Sites is a concern and will therefore be a major part of the Phase II field investigation. It is also believed that the surficial folding and faulting is a result of deep-seated thrust faulting along the Great Valley thrust fault system.

Golden Gate Dam Site

There are three damsites at Golden Gate: an upper site that was mapped and drilled by USBR in the 1960s, best for a small Sites Reservoir, and two lower sites that have not been investigated previously that are best for a large Sites Reservoir. The lower sites are the focus of this study. The damsites are on the same ridge as Sites Dam and only a few miles to the north, resulting in similar bedrock geology of predominant sandstone with interbedded mudstone and some conglomerate.

Quaternary to Recent deposits include colluvium, alluvium, landslide, and terrace deposits. Stream gravel deposits are minor and range in thickness to about 5 feet. Colluvium typically ranges from 5 feet to about 15 feet at the base of the slopes. Several landslides have occurred: one small recent one on the right abutment, and a larger older one on the left abutment. Terrace deposits are the most extensive, mostly Upper Modesto and Lower Riverbank formations. These average 15 to 20 feet thick, but may reach a thickness in excess of 25 feet. The composition is variable, but generally consists of an upper layer of silt and soil, and a lower layer of clayey gravel and cobbles.

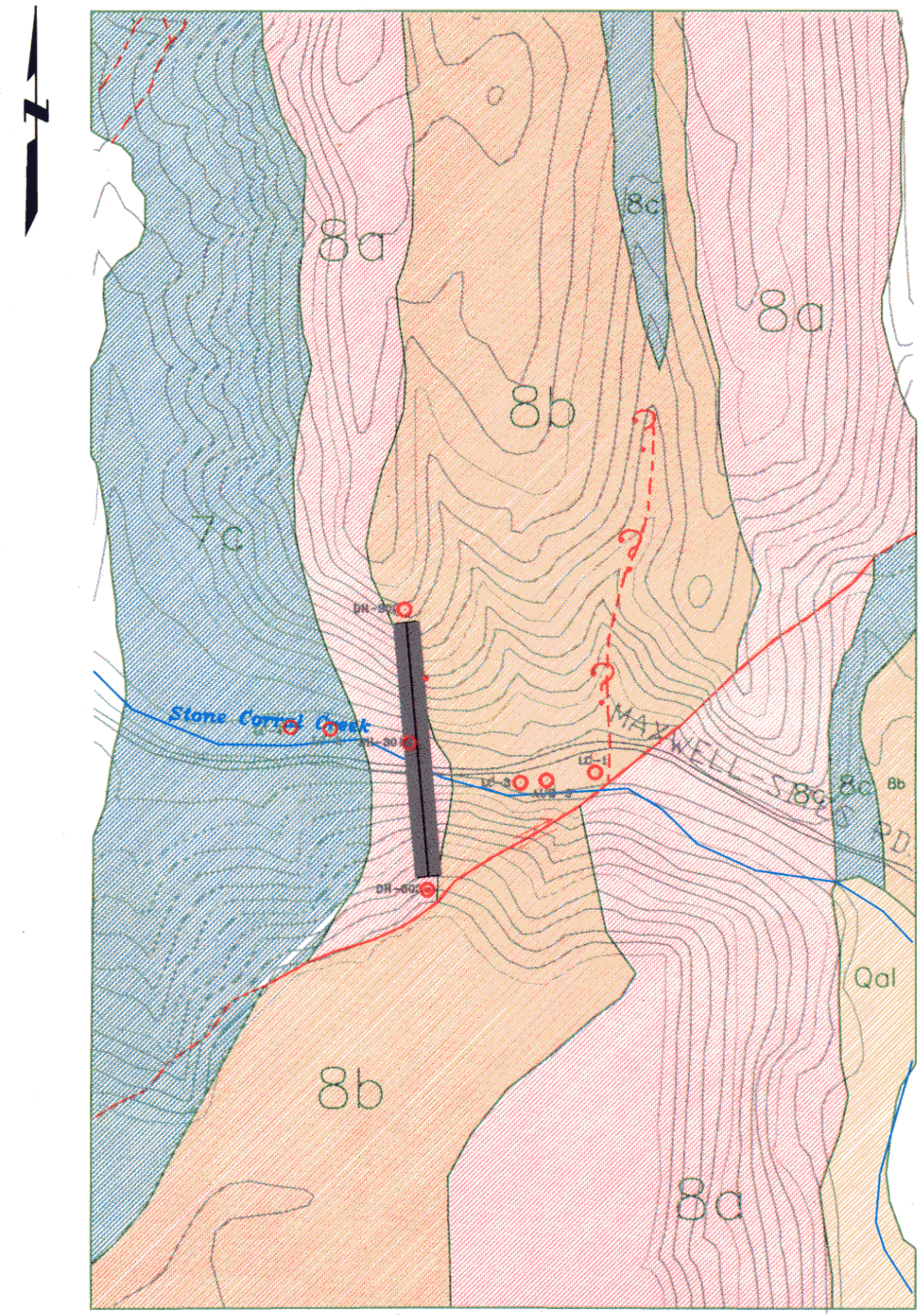
Several faults cross the foundation area. Faults GG1, GG2 and GG3 were mapped by Brown and Rich (1961). GG1 extends from the right abutment of



GOLDEN GATE DAMSITE

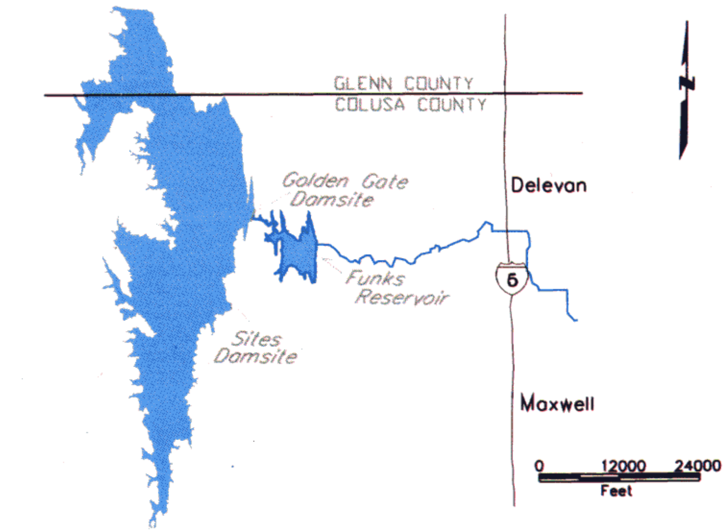
0 1000
Feet

Contour Interval 10m



SITES DAMSITE

0 500 1000
Feet
Contour Interval 10m



Proposed Project Location Features

Legend

Quaternary Units

Qal	Quaternary Alluvium	Qt	Terrace Deposits

Cortina Formation

9a	Sandstone	9b	Interbedded Sandstone and Siltstone
9c	Siltstone		

Venado Sandstone Member

8a	Sandstone	8c	Siltstone
8b	Interbedded Sandstone and Siltstone	8d	Conglomerate

Boxer Formation

7a	Sandstone	7d	Upper Conglomerate
7b	Interbedded Sandstone and Siltstone	7e	Lower Conglomerate
7c	Siltstone		

Geologic Contact, Dashed Where Approximate.
Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, U and D Showing Apparent Direction of Movement.

DWR Drill Hole Location

USBR Drill Hole Location

Dam Axis

USBR Sites Reservoir Report 1980

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Sites Project Damsite Geology

NOTE: Map has been generalized and simplified to show only regional geologic units and faults the two lower sites, crosses the channel slightly upstream of the dam axes, crosses the left abutment, and then extends an additional 2 miles in a NW direction before it ends or is lost in the mudstones to the east. Apparent right lateral displacement is estimated to be in the range of 0.3 mile.

Fault GG2 is much smaller and extends across the left abutment of the upper damsite, then trends NE and misses the left abutment of the lower damsite foundation by about one-fourth mile. Apparent right lateral displacement is estimated to be about 50 feet.

Fault GG3 is south of the damsite, but trends across the diversion alignment between Golden Gate and Funks Reservoirs. Displacement is estimated at about 1,500 feet.

Colusa Project

The Colusa Project would include the larger Sites Project, but would also expand northward into the Colusa compartment. Here Logan Dam would cross Logan Creek and Hunters Dam would cross Hunters Creek. In addition, a number of saddle dams would be required (Figure 14). No detailed geologic exploration has been conducted.

Hunters Dam Site

Brown and Rich mapped one fault crossing the left abutment. The north side is up, and apparent right lateral displacement is estimated to be less than 100 feet.

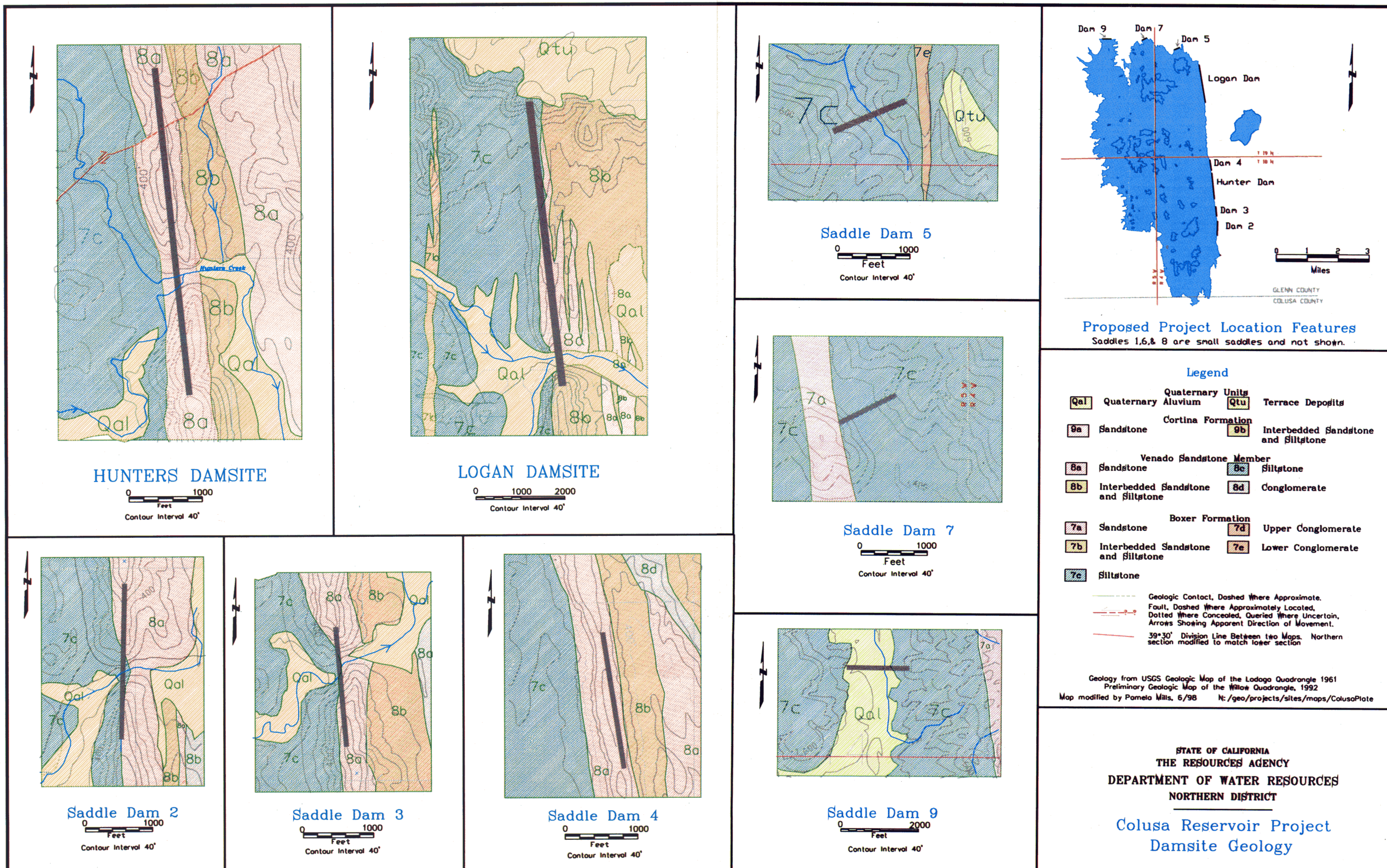
Hunters Dam site is on Logan Ridge, the same ridge as the Sites, Golden Gate, and Logan Dam sites. It is underlaid by Upper Cretaceous interbedded sandstone, mudstone, and conglomerate of the Boxer formation. Within the reservoir area to the west, the Cretaceous beds are folded by the Sites anticline. Beds strike NNW and dip 40 to 60 degrees east. The predominant unit in the foundation is massive sandstone and associated thin-bedded siltstone and claystone of the Venado sandstone member.

Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring above, on, and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation but may reach depths of 15 feet at the base of the slope.

Logan Dam Site

Logan Dam site is underlaid by the same bedrock units as all the other damsites. Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring both above and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation but may reach depths of 15 feet at the base of the slope. No faults were mapped by Brown and Rich at this site. Salt Lake fault is about 1 mile to the west.

Figure 14



HUNTERS DAMSITE
Hunters Creek
Contour Interval 40'
LOGAN DAMSITE
Contour Interval 40'
Saddle Dam 5
Feet
Contour Interval 40'
Saddle Dam 7
Feet
Contour Interval 40'
Saddle Dam 9
Feet
Contour Interval 40'
Saddle Dam 2
Feet
Contour Interval 40'
Saddle Dam 3
Feet
Contour Interval 40'
Saddle Dam 4
Feet
Contour Interval 40'
Dam 9
Dam 7
Dam 5
Logan Dam
Dam 4
Hunter Dam
Dam 3
Dam 2
Miles
GLENN COUNTY
COLUSA COUNTY
Proposed Project Location Features
Saddles 1,6,& 8 are small saddles and not shown.
Legend
Quaternary Units
Qal Quaternary Aluvium
Qtu Terrace Deposits
Cortina Formation
9a Sandstone
9b Interbedded Sandstone and Siltstone
Venado Sandstone Member
8a Sandstone
8c Siltstone
8b Interbedded Sandstone and Siltstone
8d Conglomerate
Boxer Formation
7a Sandstone
7d Upper Conglomerate
7b Interbedded Sandstone and Siltstone
7e Lower Conglomerate
7c Siltstone
Geologic Contact, Dashed Where Approximate.
Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, Arrows Showing Apparent Direction of Movement.
39°30' Division Line Between two Maps. Northern section modified to match lower section
Geology from USGS Geologic Map of the Lodoga Quadrangle 1961
Preliminary Geologic Map of the Willow Quadrangle, 1992
Map modified by Pamela Mills, 6/98
N:/geo/projects/sites/maps/ColusaPlate
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
Colusa Reservoir Project
Damsite Geology

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Attachment A

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects
Recorded by the Northern California Seismic Network
by
David Oppenheimer

United States Department of the Interior

GEOLOGICAL SURVEY
EARTHQUAKE HAZARDS TEAM
Seismology Section
345 Middlefield Road - Mail Stop 977
Menlo Park, California 94025

May 12, 1998

650-329-4792 (voice)
650-329-5163 (fax)
oppen@alum.wr.usgs.gov

Mr. Koll Y. Buer
Department of Water Resources
2440 Main Street
Red Bluff, CA 96080-2398

Dear Mr. Buer:

Enclosed find USGS Open-File Report 98-214 entitled "Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network". I hope this report addresses your needs. If you have any additional questions about the seismicity of this region, please feel free to contact me.

You also requested information regarding the installation of additional seismic stations near the Red Bank project. We would appreciate knowing whether the DWR is still interested in pursuing this effort, as we would like to be able to plan for the installation.

Sincerely,

David H. Oppenheimer
Seismologist

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network

by
David Oppenheimer[1]

Open-File Report 98-214

1998

1. Menlo Park, CA 94025

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network

Introduction

This report briefly discusses the seismicity recorded by the USGS Northern California Seismic Network (NCSN) in the general vicinity of the California Department of Water Resources Red Bank, Thomes-Newville, and Colusa projects. Because of the relatively short monitoring interval (20-25 years) compared to the seismic cycle (100-1000's of years) of many faults in this region, it is very unlikely that most seismogenic structures in the region have been illuminated by the recorded earthquake activity during the interval 1975-1998. The low rate of seismicity in the eastern Coast Ranges, relatively high earthquake detection thresholds (discussed below), and the limited accuracy of the locations makes it difficult to define discrete faults based on alignments of hypocenters. Rather, it appears that most earthquake activity occurs on isolated and independent faults. Assessments of the seismic hazard should not be limited to interpretations of the seismic data and should also consider the strain rates and geologically active faults mapped in the region (Working Group on Northern California Earthquake Potential, 1996).

Because so little seismicity occurs within 25 km radius of the Red Bank or Thomes-Newville projects, the discussion of seismicity is, by necessity, general in nature. The regional seismicity may be considered representative of the type of seismicity that may be expected in the future, subject to the above caveat. Likewise, the minimum magnitude for uniform earthquake detection is based on the analysis of less than 100 earthquakes per region. Comparable analyses of larger regions surrounding the three sites, using hundreds of events, lead to similar minimum detection thresholds within a few tenths of a magnitude unit. All dates discussed in this report are UT.

NCSN operating procedures, station locations, and velocity models are described in Oppenheimer *et. al.* (1993). All hypocenters, focal mechanisms, phase information, waveforms, and station coordinates are available via the World Wide Web from *http://quake.geo.berkeley.edu/ncedc*. Maps of real-time earthquake information are available on *http://quake.wr.usgs.gov/recenteqs*.

Red Bank

Station Distribution and Detection Threshold

In the vicinity of the DWR Red Banks project there were few stations operating until June, 1975. Installation of seismic stations occurred gradually, and the network reached its current configuration by February, 1991, when 4 stations were installed for the California Department of Water Resources (solid squares, Figure 1). Since then, only one additional station west of Cottonwood has been installed in the region. Figure 2a indicates that for the interval 1978 - 1997 earthquakes above *M*2.2 within 25 km of Red Bank could be uniformly detected.

Seismicity

The histogram of earthquakes as a function of time within 25 km of Red Bank (Figure 3a) shows that the number of earthquakes located per month is typically 3 or less and often zero. The map and cross sectional views of seismicity (Figure 1, 4a) image three general features. There are few lineations expressed in this seismicity. In the eastern Coast Ranges scattered earthquake activity occurs within the crust to depths of 15 km. Northeast of Red Bluff at the eastern edge of the Great Valley, earthquake activity occurs at greater depths, approaching 30 km, reflecting the increased thickness of the crust due to the isostatic compensation effect of the Sierra Nevada range.

The earthquakes at depths greater than 30 km west of Red Bank image the subducting Gorda slab. Because of the small numbers of earthquakes during the period of observation and uncertainties in their locations, it is not possible to ascertain whether the earthquakes occur in the slab or on the slab interface. A $M3.0$ earthquake north of Cottonwood (April 3, 1985) that locates at a depth of 70 km also suggests that the slab extends beneath Red Bluff (Cockerham, 1984, Walter, 1986). Though it is unlikely that a mega-thrust earthquake on the Gorda - North America interface would rupture to such depths due to the thermal regime of the plate (Hyndman and Wang, 1995), the seismicity indicates that intraplate Gorda earthquakes are possible.

Thomes-Newville

Station Distribution and Detection Threshold

In the Thomes-Newville region the station coverage is poor. A station at Alder Springs (GAS) was installed in 6/1980, and a station to the north at Round Mt. (GRO) was installed 12/1990. There are no stations to the east within 70 km. The nearest stations is generally greater than 15 km from an epicenter. This degrades the accuracy of the hypocentral data in this region. In particular, the depths are relatively poorly determined compared to other regions of the network. Figure 2b indicates that for the interval 1976 - 1997 earthquakes above $M2.1$ within 25 km of Newville could be uniformly detected. With the installation of additional stations to the north of Newville in 1990-1991, the regional detection threshold decreased slightly to $M1.9$.

Seismicity

The histogram of earthquakes as a function of time (Figure 3b) shows that typically only one earthquake per month occurs within 25 km of Newville, but frequently there is no detected earthquake activity. There is scattered seismicity with 25 km of Newville, but no obvious structures defined by the seismicity. Beginning May 16, 1995 a small sequence occurred 18 km west of Newville. The aftershock activity ceased 3 days later. The largest event, which occurred on May 17, had a magnitude of M_D 4.2. The seismicity shown cross section B-B' (Figure 4b) indicates that the earthquakes occur within the crust, as described above in section A-A'.

Colusa/Williams

Station Distribution and Detection Threshold

In the Williams area station coverage is also poor. While station coverage has been uniform since late 1975, the nearest station (on Sutter Butte) is generally greater than 20 km from an epicenter. This degrades the accuracy of the hypocentral data in this region. Figure 2c indicates that for the interval 1976 - 1997 earthquakes above $M2.3$ within 25 km of Colusa could be uniformly detected.

Seismicity

The histogram of earthquakes as a function of time (Figure 3c) shows that earthquake occurrence within 25 km of Newville is rare. However, two separate, north-northwest trending faults are imaged by the alignments of hypocenters near Williams. Two first-motion focal mechanisms for events on Apr 18, 1985 (M_L3.7) and on Nov 26, 1980 (M_D3.2) indicate predominant right-lateral strike-slip motion on a fault plane parallel to the orientation of seismicity (Fig. 5). In cross section C-C' (Fig. 4c) the faults are near-vertical, consistent with the focal mechanisms, and they extend to depths of about 20 km. The April 18, 1985 sequence occurred 11 km southwest of Williams. Minor aftershock activity continued until late September, 1985 (Fig. 3c). The largest event of the sequence, the M_L 3.7 event, occurred on the first day.

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Acknowledgment

I thank Rick Lester for his careful review of this report and the staff of the NCSN who maintain, operate, and process the earthquake data recorded by the NCSN.

Figure Captions

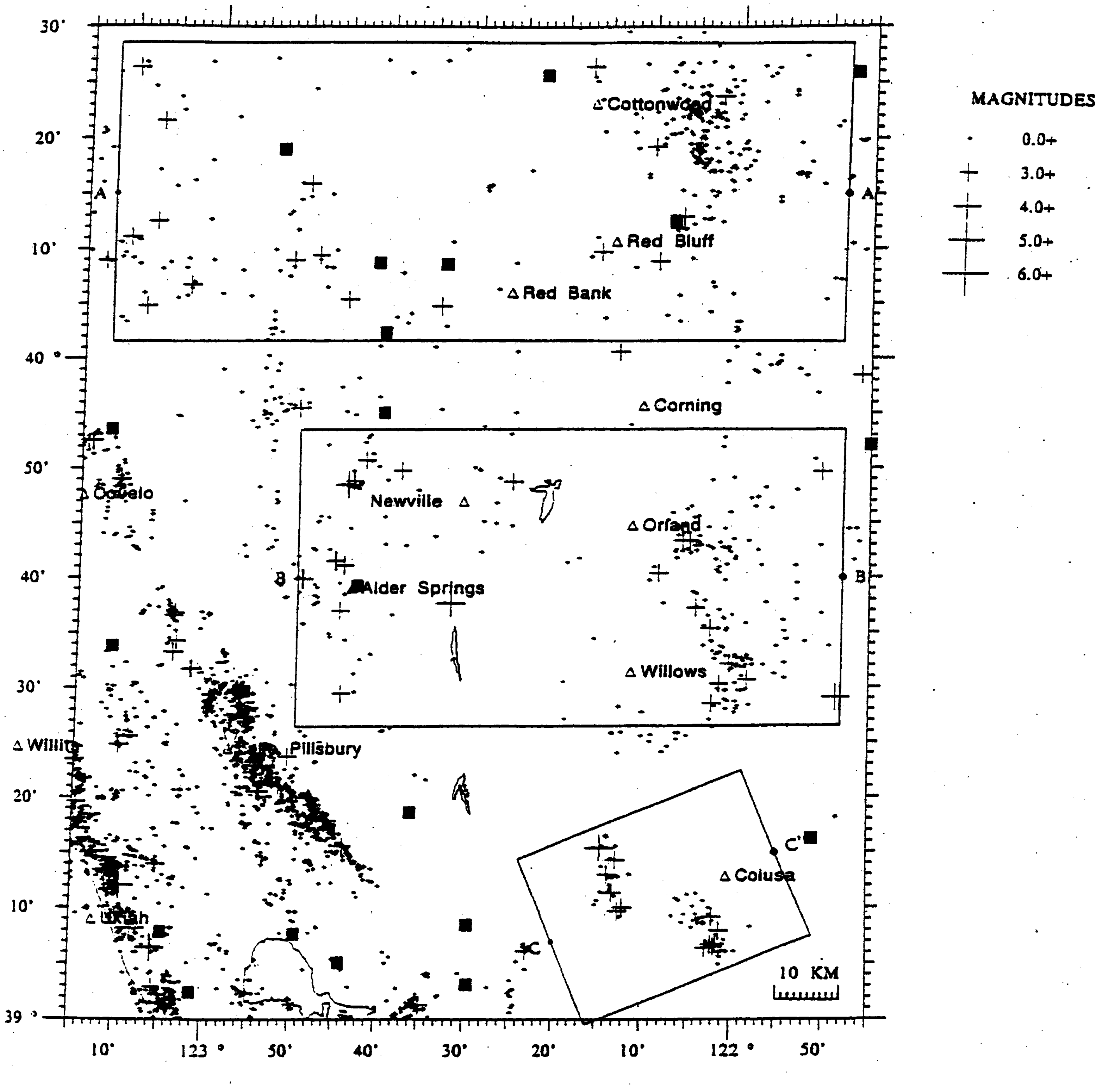
Figure 1. a) Map of well-located seismicity recorded by the Northern California Seismic Network for the period July 24, 1973 through February 7, 1998. Data have been selected with the following typical quality parameters: RMS ≤ 0.3 sec, horizontal uncertainty ≤ 2.5 km, vertical uncertainty ≤ 5.0 km, maximum azimuth gap in station distribution ≤ 180°, # of stations ≥ 8. No magnitude selection were used. Due to sparse station spacing, the above selection criteria eliminated nearly half of possible 6063 earthquakes from the plot. Solid squares depict locations of seismic stations. Open triangles denote locations of labeled cities and towns. Rectangular, labeled boxes depict selection region for cross-sections. Irregular shaped bodies depict lakes and reservoirs. Faults near Ukiah and Lake Pillsbury are Holocene or younger (Jennings, 1992). Symbol size is proportional to magnitude.

Figure 2. Histograms of the *log(N)*, where *N* = number of earthquakes, as a function of magnitude for three areas shown in Fig. 1. The (solid) open squares are the (cumulative) number of earthquakes within 0.1 bins of magnitude. The magnitude detection threshold above which the seismic network is able to uniformly locate all earthquakes is indicated at the top of the plot as "MIN.MAG" and is manually chosen by examination as the point where the slope of the cumulative number of earthquakes departs from a straight line at smaller magnitudes. The line through the cumulative number of earthquakes is a least-squares estimate of the slope ("B" value) of the data greater than the detection threshold; "A" is the M=0 intercept value (*log(N)*). a) Red Bank region (Fig. 1, A-A'), b) Newville region (Fig. 1, B - B'), c) Colusa region (Fig. 1, C - C').

Figure 3. Histograms of earthquakes/month within 25 km of a) Red Bank (40° 06.00', 122° 26.00'), b) Newville (39° 47.00', 122° 31.00'), c) Colusa (39° 12.90', 122° 00.50'). No other selection criteria were used.

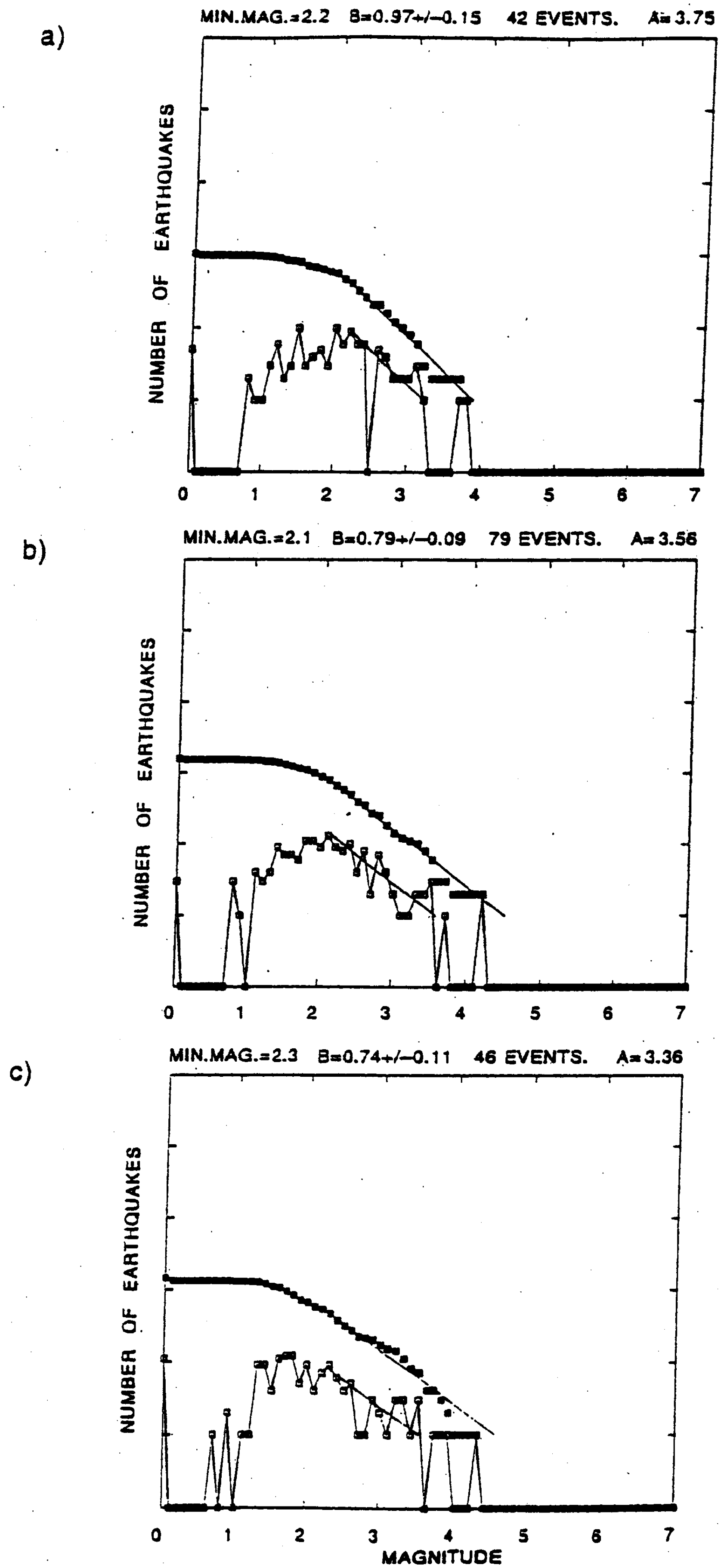
Figure 4. Cross sections of seismicity corresponding to earthquakes shown in Fig. 1. a) Red Bank region, b) Newville region, c) Colusa region.

Figure 5. Lower hemisphere, equal-area projection of fault plane solutions for earthquakes near Williams on a) 02:33 UTC, Nov 26, 1980 (M_D3.2) and b) 16:29 UTC Apr 18, 1985 (M_L3.7). Compressional and dilatational first-motion directions are indicated by circles and +'s, respectively. P and T symbols denote P-axis and T-axis, respectively. Three numbers adjacent to nodal planes correspond to strike, dip, and rake.



30'
20'
10'
40°
50'
40'
30'
20'
10'
39°
10'
123°
50'
40'
30'
20'
10'
122°
50'
A
A'
B
B'
C
C'
Cottonwood
Red Bluff
Red Bank
Corning
Newville
Orland
Alder Springs
Willows
Covelo
Willits
Pillsbury
Colusa
Ukiah
10 KM
MAGNITUDES
0.0+
3.0+
4.0+
5.0+
6.0+

Figure 1



a)
MIN.MAG.=2.2 B=0.97+/-0.15 42 EVENTS. A= 3.75
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
b)
MIN.MAG.=2.1 B=0.79+/-0.09 79 EVENTS. A= 3.56
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
c)
MIN.MAG.=2.3 B=0.74+/-0.11 46 EVENTS. A= 3.36
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
MAGNITUDE

Figure 2

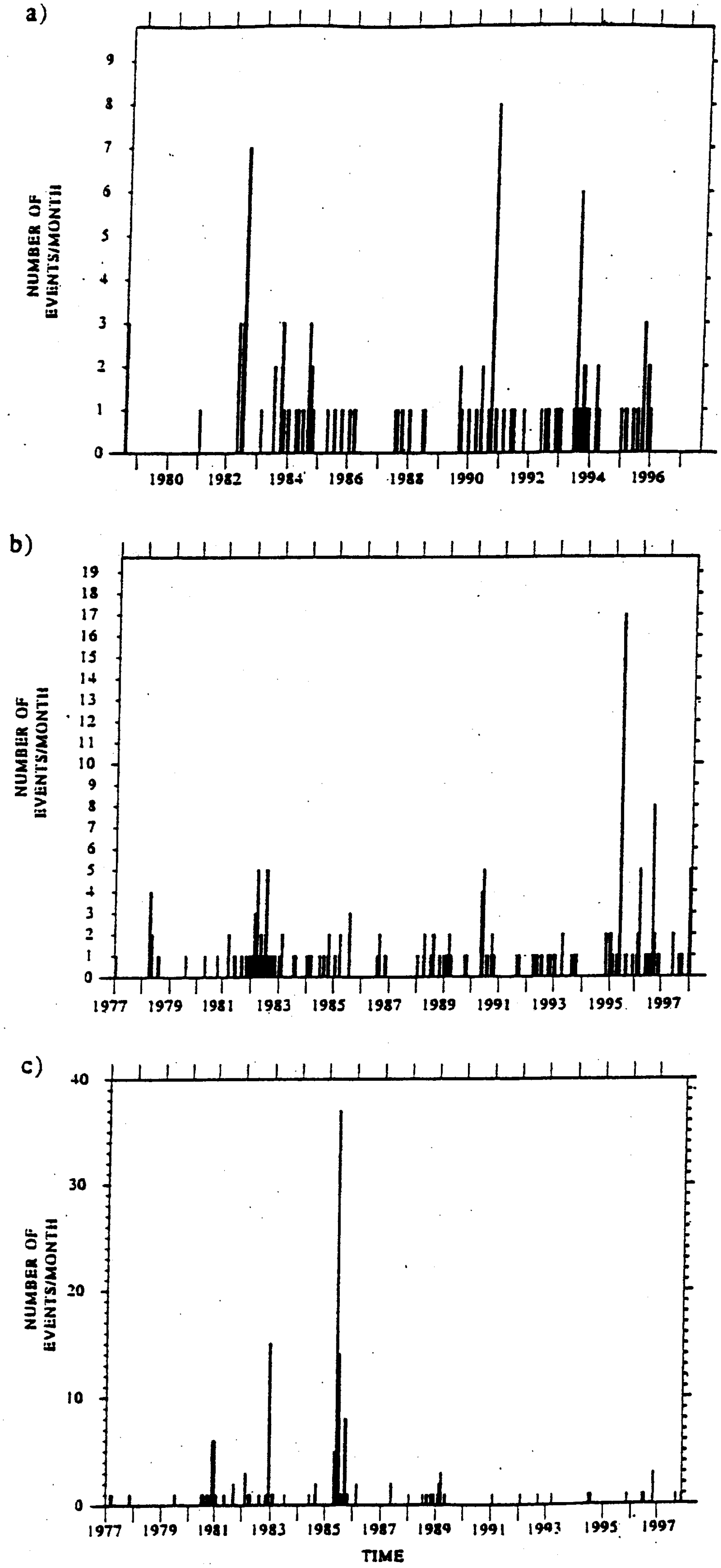

a)
NUMBER OF EVENTS/MONTH
0
1
2
3
4
5
6
7
8
9
1980
1982
1984
1986
1988
1990
1992
1994
1996
b)
NUMBER OF EVENTS/MONTH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
c)
NUMBER OF EVENTS/MONTH
0
10
20
30
40
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
TIME

Figure 3

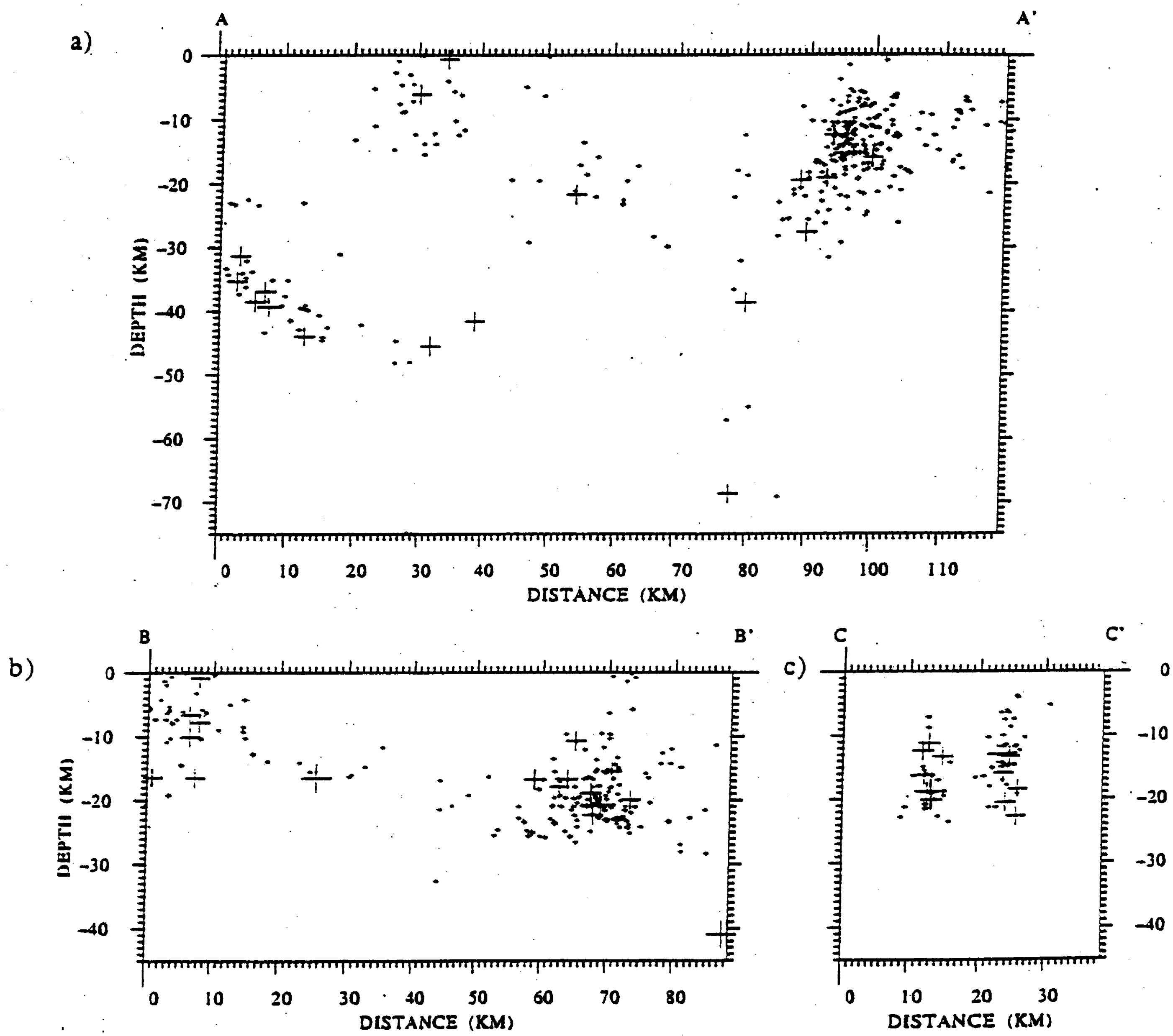
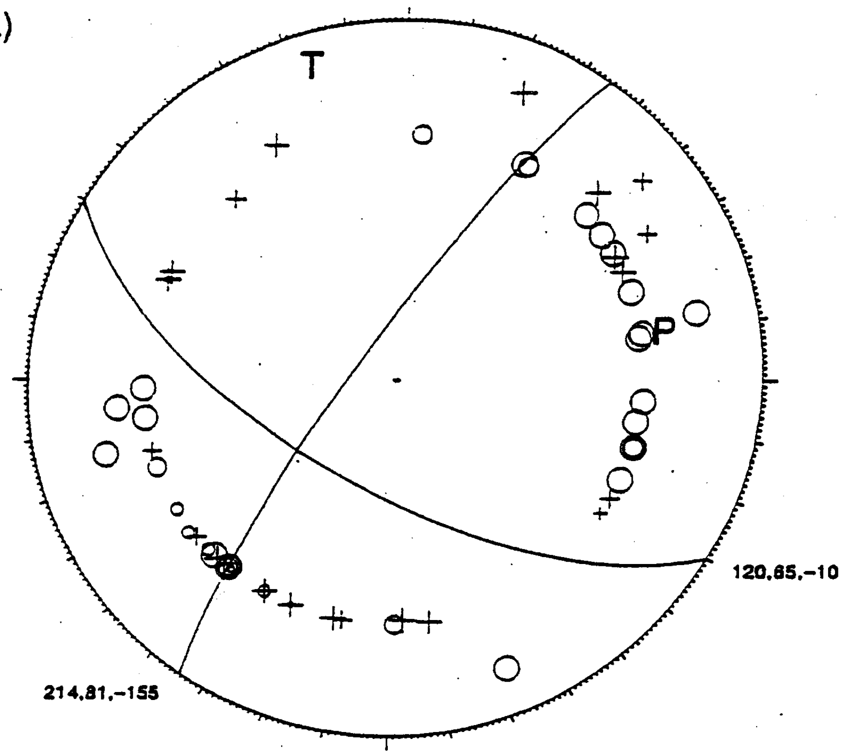

a)
A
A'
0
-10
-20
-30
-40
-50
-60
-70
DEPTH (KM)
0 10 20 30 40 50 60 70 80 90 100 110
DISTANCE (KM)
b)
B
B'
0
-10
-20
-30
-40
DEPTH (KM)
0 10 20 30 40 50 60 70 80
DISTANCE (KM)
c)
C
C'
0
-10
-20
-30
-40
0 10 20 30
DISTANCE (KM)

Figure 4

a)



b)

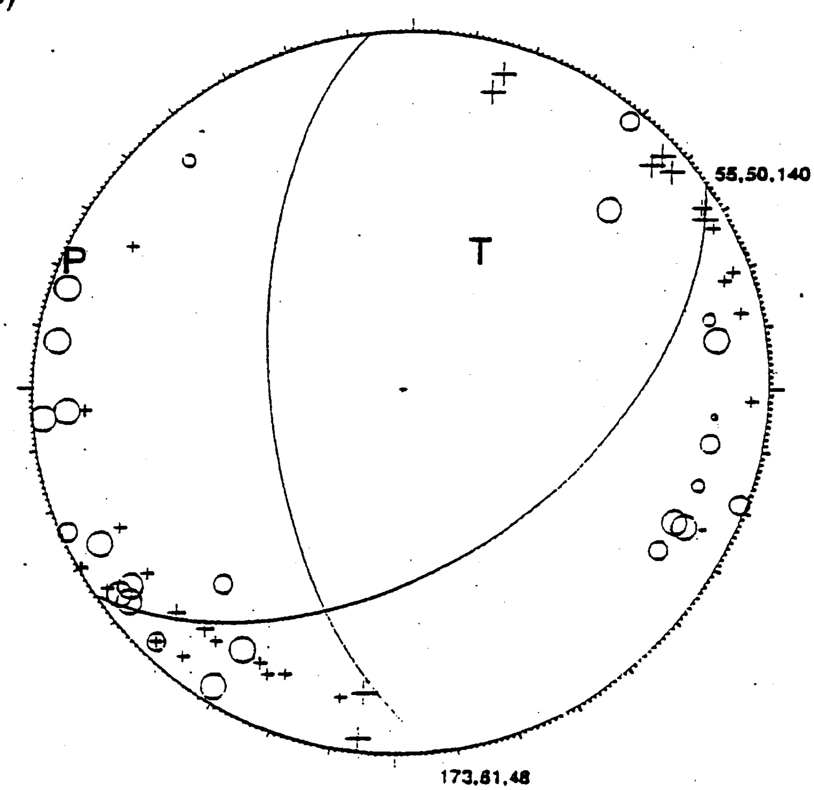


Figure 5

State of California, Gray Davis, Governor
The Resources Agency, Mary D. Nichols, Secretary for Resources
Department of Water Resources, Thomas M. Hannigan, Director

Steve Macaulay, Chief Deputy Director
Raymond D. Hart, Deputy Director
L. Lucinda Chipponeri, Assistant Director for Legislation
Susan N. Weber, Chief Counsel

William J. Bennett, Chief, Division of Planning and Local Assistance

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Ralph Hinton, Department of Water Resources
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Julia Culp, Department of Water Resources
Jennifer Davis, Department of Water Resources
Mark Dombrowski, Department of Water Resources
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Sandy Merritt, Department of Water Resources
Shawn Pike, Department of Water Resources
Carole Rains, Department of Water Resources
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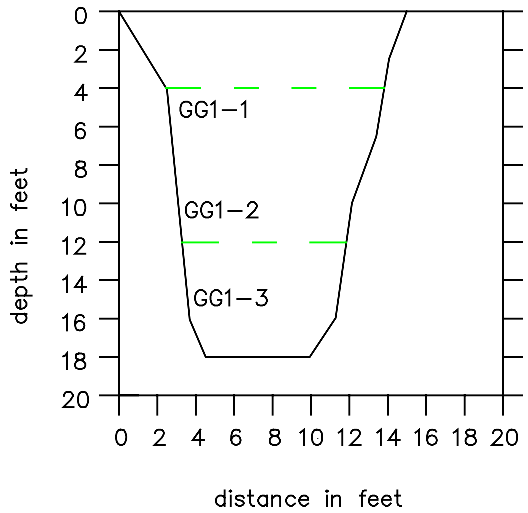
Susan Tatayon, Department of Water Resources
Caroline Warren, Department of Water Resources

**formerly with Department of Water Resources*

State of California
The Resources Agency
Department of Water Resources
Division of Planning and Local Assistance

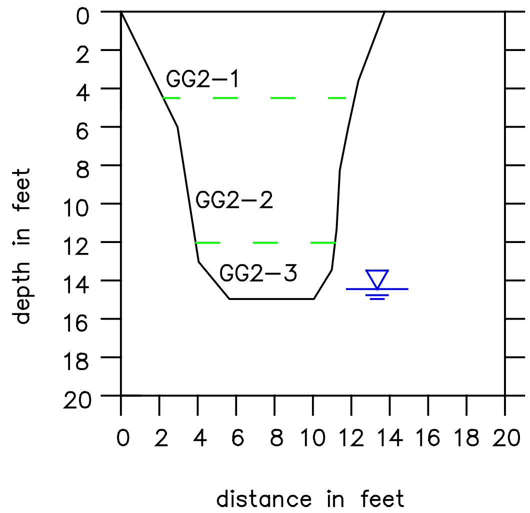
Attachment A. Test Pit Logs

GG1



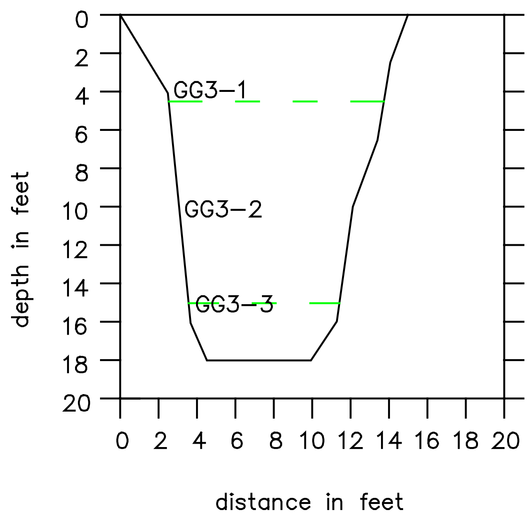
GG1–1	ML	SILT, clayey, slightly moist, Munsell color 10YR3/3, dark brown.
GG1–2	CL	CLAY, silty, moist, slightly plastic, some mottling, Munsell color 10YR4/4, dark yellowish brown.
GG1–3	CL	CLAY, minor silt, Munsell color 10YR4/4, dark yellowish brown.

GG2



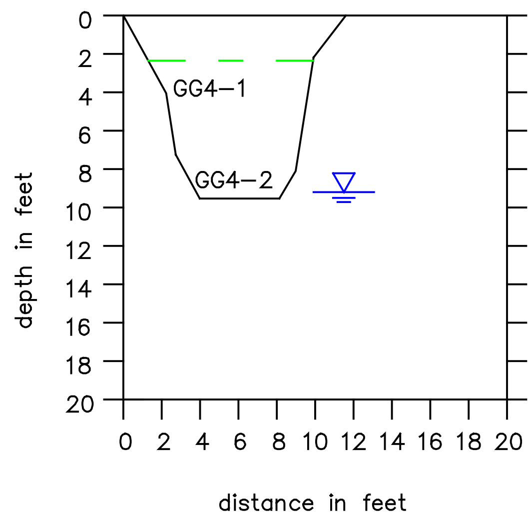
GG2–1	ML	SILT, clayey, slightly moist, Munsell color 10YR4/2, dark grayish brown.
GG2–2	CL	CLAY, silty, moist, slightly plastic, Munsell color 10YR4/4, dark yellowish brown.
GG2–3	CL	CLAY, silty, moist, slightly plastic, Munsell color 10YR4/4, dark yellowish brown.

GG3



GG3–1	ML	SILT, clayey, slightly moist, crumbly, Munsell color 10YR3/3, dark brown.
GG3–2	ML	SILT, clayey, Munsell color 10YR4/4, dark yellowish brown.
GG3–3	CL	CLAY, silty, moist, slightly plastic, Munsell color 10YR4/4, dark yellowish brown.

GG4



GG4–1	CL	CLAY, silty, moist, Munsell color 10YR4/2, dark grayish brown.
GG4–2	CL	CLAY, silty, very moist to wet Munsell color 10YR3/4, dark yellowish brown.

LEGEND

CL	Soil symbols used are from the "Unified Soil Classification System"
GG1–1	Soil and/or bedrock sample number. Sample number is located at depth taken in cross section.
— —	Contact between different materials within same geologic unit.
▽	Water table.

NOTES: Trench locations shown on Figure 6

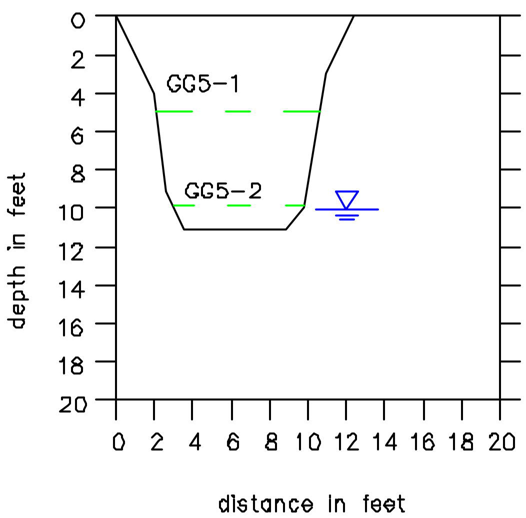
All trenches were dug using a Mitsubishi hydraulic excavator.

STATE OF CALIFORNIA
THE RESOURCE AGENCY
DEPARTMENT OF WATER RESOUCES
NORTHERN DISTRICT

THE SITES AND COLUSA PROJECTS
CONSTRUCTION MATERIALS

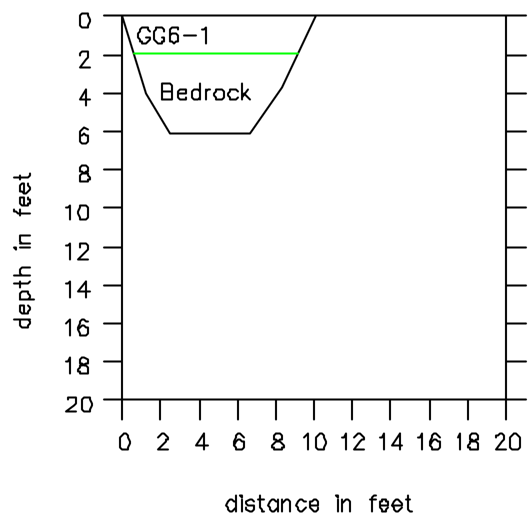
TEST PIT LOGS

GG5



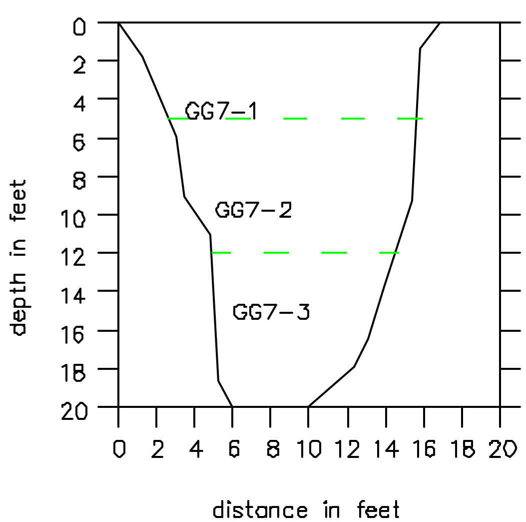
GG5-1	CL	CLAY, silty, slightly moist, stiff, Munsell color 10YR3/3, very dark brown.
GG5-2	CL	CLAY, silty, moist, slightly plastic, some mottling, Munsell color 10YR4/4, dark yellowish brown.

GG6



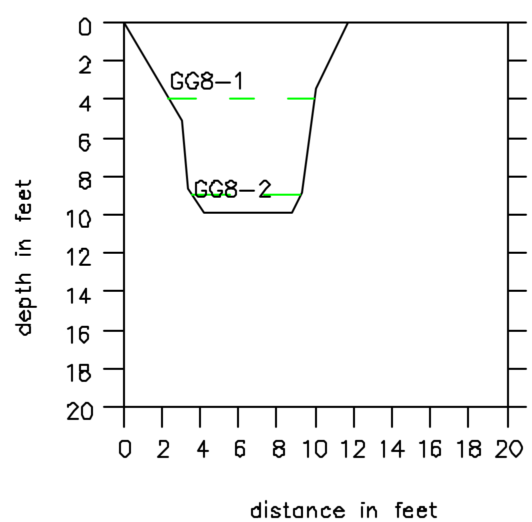
GG6-1	CL	CLAY, silty, slightly moist, tough, Munsell color 10YR3/2, very dark grayish brown.

GG7



GG7-1	ML	SILT, clayey, slightly moist, crumbly, Munsell color 10YR3/2, very dark grayish brown.
GG7-2	ML	SILT, clayey, Munsell color 10YR4/4, dark yellowish brown.
GG7-3	CL	CLAY, silty, moist, slightly plastic, Munsell color 10YR4/4, dark yellowish brown.

GG8



GG8-1	CL	CLAY, silty, gravel clasts — fine to medium, Munsell color 10YR4/2, dark grayish brown.
GG8-2		Weathered bedrock — mudstone, crumbly.

LEGEND

CL	Soil symbols used are from the "unified Soil Classification system"
GG5-1	Soil and/or bedrock sample number. Sample number is located at depth taken in cross section.
— —	Contact between different materials within same geologic unit.
——	Contact between different geologic units.
	Water table.

NOTES: Trench locations shown on Figure 6

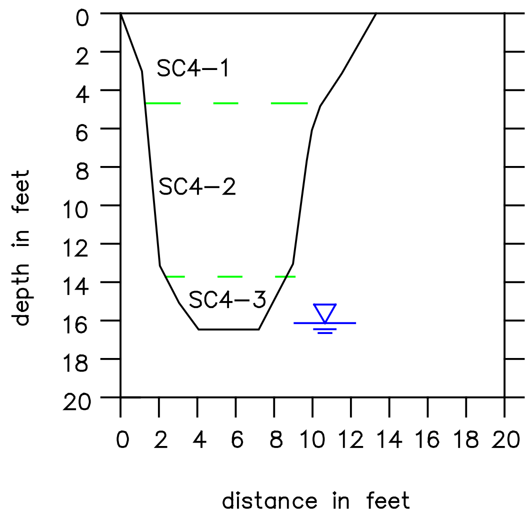
All trenches were dug using a Mitsubishi hydraulic excavator.

STATE OF CALIFORNIA
THE RESOURCE AGENCY
DEPARTMENT OF WATER RESOUCES
NORTHERN DISTRICT

THE SITES AND COLUSA PROJECTS
CONSTRUCTION MATERIALS

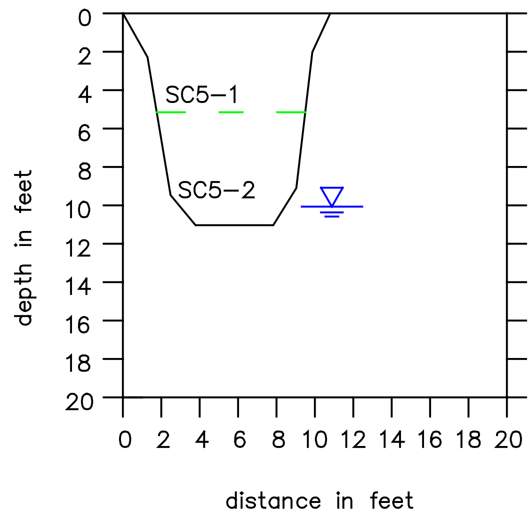
TEST PIT LOGS

SC4



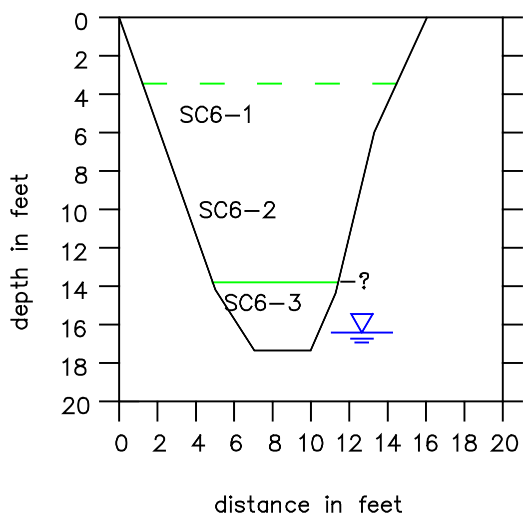
SC4–1	ML	SILT, clayey, slightly moist, Munsell color 10YR3/3, very dark brown.
SC4–2	CL	CLAY, silty, Munsell color 10YR3/6, dark yellowish brown.
SC4–3	CL	CLAY, minor silt, slightly plastic, moist, Munsell color 10YR3/2, very dark grayish brown.

SC5



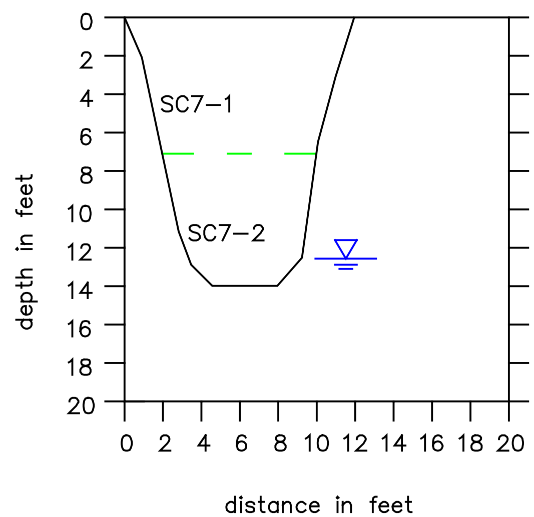
SC5–1	CL	CLAY, minor silt, Munsell color 10YR3/1, very dark gray.
SC5–2	CL	CLAY, very minor silt, medium plastic, wet below ten feet, Munsell color 10YR3/3, dark brown.

SC6



SC6–1	CL	CLAY, minor silt and gravel, Munsell color 10YR3/2, very dark grayish brown.
SC6–2	CL	CLAY, minor gravel, Munsell color 10YR4/4, dark yellowish brown.
SC6–3	CL	CLAY, clayey gravel with minor sand, gravels are subrounded black chert and red sandstone, Munsell color 7.5YR5/4, brown.

SC7



SC7–1	CL	CLAY, silty, few sand grains, Munsell color 10YR4/2, dark grayish brown.
SC7–2	CL	CLAY, minor silt, scattered fine gravel clasts, gastropod shell, Munsell color 10YR6/6, bownish yellow.

LEGEND

CL	Soil symbols used are from the "Unified Soil Classification System"
SC4–1	Soil and/or bedrock sample number. Sample number is located at depth taken in cross section.
— —	Contact between different materials within same geologic unit.
——	Contact between different geologic units.
▽	Water table.

NOTES: Trench locations shown on Figure 5

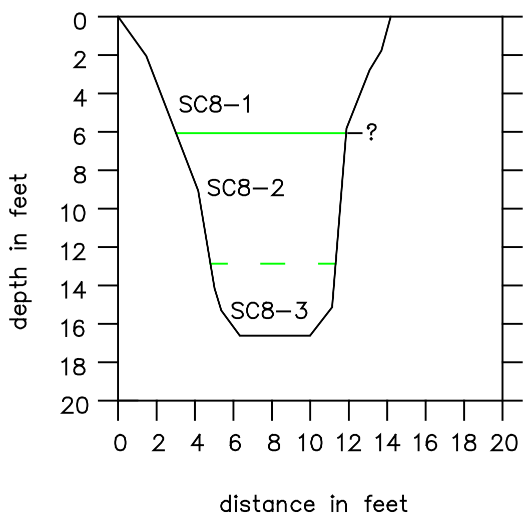
All trenches were dug using a Mitsubishi hydraulic excavator.

STATE OF CALIFORNIA
THE RESOURCE AGENCY
DEPARTMENT OF WATER RESOUCES
NORTHERN DISTRICT

THE SITES AND COLUSA PROJECTS
CONSTRUCTION MATERIALS

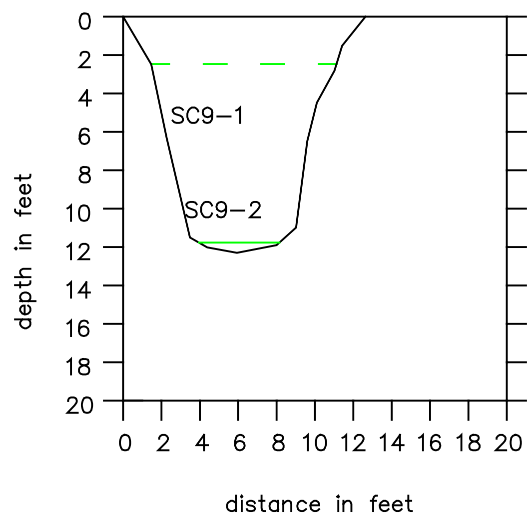
TEST PIT LOGS

SC8



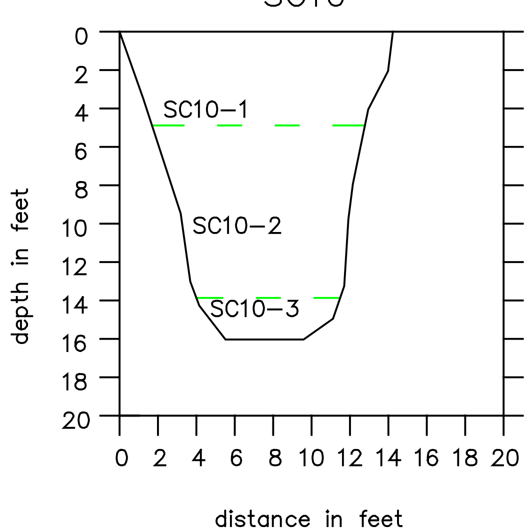
SC8–1	ML	SILT, clayey, minor gravel, gravel lens in side wall, Munsell color 10YR3/3, very dark brown.
SC8–2	SM	CLAY, silty, with sand and gravel —angular, Munsell color 7.5YR5/4, brown.
SC8–3	CL	CLAY, gravelly, rounded clasts up to cobble in size, Munsell color 10YR5/8 to 7.5YR5/8, yellowish brown to strong brown.

SC9



SC9–1	CL	CLAY, minor silt, slightly moist. calcareous streaking, Munsell color 2.5YR4/3, reddish brown.
SC9–2	CL	CLAY, moist, plastic some black mottling, Munsell color 2.5YR4/2, weak red.
		Possible bedrock at 12 feet?

SC10



SC10–1	CL	SILT, clayey, Munsell color 10YR3/4, dark yellowish brown.
SC10–2	CL	CLAY, silty, Munsell color 10YR4/6, dark yellowish brown.
SC10–3	GC	GRAVEL, clayey, Munsell color 10YR4/4, dark yellowish brown.

LEGEND

CL	Soil symbols used are from the "Unified Soil Classification System"
SC9–1	Soil and/or bedrock sample number. Sample number is located at depth taken in cross section.
— — (green dashed)	Contact between different materials within same geologic unit.
—— (green solid)	Contact between different geologic units.
▽	Water table.

NOTES: Trench locations shown on Figure 5

All trenches were dug using a Mitsubishi hydraulic excavator.

STATE OF CALIFORNIA
THE RESOURCE AGENCY
DEPARTMENT OF WATER RESOUCES
NORTHERN DISTRICT

THE SITES AND COLUSA PROJECTS
CONSTRUCTION MATERIALS

TEST PIT LOGS

Attachment B. Laboratory Results

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CLASSIFICATION TEST SUMMARY

DIVISION OF ENGINEERING
CIVIL ENGINEERING
CANALS AND LEVEES SECTION

PROJECT: Sites and Golden Gate Dams

FEATURE: Proposed Geologic Exploration for Borrow Material

LAB. NO	HOLE NO.	F.S. NO	PERCENT FINER – MECHANICAL ANALYSIS – GRAVEL 6"	3"	1 1/2"	3/4"	3/8"	4	SAND 8	16	30	50	100	200	HYDROMETER – SILT & CLAY 5M	2M	1M	ATTERBERG LIMITS L.L.	P.I.	SPEC. GRAV. -#4	ORG %	CLASSIFICATION – GROUP SYMBOL	GROUP NAME
97-157	SC-1	1										100	98	93				45	27	2.78	4.7	CL	Lean clay
97-158	"	2				100	99	99	97	96	95	91	81	70				38	23	2.79	3.6	CL	Sandy lean clay
97-159	SC-2	1								100	99	97	80	61				34	17	--	3.7	CL	Sandy lean clay
97-160	"	2						100	96	93	92	91	90	87				48	31	--	4.4	CL	Lean clay
97-161	SC-3	1						100	99	97	94	92	90	86				51	35	--	4.9	CH	Fat clay
97-162	"	2						100	94	89	86	83	81	79				53	34	--	5.0	CH	Fat clay with sand
97-163	LC-1	1							100	99	98	91	75	61				33	17	2.77	3.7	CL	Sandy lean clay
97-164	"	2							100	99	99	98	96	92				44	25	2.83	3.8	CL	Lean clay
97-165	LC-2	1									100	99	95	88				44	29	--	4.4	CL	Lean clay
97-166	"	2							100	99	97	92	84	75				34	17	--	3.1	CL	Lean clay with sand
97-167	GG-1	1									100	99	93	74				32	16	2.78	4	CL	Lean clay with sand
97-168	"	2						100	98	96	94	92	88	81				44	29	2.80	5.1	CL	Lean clay with sand
97-169	"	3							100	99	99	97	94	85				41	25	--	5	CL	Lean clay with sand
97-170	GG-2	1						100	99	99	98	96	87	67				30	13	--	3.8	CL	Sandy lean clay
97-171	"	2						100	98	97	96	94	86	68				36	18	--	4	CL	Sandy lean clay
97-172	"	3				100	99	99	99	98	97	95	91	86				59	43	--	7.2	CH	Fat clay
97-173	"	4						100	99	96	93	88	84	76				45	30	--	6.1	CL	Lean clay with sand

DATE: 6/3/98
INITIAL: RGJ
REQUEST NO.: 98-18

REMARKS:

Sheet 1 of 1

IM - INSUFFICIENT MATERIAL
NP - NON-PLASTIC
NG - NO GOOD

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

SANDSTONE TEST SUMMARY

DIVISION OF ENGINEERING
CIVIL ENGINEERING
CANALS AND LEVEES SECTION

PROJECT: Sites and Golden Gate Dams

FEATURE Sandstone Quality for Rip-Rap and RCC Aggregate

LAB. NO.	HOLE NO.	F.S. NO.	PERCENT FINER – MECHANICAL ANALYSIS – GRAVEL 3"	GRAVEL 1½"	GRAVEL ¾"	GRAVEL ⅜"	GRAVEL 4	SAND 8	SAND 16	SAND 30	SAND 50	SAND 100	SAND 200	3-inch CUBE SAMPLES compressive strength (psi)	specific gravity (ssd)	percent absorption %	CLASSIFICATION GROUP SYMBOL	GROUP NAME
98-174	SSQ-1	A												11130	2.50	2.6		
"	"	B												9960	2.48	2.6		
"	"	C												10830	2.48	2.8		
98-175	SSQ-2	A												11840	2.50	2.5		
"	"	B												11690	2.50	2.5		
"	"	C												12370	2.49	2.6		
98-176	SSQ-3	A												*	*	*		
"	"	B												*	*	*		
"	"	C												*	*	*		
98-177	SSQ-4	A												11830	2.50	2.4		
"	"	B												11630	2.50	2.5		
"	"	C												**	**	**		
98-178	SSQ-5	A												10160	2.46	3		
"	"	B												10200	2.45	2.8		
"	"	C												10820	2.45	2.8		
98-179	SSQ-6	A												9940	2.45	2.8		
"	"	B												9910	2.45	2.9		
"	"	C												10990	2.45	2.9		
98-180	SSQ-7	A												11220	2.52	2.5		
"	"	B												10320	2.51	2.3		
"	"	C												10740	2.50	2.7		
98-181	SSQ-8	A												12690	2.48	2.3		
"	"	B												12130	2.49	2.5		
"	"	C												12060	2.49	2.4		

DATE 5/25/1998
INITIAL RGJ
REQUEST NO 98-18

REMARKS: * Unable to obtain cube sample. One side of slab is fractured and uneven.
** can only secure two cube specimens from slab.

IM - INSUFFICIENT MATERIAL
NP - NON-PLASTIC
NG - NO GOOD

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

SANDSTONE TEST SUMMARY

DIVISION OF ENGINEERING
CIVIL ENGINEERING
CANALS AND LEVEES SECTION

PROJECT: Sites and Golden Gate Dams

FEATURE Sandstone Quality for Rip-Rap and RCC Aggregate

LAB. NO.	HOLE NO.	F.S. NO.	PERCENT FINER – MECHANICAL ANALYSIS – GRAVEL 3"	1 1/2"	3/4"	3/8"	4	SAND 8	16	30	50	100	200	3-inch CUBE SAMPLES compressive strength (psi)	specific gravity (ssd)	percent absorption %	CLASSIFICATION GROUP SYMBOL	GROUP NAME
98-182	SSQ-9	A												11250	2.49	2.8		
"	"	B												11040	2.49	2.6		
"	"	C												11360	2.48	2.6		
98-183	SSQ-10	A												11240	2.45	2.8		
"	"	B												10970	2.46	2.7		
"	"	C												11490	2.46	2.7		

RESULTS OF QUALITY TESTS ON CRUSHED SANDSTONE

1. ASTM C-131 Los Angeles Rattler Test (Grading A = $1\frac{1}{2}$ x 3/8 size fraction):
   - 100 revolutions = 11.4 percent loss
   - 500 revolutions = 43.4 percent loss

   Specific Gravity and Absorption tests before performing LART
   - Spec. Grav. = 2.48
   - Absorption = 4.2 percent

2. ASTM C--- Durability Index (3/4 x #4 size fration)
   - Durability Index, Dc = 42

   Specific Gravity and Absorption tests before performing Coarse Durability Index
   - Spec. Grav. = 2.50
   - Absorption = 4.1 percent

DATE 5/25/1998
INITIAL RGJ
REQUEST NO 98-18

REMARKS: In determining the absorption, the strength samples (cubes) were oven dried at 160 °F. The crushed samples were oven dried at 230 °F. All samples were soaked for 24 hours.

IM - INSUFFICIENT MATERIAL
NP - NON-PLASTIC
NG - NO GOOD

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CLASSIFICATION TEST SUMMARY

DIVISION OF ENGINEERING
CIVIL ENGINEERING
CANALS AND LEVEES SECTION

PROJECT: Sites Dam

FEATURE: ______

LAB NO.	HOLE NO.	F.S. NO.	DEPTH (feet)	PERCENT FINER – MECHANICAL ANALYSIS – GRAVEL 3.0"	1.5"	3/4"	3/8"	4	SAND 8	16	30	50	100	200	HYDROMETER SILT & CLAY 5m	2m	1m	ATTERBERG LIMITS LL	PI	MOISTURE CONTENT %	PERCENT ORGANIC	GROUP SYMBOL	CLASSIFICATION GROUP NAME
99-737	SC-4	1	5									100	97	88				35	20			CL	Lean clay
99-738		2	10					100	96	99	98	96	95	87				39	25			CL	Lean clay
99-739		3	15					100	96	98	98	97	96	84				52	37			CH	Fat clay
99-740	SC-5	1	5						100	99	98	97	96	91				48	31			CL	Lean clay
99-741		2	10					100	99	97	95	94	92	87				57	42			CH	Fat clay
99-742	SC-6	1	5			100	96	98	96	97	96	94	88	80				49	35			CL	Lean clay with sand
99-743		2	10					100	96	97	96	94	89	83				54	38			CH	Fat clay with sand
99-744		3	15			100	98	97	87	82	79	75	68	60				45	30			CL	Sandy lean clay
99-745	SC-7	1	5					100	98	96	94	92	90	88				51	36			CH	Fat clay
99-746		2	10			100	99	99	96	92	87	82	78	73				42	25			CL	Lean clay with sand
99-747	SC-8	1	5		100	99	99	98	96	94	91	87	81	74				43	29			CL	Lean clay with sand
99-748		2	10			100	89	99	96	93	90	85	72	60				43	26			CL	Sandy lean clay
99-749		3	15		100	98	84	91	78	72	68	61	47	36				36	20			CL	Clayey sand
99-750	SC-9	1	5							100	99	99	98	97				72	51			CH	Fat clay
99-751		2	10						100	99	98	98	97	97				68	48			CH	Fat clay
99-752	SC-10	1	5								100	99	95	85				46	24			CL	Lean clay with sand
99-753		2	10					100	98	99	99	99	95	85				41	25			CL	Lean clay with sand
99-754		3	15	100	86	86	80	77	78	67	65	60	53	44				36	21			CL	Clayey sand with gravel
99-755	GG-1	1	5						100	98	98	98	96	87				31	19			CL	Lean clay
99-756		2	10					100	98	98	97	97	86	90				45	28			CL	Lean clay
99-757		3	15					100	97	95	94	93	91	85				41	24			CL	Lean clay
99-758	GG-2	1	5								100	99	96	85				35	18			CL	Lean clay with sand
99-759		2	10							100	99	98	92	77				36	18			CL	Lean clay with sand
99-760		3	15							100	89	98	93	79				38	18			CL	Lean clay with sand
99-761	GG-3	1	5								100	99	95	79				38	18			CL	Lean clay with sand
99-762		2	10					100	84	80	87	81	73	62				32	15			CL	Sandy lean clay
99-763		3	15									100	97	84				38	16			CL	Lean clay with sand
99-764	GG-4	1	4					100	99	88	90	98	96	90				42	25			CL	Lean clay
99-765		2	8									100	99	91				37	22			CL	Lean clay
99-766	GG-5	1	5					100	96	96	95	94	92	89				59	42			CH	Fat clay
99-767		2	15			100	98	99	97	94	89	84	88	55				31	14			CL	Sandy lean clay
99-768	GG-6	1	3					100	99	98	97	97	94	90				52	37			CH	Fat clay
99-769	GG-7	1	5									100	98	86				35	18			CL	Lean clay
99-770		2	10					100	99	99	96	96	95	85				33	16			CL	Lean clay with sand
99-771		3	15					100	99	98	98	98	96	84				30	12			CL	Lean clay with sand
99-772	GG-8	1				100	99	98	98	96	94	93	90	84				54	38			CH	Fat clay with sand
99-773		2	6					100	98	92	91	90	88	87				44	24			CL	Lean clay

DATE: 3/17/99
INITIAL:
REQUEST NO: 99-35

REMARKS:

IM - INSUFFICIENT MATERIAL
NP - NON-PLASTIC
NG - NO GOOD

Filename: 9935.XLS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CLASSIFICATION TEST SUMMARY

DIVISON OF ENGINEERING
CIVIL ENGINEERING
CANALS AND LEVEES SECTION

PROJECT: Sites Dam

FEATURE: Composite Samples

LAB NO.	HOLE NO.	F.S. NO.	DEPTH (feet)	PERCENT FINER – MECHANICAL ANALYSIS – GRAVEL 3.0"	1.5"	3/4"	3/8"	SAND 4	8	16	30	50	100	200	HYDROMETER SILT & CLAY 5M	2M	1M	ATTERBERG LIMITS LL	PI	MOISTURE CONTENT %	PERCENT ORGANICS	GROUP SYMBOL	CLASSIFICATION GROUP NAME
99-1419	GG-Samples							100	99	98	97	97	94	83	41	33	27	38	22		3.9	CL	Lean clay w/sand
99-1420	SC-Samples							100	97	96	95	93	89	81	48	38	33	45	30		4.2	CL	Lean clay w/sand

DATE: 9/28/99
INITIAL: drat
REQUEST NO.: 99-51

REMARKS: 99-1419 Specific Gravity - 2.74; Max. Dry Density - 113.8pcf; Opt. Moist. - 17.4%
99-1420 Specific Gravity - 2.74; Max. Dry Density - 110.0pcf; Opt. Moist. - 17.0%

IM - INSUFFICIENT MATERIAL
NP - NON-PLASTIC
NG - NO GOOD

Attachment C. Terrace Descriptions

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Terrace Descriptions

Station Number	Depth	Description	USCS	Color Munsell
3-15-1	0-2	SILT, clayey, brown	ML	
	2-6	CLAY, silty lighter brown	CL	
	6-7	GRAVEL, clay matrix, clasts rounded chert	GC	
3-15-2	0-4	SILT, clayey	ML	
	4-10	GRAVEL, silty, clasts are subangular sst.	GM	
3-15-3	0-2	SILT, clayey, minor rounded, fine gravel clasts of red and black chert	ML	10YR3/4
	2-4	SILT with clay and sand to granule above silty gravel w/ rnd chert clasts 3-4in.	ML	10YR4/3
3-15-4		Boxer Fm at surface		
3-15-5	0-2	SILT, clayey with gravel clasts to 3 in	ML	10YR4/4
3-15-6	0-4	Thin terrace overlying Boxer		
3-15-7	0-2	CLAY, silty, no gravel	CL	10YR4/2
	9-11	CLAY, plastic	CL	10YR5/4
3-15-8	0-15	Clayey silt and silty clay, some gravel lenses to 4 ft., 2+ft clay at base		
3-17-1	0-4	SILT, clayey	ML	
	8-10	CLAY, plastic	CL	
3-17-2	0-3	SILT, clayey	ML	10YR4/2
	3-9	CLAY, silty	CL	10YR4/4
	9-12	CLAY, plastic	CL	10YR5/4
3-17-3	0-3	SILT, clayey	ML	
	12-15	CLAY, plastic	CL	
3-17-4	0-5	Terrace deposit above Boxer FM.		
3-17-5	0-12	Flat lying clay bed bottom 2ft of terrace		
3-17-6	0-5	SILT, clayey, with gravel, clasts large, subangular sst., no soil structure	ML	7.5YR4/2
3-17-7	0-1.5	CLAY, silty with angular mudstone fragments overlying Boxer Fm.	CL	7.5YR4/4
3-17-8	0-5	SILT, clayey	ML	10YR4/3
	5-10	CLAY. Silty	CL	10YR4/4
	10-20	??		
3-17-9	0-6	Six feet of terrace deposit overlying Boxer Fm.		

Note: Station Number is keyed to the flight line and photo number

Terrace Descriptions (Cont.)

Station Number	Depth	Description	USCS	Color Munsell
3-17-10	0-4	SILT, clayey	ML	
	4-9	GRAVEL, clayey, silty, sandstone clasts	GC	
		Just upstream, reddish silty clay at base under gravel lens (buried soil)		7.5YR4/4
3-17-11	9-11.5	Buried soil under gravel lens, SILT, fine sandy clayey	ML	7.5YR4/6
3-17-12	0-5	Upper sloped surface, 5 ft. thick overlying Boxer Fm.		7.5YR4/3
		Low, flat terrace, blocky prismatic soil structure, no Boxer at base		10YR4/2
3-17-13	0-? Not exposed	Upper sloped surface, CLAY, silty with rounded clasts, fine to medium	CL	7.5YR4/4
3-19-1	0-2.5	Thin soil overlying Boxer Fm		
3-19-2	0-2.5	Thin soil overlying Boxer Fm, bedding planes juxtaposed		
3-19-3	0	Boxer exposed at surface		
3-19-4	0-6.5	SILT, clayey at surface grading to silty clay	ML	
3-19-5	0-8	CLAY, gravelly, silty, clasts rounded to 4 inches red and black chert	CL	7.5YR4/4
3-15-1	0-2	SILT, clayey, brown	ML	
	2-6	CLAY, silty lighter brown	CL	
	6-7	GRAVEL, clay matrix, clasts rounded chert	GC	
4-13-2	0-3	SILT, clayey, blocky-prismatic structure, crumbles easily	ML	10YR3/3
	3-9	Clay, silty to clayey silt,	CL	10YR4/3
	9-12	CLAY, silty with fine gravel clasts overlying Boxer Fm.	CL	10YR5/4
		Buried soil in opposite bank		7.5YR4/4
4-13-3		Cemented gravel bed overlying Boxer Fm.		
4-13-4	0-4	SILT, minor clay, few fine gravel clasts, inset lower terrace	ML	10YR4/3
	4-6	GRAVEL, clayey, silty matrix, clasts fine to medium	GC	
4-13-5	0-3	CLAY, silty over Boxer Fm.	CL	7.5YR4/4
4-13-6		Possible Tehama Fm. on hillside, clayey silt matrix with scattered clasts		10YR6/4
4-13-7	10-12	Possible buried soil between terrace deposit and Boxer Fm., CLAY with rounded gravel clasts	CL	7.5YR4/3
4-13-8	0-3	Thin soil overlying Boxer Fm,		

Note: Station Number is keyed to the flight line and photo number

Terrace Descriptions (Cont.)

Station Number	Depth	Description	USCS	Color Munsell
4-15-1	0-15	typical terrace deposit		
	15-25	GRAVEL, sandy loose, unconsolidated, rounded sst. Clasts, rusty staining minor clay	GC	5YR4/6
	25-30	CLAY, silty moist, soft moderately plastic	CL	5Y3/2
4-15-2		lower inset? Terrace with poor soil over buried soil, 7.5YR3/4 with orange mottles		
4-15-3	0-28	terrace deposit with very little structure		10YR3/3
	28-30	Grey clay		
4-15-4	0-1	colluvium overlying terrace deposit		
	1-6	CLAY, silty, hard, blocky, base not exposed	CL	10YR4/2
4-15-5		SILT, clayey, friable	ML	10YR4/4
		CLAY, silty, blocky with orange and grey mottling	CL	10YR5/2
4-17-1	7-10	Flat lying conglomerate bed overlying Boxer, hard, cemented, medium to coarse clasts, rounded sandstone and chert, sandstone matrix	GW	
4-17-2	0-1	SILT, clayey	ML	10YR 3/3
	1-5	CLAY, sandy, silty, with gravel. Buried soil	CL	7.5YR4/6
4-17-3	0-2	SILT, clayey, minor fine gravel	ML	10YR3/2
	2-4	CLAY, silty	CL	10YR4/3
	4-5	CLAY, minor silt	CL	10YR4/2
4-17-4	0-17	Terrace Deposit		
	17-20	CLAY, grey	CH	gley
4-17-5	0-7	Thin terrace over sandstone Boxer		
4-17-6		Terrace varies from 6 to 15 ft thick		
3-25-1	0-12	Channel gravels appear to be plated onto sidewalls		
3-25-2	0-3.5	SILT, clayey with minor fine gravel clasts	ML	10YR3/3
	3.5-7.5	CLAY, gravely, subrounded sst. clasts to 8 inches, overlying Boxer	CL	10YR5/6
3-25-3	0-3.5	SILT, clayey with minor fine gravel clasts	ML	10YR4/3
	3.5-8	CLAY, silty	CL	10YR4/4
	8-11.5	CLAY, minor silt, occaisional gravel clasts	CL	10YR4/3
3-25-4	0-5	SILT, clayey	ML	10YR4/3
	5-7.5	GRAVEL, clay matrix, fine to coarse, subrounded to rounded sst and chert	GC	10YR5/6
	7.5-10	Boxer		

Note: Station Number is keyed to the flight line and photo number

Terrace Descriptions (Cont.)

Station Number	Depth	Description	USCS	Color Munsell
3-27-1	0-2	SILT,very fine sand	ML	10YR5/6
	2-6	Silt with minor fine gravel, rounded chert clasts		
3-27-2	0-1	SILT, clayey		
	1-6	GRAVEL, clay matrix, fine to medium red and black chert, rounded	GC	7.5YR5/6
3-29-1	0-2	SILT, clayey	ML	10YR4/3
	2-7	SILT, clayey, limb at 3.5 ft	ML	10YR3/2
3-29-2	0-1.2	SILT, clayey, with some granule sized clasts	ML	10YR3/2
	1.2-4.7	SILT, with fine to medium gravel clasts, CaCO3, bone fragment	ML	10YR6/3
	4.7-6.5	GRAVEL, silt matrix, medium to coarse, sandstone clasts subangular	GM	10YR4/3
3-29-3	0-6	SILT, clayey	ML	10YR3/3
	6-8	GRAVEL, silty, clayey, two lenses	GM	
	8-11	CLAY, plastic	CL	10YR5/6
3-29-4	0-6	SILT, clayey with gravel lenses, sandstone bedrock at base	ML	
3-29-5	0-2	Clay, silty to clayey silt	CL	7.5YR3/2
	2-3	SILT, crumbly	ML	10YR3/3
	3-4.7	GRAVEL, silty, clasts fine to cobble, CaCO3 coatings	GM	
	4.7-6	CLAY, silty, stiff, Boxer sst and mst exposed in channel	CL	10YR5/6
3-29-6	0-2	CLAY, silty with rounded clasts of red and black chert and sst. Conc.	CL	7.5YR4/4
4-23-1	0-25	SILT, clayey with granule clasts of mudstone and sst, weathered	ML	7.5YR5/4
4-23-2	0-2.5	SILT, clayey	ML	10YR3/2
	2.5-6.5	CLAY, silty with minor clasts of sst. and claystone	CL	10YR4/3
4-23-3	0-4	SILT with minor clay, mudstone bedrock in channel on high fan	ML	7.5YR 5/4
4-23-4	0-3.5	SILT, clayey with granule clasts of weathered sst, Boxer exposed in channel	ML	7.5YR4/3
4-23-5	0-1.5	Colluvium over lying vertical bedded Boxer		
4-29-1	0-6	SILT, clayey with some gravel, increasing downward, shale and sst. Clasts	ML	10YR4/3
	6-9	GRAVEL, clayey sandy matrix, subrounded to rounded red and black chert	GC	10YR4/3
4-29-2	0-4	CLAY, silty,with gravel clasts, upper sloped surface overlying Boxer	CL	7.5YR4/3
4-29-3	0-4	CLAY, silty	CL	10YR3/2
	4-8	CLAY, silty	CL	10YR5/4
	8-9.5	CLAY, buried soil	CL	7.5YR5/3
4-29-4	0-3	Thin terrace overlying Boxer Fm.		

Note: Station Number is keyed to the flight line and photo number

DRAFT

Terrace Descriptions (Cont.)

Station Number	Depth	Description	USCS	Color Munsell
4-29-5	0-5	SILT, clayey	ML	10YR4/3
	5-8	GRAVEL, clayey sandy matrix, subrounded to rounded chert, sst clasts at base	GC	7.5YR4/6
		Up channel Boxer is near surface, down channel Boxer is replaced by clay		10YR5/4
4-29-6	0-12	Terrace 12 ft thick		
4-29-7		Upper sloped surface appears to plunge under the Low flat terrace and pinch out against the underlying Boxer Fm. USS is GRAVEL, clayey	GC	7.5YR4/6
		QLFT is SILT, clayey with blocky prismatic soil structure	ML	10YR3/3
4-29-8	0-2	Colluvium overlying Boxer, sandstone clasts to 1+ ft.		10YR4/6
4-29-9	0-2.5	CLAY, minor silt over weathered Boxer	CL	10YR4/3
4-29-10	0-2.5	CLAY with minor silt	CL	10YR3/3
	2.5-5	Weathered claystone		10YR5/4
4-29-11	0-6	SILT, clayey	ML	10YR3/4
	6-12	CLAY with minor silt	CL	10YR4/3
3-35-1	0-4	SILT, clayey, dark, blocky prismatic structure	ML	
	4-8	GRAVEL, sandy, clayey overlying Boxer Fm.	GC	
3-35-2	0-4	SILT, clayey, dark, blocky prismatic structure	ML	10YR3/3
	4-9	GRAVEL, clayey overlying west dipping Boxer	GC	5YR4/4
3-35-3	0-6	SILT, clayey	ML	10YR3/3
	6-10	CLAY, silty with gravel	CL	7.5YR4/4
3-35-4	0-4	CLAY, silty on surface of upper sloped surface, overlying Boxer Fm.	CL	7.5YR3/4
3-35-5		CLAY, silty with some gravel, upper sloped surface, cemented gravel breccia in channel	CL	7.5YR4/3
3-35-6	0-5	Typical QLFT deposit, overlying possible Tehama Fm.??		

Note: Station Number is keyed to the flight line and photo number

Geology

The following discussion of geology is adapted USBR (1969). The Sites Reservoir is on the west side of the Sacramento Valley in the foothills of the Coast Ranges. The area is underlain by Lower and Upper Cretaceous sedimentary rocks of the Great Valley Sequence folded along northerly trending axes and cut by north- and northeast-striking faults. The regional geology is shown in Figure 4.

The major structural features in the region include the Sites anticline, a major anticlinal flexure on the west side of the Sacramento Valley that passes through the long axis of the reservoir and is paralleled to the west by a broad shallow syncline, called the Fruto syncline. The Salt Lake fault parallels the axis of the anticline near the center of Antelope Valley. The Sites anticline is interpreted by Phipps and Unruh (1992), as a major, west-vergent thrust (Salt Lake fault) juxtaposing moderately to steeply east-dipping rocks in its hanging wall against the west-dipping east limb of the Fruto syncline, which plunges to the north. The Salt Lake fault is known from south of Cache Creek to west of Willows and is a bedding plane fault in its hanging wall. The fault is steeply cross cutting in its foot wall near Sites and approaches bedding plane geometry towards the south (Leesville grade to Cache Creek canyon).

Great Valley Sequence

The Sites and Golden Gate dam sites are on the eastern flank of the Sites anticline near the contact between the Venado sandstone member of the Cretaceous Cortina Formation and the underlying siltstone/mudstone of the Boxer Formation. The contact between the Boxer and the Cortina is generally taken to be the lowest major sandstone unit.

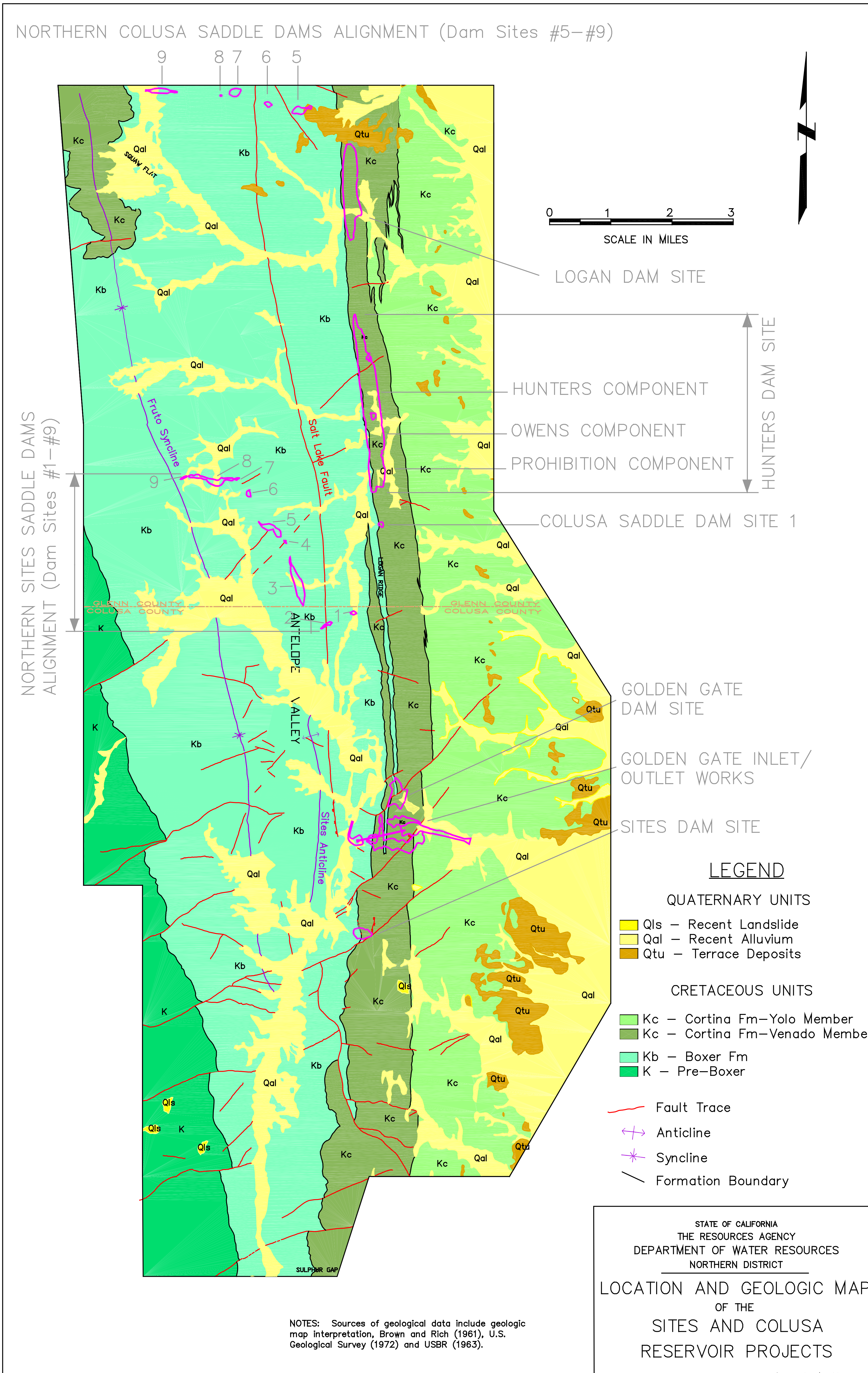
The Boxer Formation consists of thin bedded mudstone with scattered thin to medium sandstone interbeds representative of basin-plain deposits of distal turbidites. The base of the Boxer Formation includes the Salt Creek conglomerate member but it is not exposed in this area (Ingersoll 1981). The Boxer Formation is less resistant to weathering and erosion, underlies the valley east of the sandstone ridges of the Venado, and makes up the core of the Sites anticline.

The Cortina Formation includes three mapped members, the Venado sandstone, the Yolo shale, and the Sites sandstone. The basal unit of the Venado sandstone is primarily fine- to medium-grained, hard, and occurs chiefly in 1- to 10-foot-thick beds. Petrographic studies indicate that the rock is cemented by carbonates and by a silica-clay matrix. The Venado includes a lesser amount of well indurated, crudely fissile mudstone that occurs as 1/8 to 6-inch beds. Mudstone constitutes about five percent of the basal Venado.

Above the basal unit, mudstone beds increase to nearly 50 percent of the section. Further up the section, the Venado consists of repetitive intervals of medium to thick bedded sandstone and thinner bedded sandstone with subordinate mudstone (USBR 1969).

These bedded sandstones form the eastern ridge that is the current proposed location of Golden Gate Dam.

FIGURE 4



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

LOCATION AND GEOLOGIC MAP
OF THE
SITES AND COLUSA
RESERVOIR PROJECTS

The mudstones of the Yolo shale member are laminated to thin-bedded, range from 800- to 1,000-feet thick, and occupy the strike valleys between the Venado and Sites sandstone members east of the dam sites.

Exposures of the Sites sandstone are located within 15 miles south of the reservoir area and consist of 1,500 to 2,000 feet of interbedded sandstone and siltstone. This sandstone member wedges out into a thick mudstone sequence about 8 miles south of the southern edge of the reservoir boundary.

Cenozoic Deposits

The rocks of the Great Valley sequence have been eroded and, along the valleys and streams, have been partially covered with alluvial deposits and terraces of recent to middle Pleistocene age. These deposits were mapped in the project area by Helley and Harwood, (1985) and include recent stream channel deposits, Holocene alluvium and basin deposits, terraces of the Upper and Lower Modesto Formation, and Upper and Lower Riverbank Formation. The unit descriptions used by Helley and Harwood are summarized below. Stream channel deposits are active deposits of sand and gravel along streams and are without permanent vegetation. The Holocene alluvium consists of gravel, sand, and silt deposited by streams, and occurs outside of the stream channel deposits, but inside of the lowest terrace deposits. Basin deposits are fine-grained silt and clay derived from the same sources as the alluvium. The dark gray to black deposits are the distal facies of the alluvium.

The Upper and Lower Modesto Formation are the lowest distinct alluvial terraces lying topographically above the Holocene stream deposits. The Modesto includes tan and light gray gravelly sand, silt, and clay. The upper member is unconsolidated and unweathered, and it forms the topographically lowest terraces only a few meters thick. The surface preserves the original fluvial morphology with relief of 1-2 meters. The soils on the upper member have A/C horizons but lack an argillic B horizon. The lower member can be slightly weathered and forms terraces that are topographically higher than the upper member. The surface morphology is smooth and it is more extensive than the upper member. The soils on the lower member contain an argillic B horizon with an increase in clay content and red color.

The Riverbank Formation consists of weathered reddish gravel, sand, and silt. The Riverbank is differentiated from the younger Modesto by its terraces being topographically higher and by its more highly developed soil profile. The upper riverbank member is unconsolidated but compact dark brown to red alluvium, and forms the lower of the Riverbank terrace levels about 3 meters to 5 meters above the lower Modesto terrace. The lower member consists of red semi-consolidated gravel, sand, and silt. Its surface is higher and much more dissected than the upper member and has much stronger soil profiles.

Construction Materials

Construction materials needed for the proposed embankment dams include impervious fill for the core, random fill, rockfill, riprap, filter and drain material, and aggregate for concrete structures. The terrace deposits upstream of the dam sites are the proposed source of the impervious material. Earlier reports by USBR was estimated that 4.4 million cubic yards of impervious material were available within 1 mile of the Golden Gate Dam site and 2.8 mcy of impervious material were available within 1 mile of the Sites Dam site. This material would be from terrace deposits within the footprint of the reservoir.

Random or rockfill for Sites Dam was proposed to come from the existing Sites quarry in the Venado sandstone downstream of the dam site. Random fill for Golden Gate Dam was proposed to come from the ridge to the southeast of the originally proposed dam site. The current design uses this ridge as the abutment for the dam. Therefore, we are proposing using the northwest ridge of Venado sandstone for the rock quarry to supplement the materials excavated for the spillway and outlet works. This is within the footprint of the reservoir and would not result in additional environmental effects.

Testing of the Sites quarry materials indicate they are of relatively low strength, and have been identified by previous studies to lack wet-dry durability. The Sites quarry material has sufficient strength characteristics for use as rockfill, but may not be suitable for use as riprap without periodic maintenance. Wet-dry testing by the USBR found the material to have poor durability. DWR is presently conducting a wet-dry test to verify the USBR findings.

Preliminary indications are that the crushed quarried rock would probably not be suitable for the filter and drain material. During the spring of 1998, ten 3-inch cube samples of the quarry rock were collected for analysis. The results are summarized in Tables 8 and 9. During March 1999, approximately 5 yd^3 each of the weathered and unweathered sandstone were crushed to 1.5-inch minus and taken to the Bryte Laboratory for further testing. During May 1999, ten rock cores each of the weathered and unweathered sandstone were collected from the Sites quarry. Further testing is being performed to assess the properties of the quarry rock. If it is not suitable, then filter and drain material would have to be brought from another source. Channel gravels associated with the active streams within the reservoir are too discontinuous to provide an adequate supply of gravel. The alternative source would include paleochannels of the Stony Creek fan that are being mined commercially. These operations are in Willows and Orland. Previously there was a commercial aggregate operation on Cortina Creek south of Williams.

Crushed quarried sandstone is not suitable for use as concrete aggregate. Concrete aggregate sources include the Stony Creek fan deposits described above.

Table 8. Results for Terrace Samples Collected Spring 1998

IMPERVIOUS MATERIALS						
SAMPLE LOCATION	Liquid Limits	TEST				Sample Description
		Plasticity Index	Specific Gravity	Organic Content	Soil Classification	
SC-1	38-45	23-27	2.78-2.79	3.6-4.7	Lean Clay to Sandy Lean Clay (CL)	Dark brown clayey silt, clay rich at 2 ft.; Clay sticky with small round pebbles at 6 ft. (Lower Modesto)
SC-2	34-48	17-31	N/A	3.7-4.4	Lean Clay to Sandy Lean Clay (CL)	Dark clay, homogeneous at 4 ft.; weathered bedrock at 8ft
SC-3	51-53	34-35	N/A	4.9-5.0	Fat Clay to Fat Clay with Sand (CH)	Dark brown silty clay, sticky at 2.5 ft.; weathered bedrock clayey, sticky yellowish gray at 6.5 ft.
LC-1	33-44	17-25	2.77-2.83	3.7-3.8	Lean Clay to Sandy Lean Clay (CL)	Dark brown silty clay (Modesto) at 4.6 ft.; thick clay orange/brown rolls, in balls, possibly weathered bedrock, no chips at 8.0 ft.
LC-2	34-44	17-29	N/A	3.1-4.4	Lean Clay to Lean Clay with Sand (CL)	dark brown organic loam at 1.5 ft.; clayey orange-brownish tan with scattered rounded gravel at 6.0 ft.
GG-1	32-44	16-29	2.78-2.80	4-5.1	Lean Clay with Sand (CL)	Light brown silty clay gravel layers (slight) caliche layer chunks (CaCO3) at 3.5 ft.; medium brown silty clay, caliche with small scattering of pebbles at 13.8 ft.; orangish brown clay layer, no pebbles, water flowing at 17.2 ft.
GG-2	30-59	13-43	N/A	3.8-7.2	Sandy Lean Clay to Fat Clay (CL_CH)	Reddish brown silty clay scattered pebbles at 5.5 ft.; reddish weathered silty clay (Riverbank) at 11 ft.; gray to dark brown weathered clay with white mineralized CaCO3 or salts leaching out from groundwater at 15 ft.; blue clay in channel at 18 ft.

Table 9. Results for Quarry Samples Collected Spring 1998

QUARRY ROCK 3" CUBE SAMPLES			
Sample Number	Compressive Strength (psi)	Specific Gravity	Percent Absorption
SSQ-1	9,960 - 11,130	2.48-2.50	2.6-2.8
SSQ-2	11,690 - 12,370	2.49-2.50	2.5-2.6
SSQ-3	No Sample		
SSQ-4	11,630 - 11,830	2.5	2.4-2.5
SSQ-5	10,160 - 10,820	2.45-2.46	2.8-3.0
SSQ-6	9,910 - 10,990	2.45	2.9-2.9
SSQ-7	10,320 - 11,220	2.50-2.52	2.3-2.7
SSQ-8	12,060 - 12,690	2.48-2.49	2.3-2.5
SSQ-9	11,040 - 11,360	2.48-2.49	2.6-2.8
SSQ-10	10,979 - 11,490	2.45-2.46	2.7-2.8

Crushed Sandstone	
L.A. Rattler 1.5"x.375"	11.4% loss/100 rev.
	43.4% loss/500 rev.
Specific Gravity	2.48
Absorption	4.20%
Durability Index 0.75"x#4	Dc=42
Specific Gravity	2.5
Absorption	4.10%

The aggregate testing indicates that both the fresh and weathered sandstone from Sites Quarry are poor quality materials for use as concrete aggregates. The average loss for both sandstones by the Los Angeles Rattler Test was greater that the 45 percent maximum allowable for concrete mix designs. USBR's poor soundness, and wet-dry results, further indicate the low quality as a concrete aggregate.

The investigation of sources for impervious material was performed by a detailed analysis of the aerial photographs taken May 12, 1997. Terrace boundaries were mapped for the three different geomorphic expressions that were recognized in the aerial photographs. The aerial photo interpretations were field checked, the terrace deposits along the incised stream channels in the project area were described, and the exposed thickness was measured. As a result of field checking, one additional terrace type was recognized.

The four terraces recognized for this investigation include from youngest to oldest:

A low terrace that occurs as small isolated remnants along the stream courses of Stone Coral, Antelope, and Funks Creeks between the bottom of the channel and the surface that occupies the valley floors. This terrace is generally 4 to 6 feet thick with weak soil development and consists of clayey silt with some minor gravel. The color is generally very dark grayish brown (10YR3/2) to dark yellowish brown (10YR4/4). Gravel clasts are sub-angular sandstone displaying the original bedding planes. This terrace is tentatively correlated with the younger (upper) Modesto terrace of Helley and Harwood. This terrace was not extensive enough to show on Figures 5, 6, and 7.

The next terrace occurs as a broad, flat surface with very little relief occupying the floor of the valleys. This terrace is widespread in its lateral extent and is generally 12 to 20 feet thick although locally it is more than 30 feet thick. Soil development is greater than on the lower terrace but is still weak. The upper part of this terrace is clayey silt with increasing clay downward. Some gravel lenses were observed along the sides of the incised stream channels and in places there was a clay bed at the base of the observable deposit. The upper 2 to 3 feet is very dark grayish brown (10YR3/2 or 3), becoming lighter downward, brown or dark yellowish brown (10YR4/3 or 4). This terrace is tentatively correlated with the older (lower) Modesto terrace of Helley and Harwood. The map symbol for this terrace is Qlft (Quaternary low flat terrace).

The third terrace has very little surface relief but slopes gently up the tributary drainages. This terrace is generally thinner with observed thicknesses of 8 to 12 feet but the deposits resemble those of the Qlft surface. The upper 2 to 3 feet are dark clayey silts that grade downward to lighter silty clays. Colors are in the very dark grayish brown to brown range (10YR3 to 4), with weak soil development. This terrace is probably also Modesto in age. The map symbol for this surface is Qiss (Quaternary intermediate sloped surface).

The fourth terrace is found sporadically throughout the reservoir area generally above the valley floor. It usually has a sloped surface with some local relief. Observed thicknesses were generally 8 to 10 feet, but were as great as 25 feet along the western front of Logan Ridge and as little as 3 to 4 feet overlying the Boxer mudstone in some areas. Composition of this unit was generally clay to gravelly clay with the clasts subrounded to rounded, including red and black chert and igneous rocks. The color of this unit was usually brown to light brown (7.5 YR4 to 6). In several places this terrace is overlain by the Qlft surface, or the Qlft surface is cut into this surface. This terrace is tentatively correlated with the Riverbank terrace of Helley and Harwood. The map symbol for this terrace is Quss (Quaternary upper sloped surface).

Another surface was observed in the project area that consisted of horizontal, flat-lying ridge tops and notches. This surface was generally erosional on the Boxer Formation, contains no construction material, and was therefore disregarded for this report.

In spring 1998, terrace samples were collected at seven streambank exposures in Funks and Stone Corral Creeks. These samples were analyzed for Atterberg Limits, plasticity, specific gravity, and classification. Summary results are presented in Table 8.

Fifteen test pits were dug into the various terrace deposits in the Sites Reservoir area during the second week of June 1999. Generally three samples were collected from each test pit for future laboratory analysis. Test pit logs are shown in Attachment A. Summary field descriptions of the samples are shown in Table 10. The results of the materials testing for these samples are included in Attachment D.

Sites Dam

Impervious Materials

The terrace deposits mapped in the Antelope Creek and Stone Corral Creek drainages within 5 miles of Sites Dam site are shown in Figure 5. The mapped area of the valley floor occupied by the Qlft terrace is 1,070 acres. With a conservative estimate of the thickness of the terrace of 10 feet, the volume of material in this terrace deposit is 17 million yd^3. The field classification of this material is silty clay to clayey silt with a slight amount of gravel in the stream channel, and it appears to be suitable for the impervious fill zone. The volume of impervious material required for the Sites Dam is about 1 million cubic yards, which is 60 acres at 10 feet thick. This volume of material is available within 1 mile of the dam site.

Seven test pits were placed in the terrace deposits upstream from Sites Dam as shown in Figure 5. Four of the test pits encountered groundwater at depths of 10 to 16 feet and were terminated, two reached 16 feet with no groundwater, and one encountered bedrock at 12 feet. Generally there was a lack of stratification in the test pits with the material grading downward from clayey silt to silty clay. A clayey gravel was found in test pits SC-10 and SC-6 at 14 feet. There was no lithologic distinction observed between test pits in the Qlft surface and the Quss surface.

Soil classification tests and Atterberg limits were run on each of the test pit samples. The results are included in Attachment B. Generally the samples were classified as lean clay or lean clay with sand, USCS symbol CL. Six samples were classified as fat clay having liquid limits above 50.

Random Fill and Rockfill

The source of random fill and rockfill for Sites Dam is the Venado sandstone north of the existing Sites Quarry. Discounting the effects of swell and waste, a wedge of material in a parallelogram shape 300 feet wide by 300 feet high and 1,000 feet long at minimum would be needed to provide the 3.2 mcy random fill required. A quarry in the Venado sandstone was judged by DOE to produce both shell and random rockfill. By selective loading or processing with crushing and screening, it was estimated that the fresh sandstone would produce shell rockfill and the weathered sandstone, siltstone, and claystone would produce random rockfill. This quarry area is outside the footprint of the proposed reservoir area.

Filter and Drain

Filter and drain material will probably require aggregate from a source outside the vicinity of the reservoir area.

Table 10. Field Descriptions of Test Pit Samples[1]

SAMPLE #	DESCRIPTION	USCS[2]	COLOR (MUNSELL)
SC4-1	SILT, clayey, slightly moist.	ML	10YR3/3
SC4-2	CLAY, silty.	CL	10YR3/6
SC4-3	CLAY, minor silt, slightly plastic, moist.	CL	10YR3/2
SC5-1	CLAY, minor silt.	CL	10YR3/1
SC5-2	CLAY, very minor silt, medium plastic, wet below ten feet.	CL	10YR3/3
SC6-1	CLAY, minor silt and gravel.	CL	10YR 3/2
SC6-2	CLAY, minor gravel.	CL	10YR4/4
SC6-3	CLAY, clayey gravel with minor sand, gravels are subrounded black chert & red sandstone.	CL	7.5YR5/4
SC7-1	CLAY, silty, few sand grains.	CL	10/YR4/2
SC7-2	CLAY, minor silt, scattered fine gravel clasts, gastropod shell.	CL	10YR6/6
SC8-1	SILT, clayey, minor gravel, gravel lens in side wall.	ML	10YR3/3
SC8-2	CLAY, silty, with sand and gravel, angular.	SC	7.5YR5/4
SC8-3	CLAY, gravelly, rounded clast up to cobble in size.	GC	7.5YR5/8
SC9-1	CLAY, minor silt, slightly moist, calcareous streaking.	CL	2.5YR4/3
SC9-2	CLAY, moist, plastic, some black mottling.	CL	2.5YR4/2
SC10-1	SILT, clayey.	ML	10YR3/4
SC10-2	CLAY, silty.	CL	10YR4/6
SC10-3	GRAVEL, clayey.	GC	10YR4/4
GG1-1	SILT, clayey, slightly moist.	ML	10YR3/3
GG1-2	CLAY, silty, moist, slightly plastic, some mottling.	CL	10YR4/4
GG1-3	CLAY, minor silt.	CL	10YR4/4
GG2-1	SILT, clayey, slightly moist.	ML	10YR4/2
GG2-2	CLAY, silty, moist, slightly plastic.	CL	10YR4/4
GG2-3	CLAY, silty, moist, slightly plastic.	CL	10YR4/4
GG3-1	SILT, clayey, slightly moist, crumbly.	ML	10YR3/3
GG3-2	SILT, clayey.	ML	10YR4/4
GG3-3	CLAY, silty, moist, slightly plastic.	CL	10YR4/4
GG4-1	CLAY, silty, moist.	CL	10YR4/2
GG4-2	CLAY, silty, very moist to wet.	CL	10YR3/4
GG5-1	CLAY, silty, slightly moist, stiff.	CL	10YR3/3
GG5-2	CLAY, silty, moist, slightly plastic, some mottling.	CL	10YR4/4
GG6-1	CLAY, silty, slightly moist, tough.	CL	10YR3/2
GG7-1	SILT, clayey, slightly moist, crumbly.	ML	10YR3/2
GG7-2	SILT, clayey.	ML	10YR4/4
GG7-3	CLAY, silty, moist, slightly plastic.	CL	10YR4/4
GG8-1	CLAY, silty, gravel clasts - fine to medium.	CL	10YR4/2
GG8-2	Weathered bedrock - mudstone, crumbly.	bedrock	-

[1] Sample locations are shown on Figures 5, 6, and 7.

[2] Unified Soil Classification System

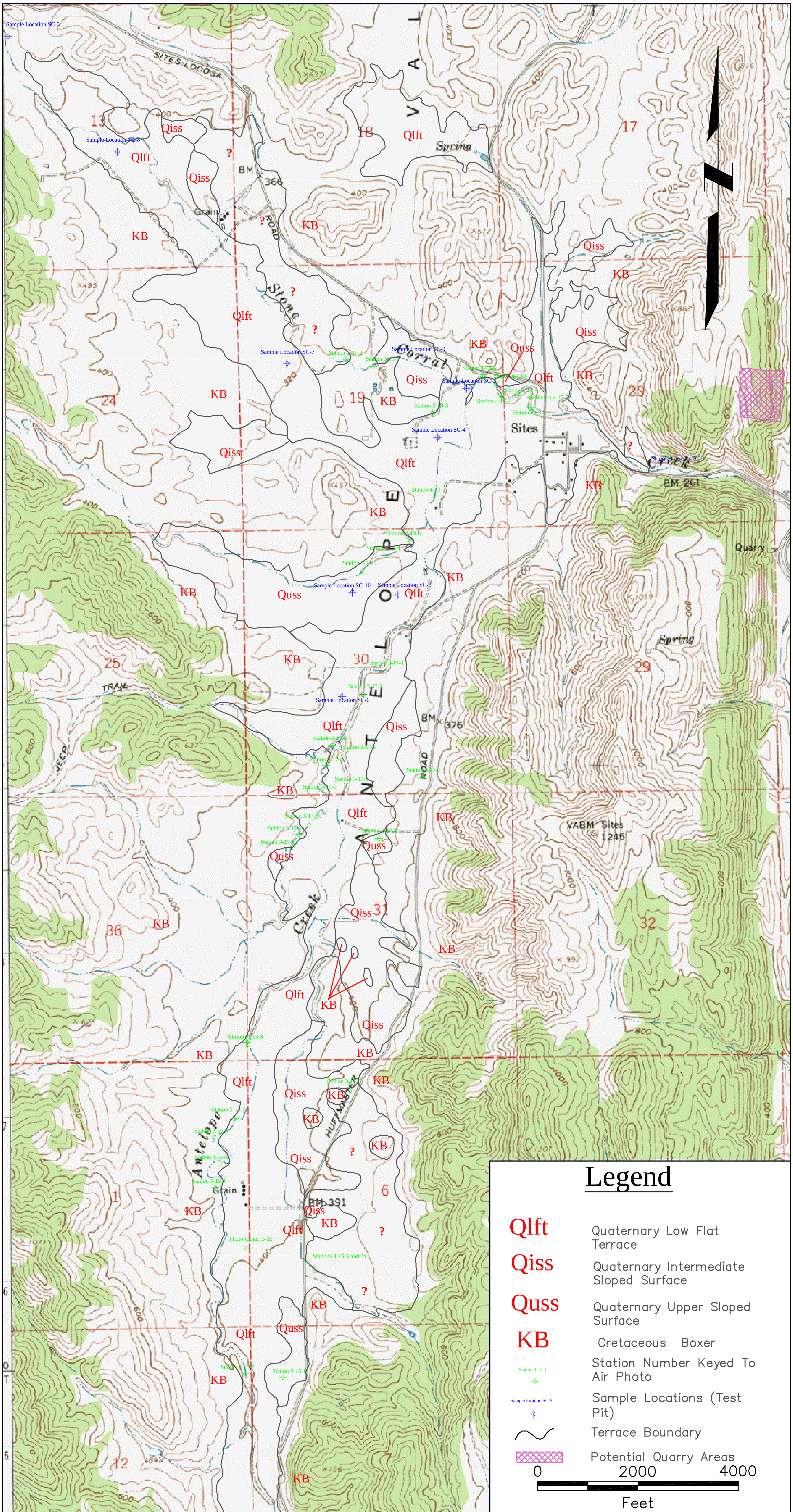


Figure 5. Terrace Deposits, Antelope and Stone Corral Creeks

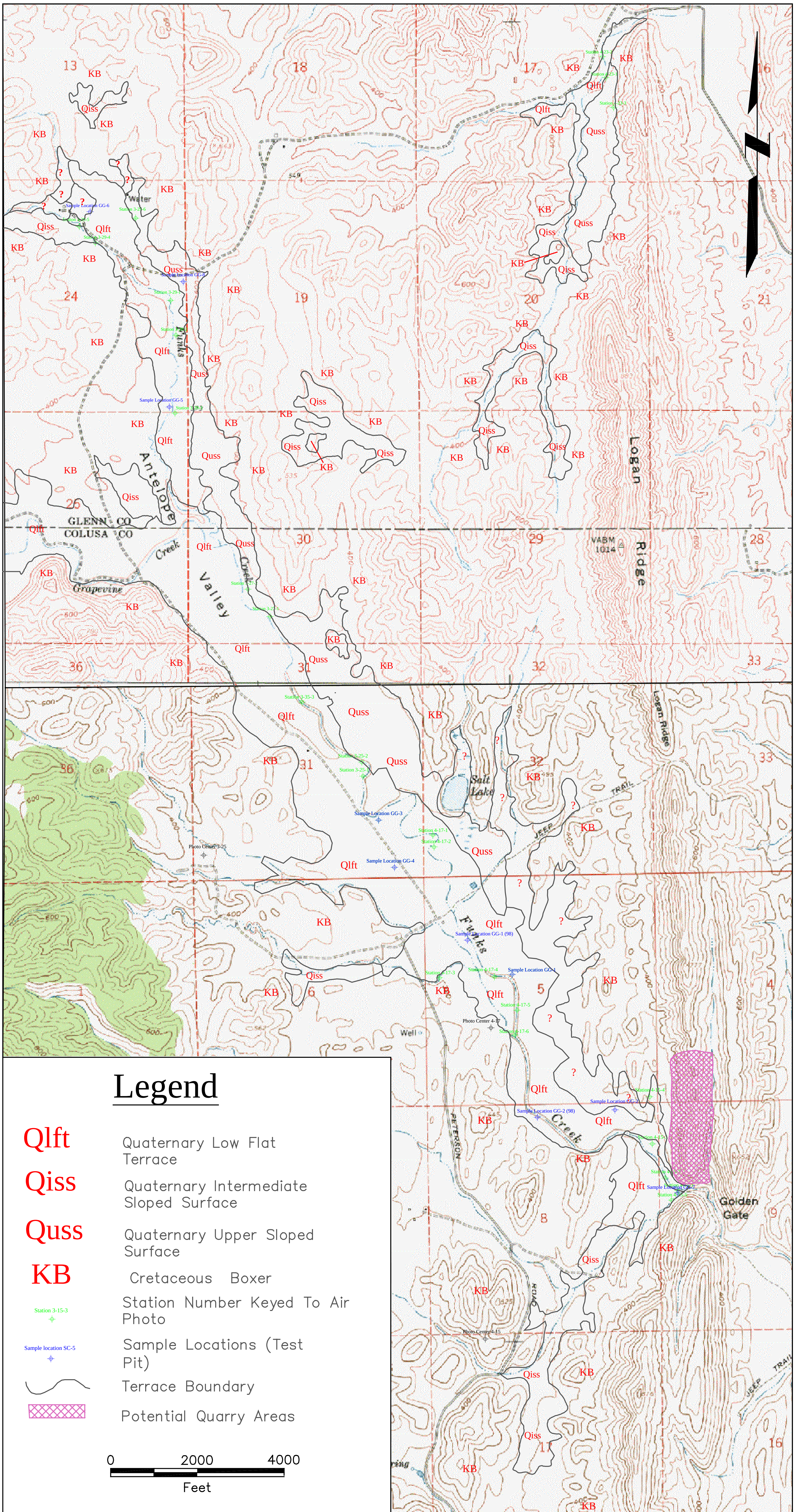


Figure 6. Terrace deposits, Funks and Grapevine Creeks

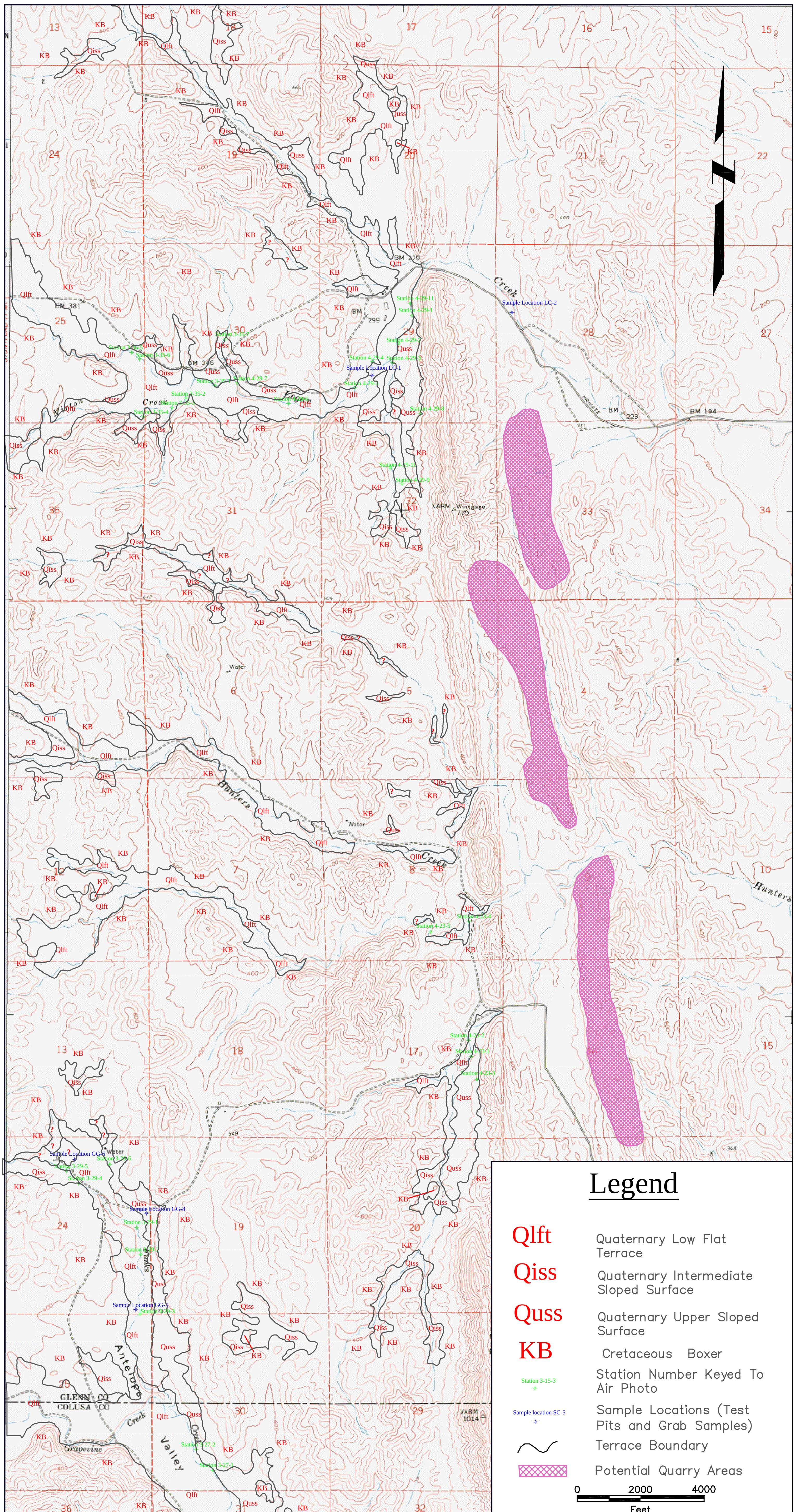


Figure 7. Terrace Deposits Hunters and Logan Creeks

Golden Gate Dam

Impervious Materials

Terrace deposits mapped in the Funks Creek drainage within 3 miles of the dam site are shown in Figure 6. The mapped area of the valley floor occupied by the Qlft terrace is 628 acres. With a conservative estimate of 10 feet for the terrace thickness, the volume of material in this terrace deposit is 10 million yd^3. The field classification of this material is silty clay to clayey silt with some gravel in the stream channel, and it appears to be suitable for the impervious fill zone. The material along Funks Creek appears to have more silt content in the upper 10 feet than the Stone Corral/Antelope Creek material. The volume required for the Golden Gate Dam is about 2,552,000 yd^3, which is 158 acres at 10 feet thick (3.5 mcy for the downstream curved alignment, 220 acres). This volume of material is available within 1 mile of the dam site.

Five test pits were placed along Funks Creek within 2 miles of the Golden Gate Dam site. Two test pits encountered groundwater at 8 to 14 feet and were terminated, two reached 18 feet and one reached 20 feet. The lithologies were mostly clayey silt with increasing clay content downward. Samples from GG-4 were clay rich. All test pits were placed in the Qlft surface.

Soil classification tests and Atterberg limits were run on each test pit sample. The results are included in Attachment B. All the samples were classified as lean clay or lean clay with sand, Unified Soil Classification System symbol CL.

Random Fill

The proposed source of the random fill for Golden Gate Dam is the Venado sandstone to the northwest of the downstream alignment. Discounting the effects of swell and waste, a wedge of material in a parallelogram shape, 300 feet wide by 300 feet high and 2,400 feet long at a minimum, would be required to provide the 8 million yd^3 of random fill required. No testing has been performed on this quarry site but its properties should be similar to the Sites Quarry. A quarry in the Venado sandstone was judged by DOE to produce both shell and random rockfill. By selective loading or processing with crushing and screening, it was estimated that the fresh sandstone would produce shell rockfill and the weathered sandstone, siltstone, and claystone would produce random rockfill. This quarry is inside the reservoir footprint.

Filter and Drain

Filter and drain material will probably require aggregate from a source outside the vicinity of the dam site.

Concrete Aggregate

Sample results indicate that crushed Venado sandstone will not be suitable for use as concrete aggregate. The nearest commercial sources of aggregate are on the Stony Creek fan between Willows and Artois and near Orland. Stony Creek aggregate has been found suitable for use with high-alkali cement and has been used in the construction of East Park Dam, Stony Gorge Dam, and Black Butte

Dam. Currently permitted reserves of Stony Creek aggregate are 61 million tons with a total estimated reserve of 1,031 million tons (Glenn County ARMP 1997).

In addition to commercial sources on the Stony Creek fan, it is estimated that 41 million tons of sand and gravel are impounded behind Black Butte Dam. These deposits probably contain a higher amount of silt and clay and would need to be cleaned before use. Extraction of these deposits would result in an increase in capacity of Black Butte Reservoir. Similar conditions exist on East Park Reservoir 20 miles west of Sites.

There was a commercial gravel operation on Cortina Creek south of Williams that has closed. The quantity and quality of aggregate that may be available along Cortina Creek is unknown.

Saddle Dams

Impervious Materials

The terrace deposits mapped in the middle Funks Creek and Grapevine Creek drainages are shown in Figure 6. The mapped area of the valley floor occupied by the Qlft terrace is 461 acres. With a conservative estimate of the thickness of the terrace of 10 feet, the volume of material in this terrace deposit is 7,437,500 yd^3. The field classification of this material is silty clay to clayey silt with some gravel in the stream channel, and it appears to be suitable for the impervious fill zone. The volume required for the saddle dams is about 2,626,000 yd^3, which is 162 acres at 10 feet thick. This volume of material is available along Funks Creek generally within 1 mile of the saddle dam alignment.

Three test pits were placed toward the northern end of Funks Creek near the saddle dam alignment. Bedrock was encountered at 6 feet in GG-6 and 9 feet in GG-8, and groundwater was encountered at 10 feet in GG-5. The lithology of the terrace deposits was silty clay. Test pits GG-6 and GG-8 were placed in the Quss surface and GG-5 in the Qlft surface.

Soil classification tests and Atterberg limits were run on each test pit sample. The results are included in Attachment B. One sample from each test pit was classified as fat clay, USCS symbol CH.

Random Fill

The proposed source of random fill for saddle dams is the Venado sandstone ridge northwest of the proposed Golden Gate Dam. A wedge of material in a parallelogram shape 300 feet wide by 300 feet high and 1,400 feet long would be required to provide 4.6 mcy of fill. No testing has been performed on this quarry site but its properties should be similar to the Sites quarry.

This quarry is inside the reservoir footprint and is the same quarry that would provide random fill material for Golden Gate Dam. Haul distance to the major saddle dams would be 1 to 3 miles.

Drain and Transition

There is a possibility that the transition material can be supplied by crushed Venado sandstone. Drain material will probably require aggregate from a source outside the vicinity of the dam site.

Colusa Reservoir Dams

Impervious Materials

The terrace deposits mapped in the Hunters, Logan, and Minton Creeks and other unnamed drainages are shown on Figure 7. The mapped area of the valley floors occupied by the Qlft terrace is 964 acres. Assuming the terrace thickness is 10 feet, the volume of material in these terrace deposits is about 15 million yd^3. The terrace deposits along the drainages in the Colusa Reservoir area are not as extensive as those along Funks, Stone Corral, and Antelope Creeks. The field classification of the terrace material exposed in the incised stream channels is silty clay to clayey silt with some gravel.

The volume of impervious fill required for the Hunters and Logan Dams and the Colusa saddle dams is 13,200,000 yd^3, which is 818 acres at 10 feet thick. Haul distances of 3 or more miles will be required to transport this material to the dam sites. Nearly all of the Qlft terrace deposits inside the reservoir footprint will be required. Another potential source of impervious fill material is the deposits of weathered Boxer Formation mudstones that occur in the area. Some of these deposits have been observed with thicknesses of 12 or more feet.

No test pits have been placed in the Colusa Reservoir footprint for material testing and classification.

Random Fill

A source for the random fill for the dams for the Colusa complex has not yet been identified. The required volume of material is approximately 60,000,000 yd^3. This volume of Venado sandstone is not available within the reservoir footprint. There are some Boxer sandstones mapped along the western margin of the reservoir, but these are also outside the footprint. The ridges of Venado sandstone upon which the Hunters Dam and Logan Dam are based are single ridges, not double ridges like the Golden Gate Dam and Sites Dam sites. Using the analogy of a ridge quarry of 300 by 300 feet, a ridge over 3 miles long would be required to supply the required volume of material. There is a 250-foot-high ridge about 1/2 to 3/4 mile east of Hunters Dam site that apparently consists of sandstone beds that could provide a source for the random fill. This ridge has not been mapped or sampled for an evaluation of its properties. It would also require an environmental study as it is outside the reservoir footprint.

Drain and Transition

There is a possibility that the transition material can be supplied by crushed Venado sandstone. Drain material will probably require aggregate from a source outside the vicinity of the dam site.

Conclusions

Construction materials in the vicinity were investigated for the Sites Project. Materials required include impervious core, random fill, shell and rockfill, and filter and drain. The geologic materials investigated include terrace deposits, sandstone beds, and sand and gravel deposits. For Sites Dam, Golden Gate Dam, and the saddle dams, there is an adequate reserve of terrace deposits with the appropriate properties to supply the material for the impervious core. There is an adequate quantity of quarry sandstone either within or just outside of the reservoir to supply the random rock. The sandstone may be of marginal quality to provide the shell zone, and it is undergoing further testing. Degradation of the shell by weathering of the exposed rock should be expected during the life of the structure and may require selective replacement. If the sandstone will not meet properties needed for pervious shell material, the preliminary zoned rockfill design will have to be revised or, another source would be required. Sources of stronger rock have not yet been investigated. Filter and drain and concrete aggregate would need to be provided from sand and gravel deposits outside the reservoir area. Adequate reserves of developable sand and gravel exist on the Stony Creek fan in the vicinity of Willows and Orland.

A reconnaissance-level investigation was performed for construction materials for the Colusa Reservoir dams. Required materials include impervious core, random fill, rockfill, filter, and drain. For Hunters Dam and Logan Dam, the volume of nearby terrace deposits for the impervious core equal the volume required. Terrace deposits have not been sampled. The source of the random fill has not been identified. Sandstone beds of the Cortina Formation do not exist within the reservoir footprint in the Colusa Cell of the reservoir and the ridge occupied by the dam is a single ridge. There is a ridge about 1/2 mile east of Hunters Dam but it has not been mapped or sampled. Filter and drain, and concrete aggregate would need to be provided from sand and gravel deposits outside the reservoir area. Adequate reserves of developable sand and gravel exist on the Stony Creek fan in the vicinity of Willows and Orland.

Recommendations

Sites Dam

- Detailed geologic mapping of sandstone quarry area to estimate sandstone versus mudstone volume. May include limited drilling.
- Sample and test weathered and unweathered mudstone to determine physical properties to establish whether it can be used as random or rock fill.
- Perform further tests on the sandstone to establish whether it can be used as the dam's upstream shell.

Golden Gate Dam

- Detailed geologic mapping of sandstone quarry area (may be spillway alignment) to estimate sandstone versus mudstone volume. May include limited drilling.
- Sample and test weathered and unweathered mudstone to determine physical properties to establish whether it can be used as random or rock fill.
- Perform further tests on the sandstone to establish whether it can be used as the dam's upstream shell.
- Sample sandstone to confirm properties are consistent with those of rock from Sites quarry area.

Hunters and Logan Dams

- Test pit, sample and analyze terrace deposits.
- Map areas of thick soil development on the Boxer Formation.
- Test pit, sample and analyze thick soils.
- Obtain right of entry to Logan Land and Cattle Co. property east of Hunters Dam, and map sandstone ridge that is potential source of random fill.
- Sample and test sandstone and mudstone from ridge.
- If sandstone is suitable for random fill, then perform full environmental analysis of ridge (botanical, biological, cultural, etc.).

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North of the Delta
Offstream Storage Investigation

Progress Report

Appendix P: Sites and Colusa Reservoir Projects, Construction Materials Sampling and Testing

August 2000

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North of the Delta
Offstream Storage Investigation

Progress Report

Appendix P: Sites and Colusa Reservoir Projects, Construction Materials Sampling and Testing

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Integrated
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Introduction

This report presents the results of ongoing and previous investigations of construction materials for the proposed Sites Dam, Golden Gate Dam, and associated saddle dams for Sites Reservoir, and to a lesser extent the proposed Hunters Dam and Logan Dam for Colusa Reservoir. This investigation is part of the analysis of several alternative dam/reservoir sites being proposed for offstream storage as part of the North of the Delta Offstream Storage Investigation. The investigation focused on the materials required for earthfill and rockfill structures. Issues addressed include the geology of the site vicinity; occurrence of impervious materials in terrace deposits; suitability of sandstone for random fill, aggregate, and riprap; and occurrence of appropriate aggregate sources within a reasonable haul distance.

The proposed Sites Dam and Golden Gate Dam would impound a reservoir (Sites Reservoir) with a capacity of 1.8 million acre-feet and the addition of Hunters Dam and Logan Dam would result in a reservoir (Colusa Reservoir) with a capacity of 3.0 million acre-feet. The location of the proposed reservoirs is shown on Figure 1.

Previous Work

Sites and Golden Gate dam sites were previously investigated by the United States Bureau of Reclamation in 1969 and 1980. The Hunters and Logan dam sites have only had reconnaissance-level work performed by the Department of Water Resources. Several studies have investigated the availability and suitability of construction materials for these dam sites.

A report entitled *Engineering Geology Appendix-Part II* (USBR, Project Development Division, Geology Branch, 1969) provides geologic data for USBR's use in preparing cost estimates for proposed canals, dams, and a pumping-generating plant. That report includes: 1) descriptions of the sandstone units and terrace deposits proposed for use as aggregate, riprap, random fill, and impervious material; 2) maps of the units and locations of trench and auger sites; 3) results of laboratory testing; and 4) estimates of the volume of construction materials located near each proposed dam site. The USBR investigation included mapping proposed impervious materials from terrace deposits in the valley upstream from each site and delineating proposed rock quarrying at the old Sites Quarry and on the southeast ridge at Golden Gate. Summary results of the USBR testing and analysis, and volume estimates are presented in Table 1 and areas investigated are shown on Figure 2.

USBR conducted additional studies on saddle dams and rock testing and published a report *Construction Materials Report for Sites Dam, Golden Gate Dam, and Dike Sites* (USBR, Mid-Pacific Region Geology Branch) in 1980. The results of this testing are presented in Table 2. DWR reviewed data from previous work and submitted a Memorandum Report entitled "Colusa Reservoir Complex" in 1978. This report gives preliminary cost estimates for dam and spillway construction for the proposed Colusa Reservoir.

Table 1. Construction Materials Summary from USBR (1969)

Designation (Figure 1)	Stripping Depth (ft)	Avg. Thickness (ft)	Depth to Water (ft)	Oversize	Volume of Material (cu. yd.)	Lithology	Source	Liquid Limits	Plasticity Indices	Compacted Density lb/ft^3
IMPERVIOUS SOURCES										
Area 1	0.5-1	10.5	8.0-15.7	0-5% 5"max.	9,800,000	Lean clay (CL), minor clayey gravelly sand (SC)	Quaternary Terrace Deposits	35.8-36.3	16.4-17.5	106.4-107.8
Area 1a		9	9.0-11.7	None encountered	2,800,000	Lean clay (CL)	Quaternary Terrace Deposits			
Area 2	0.5-1	9	5.5-30	None encountered	13,700,000	Lean clay (CL), minor Sandy Clay (CL-ML) and silty Sand (SM-GM)	Quaternary Terrace Deposits and Alluvium	30.2-34.9	10.9-16,2	105.7-110.0
Area 2a		10.7	6.5-30	None encountered	4,400,000	Same	Same			
Area 3	0.5	8	Not in Alluvium	None encountered	2,400,000	Lean Clay (CL)	Quaternary Alluvium	35.5-40.7	15.7-21.6	106.8
Area 4	0.5	7.5	7.5-10.5	Trace 5" max.	2,900,000	Lean Clay (CL), minor Clayey Gravelley Sand (SC)	Quaternary Terrace Deposits	NA	NA	NA
RIPRAP - ROCKFILL, BEDDING										
Area 5	5.0-10	250	Not in quarry area	NA	15,000,000	Lightly weathered to fresh cemented sandstone	Venado Formation			
					2,000,000	Slopewash, moderatedly weathered sandstone, siltstone, claystone, thin bedded sandstone				
Area 6	5.0-10	250		NA	6,000,000	Lightly weathered to fresh cemented sandstone	Venado Formation			
					800,000	Slopewash, moderatedly weathered sandstone, siltstone, claystone, thin bedded sandstone				
Area 7	5.0-10	250	Not in quarry area	NA	11,900,000	Lightly weathered to fresh cemented sandstone	Venado Formation			
					1,800,000	Slopewash, moderatedly weathered sandstone, siltstone, claystone, thin bedded sandstone				

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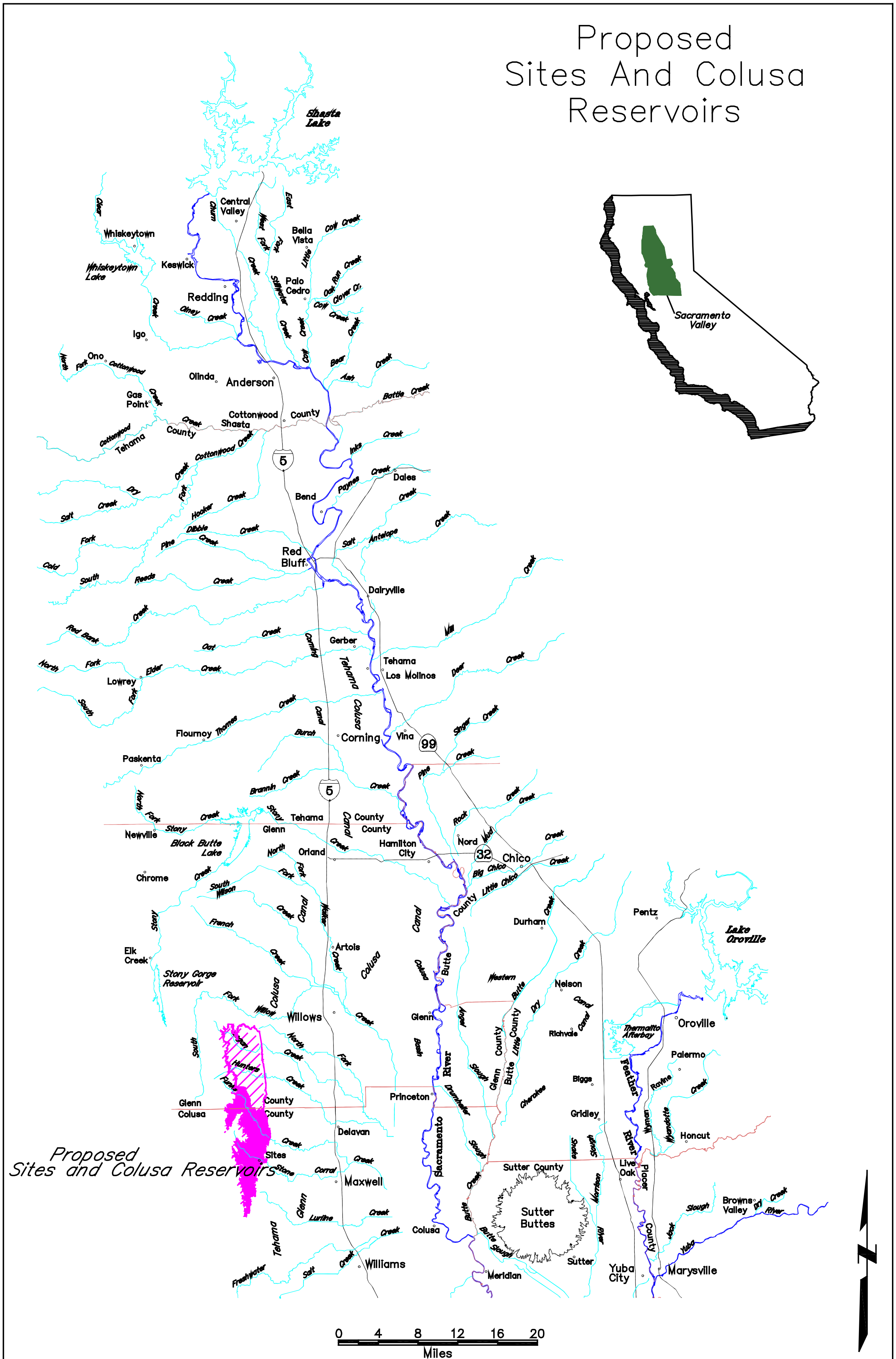

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Figure 1. Sites and Colusa Reservoirs Regional Location Map

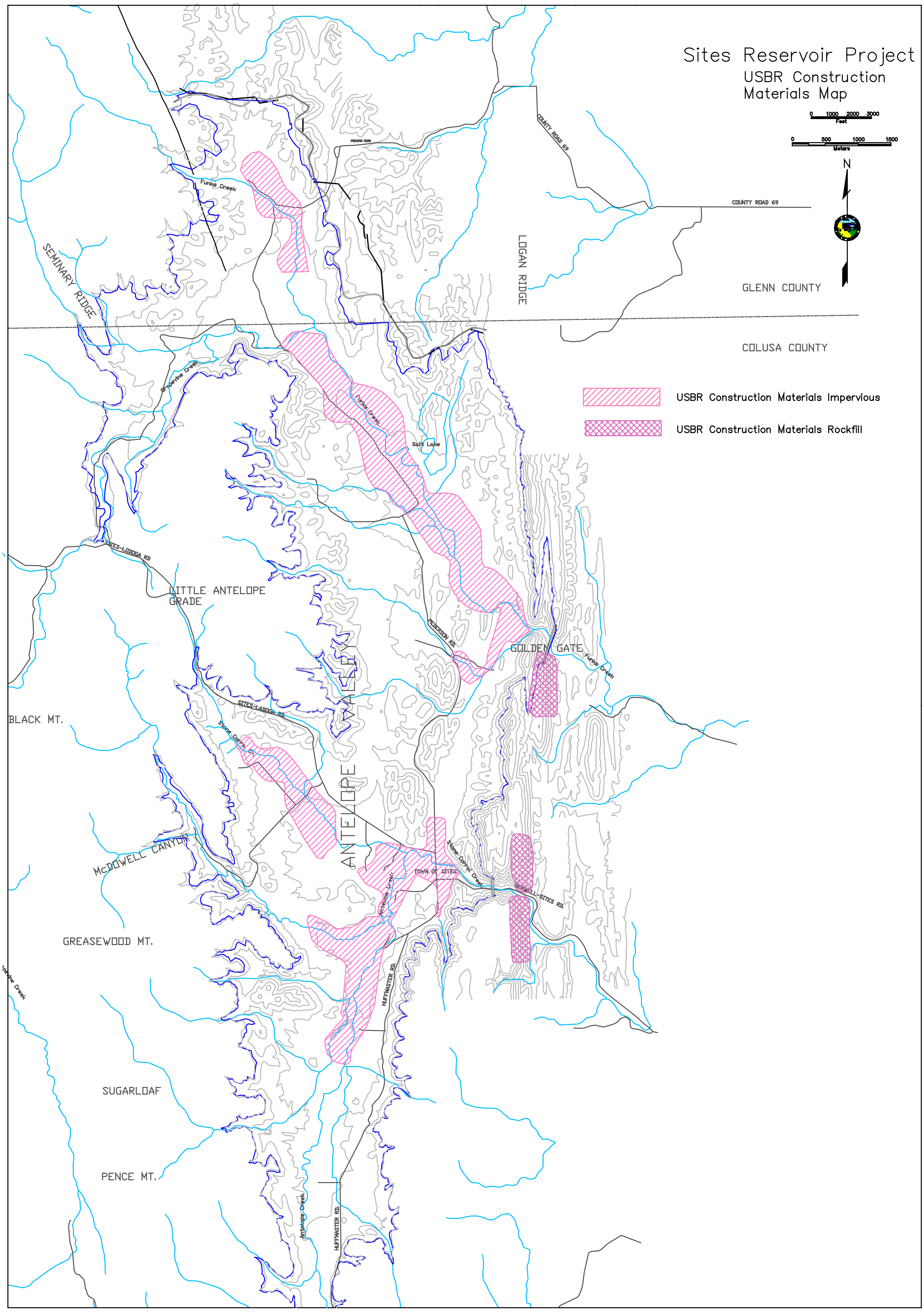


Figure 2. USBR Construction Materials Source Areas

Table 2. Historic Rock Test Data from USBR, 1969 and 1980

Date of Sampling	Sample	Specific Gravity S.S.D.	Absorption	Abrasion (L.A. Rattler)	Soundness (Mg SO4)	Wetting and Drying	Notes
1962	#1 Weathered Sandstone	2.44	3.4%	45% loss	Relatively High Loss	"after 15 cycles in fresh & salt water a noticeable softening and loosening of surface grains is evident"	Samples from old Sites Quarry tested by the U.S. Army Corps of Engineers for use as riprap on Sacramento River levees.
	#2 Fresh Sandstone	2.58	3.3%	39.1% loss	92.50%	"Slight surface sloughing"	
	#3 Fresh Sandstone	2.5	3.5%	34.1% loss	15% loss	Not Reported	
1972	Poorer of The Brown #1	2.42	6.1%				Sample of 500 pounds of rock from Sites Quarry 1 mile east of Sites, California. Samples analyzed by USACE
	#2	2.37	7.0%				
	#3	2.41	6.3%				
	Better of The Brown #1	2.44	4.8%	39%		"Better of the Brown" specimens flaked during the entire test.	
	#2	2.44	4.8%				
	#3	2.41	4.1%				
	Blue #1	2.43	4.1%	26%		"blue" rock parted along joints during the twelfth cycle. Minor flaking occurred to all "Blue" specimens throughout the test	
	#2	2.5	2.9%				
	#3	2.45	3.1%				
1974	1.5"-.75"	2.47	4.4%	18.9%/100			Sample of quarry rock from Sites Quarry South tested by Bureau of Reclamation Denver, CO. Sample from lower in quarry
	.75"-.375"	2.47	5.1%	52.6%/500			
	.375"-#4	2.45	6.0%				

Scope of Study

This study assessed the availability of adequate construction materials for the proposed earthfill dams. This was accomplished by reviewing the available data, performing field investigations, sampling, laboratory testing, and compiling the data into this report. The types of construction materials required for dam construction include impervious materials, rock and random fill, filter and drain material, and concrete aggregate. The geologic materials investigated include terrace deposits, sandstone, and commercial or developable sand and gravel deposits.

This study concentrated on refining the volume estimates and boundaries of the terrace and sandstone deposits previously investigated, performing additional laboratory testing of the materials to ensure conformance to the necessary standards, and evaluating additional rock sources for Golden Gate Dam.

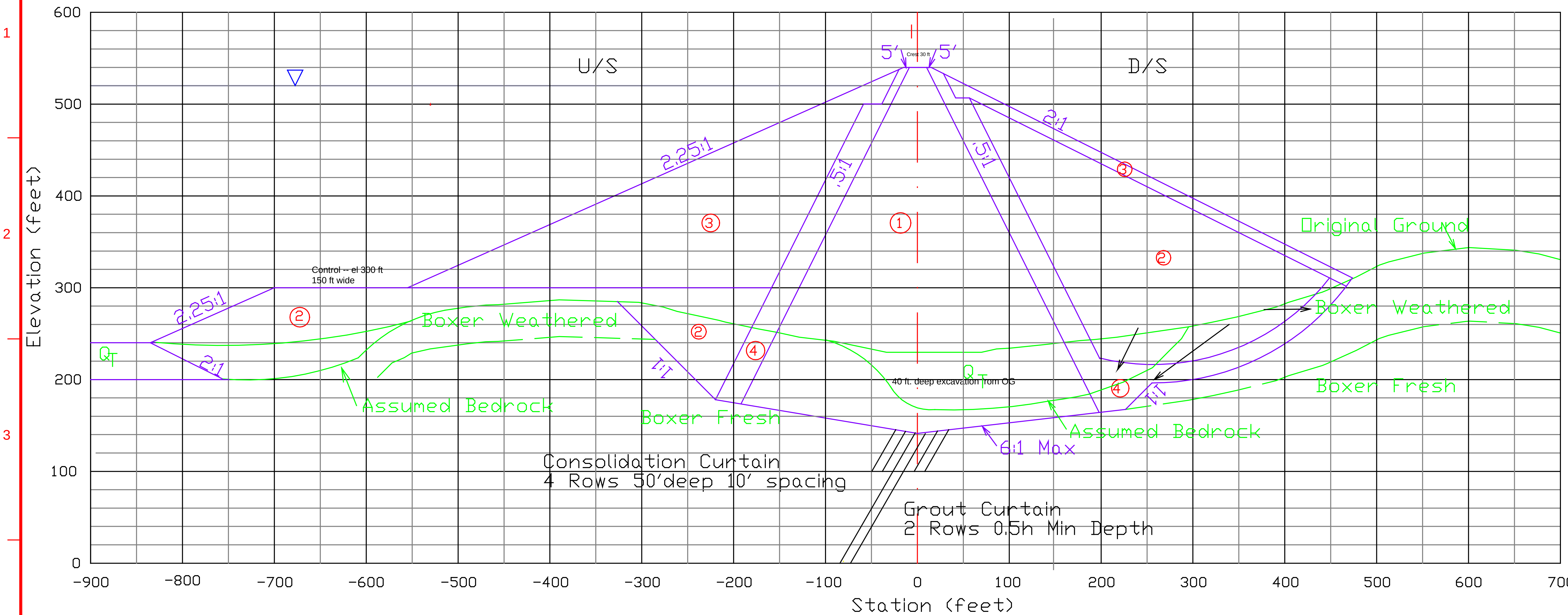
Previous investigations for the Logan and Hunter dam sites were limited, so this study provides preliminary mapping of source areas, field reconnaissance, and limited laboratory testing to confirm the suitability of the material.

Aggregate studies were done because it was questionable that available on-site materials were of satisfactory quality. These studies included an assessment of gravel mining operations currently operating, historic operations, and other potential sources.

Field investigations for impervious materials included measuring the thicknesses of terrace deposits exposed in stream channels, confirming terrace deposit boundaries, confirming depths and soil types using test pits, and sampling test pits for materials testing. The field investigation of rock sources included mapping sandstone units, measuring the thickness of sandstone and mudstone interbeds, and assessing the amount of weathering.

Material Requirements

Based on preliminary studies, each of the earthfill structures contains four zones of material. Current design studies for the Golden Gate Dam and Sites Dam (see Offstream Storage Investigation Progress Report) calls for impervious core, random rock, shell zone, and filter and drain (see Figure 3). The most recent design for Hunters Dam, Logan Dam, and the saddle dams (Northern District 1999) includes impervious core, random fill, filter, and drain. The estimated volume requirements of these materials for each dam are presented in Tables 3, 4 (Northern District), and 5 (DOE). Recommended laboratory tests and preferred material properties of each construction material zone are presented in Tables 6 and 7.



Zone 1 Core
Zone 2 Random
Zone 3 Shell and Rockfill
Zone 4 Filter and Drain

Source: DOE June 1999

GOLDEN GATE DAM
CROSS-SECTIONS
CURVED ALIGNMENT
DOWNSTREAM LOCATION
6/10/99

REV.	DATE	DESCRIPTION	DRAWING SCALES	GEOLOGY REPORT No. / CONSTRUCTION SPEC. No. / GEOLOGY DRAWING No.	GEOLOGIC MAPPING AND/OR LOGGING BY: / DRAWING PREPARED BY: DATE: 06/30/99	STATE OF CALIFORNIA THE RESOURCES AGENCY DEPARTMENT OF WATER RESOURCES DIVISION OF PLANNING & LOCAL ASSISTANCE NORTHERN DISTRICT GEOLOGY SECTION	Figure 3 Typical Golden Gate Dam Cross-section (Looking Northerly)	RELEASE DATE: / SHEET No. / PLATE

Plot Time: Jun 09, 2000 - 10:04am Filename:N: \geo\EMPLOYEES\ber\Cmreport\FINALFIGURES\Figure3actual.dwg

Table 3. Sites Reservoir Required Construction Materials Quantities (in cubic yards)

	Sites Dam	Golden Gate Dam	Saddle Dam 1	Saddle Dam 2	Saddle Dam 3	Saddle Dam 4
Excavation	**731,941**	**1,556,621**	**72,267**	**146,240**	**1,398,431**	**33,208**
Stripping:	641,211	1,337,940	61,139	124,033	1,189,128	28,180
Cutoff Trench:	90,730	218,682	11,128	22,206	209,302	5,028
Fill	**4,745,177**	**11,276,180**	**130,854**	**208,429**	**4,665,816**	**39,607**
Zone 1 - Impervious Core:	970,723	2,551,828	42,514	67,472	1,199,498	39,607
Zone 2 - Random:	3,217,399	7,374,246	43,586	57,352	2,586,890	
Drains:	289,090	700,653	21,908	40,927	430,503	
Transition:	267,965	649,453	22,846	42,678	448,925	

	Saddle Dam 5	Saddle Dam 6	Saddle Dam 7	Saddle Dam 8	Saddle Dam 9	Sites Reservoir Total
Excavation	**615,743**	**123,126**	**45,835**	**901,482**	**56,051**	**5,700,000**
Stripping:	508,002	102,697	37,415	761,967	45,640	4,800,000
Cutoff Trench:	107,741	20,429	8,420	139,514	10,411	800,000
Fill	**1,843,907**	**248,596**	**62,992**	**2,118,213**	**78,578**	**25,400,000**
Zone 1 - Impervious Core:	533,357	78,421	26,800	606,304	31,816	6,100,000
Zone 2 - Random:	863,684	88,732	4,131	939,140	6,454	15,200,000
Drains:	218,752	39,869	15,695	280,385	19,732	2,100,000
Transition:	228,113	41,575	16,366	292,383	20,576	2,000,000

Sites Reservoir Summary--Earthfill Dam with a crest of 540 feet

Water Surface Elevation=520 feet

Capacity=1,800 taf

Source: DWR Northern District, 1999

Table 4. Colusa Reservoir Required Construction Material Quantities (in cubic yards)

	Sites Dam	Golden Gate Dam	Colusa Saddle Dam 1	Prohibition Dam	Owens Dam	Hunters Dam	Colusa Saddle Dam 2
Excavation	**731,941**	**1,556,621**	**104,753**	**2,549,068**	**2,856,598**	**5,247,086**	**727,234**
Stripping:	641,211	1,337,940	92,262	2,349,513	2,672,818	4,841,493	687,076
Cutoff Trench:	90,730	218,682	12,491	199,556	183,780	405,593	40,158
Fill	**4,745,177**	**11,276,180**	**214,004**	**11,333,934**	**11,679,831**	**24,766,228**	**2,283,531**
Zone 1 - Impervious Core:	970,723	2,551,828	51,152	1,630,785	1,577,253	3,341,283	173,205
Zone 2 - Random:	3,217,399	7,374,246	113,600	8,494,550	8,991,069	18,965,043	1,949,320
Drains:	289,090	700,653	24,110	627,216	576,830	1,276,594	78,817
Transition:	267,965	649,453	25,142	581,383	534,679	1,183,308	82,189

	Logan Dam	Colusa Saddle Dam 3	Colusa Saddle Dam 4	Colusa Saddle Dam 5	Colusa Saddle Dam 6	Colusa Saddle Dam 7	Colusa Reservoir Total
Excavation	**5,345,029**	**490,790**	**145,981**	**378,760**	**21,859**	**604,022**	**20,800,000**
Stripping:	4,736,104	409,376	120,798	319,774	17,989	502,162	18,700,000
Cutoff Trench:	608,925	81,414	25,182	58,986	3,870	101,860	2,000,000
Fill	**30,573,933**	**1,579,686**	**351,868**	**1,306,592**	**26,760**	**1,575,250**	**101,700,000**
Zone 1 - Impervious Core:	5,043,213	423,807	109,428	334,297	26,760	469,192	16,700,000
Zone 2 - Random:	21,808,058	815,237	139,572	723,316	0	687,248	73,300,000
Drains:	1,931,918	166,753	50,357	121,882	0	205,018	6,000,000
Transition:	1,790,744	173,888	52,511	127,097	0	213,791	5,700,000

Colusa Reservoir Summary-Earthfill Crest--540 feet

Water Surface Elevation=520 feet capacity=3,100 taf

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Table 5. Updated Dam Volumes for the Revised Section for Sites and Golden Gate Dams (in cubic yards)

	Sites Dam	Golden Gate Dam*	Description
Core (Zone 1)	1,068,600	3,459,600	Impervious core from reservoir site deposits consisting predominately of lean clay (CL), with some sandy clay and clayey sand (SC)
Random (Zone 2)	1,085,400	2,796,900	Random rock consisting of moderately to slightly weathered rock up to 30-inch maximum particle size, with fines not to exceed 35% minus No. 4.
Total Shell (Zone 3)	1,180,500	2,866,300	Shell zone of fresh rock up to 30-inch maximum particle size, with fines not to exceed 20% minus No. 4.
Filter/Drain (Zone 4)	501,400	1,467,300	Filter and drain consisting of fresh rock processed to various sizes, generally 1-1/2-inch maximum particle size (3% limit on minus No. 200 sieve material).
	3,835,900	10,590,100	

*Volumes for Golden Gate Dam are for the downstream curved alignment.

Source: DWR, DOE, 1999 (refer to Figure 3)

Table 6. Construction Materials Tests and Preferred Properties

	Atterberg Limits		Gradation	Organic Content	Compaction	Permeability	Triaxial Shear	Specific Gravity	Classification
	Liquid Limit	**Plastic Limit**							
ASTM	D 4318	D 4318	D 422	D 2974	D 1557	D 5084	D 4767	D 854	D 422
Impervious Core (Zone 1)	36%	17%	Less than 15-35% sand		107pcf@18 %moisture	1 X 10-6cm/sec	F30		Predominately lean clay (CL), with some sandy clay and clayey sand (SC).
	Unconfined Compression	Wet Dry test	Abrasion-L.A. Rattler	Soundness	Specific Gravity and Absorption	Bulk Density	Splitting Tensile Strength	Bulk Density	Classification
ASTM	D 3148	D 5313	C 131/535	C 88	C 127/128	C 29	C 496	C 29	C 136
Random Rock Zone 2	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	138	Not Specified	Not Specified	Moderately to slightly weathered rock up to 30-inch maximum particle size, with fines not to exceed 35% minus No. 4.
Shell and Rockfill Zone 3	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	145	Not Specified	Not Specified	Fresh rock up to 30-inch maximum particle size, with fines not to exceed 20% minus No. 4.
Filter and transition Zone 4	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified	125	Not Specified	Not Specified	Fresh rock processed to various sizes, generally 1 1/2-inch maximum particle size (3% limit on minus No. 200 sieve material).

Table 7. Preferred Embankment Material Properties and Description

Material	Shear Strength Parameters				Dens			Description
	Effective		Total		Dry	Moist	Saturated	
	F'	c" (psf)	F	c (psf)				
Impervious Core (Zone 1)	34	0	16	800	107	111	131	Predominately lean clay (CL), with some sandy clay and clayey sand (SC).
Random Rock (Zone 2)	39	0	Not Specified	Not Specified	138	Not Specified	Not Specified	Moderately to slightly weathered rock up to 30-inch maximum particle size, with fines not to exceed 35% minus No. 4.
Shell and Rockfill (Zone 3)	42	0	Not Specified	Not Specified	145	Not Specified	Not Specified	Fresh rock up to 30-inch maximum particle size, with fines not to exceed 20% minus No. 4.
Filter and Drain (Zone 4)	42	0	Not Specified	Not Specified	125	Not Specified	Not Specified	Fresh rock processed to various sizes, generally 1-1/2-inch maximum particle size (3% limit on minus No. 200 sieve material).

Source: Bill Verigin Memo, February 1999

Golden Gate Inlet/Outlet Works

The Golden Gate inlet-outlet works site is about 3,200 feet directly south of the right abutment for Golden Gate Dam site in Sections 16 and 17, R4W, T17N on the Sites 7.5-minute USGS topographic quadrangle. The outlet works would include a shared intake structure, a 30-foot diameter intake-outlet tunnel with penstock extending 3,300 feet through both ridges, and a 400-foot deep vertical access shaft along the tunnel gate works. It would also include a spillway cutting across both ridges, a combination pumping plant/hydroelectric facility, and a shared approach channel that would terminate in Funks Reservoir. For the purposes of this foundation investigation, these structures have been grouped into four areas by similar topography and lithology. These are the shared intake structure, the tunnel through the ridges, the spillways, and the approach channel from the pumping plant to Funks Reservoir (Photo 18). Water from the Sacramento River will be conveyed via canal and pumped into the proposed Sites and/or Colusa Reservoirs through the pumping plant and 30-foot diameter tunnel. Releasing flows back through the tunnel and hydroelectric facility will generate power. The spillway will be required to release 10 percent of the reservoir height in 10 days. Two possible locations for the spillways exist. A smaller one is proposed north of the tunnel alignment or a larger one proposed south of the tunnel alignment.

Site Geology

The site was first mapped by USBR in 1963 as part of its *West Sacramento Canal Unit Report* (DOI-USBR 1964) and again in 1980. This mapping was used as the basis for DWR Northern District's geologic mapping of the site from September through October 1998. DWR's Division of Engineering assisted with this mapping, and both its mapping and Northern District's mapping have been incorporated into this report. The proposed facilities would be built on northerly trending, easterly dipping Cretaceous sedimentary rocks of the Boxer Formation to the west, and the Cortina Formation to the east. These formations consist of layered sandstones and mudstones, with the more resistant sandstones forming two parallel ridges, and the less resistant mudstones forming valleys in between. These ridges also comprise the various proposed Golden Gate Dam foundations to the north. Colluvial cover on the sandstone ridges averages up to 5 feet in depth. Alluvial and terrace deposits cover bedrock in the valleys to a greater depth, especially toward Funks Reservoir to the east. These Quaternary terrace deposits occur along the proposed approach channel to a depth of about 20 feet, and are composed of sand, gravel, and cobbles, mantled by a clayey soil.

Plates 6 and 7 are the geologic plan and geologic cross sections and profiles with core logs and analysis of water pressure testing at the site. Detailed logging and photodocumentation of the drill core is presented in Technical Memorandum A. Details of the water pressure testing are presented in Technical Memorandum B. Details of the piezometer construction and water levels are presented in Technical Memorandum C.

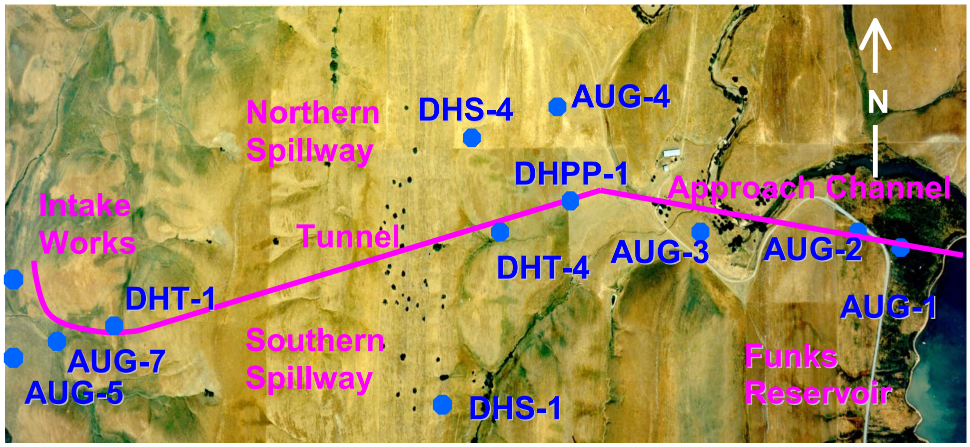

Photo 18. Aerial view of Golden Gate Inlet-Outlet Works and drill holes (see Plate 6)

Bedrock Units

The proposed Golden Gate inlet-outlet works trends nearly normal to the interlayered beds of Upper Cretaceous sandstone, siltstone, mudstone, and very minor conglomerate of the Boxer and Cortina Formations. The relative percentages of the sandstone and mudstone change frequency along the alignment. This is detailed on Plate 7, Geologic Cross Section of Golden Gate Diversion Tunnel. The shared intake structure is founded primarily on mudstone of the Boxer Formation. The diversion tunnel intersects dominantly sandstone units that comprise the two main ridges. The majority of each of the foundations for the two proposed spillways extend through these ridges, with the eastern portions terminating in a greater percentage of mudstone in the Yolo Member of the Cortina Formation. The shared approach then continues eastward across this formation, terminating in Funks Reservoir.

These bedrock units were differentiated into mappable units as follows:

- KCVs - predominantly silty sandstone (70 to 100 percent) of the Venado member of the Cortina Formation with mudstone intervals (0 to 30 percent) up to 5 feet in thickness.

- KCVsm - interbedded mudstones (30 to 70 percent) and silty sandstones (30 to 70 percent) of the Venado member of the Cortina Formation.

- KBm - predominantly mudstone (70 to 100 percent) of the Boxer Formation with silty sandstone intervals (0 to 30 percent) up to 5 feet thick.

Sandstone is the most resistant rock type at the site and comprises about 55 percent of the total areal extent of the spillways and tunnel alignment. Where fresh, it is light to medium olive gray in color, but where weathered, it is yellowish brown. The sand is very fine to medium grained, angular to subangular, and poorly sorted. The matrix is mostly calacareous clay. Bedding is thin to massive and outcrops in layers ranging from less than a foot to tens of feet in thickness. It contains thin interbeds of siltstone and mudstone that range from laminar up to 5-feet thick. It is mostly weathered near the surface and slightly weathered to a depth of at least 20 feet. It is moderately to well indurated, moderately to slightly fractured, moderately hard to very hard, and strong. Internal structure is well developed where laminar and vague where massive. Fractures are commonly healed with calcite and minor pyrite.

The sandstone also grades transitionally into siltstones. These are olive gray when fresh to olive green where weathered, and contain sandstone and mudstone interbeds. The siltstone is moderately to well indurated, moderately hard to hard and strong, and moderately to slightly fractured.

Mudstone is the least resistant rock type in the area and comprises about 45 percent of the total areal extent of the spillways and tunnel alignment. Where fresh, it is dark gray to black in color; it's tan where weathered. Bedding is laminar with thin sandstone and siltstone interbeds. It is brittle, and in outcrop it slakes readily when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak, and closely fractured.

Unconsolidated Deposits

Unconsolidated deposits overlying the bedrock for the proposed structures consist of Quaternary stream channel deposits of sand and gravel, several stream terraces, colluvium, and landslides. The approach channel to Funks Reservoir also crosses alluvium in Funks Creek. The alluvium consists of sand and gravel with lesser amounts of clay, silt, and cobbles, and with depths averaging up to 5 feet. Minor alluvium also occurs as deposits from minor drainages along the slope breaks off each of the ridges and as discontinuous deposits in the north-draining gully between these ridges. A terrace deposit (Qt2) up to 36-feet thick overlies most of the foundation for the shared approach channel. It has moderate soil development. The upper part of this terrace is clayey silt with a clay content that increases with depth. The upper 2 to 3 feet is very dark grayish brown that becomes lighter with depth to a dark grayish brown. A few gravel lenses are exposed along the sides of the incised stream channel of Funks Creek and also encountered in several of the auger holes. In places there is a clay bed at the base of the observable deposit. This terrace may be correlative with the Lower Modesto Formation as mapped by Helley and Harwood (Calif., Sacramento Valley 1982).

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular rock fragments. The colluvium ranges up to 5 feet in thickness overlying bedrock and terrace deposits at the base of the hillsides. Numerous landslides exist that have yet to be mapped. They are mostly shallow seated earth flows that are relatively small in scale.

Structure

The primary structural feature at the Golden Gate inlet-outlet works is the northerly striking, east-dipping homoclinal bedding of the Great Valley sequence. Local attitudes vary in strike from N10°W to N10°E, and bedding dips eastward, ranging from 45 to 55 degrees. These bedding attitudes are fairly uniform within the project area.

Faults and Folds

USGS mapped the Salt Lake thrust fault and three associated right lateral tear faults at and in the vicinity of the Golden Gate outlet works (Calif., Glenn and Colusa Counties 1961). The regional trend for these tear faults is to the northeast with a near vertical dip. Associated with these faults are narrow zones of gouge, slickensides, and sheared mudstone.

The northerly trending Salt Lake fault parallels the western side of the main sandstone ridges where the facilities would be located. It is about a half mile to the west of the inlet works (WLA 1997).

William Lettis and Associates have trenched these faults as part of its DWR-funded phase II fault and seismic investigation.

Tear fault GG-2 starts just east of the Salt Lake fault about 2 miles north of the town of Sites. It then extends to the northeast about a half mile where it trends through the intake channel for the proposed intake works, continuing northeast about another 3 miles.

Tear fault GG-3 starts close to the town of Sites, then extends to the northeast about 2 miles where it trends through the proposed upstream dam spillway and the approach channel to the pumping plant (Photo 19). It parallels and is between the NE tear fault S-2 that trends through Sites Dam site to the south and the NE GG-2 fault that trends through Golden Gate Dam site to the north. There may be another smaller northeastern splay off this fault that would intersect the outlet works farther east in the Funks Creek channel.

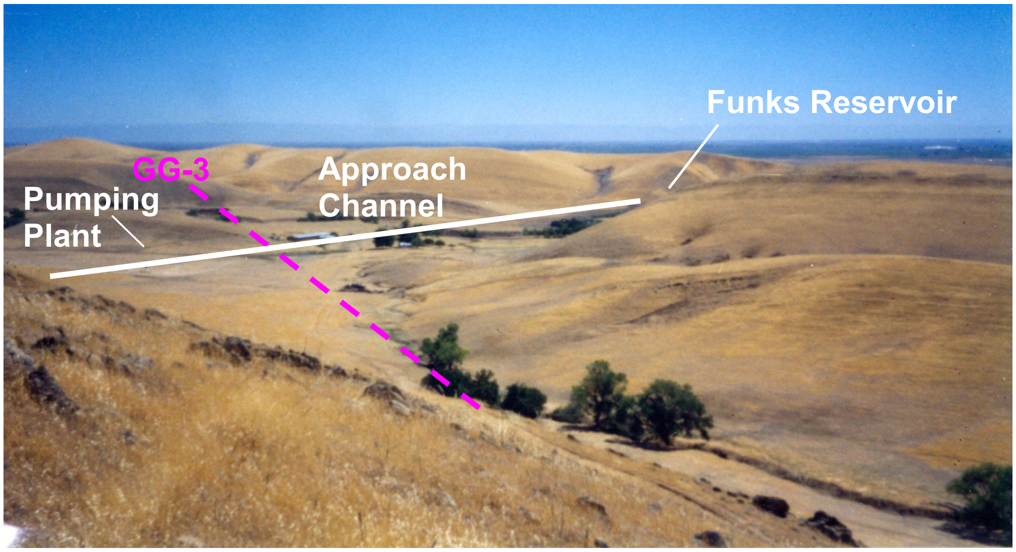

Photo 19. Northeast view of GG-3 fault relative to the approach channel (View from top of ridge at proposed southern spillway)

Joints

At least two distinct joint sets have been mapped at the central ridges for the Golden Gate outlet works. The dominant joint set trends roughly east west with near vertical dips. A secondary set trends N60°E with a generally NW dip averaging 70 to 80 degrees. There may be some jointing associated with the GG-3 fault, as suggested by jointing attitudes in outcrops that roughly parallel the western side of the fault in the Funks Creek channel.

Foundation and Tunneling Conditions and Exploration

The bedrock that the inlet-outlet works, tunnel, pumping plant, spillways, and approach channels will be excavated in should provide a good foundation for the works as proposed. The sedimentary rocks comprising the ridges are not anticipated to create difficult tunneling conditions. These rocks should also be easily excavated at either of the possible spillway locations. Only moderate clearing and stripping will be required. Also, numerous small shallow earth flows would be removed. At least two faults intersect some of the proposed structures but are not active. One of these, GG-3, intersects the southern spillway and pumping plant foundation; the other, GG-2, intersects the intake channel foundation. Neither should present a problem for construction. Table 10 summarizes the foundation conditions, and Figure 6 summarizes the surficial geology for each of the proposed components.

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The site was mapped on a regional scale initially by USGS in 1961, by USBR in 1963 and 1980, and then modified by DWR's Northern District with assistance from DWR's Division of Engineering. Mapping the central sandstone ridges generally showed good exposure of outcrops. Mapping of the western-shared intake foundation and eastern approach channel was more difficult due to limited exposures.

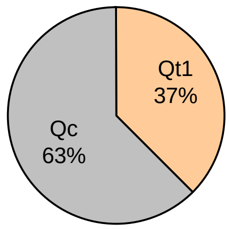
TABLE 10 –Sites Reservoir Project, Golden Gate Inlet - Outlet Works Foundation Conditions

FEATURE	AREAL GEOLOGY	CLEARING ESTIMATES	STRIPPING ESTIMATES	WATER LEVELS	GROUTING ESTIMATES	STRUCTURAL REMARKS
Shared Intake Works Width Max. = 830 feet Length Max. = 2,200 feet Elev. Max. = 390 feet Elev. Min. = 290 feet Drill holes = DHT-1, AUG-5, AUG-6, AUG-7 Seismic = SL-12, SL-13	Surficial Qt_1 = 325,000 feet^2 (37%), Qc = 543,400 feet^2 (63%), Total Area = 868,400 feet^2 Bedrock KBsm = 814,200 feet^2(94%), KBm = 54,200 feet^2 (6%) ,Total Area = 868,400 feet^2 therefore: Ss = from 224,300 feet^2 (28%), to 586,200 feet^2 (68%), Ms = from 624,100 feet^2 (72%) to 282,200 feet^2 (32%)	LIGHT: Open pastureland with scattered grasses and rare brush.	The upper 20 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 4 feet of moderately weathered rock may need to be excavated.	In the Summer and Fall of 1999 the depth to water below ground surface varied from 7.3 to 8.5 feet below ground surface at AUG-6 and 29 to 30 feet at DHT-1.	DWR Drill Hole DHT-1: High grout takes at 9 to 20 feet in intensely weathered and fx Ms/Ss, and at 103 to 114 feet in fx Ms/Ss. Low grout takes at 82 to 93 feet in fx Ms/Ss.	Fault (GG-2) strikes N65°E through the northern end.
Gate Intake and Penstock Width = 750 feet Length =800 feet Elev. Max. = 730 feet Elev. Min. = 540 feet Elev. Peak = 800 feet. Not drilled. No seismic.	Surficial Qc = 439,300 feet^2 (100%), Total Area = 439,300 feet^2 Bedrock KBm = 184,900 feet^2 (42%), KCVs = 254,400 feet^2 (58%),Total Area = 439,300 feet^2 Therefore: Ss = from 178,100 feet^2 (41%) to 309,800 feet^2 (71%), Ms = from 261,200 feet^2 (59%) to 129,400 feet^2 (29%)	LIGHT: Open pastureland with scattered grasses.	Not Drilled	Not drilled	Not drilled.	Bedding strikes north-south; dip averages 50 degrees east
Shared Diversion Tunnel Width = 30 feet Length = 4,000 feet Elev. Max. = 350 feet Elev. Min. = 270 feet Drill holes = DHT-1, DHT-4	Surficial Qt_1 = 900 feet^2 (0.5%), Qc = 185,600 feet^2 (99.5%), Total Area =186,500 feet^2 Bedrock KBsm = 30,600 feet^2 (16%), KBm = 37,500 feet^2 (20%), KCVs = 64,100 feet^2 (34%), KCVsm = 36,000 feet^2 (19%), KVm = 18,300 feet^2 (10%), Total Area = 186,500 feet^2 therefore: Ss = from 64,900 feet^2 (35%), to 127,500 feet^2 (68%), Ms = from 121,700 feet^2 (65%) to 59,100 feet^2 (32%)	Not Applicable (Subsurface)	The upper 20 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 5 feet of moderately weathered rock may need to be excavated.	In the Summer and Fall of 1999 the depth to water below ground surface varied from 29 to 30 feet at DHT-1 and 9 to 11 feet at DHT-4.	DWR Drill Hole DHT-1: High grout takes at 9 to 20 feet in intensely weathered and fx Ms/Ss, and at 103 to 114 feet in fx Ms/Ss. Low grout takes at 82 to 93 feet in fx Ms/Ss. DWR Drill Hole DHT-4: High grout takes at 17 to 70 feet in fx/sheared Ms/Ss.	Bedding strikes north-south; dip averages 50 degrees east
Pumping Plant Width = 1,100 feet Length = 1,800 feet Elev. Max. = 350 feet Elev. Min. = 240 feet Drill holes = DHPP-1, Seismic = SL-9	Surficial Qt_1 = 871,100 feet^2 (57%), Qc = 656,600 feet^2 (43%), Total Area = 1,527,700 feet^2 Bedrock KCVs = 93,100 feet^2 (6%), KCVsm = 1,240,600 feet^2 (81%), KCVm = 194,000 feet^2 (13%), Total Area = 1,527,700 feet^2 therefore: Ss = from 437,300 feet^2 (29%) to 1,019, 700 feet^2 (67%), Ms = from 1,090,400 feet^2 (71%) to 508,000 feet^2 (33%)	LIGHT: Open pastureland with scattered grasses and rare brush.	The upper 10 to 27 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 10 feet of moderately weathered rock may need to be excavated.	In the Summer and Fall of 1999 the depth to water below ground surface varied from12 to 15 feet at DHPP-1.	DWR Drill Hole DHPP-1: High grout takes at 6 to 38 feet in weathered and fx/sheared Ss/Ms, at 79 to 111 feet in fx Ss/Ms, and at 142 to 164 feet in fx Ss/Ms.	Fault (GG-3) strikes N40°E through the eastern end.
Northern Spillway Alternative #1 Width = 950 feet Length = 2,900 feet Elev. Max. = 610 feet Elev. Min. = 245 feet Drill hole = DHS-4, AUG-4 Seismic = SL-8	Surficial Qt_1 = 117,900 feet^2 (8%), Qc = 1,311,600 feet^2 (92%), Total Area = 1,429,500 feet^2 Bedrock KCVs = 427,900 feet^2 (30%), KCVsm = 653,200 feet^2 (46%), KCVm = 348,400 feet^2 (24%), Total Area = 1,429,500 feet^2 therefore: Ss = from 495,500 feet^2 (35%) to 989,700 feet^2 (69%), Ms = from 934,000 feet^2 (65%) to 439,800 feet^2 (31%)	LIGHT: Open pastureland with scattered grasses and rare brush.	The upper 7 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. An additional 7 feet of moderately weathered rock may need to be excavated.	In the Summer and Fall of 1999 the depth to water varied from being dry to 27 feet below ground surface at DHS-4	DWR Drill Hole DHS-4: High grout takes at 6 to 38 feet in weathered and fx Ms/Ss.	Bedding strikes north-south; dip averages 50 degrees east
Southern Spillway #2 Width (Avg.) = 1,000 feet Width (Max.) = 2,900feet ~350 feet wide Length = 5,000 feet Elev. Max. = 730 feet Elev. Min. = 240 feet Drill holes = DHS-1, FT6-AUG-1, FT6-AUG-2, FT6-AUG-3, FT6-AUG-4 No Seismic	Surficial Qt_1 = 152,300 feet^2 (4%), Qc = 4,194,300 feet^2 (96%), Total Area = 4,346,600 feet^2 Bedrock KBm = 152,500 feet^2 (4%), KCVs = 1,566,900 feet^2 (36%), KCVsm = 2,313,500 feet^2 (53%), KCVm = 313,700 feet^2 (7%),Total Area = 4,346,600 feet^2 therefore: Ss = from 1,790,900 feet^2 (41%) to 3,326,200 feet^2 (77%), Ms = from 2,555,700 feet^2 (59%) to 1,020,400 feet^2 (23%)	LIGHT: Open pastureland with scattered grasses and rare brush.	The upper 15 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. Additional 17 feet of moderately weathered rock may need to be excavated.	In the Summer and Fall of 1999 the depth to water below ground surface varied from 16 to 17 feet at FT6-AUG-1 and DHS-1 has been artesian continuously since being drilled	DWR Drill Hole DHS-1: High grout takes at 16 to 38 feet in fx/sheared Ss.	Fault (GG-3) strikes N40°E along the eastern dip-slope of ridge. Possible fault (lineament) strikes at N55°E near the eastern end of spillway.
Shared Outlet Width = 500 feet Length = 4,300 feet Elev. Max. = 240 feet Elev. Min. = 200 feet Drill holes = AUG-1, AUG- 2, AUG-3 Seismic = SL-10, SL-11	Surficial Qt_1 = 498,900 feet^2 (46%), Qt_2 = 139,900 feet^2 (13%), Qal = 34,600 feet^2 (3%), Qc = 410,900 feet^2 (38%), Total Area = 1,084,300 feet^2 Bedrock KCVs = 154,500 feet^2 (12%), KCVsm = 1,126,100 feet^2 (88%), Total Area = 1,280,600 feet^2 Therefore: Ss = from 446,000 feet^2 (35%) to 942,700 feet^2 (74%), Ms = from 834,600 feet^2 (65%) to 337,800 feet^2 (26%)	LIGHT: Open pastureland with scattered grasses and rare brush.	Auguring indicates up to 36 feet of soil, colluvium, and intensely weathered rock can be stripped with common methods. The additional depth to fresh bedrock is unknown.	In the Summer and Fall of 1999 the depth to water below ground surface varied from24 to 25 feet at AUG-3	Not drilled.	Possible Fault (lineament) strikes at N60°E near the eastern end.

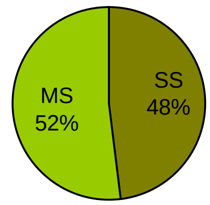
Ss = Sandstone Ms = Mudstone Cgl = Conglomerate Qal = Quaternary Alluvium Qc = Quaternary Colluvium Qt_1 = Quaternary Terrace (lower) Qt_2 = Quaternary Terrace (upper)
Fx = Fracturing

FIGURE 6: Sites Reservoir Project, Golden Gate Inlet-Outlet Works Foundations, Surficial and Bedrock Lithology By Percentage

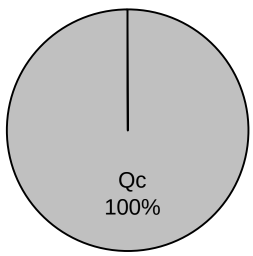
Areal Surficial Lithology of the Shared Intake Foundation



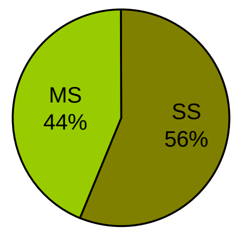
Areal Bedrock Lithology of the Shared Intake--Average Proportion of Sandstone and Mudstone



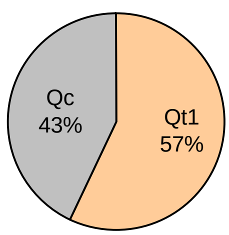
Areal Surficial Lithology of the Gate Works



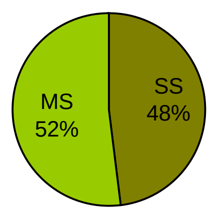
Areal Bedrock Lithology of the Gate Works - Sandstone Minimum/ Mudstone Maximum



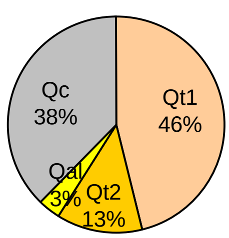
Areal Surficial Lithology of the Power Plant Foundation



Areal Bedrock Lithology of the Power Plant Foundation -- Sandstone Minimum /Mudstone Maximum



Areal Surficial Lithology of the Shared Outlets Approach Channel



Areal Bedrock Lithology of the Shared Outlets Approach Channel--Sandstone Minimum /Mudstone Maximum

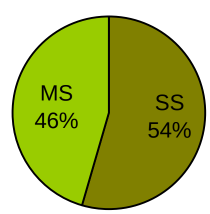
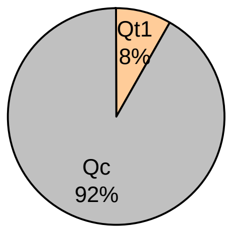
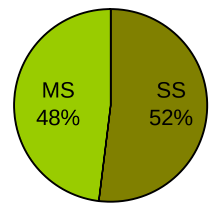


FIGURE 6: (continued)

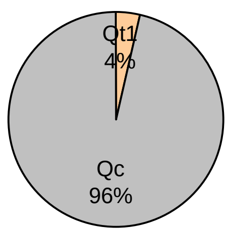
Areal Surficial Lithology of the Northernmost Spillway



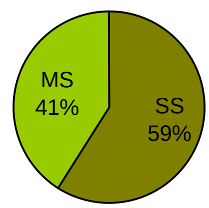
Areal Bedrock Lithology of the Northernmost Spillway--Sandstone Minimum/Mudstone Maximum



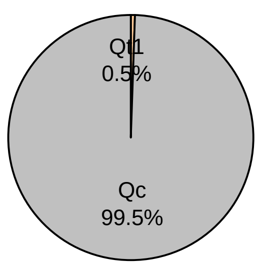
Areal Surficial Lithology of the Southernmost Spillway



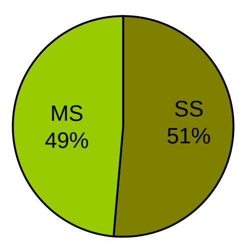
Areal Bedrock Lithology of the Southernmost Spillway--Sandstone Minimum/Mudstone Maximum



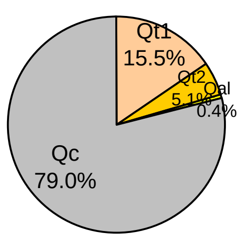
Areal Surficial Lithology of the Tunnel



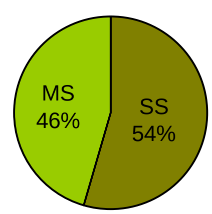
Areal Bedrock Lithology of the Tunnel--Sandstone Minimum/Mudstone Maximum



Total Areal Surficial Lithology of the Outlet Works



Areal Bedrock Lithology of the Outlet Works Footprint-Sandstone Minimum/Mudstone Maximum



In spring 1999 DWR's Northern District contracted with Layne-Christensen Drilling to provide drilling and testing services as part of this investigation. Five vertical diamond core and seven auger holes were drilled in summer 1999 to evaluate foundation and tunneling conditions (Table 11). One core hole was drilled at the proposed pumping plant, one at each portal of the inlet-outlet tunnel, and one each at the possible spillways. Each of these was water pressure tested to estimate grouting requirements (Technical Memorandum B). The auger holes were augured to bedrock along the shared intake and approach channels.

Table 11. DWR drilling footage of the Golden Gate Inlet-Outlet Works

Drill Site	Drill Hole	Date Started	Date Completed	Drilled Footage
Golden Gate Outlet Works	DHPP-1	Jun 22, 1999	Jun 24, 1999	199.6
	DHPP-1B	Jun 26, 1999	Jun 26, 1999	20.3
	DHT-1	Jun 27, 1999	Jun 30, 1999	224.5
	DHT-4	Jul 06, 1999	Jul 08, 1999	199.5
	DHS-4	Jul 10, 1999	Jul 12, 1999	199.5
	DHS-1	Jul 13, 1999	Jul 19, 1999	199.0
	Total HQ Diamond Drill Footage			1042.4
	AUG-3	Jun 26, 1999	Jun 26, 1999	36.3
	AUG-5	Jun 30, 1999	Jun 30, 1999	13.4
	AUG-6	Jun 30, 1999	Jun 30, 1999	19.0
	AUG-7	Jun 30, 1999	Jun 30, 1999	5.9
	AUG-2	Jul 01, 1999	Jul 01, 1999	13.5
	AUG-4	Jul 13, 1999	Jul 13, 1999	13.9
	AUG-1	Jul 22, 1999	Jul 22, 1999	11.0
	Total Auger Footage			113.0
	Total Footage			1155.4

LA = Left abutment drill hole
LC = Left channel drill hole
RC = Right channel drill hole
RA = Right abutment drill hole
DHPP = Drill hole power plant
DHS = Drill hole spillway
DHT = Drill hole tunnel
SSD = Sites saddle dams
AUG = Auger hole

Shared Intake Structure

The shared intake structure consists of a 2,200-feet long by 830-feet wide concrete apron that will channel water to the western tunnel portal on the east side of the Sites Reservoir. The northern end of this intake follows a local drainage north to Funks Creek. The intake invert would range in elevation from 290 feet on the western end to 390 feet on the eastern end with a grade of about 4.5 percent. Excavation is estimated to be about 80 percent mudstone of the Boxer Formation with 20 percent sandstone and siltstone interbeds. It will be below the perched groundwater table, so dewatering will be required. Some small surficial slumps exist on the upslope end of the foundation. Vegetation is very light, consisting primarily of open pasture land. Holes AUG-5 through AUG-7 were augered to evaluate the depth of soil and foundation suitability along the proposed intake canal (Photo 20). AUG-5 was augered to a depth of 13.4 feet, AUG-6 to a depth of 19.0 feet, and AUG-7 to a depth of 5.9 feet to refusal. They all encountered clayey colluvial soil.

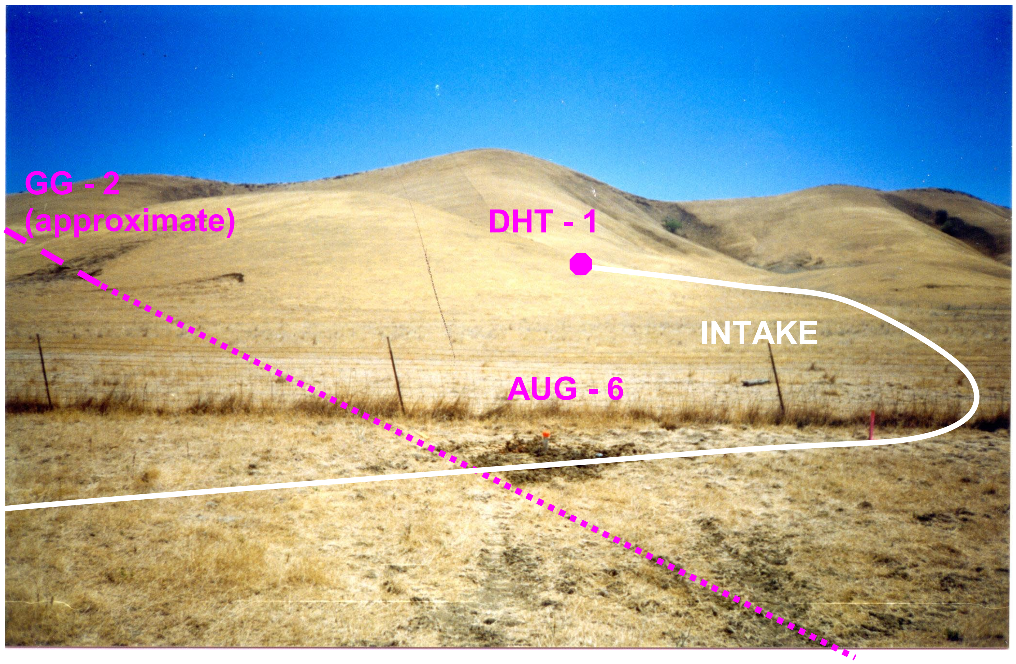


Photo 20. Eastern view of Golden Gate Intake Structure with AUG-6 and GG-2 fault

Seismic Refraction Surveys and Rippability

Six seismic refraction surveys totaling 600 feet in length were performed at the Golden Gate inlet-outlet works. Two of these were along the alignment for the intake works (SL-12 and SL-13), two were along the alignment for the outlet works (SL-10 and SL-11), one for the northernmost spillway option (SL-8), and one for the pumping plant (SL-9). Table 12 is a summary of the values calculated for depths to bedrock, estimated seismic velocities and rippability for the foundation at these locations.

Seismic lines SL-12 and SL-13 were surveyed on the far western edge of the shared intake. They indicated an alluvial thickness of about 10 to 10.5 feet, with seismic velocities ranging from 1,156 to 1,370 feet per second, averaging about 1,200 feet per second. These overburden materials can be excavated by common methods. The underlying mudstone and interlayered sandstone rocks of the Boxer Formation have seismic velocities ranging from 5,828 to 9,872 feet per second, averaging about 7,500 feet per second. These rocks may be rippable, especially where heavily weathered (Table 13).

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Table 12. Golden Gate Inlet-Outlet Works-Seismic refraction data

First Horizon - Terrace Deposits							
Date	Line	Length (Feet)	Velocity 1 Forward (ft/sec)	Velocity 1 Reverse (ft/sec)	Composition	Rippability	Average Thickness (feet)
5/26/99	SL-7	80	1,300	1,300	Alluvium	Rippable	20
6/22/99	SL-8	100	1,600	1,500	Alluvium	Rippable	11
6/23/99	SL-10	100	800	800	Alluvium	Rippable	10
6/23/99	SL-11	100	1,200	1,200	Alluvium	Rippable	21
6/24/99	SL-12	100	1,300	1,200	Alluvium	Rippable	11
6/24/99	SL-13	100	1,200	1,400	Alluvium	Rippable	10

Second Horizon – Interbedded Sandstone and Shale						
Date	Line	Length (Feet)	Velocity 2 Forward (ft/sec)	Velocity 2 Reverse (ft/sec)	Composition	Rippability
5/26/99	SL-7	80	6,900	6,800	Sandstone/Shale	Rippable
6/22/99	SL-8	100	7,600	7,100	Sandstone/Shale	Rippable
6/23/99	SL-10	100	9,000	8,000	Sandstone/Shale	Marginal
6/23/99	SL-11	100	**	8,600	Sandstone/Shale	Marginal
6/24/99	SL-12	100	7,500	6,700	Sandstone/Shale	Rippable
6/24/99	SL-13	100	9,900	5,800	Sandstone/Shale	Marginal

* Seismic line 9 data was thrown out for inconclusive picks because of excessive seismic noise. The noise was most likely the result of active drilling of drill hole DHPP-1 within relative proximity when this line was being conducted.

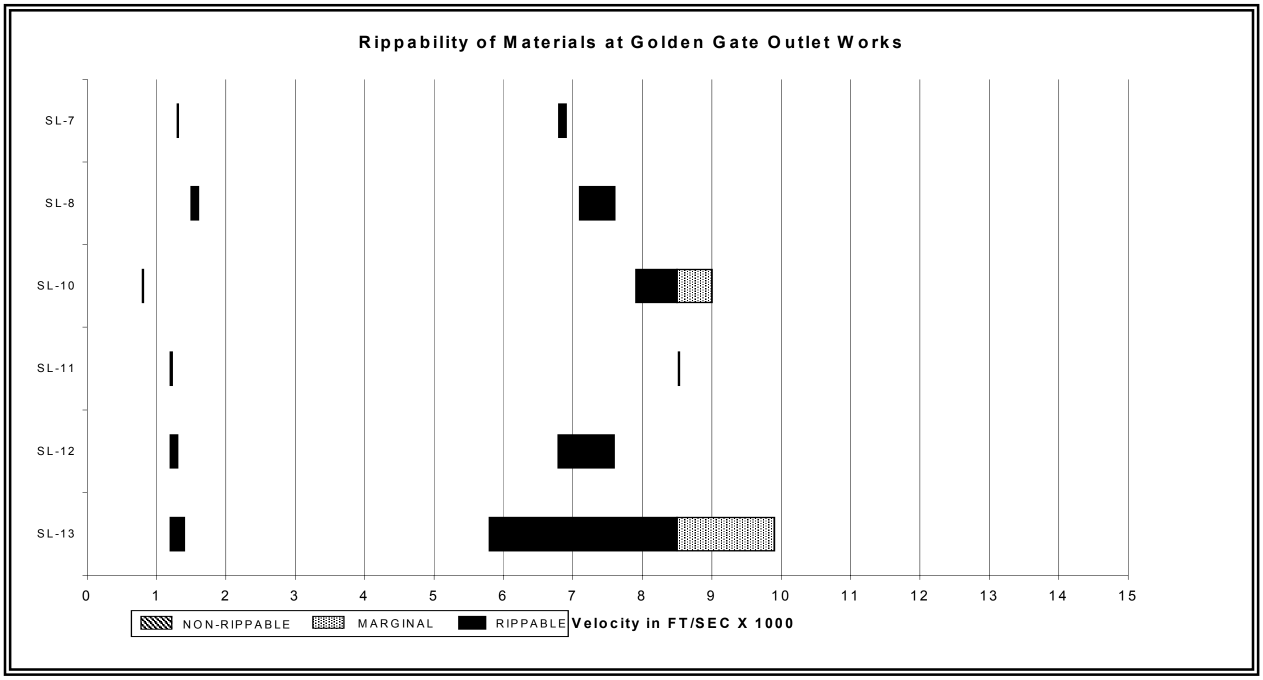
** Seismic line 11 has an excessively high forward velocity. This is probably due to bad picks; thus, this velocity was not used in any calculations

Rock strengths and grouting requirements of the foundation were not evaluated for the shared intake works because no core holes were drilled for this purpose.

Dewatering will be required during excavation of the intake works since groundwater is relatively shallow. A piezometer was placed in AUG-6 at the low western end of the intake in the drainage. It showed that water surfaces ranged between 7.3 and 8.5 feet in depth from August to December 1999.

Foundation preparation should include the removal of 20 feet of soil overburden and intensely weathered bedrock by common methods, with another 9 feet of moderately weathered bedrock that may have to be blasted and removed until firm foundation rock is reached. The underlying mudstone unit generally exhibits low permeability. Only minimal clearing will be required, as this is almost entirely open pastureland and grasses. A few small bushes exist in the drainage to Funks Creek.

Table 13. Golden Gate Inlet-Outlet Works-Rippability of proposed foundations



Tunnel, Penstock, and Gateworks

The proposed tunnel will be about 3,300 feet south of the right abutment of the Golden Gate Dam site. As at that site, the tunnel and gateworks will be excavated through sandstones and mudstones of the Cortina and Boxer Formations. Strike of the bedding is roughly north-south, nearly normal to the tunnel alignment, with a dip of 45 to 55 degrees to the east. A prominent joint set trends approximately east-west with near vertical dips. Based on preliminary drill hole data, tunneling conditions are not anticipated to be difficult. The east portal cut will be excavated in mostly sandstone with some mudstone interbeds. Some bedding plane failures may occur within the crown along laminar mudstone interbeds. Moderate overbreak may occur where shears and associated fractured rock are present. Support requirements are expected to be at most moderate for the tunnel with heavy support required only locally. Light to moderate weight steel supports on about 4-foot centers should be adequate for most of the tunnel length. The 30-foot diameter concrete-lined tunnel will extend about 4,000 feet with a maximum elevation at the western end of 350 feet and a minimum elevation at the eastern end of 270 feet. A 40-foot diameter, 350-feet deep gate shaft will be excavated about 1,200 feet upslope of the west portal at an elevation of about 550 feet.

Vertical drill hole DHT-1 was drilled to evaluate the rock conditions at the western tunnel portal (Photo 21). It was drilled to a total depth of 224.5 feet. No sample was taken in the upper 2.0 feet of overburden. From 2.0 to 224.5 feet the hole drilled through 60 percent mudstone with 40 percent sandstone interbeds. The permeability in the top 20.3 feet of the tested interval for DHT-1 is 0.24 feet per day and the Lugeon value is 8. From 19.4 to 219.3 feet permeabilities range from 0.00 to 0.26 feet per day, averaging 0.027 feet per day with Lugeon values ranging from 0 to 11, averaging 1.

Photo 21. CME-850 drill rig at western tunnel portal drill hole DHT-1 (note location of gate works still to be drilled)

Vertical drill hole DHT-4 was drilled to evaluate the suitability of the foundation rock at the eastern tunnel portal (Photo 22). It was drilled to a depth of 199.5 feet. It was drilled to 199.5 feet from July 6 to July 8, 1999. It drilled through 85 percent sandstone interbeds. Numerous shears were logged throughout the hole account for some of the high permeabilities and grouting requirements seen. Extremely pervious conditions are encountered from 17.1 to 70.0 feet, with an average permeability of 19.34 feet per day. A high grouting requirement (Lugeon value >100) is also necessary in this zone.

From 70.1 to 195.2 feet, Lugeon values are zero, indicating that grouting is not necessary. Permeabilities average 0.14 feet per day and range from 0.00 to 0.084 feet per day showing impervious to pervious conditions.

No seismic lines were surveyed at either of the tunnel portals.

RQD is often used as an indicator of the competence of rock. It is calculated by measuring all core recovered over 4 inches in length, then expressing that as a percentage of the total core recovered.

Photo 22. Eastern tunnel portal drill hole DHT-4

In general, calculation of RQD indicates that drill hole DHT-1 for the western tunnel portal drilled through rock of fair quality from 25 to 50 feet in depth, then excellent quality to 225 feet, except for a fair zone from 140 to 159 feet near the tunnel invert (Table 14).

Groundwater will be encountered during the excavation. Piezometers were placed in drill holes at either end of the tunnel alignment and in two auger holes along the shared outlet works. These showed that water surface elevations at the western tunnel portal have remained constant at about 30 feet in depth from August to December 1999. Water surface elevations at the eastern tunnel portal ranged from about 12.5 to 14 feet in depth from July to December 1999. The piezometer in AUG-3 bordering Funks Creek along the shared outlet works shows water levels ranged from 24 to 25 feet in depth from July to December 1999 (see Technical Memorandum C).

Water pressure testing was performed in each of the two tunnel portal drill holes. Water pressure tests in the western tunnel portal drill hole DHT-1 indicate that there will be low to no grout take to 225 feet, except for high grout takes from 9 to 20 feet, and 103 to 114 feet in weathered and/or fractured mudstone and sandstone. Water tests in the eastern tunnel portal drill hole DHT-4 indicate that there will be low to no grout take to 200 feet, except for high grout takes from 17 to 70 feet in weathered and/or fractured mudstone and sandstone.

Contact grouting and lining will be necessary for the full length of the tunnel. Grouting near the tunnel intake may be necessary depending on rock conditions.

The soil, colluvium, and intensely weathered rock at both tunnel portals can be stripped with common methods. It is estimated to be about 2 feet in depth at the western tunnel portal and less than 1 foot in depth at the east tunnel portal. Moderately weathered bedrock extends an additional 5 feet at both portals and should also be excavated.

Clearing will be minimal as the only vegetation is light grass.

Pumping Plant and Approach Channel

The proposed pumping plant is located with the western end of the approach channel about 2,000 feet southeast of the right abutment of the proposed downstream straight Golden Gate Dam site alignment. The channel extends about 4,300 feet east to Funks Reservoir. Sandstone and mudstone of the Cortina Formation would comprise the foundations. The strike of the bedding is generally north-south with a dip of 45 to 55 degrees to the east. Jointing trends mostly east-west with near vertical dips. The mudstone and interbedded sandstone is anticipated to be fresh and hard at foundation grade and should have adequate bearing capacity for the support of the structures. The colluvium and alluvium along the approach channel ranges from about 10 feet in depth on the east end to at least 35 feet at the west end. It is primarily silty clay with some gravel interlayers. The area of excavation for the pumping plant foundation is proposed to be roughly 1,800-feet long by 1,800-feet wide. Maximum depth of excavation will be up to 140 feet.

Vertical drill core hole DHPP-1 was drilled to help evaluate the suitability of the foundation for the proposed pumping plant (Photo 23). It was drilled to a total depth of 199.6 feet. No sample was taken of the top 5.3 feet of overburden. The rest of the hole consisted of 85 percent sandstone with 15 percent mudstone interbeds. Water testing of this hole showed high permeability in various zones, most likely due to fractured rock. The average Lugeon value from 38.3 feet to the top of the tested interval is 54; average permeability is 0.69 feet per day, indicating pervious conditions. Permeabilities throughout the remainder of the hole range from 0.0 feet per day to 2.48 feet per day, (average of 0.73 feet per day), with corresponding Lugeon values ranging from 0 to greater than 100, averaging 25.6.

Photo 23. CME-850 drill rig at pumping plant drill hole DHPP-1

Auger holes AUG-1 through AUG-3 were augered to evaluate the depth of soil and foundation suitability for the proposed approach channel (see Technical Memorandum A). AUG-1 was augered 11.0 feet to refusal on July 22. AUG-2 was augered 13.5 feet to refusal on July 1 (Photo 24). AUG-3 was augered 36.3 feet to refusal on June 26 (Photo 25). These all intersected terrace deposits bordering Funks Creek that consist of clay, silt, sand, and gravels.

In general, calculation of RQD indicates that the pumping plant foundation should have very poor rock quality to 36 feet in depth, then excellent quality to 200 feet (Table 14). The upper 20 feet of soil, colluvium, and weathered rock at the pumping plant foundation can be excavated with common methods. Below about 20 feet, the bedrock will require blasting down to invert grade. The upper 35 feet of terrace deposits, soil, alluvium, colluvium, and intensely weathered rock along the approach channel can be excavated with common methods. An additional 8 feet of bedrock may need to be blasted and removed to reach fresh rock.

Table 14. Rock quality designation in drill holes at Golden Gate Dam Inlet–Outlet Works

Agency	Drill Hole	Vertical Depth (feet)	Minimum RQD*	Maximum RQD*	Avg. RQD*	Description
DWR	DHPP-1	27 35	18	32	25	Very Poor
DWR	DHPP-1	36 200	84	100	98	Excellent
DWR	DHS-1	14 19	70	70	70	Fair
DWR	DHS-1	20 199	82	100	97	Excellent
DWR	DHS-4	32 55	0	70	38	Poor
DWR	DHS-4	56 200	60	100	96	Excellent
DWR	DHT-1	25 59	30	100	66	Fair
DWR	DHT-1	60 139	78	100	93	Excellent
DWR	DHT-1	140 159	28	100	67	Fair
DWR	DHT-1	160 225	94	100	99	Excellent
DWR	DHT-4	20 39	0	28	7	Very Poor
DWR	DHT-4	40 59	60	98	76	Good
DWR	DHT-4	60 74	100	100	100	Excellent
DWR	DHT-4	75 124	8	92	51	Poor
DWR	DHT-4	125 184	92	100	99	Excellent
DWR	DHT-4	185 200	48	90	69	Fair

*Rock quality designation (RQD) is developed by summing the total length as measured along the centerline of the drill core recovered in each run, but only those pieces of core which are at least 4 inches in length are counted that are "hard and sound." The sum is then represented as a percentage over the length of the run.

The first hole tested, DHPP-1, consists of sandstone and mudstone and has high permeability and grouting requirements in various zones throughout the hole, most likely due to fractured intervals. The average Lugeon value from 38.3 feet to the top of the tested interval is 54; average permeability is 0.69 feet per day, indicating pervious conditions. Permeabilities throughout the remainder of the hole range from 0.0 feet per day to 2.48 feet per day, (average of 0.73 feet per day), with corresponding Lugeon values ranging from 0 to greater than 100, averaging 25.6.

Photo 24. Site preparation at approach channel auger hole AUG-2

Groundwater will be encountered during the excavation. Piezometers were installed in the DHPP-1 drill hole and in the AUG-3 auger hole about 1,150 feet downstream to the east. The piezometer in DHPP-1 has shown water levels to be 15 feet below ground surface in summer 1999 and water levels to be 12 feet below the ground surface in winter 1999. The piezometer in AUG-3 bordering Funks Creek along the shared outlet works shows water levels range from 25 to 26.5 feet in depth from July to December 1999 (see Technical Memorandum C).

Clearing will be minimal at the pumping plant as the only vegetation is light grasses. Clearing at the approach channel will also be minimal except for some scattered pockets of riparian growth in the Funks Creek channel.

Spillways

The outlet works will also have a spillway designed to reduce the level of a full reservoir by 10 percent of its maximum depth in 10 days as mandated by DWR's Division of Safety of Dams. The location for spillway excavation depends on which Golden Gate Dam design configuration is selected. Two main locations are being considered. The northernmost spillway is linked to a curved dam axis configuration at the downstream ridge. The southernmost spillway location is linked to a straight dam axis at the upstream ridge. Each excavation would cross the two main sandstone ridges and have foundations consisting of Cortina sandstone with mudstone interbeds. Strike of the bedding is roughly north-south with a dip averaging 50 degrees to the east. A prominent joint set trends about east-west with near vertical dips.

Photo 25. CME-850 drill rig at approach channel auger hole AUG-3

Vertical drill hole DHS-1 was drilled to evaluate the suitability of the foundation rock for the northernmost of the two possible locations for the spillway (Photo 26). It was drilled to 199.0 feet at the base of the main sandstone ridge, at about the center of the proposed structure. It drilled through a reddish brown clay to 4.5 feet. From 4.5 to 130.9 feet, the hole drilled through 100 percent sandstone. From 130.9 to 163.0 feet, it drilled through 70 percent mudstone with 30 percent sandstone interbeds. It then went through 100 percent sandstone from 163.0 to 173.5 feet. From 173.5 to 194.8 feet, it drilled through 60 percent sandstone with 40 percent mudstone interbeds. From 194.8 feet to 199.0 feet, there is 100 percent sandstone. Water pressure tests in the northernmost spillway drill hole DHS-1 indicate that there will be low to no grout take to 200 feet, except for high grout takes from 17 to 70 feet in heavily weathered and fractured mudstone and sandstone. Average permeability from 16.0 to 58.9 feet is 1.01 feet per day, with an average Lugeon value 66. From 58.0 to 194.9 feet, Lugeon values and permeabilities both average zero.

DHS-1 is also a tight hole, consisting mainly of sandstone. Average permeability from 16.0 to 58.9 feet is 1.01 feet per day, with an average Lugeon value 66. From 58.0 to 194.9 feet, Lugeon values and permeabilities both average zero.

Vertical drill hole DHS-4 was drilled to evaluate the suitability of the foundation rock for the southernmost of the two possible locations for the spillway (Photo 27). It was drilled at the eastern base of the main sandstone ridge, at about the center of the proposed structure. It was drilled from July 10 through 12, 1999, for a total depth of 199.5 feet. The upper 0.0 to 2.2 feet of the section is composed of colluvial soil overburden and weathered sandstone and mudstone. From 2.2 to 167.5 feet, the section is composed of 80 percent mudstone and 20 percent sandstone interbeds. From 167.5 to 199.5 feet, the section is composed of 80 percent sandstone and 20 percent mudstone interbeds. Water pressure tests indicate that there will be low to no grout take to 225 feet except for high grout takes from 9 to 20 feet and from 103 to 114 feet in heavily fractured mudstone and sandstone. Average Lugeon values for DHS-4 are 72 in the top 38.0 feet of the hole, indicating a high grouting requirement. Correspondingly, average permeability in the same interval is 4.5 feet per day. From 37.1 feet to the bottom of the hole at 195.0 feet, the formation is competent with an average Lugeon value of 0 and an average permeability of 0.02 feet per day.

Photo 26. Site of proposed northernmost spillway at Golden Gate Inlet-Outlet Works

Photo 27. Site of proposed southernmost spillway at Golden Gate Inlet-Outlet Works

Seismic refraction line SL-8 was surveyed along the northernmost spillway alignment at the eastern base of the main sandstone ridge. It indicated a colluvial thickness of about 11 feet, with seismic velocities ranging from 1,481 to 1,582 feet per second, averaging about 1,530 feet per second. These overburden materials should be easily rippable. The underlying mudstone and interlayered sandstone rocks of the Venado Formation have seismic velocities range from 7,128 to 7,570 feet per second but average about 7,350 feet per second. These rocks will not be rippable.

In general, calculation of RQD indicates that the northernmost spillway should have fair rock quality from 25 to 50 feet in depth, then excellent quality to 225 feet, except for a fair zone from 140 to 159 feet (Table 13). The southernmost spillway should have very poor rock quality to 40 feet in depth, then fair to excellent quality to 200 feet except for a poor zone from 75 to 124 feet.

Groundwater will be encountered during excavation. Piezometers were placed in both drill holes at each of the possible spillway locations. These show that water surface elevations at the northernmost spillway drill hole DHS-4 have decreased in depth from a maximum of about 200 feet in July 1999 to a minimum of about 27 feet in December 1999. Water surface elevations at the southernmost spillway drill hole DHS-1 have been artesian since the piezometer was placed.

On July 22, 1999, drilling exploration ended at the outlet works and the drill rig was moved north to the Sites northern saddle dam alignment.

Conclusions and Recommendations

The rocks that have been drilled should be adequate for the proposed foundations for each component. However, prior to construction we need to:

- Further evaluate the potential for seepage and/or wedge failure along the proposed tunnel alignment by drilling and water pressure testing. Dewatering may be an issue at the proposed southern spillway location.

- Drill three vertical diamond core holes along the top of the easternmost ridge, one to intercept the proposed tunnel at grade, and one for each of the possible spillway locations. (DH-3, DHS-2, DHS-3 on attached Plate 1)

- Drill a vertical drill hole at least 350 feet in depth down the center of the shaft for the proposed gateworks in the tunnel (DHT-2). This will probably require helicoptering a small skid rig to the drill site because the topography is so steep that grading a road for access will be prohibitive.

- Drill the right lateral tear faults that strike through the foundations for the pumping plant, approach channel, and southernmost spillway.

- Evaluate the possibility that the Salt Lake fault or associated deformation extends as far as the western base of the main sandstone ridge. This could mean that there are structural weaknesses in the proposed foundation for the intake works. This should be further evaluated prior to construction.

- Perform more seismic refraction surveys and auger holes as needed to better define overburden depths.

- Map all landslides that either exist on the footprints for the outlet works or that could impact the proposed facilities in any way.

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February 2001

Integrated
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Appendix Q: Sites and Colusa Reservoir Foundation Studies

February 2001

Integrated
Storage
Investigations

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PROGRAM

This report was prepared in the Northern District Geology Section under the supervision of
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Introduction

In July of 1997 the California Department of Water Resources, Northern District, Geology Section began investigating the Sites Reservoir and Colusa Reservoir Projects. These projects are in the Stone Corral, Funks, Hunters, and Logan Creek watersheds on the west side of the Sacramento Valley (Figure 1). The Sites Reservoir Project consists of two major dams, nine smaller saddle dams, and an inlet-outlet tunnel works structure (Figure 2). This project would create a reservoir with a total capacity of 1.8 million acre-feet. The Colusa Reservoir Project is similar to the Sites Reservoir Project, except it adds additional reservoir area to the north, increasing the storage capacity to 3.1 million acre-feet. This would be done by adding two additional major dams, seven smaller saddle dams, and replacing the nine saddle dams along the ridge between the two areas with a canal or tunnel to join the two cells. The outlet works would remain at the same location.

These reservoirs would store water for agricultural, environmental, and municipal use; provide some flood control; and provide water-related recreation.

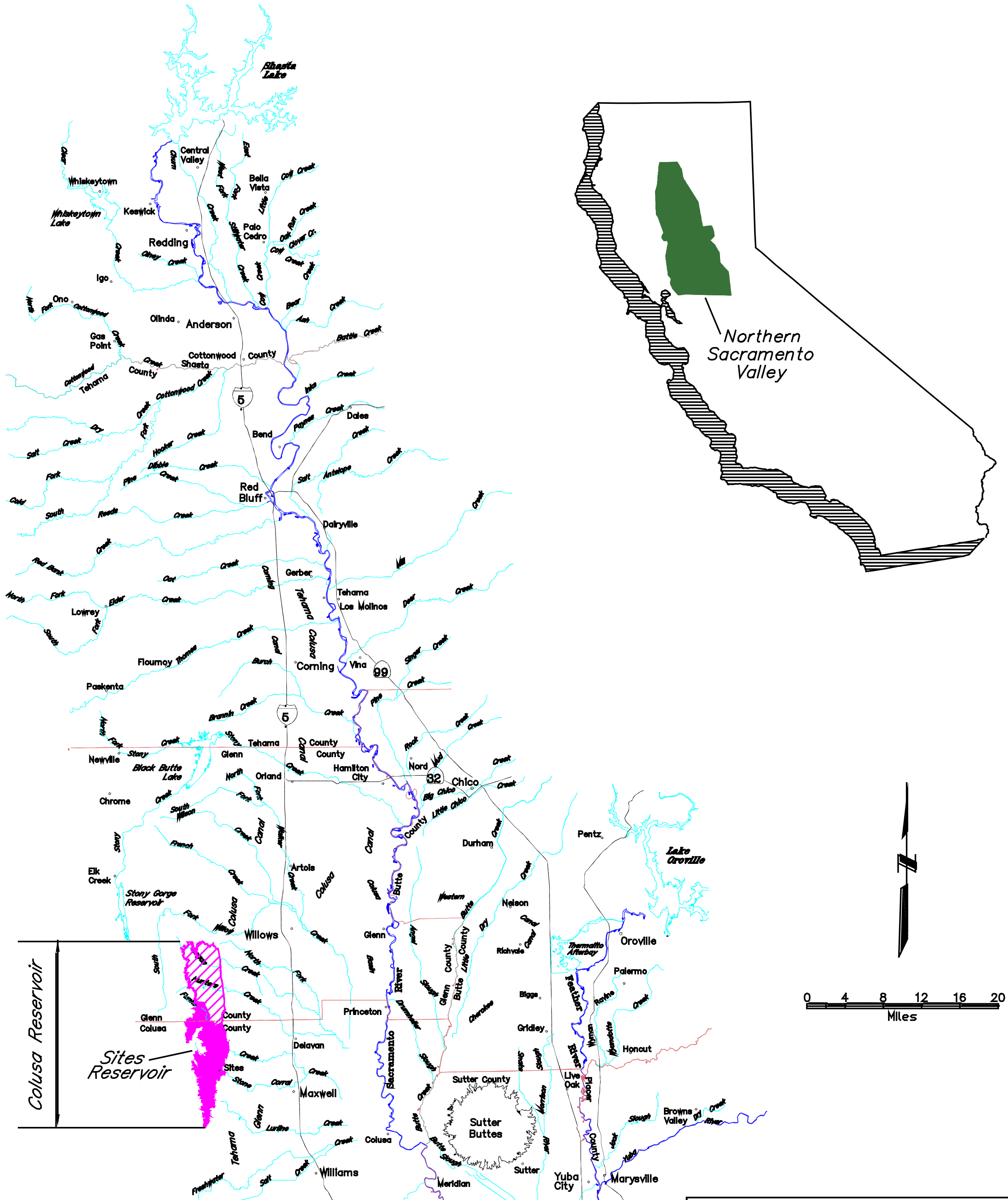
Purpose and Scope

The purpose of this investigation is to determine the geologic suitability of the foundations for the proposed structures and to provide engineers with adequate geologic data to develop designs and construction cost estimates. Seven sites were mapped in both projects between May 1998 and November 1999. These include four major dam sites, two saddle dam sites, and the outlet works site. Six of these sites were drilled.

A total of 12 diamond core holes and 6 auger holes were drilled, and the core holes were water pressure tested at the Sites, Golden Gate, and Owens Dam sites from May through October of 1998. An additional 8 core holes and 10 auger holes were drilled at the Golden Gate inlet-outlet works and the Sites saddle dams from June through July of 1999. Locations of geologic exploration are shown on Figure 2 and Plates 1, 5, 9, 11,12,13. Photographs, drilling and sampling logs, and drilling chronologies are in Technical Memorandum A.

Double packer water pressure tests were performed in conjunction with the core drilling to determine foundation permeability and to estimate grout takes. These tests and analyses are summarized in this report and presented in detail in Technical Memorandum B. Piezometers were placed in most of the drill and auger holes, and groundwater levels were monitored monthly. Well completion forms and hydrographs of these water levels are summarized in this report and presented in detail in Technical Memorandum C. Seismic refraction surveys were performed at the Golden Gate Dam site and outlet works to determine seismic velocities to help estimate stripping and rippability of the foundation materials. These results are summarized in this report. The technical memoranda are published separately.

FIGURE 1

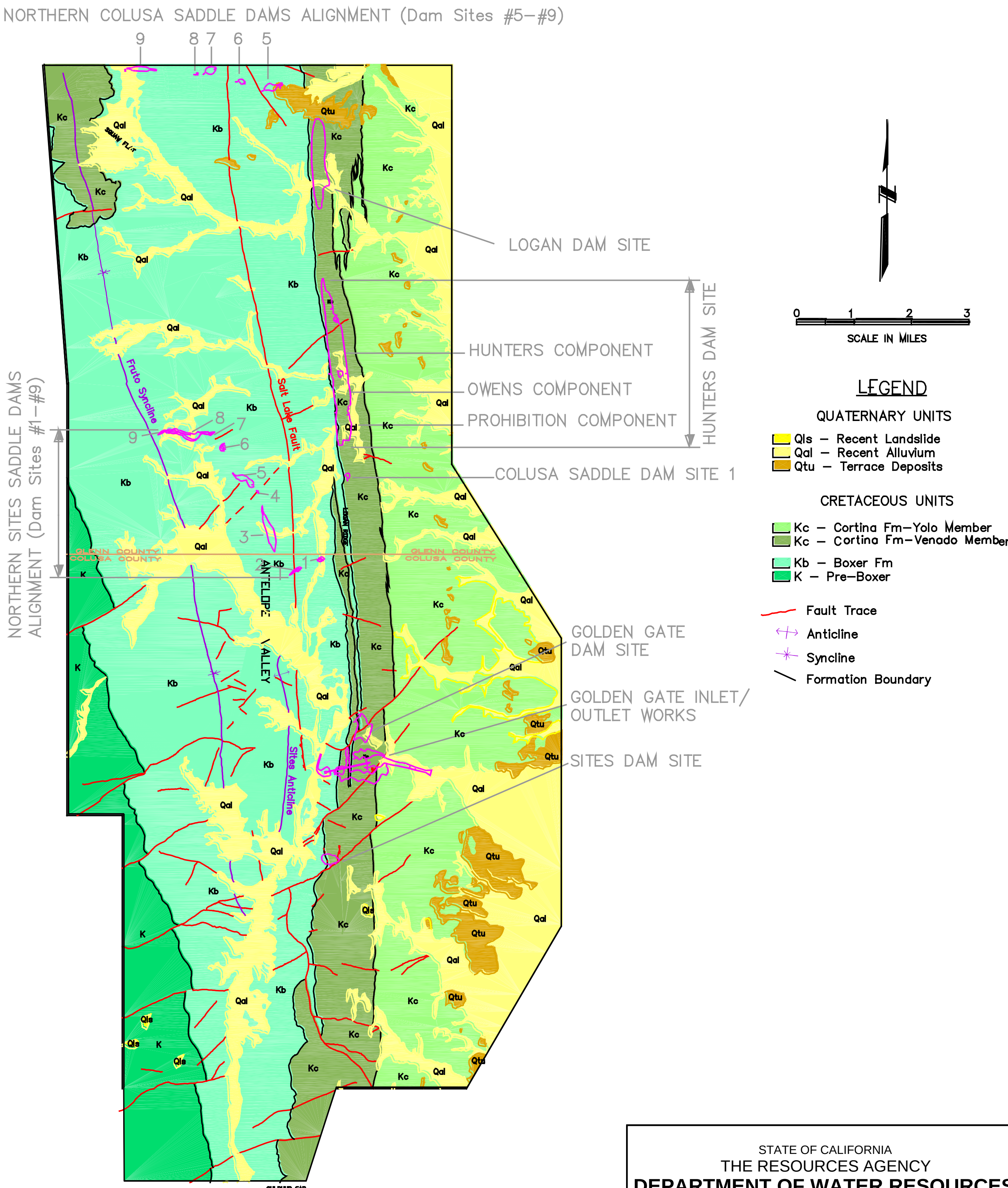


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

LOCATION OF SITES & COLUSA RESERVOIR PROJECTS

Filename:N:\NDSharedInfo\typing\geo\Final 1999 Sites Report\Figures\original\Figure 1--Sites Location--01-19-01--JHM.dwg

FIGURE 2



NOTES: Sources of geological data include geologic map interpretation, Brown and Rich (1961), U.S. Geological Survey (1972) and USBR (1963).

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NORTHERN DISTRICT

LOCATION AND GEOLOGIC MAP OF THE SITES AND COLUSA RESERVOIR PROJECTS

Filename:N:\NDSharedInfo\typing\geo\Final 1999 Sites Report\Figures\original\Figure 2--Sites and Colusa Proj Geology--01-19-01--JHM.dwg
Layout Name:Layout1 Plot Time: Jan 19, 2001 - 4:15pm

Logan Dam Site

Logan Dam site is located on Logan Creek, about 7 miles west to southwest of the town of Willows in Glenn County (Photo 38). The dam site extends from Section 20 to Section 29, R4W, T19N on the Logan Ridge 7.5-minute USGS topographic quadrangle map. Access is via private roads; the entire dam site is on the Elworthy cattle ranch. The proposed dam, in conjunction with the Sites Dam, Golden Gate Dam, Hunters Dam, and the northern Colusa saddle dams, would impound 3.0 million acre-feet of water in Colusa Reservoir. The dam would be a 270 foot-high earthfill embankment structure with a 7,200-foot crest length at an elevation of 540 feet. The embankment would completely cover the north-south trending main ridge and drape over into the lower areas east and west of the crestline.

Previous geologic work for the Logan Dam site was limited to a brief assessment performed by the Department for the Klamath-Trinity Development Project conveyance system in the 1960s. The current Northern District investigation consisted only of reconnaissance geologic mapping.

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Photo 38. Aerial view of Logan water gap at Logan Dam site

Dam Site Geology

Foundation rocks are Cretaceous sedimentary rocks of the Cortina and Boxer Formations. These have been upturned to form a series of north- to northwest-trending homoclinal ridges that dip 55 to 75 degrees to the east. The Boxer Formation, primarily mudstone with some sandstone interbeds crops out along the western side of the ridge. The Venado sandstone member of the Cortina Formation, massive to bedded sandstone with minor mudstone interbeds, forms the ridge. Excellent exposures of the bedrock are found in Logan Creek where it cuts through the ridgeline.

The ridge top is generally covered with thin soil, and the side slopes are mantled with colluvium. Quaternary alluvial deposits cover bedrock locally and Quaternary terrace deposits occur along the stream channels at depths up to 20 feet. They consist of sand, silt, and gravel, mantled by a clayey soil.

Plate 10 presents DWR's geologic mapping. Plate 11 presents one geologic profile parallel to the dam axis, and one cross section perpendicular to the axis through the Logan Creek water gap.

Bedrock Units

The majority of the dam foundation is a ridge composed of interbedded Upper Cretaceous sandstone and mudstone of the Boxer and Cortina Formations. The foundation bedrock consists of about 55 percent mudstone and 45 percent sandstone.

These bedrock units were differentiated into mappable units (see Plates 10 and 11) as follows:

- KCVm - Mudstone (70 to 100 percent) with sandstone intervals (0 to 30 percent) up to 5 feet in thickness of the Venado member of the Cortina Formation,

- KCVs - Sandstone (70 to 100 percent) of the Venado member of the Cortina Formation with mudstone intervals (0 to 30 percent) up to 5 feet in thickness,

- KCVsm - Interbedded mudstones (30 to 70 percent) and sandstones (30 to 70 percent) of the Venado member of the Cortina Formation,

- KBm - Mudstone (70 to 100 percent) of the Boxer Formation with sandstone intervals (0 to 30 percent) up to 5 feet in thickness,

- KBsm – Interbedded mudstones (30 to 70 percent), and sandstones (30 to 70 percent) of the Boxer Formation.

Fresh sandstone is light to medium olive gray in color and yellowish brown where weathered. It is mostly a very fine to medium-grained well-sorted arkosic sandstone with a silty to clayey matrix. Bedding is massive to cross-bedded and outcrops in units ranging from less than a foot to tens of feet in thickness. It contains thin interbeds of siltstone and mudstone that range from laminar up to 5 feet in thickness. It is typically weathered at the surface. It is moderately to well indurated, moderately to slightly fractured, moderately hard to very hard and strong. Internal structure is well developed in the areas of cross bedding and vague where massive. Calcite healing along fractures is common, with some pyritization. The unit contains discontinuous beds of well-rounded coarse pebble conglomerates up to 5 feet in thickness and within 50 feet of the Boxer–Cortina contact. A thin fossiliferous bed occurs in the basal sandstone unit approximately 80 feet above the Boxer–Cortina contact. The fossil bed is 1- to 3-feet thick, and the fossils are composed predominantly of pelecypod shell fragments. The fossil bed matrix often grades to a fine pebble conglomerate, indicating a high-energy depositional environment (Photo 39).

Photo 39. Fossiliferous sandstone and conglomerate at Logan Dam site

Mudstone is the least resistant rock type in the area. Fresh mudstone is dark gray to black in color and tan where weathered. Bedding is thinly laminar with thin sandstone and siltstone interbeds. It is brittle and slakes when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak and closely fractured.

Unconsolidated Deposits

Unconsolidated deposits at the dam foundation consist of Quaternary alluvium, stream terraces, colluvium, landslides, and older upper terrace deposits.

Quaternary Alluvium (Qal) is located in the active stream channel of Hunters Creek and tributaries and consists mainly of lean clay, silt, and poorly graded to well-graded sand, gravel, cobbles, and boulders. It occurs along the channel sides and as discontinuous deposits in the channel. Deposits are estimated to range up to 5 feet in thickness. Deposits of Qal were too small to show on the map.

Two Terrace deposits (Qt2 and Qt3) border the active stream channel both upstream and downstream of the dam axis. Qt2 is a broad flat surface 5 to 10 feet above the stream channel. Observed thickness ranges from 5 to 10 feet. Soil development is moderate. The upper part of this terrace is clayey silt with increasing clay content downward. Some gravel lenses are exposed along the sides of the incised stream. In places there is a clay bed at the base of the deposit. The color of the upper 3 feet is very dark grayish brown, grading lighter downward to brown. This terrace may be correlative with the Modesto Formation as mapped by Helley and Harwood (Calif., Sacramento Valley 1985). Qt3 is a higher topographic surface 10 to 20 feet above the stream channel and has some slope. In places the Qt2 surface is set into the Qt3 surface. Where exposed the Qt3 deposits are a brown (Munsell color-code 7.5 YR4/3), silty clay with some rounded gravel. The Qt3 surface merges with the colluvium along the ridge front.

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular rock fragments up to 10 feet in thickness.

Five small landslides have been mapped at or near the proposed dam axis. Three of them occur on the north-facing slope of the right abutment, and the other two occur on the moderately steep west-facing slope of the left abutment in the Boxer Formation. All five landslides are small earth flows or debris slides with thicknesses of 2 to 5 feet and should not affect the proposed dam foundation. The Red Bluff Formation occurs at the northern edge of the map outside of the dam footprint (Photos 40 and 41). The formation consists of medium to coarse gravels with abundant sand, silt and clay.

Structure

The primary structural feature at the Logan Dam site is the northerly striking, east-dipping homoclinal bedding of the Great Valley sequence. Local attitudes vary in strike from N3°E to N14°W, and bedding dips in an eastward direction, mostly ranging from 60 to 70 degrees at the south end of the dam site to 65 to 75 degrees at the north end.

Photo 40. Tertiary Red Bluff Formation overlying Cretaceous Boxer Formation

Photo 41. Contact between the Red Bluff and Boxer Formations (close-up)

Lineaments

Several lineaments have been identified in the bedrock at or near the dam site.

The northernmost lineament, L-1, crosses the dam alignment through a prominent windage approximately 3,600 feet north of Logan Creek and trends southwest to northeast (Photo 42). It is the most easily discernible lineament, with a definite shift in the rock units along the ridgeline. If this lineament is a fault, the sense of movement would be right lateral, with an apparent offset of 100 to 150 feet; and the fault plane would be near vertical. The lineament feature cannot be followed very far on either side of the ridgeline because of the sparsity of mappable sandstone units.

The middle lineament, L-2, crosses the dam alignment through a saddle about 2,400 feet north of Logan Creek and also trends southwest to northeast. If this lineament is a fault, the sense of movement would be right lateral, with an apparent offset of about 50 feet. Eastward, the lineament bifurcates with a splay trending east. Like L-1, the lineament feature cannot be followed very far on either side of the ridgeline because of the sparsity of mappable sandstone units.

About 2,000 feet north of Logan Creek and 400 feet south of L-2, a short lineament, L-3, crosses the dam alignment and also trends southwest to northeast. If this lineament is a fault, the sense of movement would be right lateral, with an apparent offset of less than 5 feet.

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Photo 42. Lineament L-1 passing through the wind gap just above the center of the photo, with a noticeable shift in the ridge-forming sandstone.

Joints

No joints were mapped in the area of the dam site, except in a very small quarry site on the northwest side of the right abutment. Jointing is expressed at N80°W with a dip of 70 degrees east, and N45°W with a dip of 67 degrees east.

Foundation Conditions and Exploration

Logan Dam site was mapped by DWR's Northern District in November and December 1999. Mapping was easiest along the central sandstone ridges with generally good exposure of outcrops. At least two suspected faults traverse through the foundation. The rock at Logan Dam site should provide a good foundation for the proposed dam with minor to moderate stripping. Bedrock consists of sandstone, interbedded sandstone and mudstone, and mudstone. Because of the interbedded nature, the percentage of sandstone and mudstone vary widely. Overall, sandstone is estimated to form approximately 45 percent (ranging from 30 percent to 60 percent) of the total dam footprint, and mudstone is estimated to be about 55 percent (ranging from 40 percent to 70 percent) of the total dam footprint. The possibility and recency of faulting on the mapped lineaments has not been determined. Foundation conditions are summarized in Table 21, and the surficial geology is summarized in Figure 8.

Left Abutment

This abutment has a slope angle averaging 45 degrees on the western face of the main ridge and a gentler slope (25 degrees) on the eastern face. A secondary lower ridge, composed primarily of sandstone, extends parallel to the main ridge from Logan Creek channel approximately 2,500 feet north where it becomes more subdued as the sandstone bed pinches out (Photo 43). In addition, the western portion of the abutment extends approximately 600 feet out into the very gentle slopes of the Boxer Formation.

Stripping requirements may vary from a few feet in the more competent ridge-forming sandstones to 15 feet in the mudstones of the Boxer Formation. Stripping estimates are based only on visual surface observation because no subsurface exploration has been completed at this time.

Vegetation on the left abutment consists exclusively of scattered grasses.

TABLE 21 – Colusa Reservoir Project, Logan Dam Site Foundation Conditions (total area of Dam Site Footprint = 8,684,800 feet^2)

FEATURE	SURFICIAL/BEDROCK GEOLOGY (by area in feet^2)*	CLEARING ESTIMATES	STRIPPING ESTIMATES	WATER LEVELS	GROUTING ESTIMATES	STRUCTURAL REMARKS
Left Abutment 74.9% of total area of dam footprint. More detailed mapping of dam footprint is needed.	Surficial Qls = 2,800 feet^2 (<1%) Qt_1 = 67,200 feet^2 (1%) Qt_2 = 620,100 feet^2 (10%) Qc = 5,815,300 feet^2 (89%) Total Area = 6,505,400 feet^2 Bedrock KBm = 2,683,300 feet^2 (41%) KCVs = 981,300 feet^2 (15%) KCVsm = 2,789,600 feet^2 (43%) KCVm = 51,200 feet^2 (1%) Total Area = 6,505,400 feet^2 Therefore: Ss = from 2,247,100 feet^2 (35%) to 4,296,900 feet^2 (66%) Ms = from 2,208,500 feet^2 (34%) to 4,258,300 feet^2 (65%)	Light: Scattered grasses interspersed between open sandstone outcrops.	Not Drilled	Not Drilled	Not Drilled	Two major lineaments cross the dam site approximately 2,400 feet north and 3,600 feet north of Logan Creek. These features have not been drilled.
Channel Section 13.2% of total area of dam footprint. More detailed mapping of dam footprint is needed.	Surficial Qls = 1,800 feet^2 (<1%) Qt_1= 146,300 feet^2 (100%) Total Area = 1,148,100 feet^2 Bedrock KBm = 914,500 feet^2 (80%) KCVs = 75,200 feet^2 (7%) KCVsm = 141,900 feet^2 (12%) KCVm = 16,500 feet^2 (1%) Total Area = 1,148,100 feet^2 Therefore: Ss = from 121,900 feet^2 (11%) to 473,800 feet^2 (41%) Ms = from 674,300 feet^2 (59%) to 1,026,200 feet^2 (89%)	Light: Light riparian bordering stream = grasses, trees, grasses on terrace deposits	Not Drilled	Not Drilled	Not Drilled	Not enough site-specific data has been gathered to evaluate.
Right Abutment 11.9% of total area of dam footprint. More detailed mapping of dam footprint is needed.	Surficial Qls = 5,200 feet^2 (1%) Qc = 1,026,200 feet^2 (99%) Total Area = 1,031,400 feet^2 Bedrock KBm = 592,000 feet^2 (57%) KCVs = 173,400 feet^2 (17%) KCVsm = 253,200 feet^2 (25%) KCVm = 12,800 feet^2 (1%) Total Area = 1,031,400 feet^2 Therefore: Ss = from 229,300 feet^2 (22%) to 556,000 feet^2 (54%) Ms = from 475,400 feet^2 (46%) to 802,100 feet^2 (78%)	Light: Scattered grasses interspersed between open sandstone outcrops	Not Drilled	Not Drilled	Not Drilled	Not enough site-specific data has been gathered to evaluate.

Ss = Sandstone Ms = Mudstone Cgl = Conglomerate Qal = Quaternary Alluvium Qc = Quaternary Colluvium Qt_1 = Quaternary Terrace (lower) Qt_2 = Quaternary Terrace (upper) Fx = fracturing
*** Total Foundation Area of Damsite Footprint = 8,684,800 feet^2, therefore total Ss = from 2,598,200 feet^2(30%) to 5,326,700 feet^2 (61%); total Ms = from 3,358,200 feet^2 (39%) to 6,086,600 feet^2 (70%)**

FIGURE 8: Colusa Reservoir Project, Logan Dam Site Surficial and Bedrock Lithology By Percentage

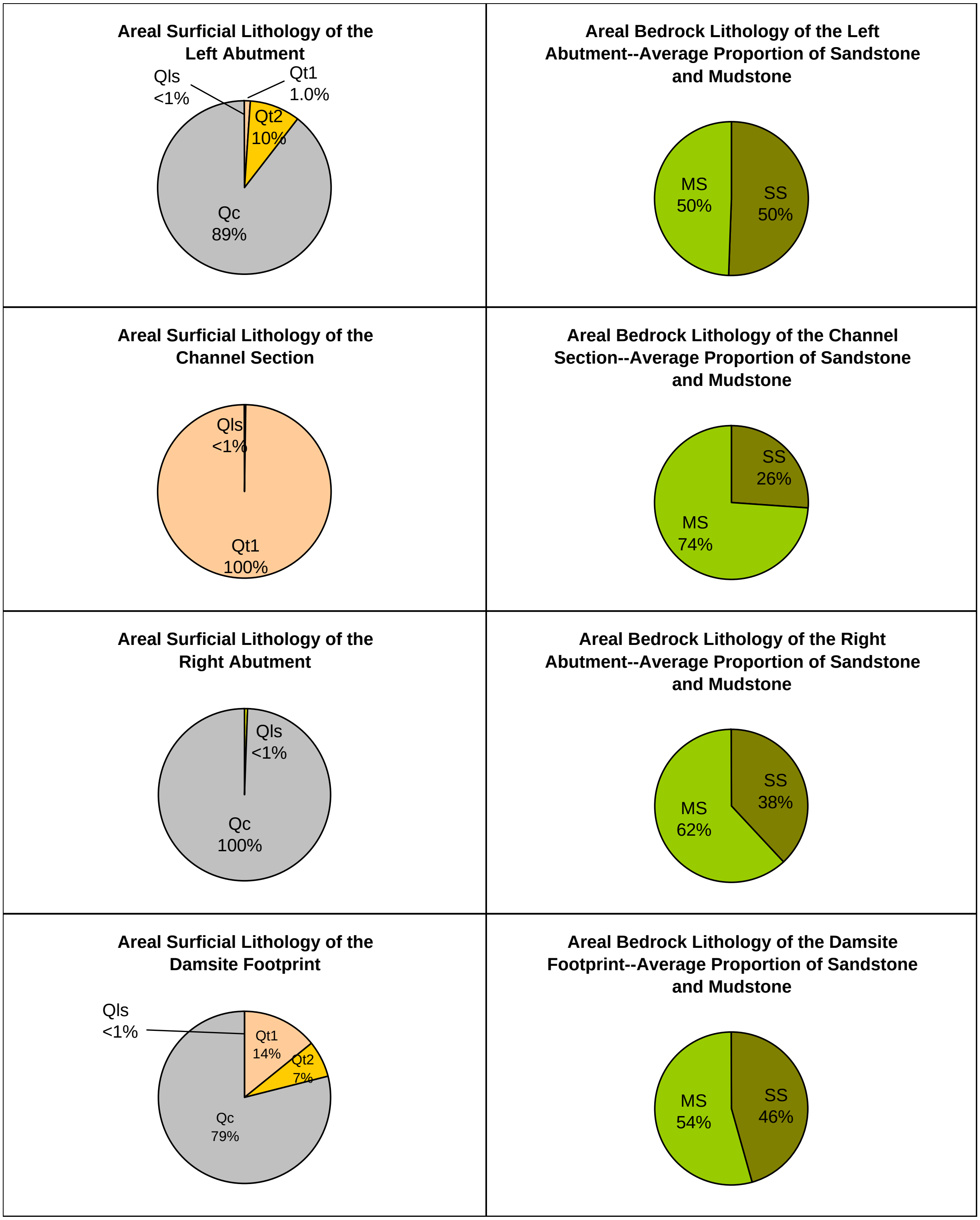

Photo 43. Northern view of left abutment and channel of Logan Dam site

Channel

The Logan Creek stream channel and its associated terrace deposits average 300 feet in width at the dam axis. The stream splits very near the dam axis, and terrace deposits occupy the areas between the two stream branches. The width of the intervening terrace deposit increases to 1,600 feet at the western edge of the dam footprint.

Bedrock is exposed in the base of the stream channel, with very minor deposits of recent Quaternary alluvium occupying lower areas in the channel. Depth of the Quaternary alluvium is estimated to be less than 5 feet. Terrace deposits alongside the stream channel may be as thick as 25 feet, based on visual inspection.

Stripping requirements include removing all of the exposed terrace deposits down to bedrock. Some bedrock underneath the terrace deposits may need to be removed.

Channel vegetation consists of scattered grasses and trees.

Right Abutment

This abutment has a slope angle averaging 50 degrees on the western face of the ridge and a slightly gentler slope of 35 degrees on the eastern face (Photo 44). In addition, the western portion of the abutment extends about 600 feet out into the very gentle slopes of the Boxer Formation. Stripping requirements may vary from a few feet in the more competent ridge-forming sandstones to 15 feet in the mudstones. Stripping estimates are based only on visual surface observation since no subsurface exploration has been completed at this time. Vegetation on the right abutment consists exclusively of scattered grasses.

Photo 44. Southern view of right abutment of Logan Dam site

The rock at Logan Dam site should provide an adequate foundation with minor to moderate stripping.

Not enough site-specific data have been gathered to analyze the requirements for grouting along the dam alignment. Core holes with water tests will be needed to evaluate the subsurface conditions at this site.

Faults uncovered in the foundation may require some cleaning and excavation of weakened and sheared rock before the embankment is placed. These faults/shears, beds, and joints are potential seepage paths through the abutments and will undoubtedly require grouting. Therefore, for estimating purposes, blanket grouting should be considered to seal near-surface fractures and joints.

Not enough detailed exploration has been performed to assess the clearing and stripping requirements over the entire 7,200-foot length of the dam.

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Conclusions and Recommendations

Seismic Lines:

- Run one seismic line east-west through the Logan Creek water gap to evaluate the depth to bedrock.
- Run two north-south seismic lines across Logan Creek both upstream and downstream of the water gap to evaluate how thick the terrace deposits are on the abutments.
- Run at least one northwest-southeast trending seismic line across the lineament on the left abutment to investigate possible fault evidence in the recent overburden.

Drill holes:

- Drill two diamond core drill holes along the Logan Creek water gap to determine depth to bedrock, rock type, and permeability.
- Drill one diamond core drill hole in the right abutment to determine rock type and permeability.

Northern Colusa Saddle Dam Sites

The northern Colusa saddle dam alignment is along the far northern end of the proposed Colusa Reservoir (Figure 9). It is along a 3 -mile long ridge that is in portions of Section 18, T19N, R4W, and Sections 13, and 14, T19N, R5W on the Fruto and Stone Valley 7.5-minute USGS topographic quadrangles. The ridge varies in elevation from 399 to 699 feet and will require five saddle dams to close gaps that are below the proposed dam crest elevation of 540 feet. These dams would range in length from 200 to 3,180 feet and in height from 20 to 142 feet.

The USBR or DWR has performed no prior geologic work. No exploration other than a cursory overview was performed as part of this investigation.

Alignment Geology

The geology of the area consists of a series of interbedded mudstone, sandstone, and conglomerate units of the Great Valley sequence. These trend roughly north-south with a dip that varies from west to east. The Fruto syncline is west of the alignments, with moderate westerly dips on the eastern limb. These dips change from westerly to easterly southeast along the alignment since the Sites anticline intersects the eastern portion of the alignment. The alignment lies mostly within mudstone and siltstone of the Boxer Formation with some scattered sandstone interlayers.

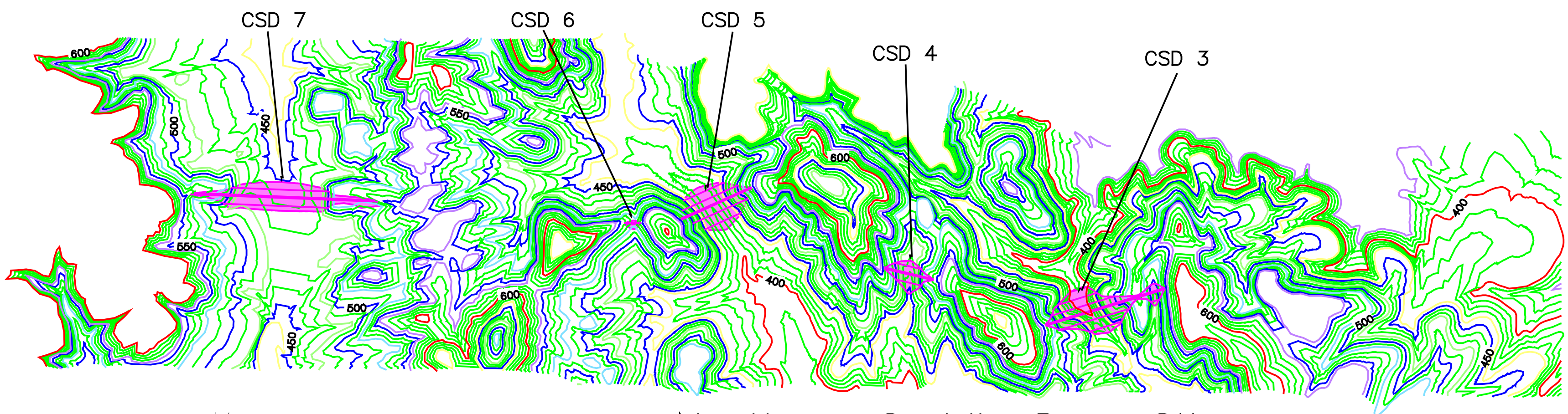
Bedrock Units

The proposed alignment strikes across sedimentary rocks that strike slightly northeast and dip easterly 50 to 55 degrees. This means that the foundation conditions vary as the relative percentages of the sandstone and mudstone change across the geologic structure.

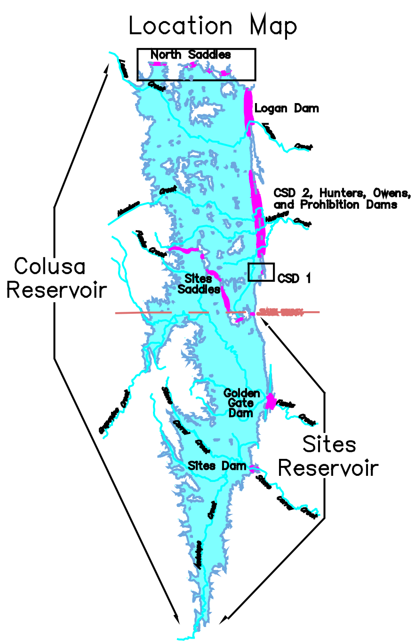
The foundations of the five proposed saddle dams are composed of interlayered beds of Upper Cretaceous sandstone, siltstone, mudstone, and conglomerate of the Boxer Formation.

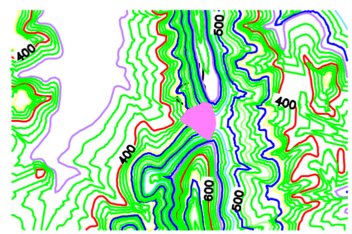
The mudstone unit in bedrock is dark gray to black in color and tan where weathered. Bedding is thinly laminar with thin sandstone and siltstone interbeds. It is brittle and slakes and weathers rapidly when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak and closely fractured.

The Pleistocene age Tehama Formation outcrops on the ridge tops in the vicinity of the Colusa saddle dam alignment. Where it has been observed in this area it consists of a buff-colored tuffaceous sandstone resting with a sharp angular unconformity on the upturned beds of the Boxer Formation.

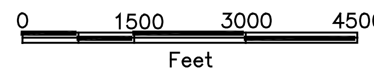


Northern Saddle Dam Sites





Saddle Dam Site 1 (CSD 1)



Dam footprints shown have a 20 foot crest width
Side slopes of 3:1 U/S and 2.5:1 D/S

40 foot contours digitized from USGS 7.5 minute quadrangle maps.
10 foot contours generated by Eagle Point software.

Proposed Dam Crest = 540 ft
Spillway Crest = 520 ft
Minimum Pool = 320 ft
Contour Interval = 10 ft

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

LOCATION MAP
OF THE
COLUSA
SADDLE DAM SITES

FIGURE 9

Filename:N:\NDSharedInfo\typing\geo\Final 1999 Sites Report\Figures\original\Figure 9--North Saddle Dams Loc--01-19-01--JHM.dwg
Layout Name:Layout1 Plot Time: Jan 19, 2001 - 4:10pm

Unconsolidated Deposits

Unconsolidated deposits at the saddle dam alignment consist of alluvium and colluvium.

Alluvium occurs along the valley floor and stream channels that are crossed by the saddle dams.

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular rock fragments. This deposit ranges from 2 to 5 feet in thickness.

Structure

The primary structural feature along the northern Colusa saddle dam alignment is the Sites anticline and the associated Salt Lake fault. Northerly striking, east-dipping homoclinal bedding of the Great Valley sequence has been folded by the Salt Lake fault to vary the dip of the bedding from west to east. This is complicated by associated northeast-trending tear faults that also cut across structure.

Faults and Folds

U.S. Geological Survey mapped (Calif., Glenn and Colusa Counties 1961) the Salt Lake fault as intercepting the proposed alignment. It is a major north-south trending thrust fault that is associated with the adjacent Sites anticline. It extends from near Cache Creek to the south up the Antelope Valley, then attenuates about 10 to 15 miles to the north of the alignment. The Salt Lake fault parallels the Sites anticline, a major doubly plunging, isoclinal anticline on the west side of Logan Ridge. This anticline and the Fruto syncline to the west extend a distance of at least 40 miles or more. This anticline and fault are being mapped in more detail by the consulting firm of William Lettis and Associates as part of the ongoing Sites and Colusa Reservoir project fault and seismic investigation.

Foundation Conditions and Exploration

The work performed has led to three basic conclusions. The first is that very few rock outcrops exist within the areas proposed for the saddle dams. This makes it difficult to analyze the current geotechnical data for design purposes and has led to the recommendations for additional work. The second conclusion is that several of the dam axes trend normal to the strike of the geologic units. Additional work will be needed to evaluate these conditions. The third conclusion is that the presence of fault or fracture zones crossing dam alignments may create foundation and/or permeability problems and need further evaluation. The rock at the northern Colusa saddle dam alignment will probably provide good foundations for the proposed saddle dams with moderate stripping; however, several other concerns exist. There is a possibility that faults intersecting the alignment are active. Following is a site-by-site discussion of geologic conditions and additional work recommended. The discussion starts at DWR saddle dam site number 3 and proceeds westward through DWR saddle dam site number 7.

DWR Saddle Dam Site Number 3

This dam will have a maximum height of approximately 142 feet and a total length of 1,900 feet. Surface conditions are clayey topsoils underlain by mostly siltstones of the Boxer Formation. The Tehama Formation occupies the east abutment of this saddle dam.

A significant geologic concern at this site is that the dike structure will be constructed across the strike of the beds and across the contact between the Tehama and Boxer Formations. Because the area has a thick soil cover, additional drilling and trenching may be required to better define the geologic conditions.

DWR Saddle Dam Site Number 4

This dam will have a maximum height of approximately 80 feet and a total length of about 915 feet. Surface conditions consist of clayey soils with no rock outcrops mapped within the footprint of the dam. Like that of saddle dam site number 3, the axis of number 4 trends normal to the strike of the beds. It is recommended that trenching be performed along the axis to define the depth to bedrock. An additional drill hole may be required to determine in-situ geologic conditions beneath the dam.

DWR Saddle Dam Site Number 5

This dam will have a height of about 130 feet and a length of 1,300 feet. Surface conditions vary from sandy to clayey rich soils, underlaid by sandstones, siltstones, and claystones of the Boxer Formation.

DWR Saddle Dam Site Number 6

This dam occupies a small saddle, has a maximum height of 20 feet, and a length of approximately 200 feet. Surface conditions are clayey soils, with occasional sandstone and calcareous material appearing as float.

DWR Saddle Dam Number 7

This dam will have a maximum height of 100 feet and a total length of more than 3,180 feet. Surface conditions are sandy to clayey soils with a few scattered sandstone outcrops.

Conclusions and Recommendations

This is only a brief office assessment of the alignment since DWR does not have access onto this private property. As such, it is very preliminary and will require the following work for an acceptable evaluation.

- Perform geologic mapping of the dam sites and some limited subsurface exploration to assess the subsurface conditions.
- Perform seismic refraction surveys and auger holes to estimate depths of overburden in the saddles for stripping estimates.
- Map all landslides that either exist on the footprints for the outlet works or that could impact the proposed facilities in any way.

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Other Cited References

The following draft documents are available for viewing at Northern District offices, California Department of Water Resources:

Technical Memorandum A. Drill core logs, soil logs, drilling chronologies and photographs.

Technical Memorandum B. Water pressure testing analysis.

Technical Memorandum C. Well completion and water level monitoring.

Sites Dam Site

The Sites Dam site is in a narrow, V-shaped water gap on Stone Corral Creek about a quarter of a mile east of the town of Sites and 8 miles west of the town of Maxwell in Colusa County (Photo 2). It is in Sec. 20, R4W, T17N on the Sites 7.5-minute USGS topographic quadrangle. The proposed dam, in conjunction with the Golden Gate Dam and the Sites northern saddle dams, would impound 1.8 million acre-feet of water in Sites Reservoir. The dam would be a 277-foot high embankment structure with a 900-foot crest length at an elevation of 540 feet. No spillway is associated with Sites Dam. The only spillway is part of the Golden Gate outlet works just south of the Golden Gate Dam site.

Previous geologic work was performed by USBR in the early 1960s with additional work in the early 1980s. This included geologic mapping at the site and drilling two vertical drill holes and one angle hole along the proposed axis. The current investigation by the Northern District and Project Geology staff consists of additional geologic mapping, diamond core drilling, and auger holes.

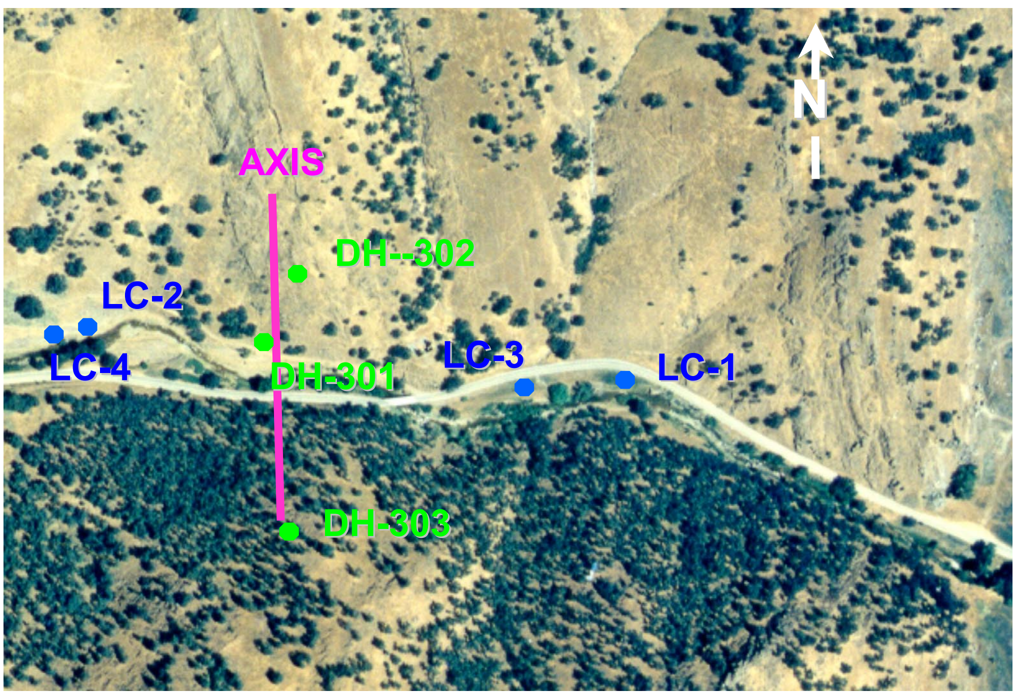


Photo 2: Aerial view of Sites Dam site on Stone Corral Creek

Dam Site Geology

The site was first mapped by USBR in 1963 as part of its *West Sacramento Canal Unit Report* (DOI-USBR 1964). This information was used as the basis for Northern District's geologic mapping of the site July through October of 1998. DWR's Division of Engineering assisted with this project, and mapping data from DWR's DOE and Northern District have been incorporated into this report.

Foundation rocks at the proposed Sites Dam site are Cretaceous sedimentary rocks of the Cortina and Boxer Formations that are upturned to form a series of north- to northwest-trending homoclinal ridges that dip from 45 to 55 degrees to the east. The sandstones and siltstones are more resistant and form ridge crests in the area. The proposed axis for the dam keys into one of these prominent ridges. The mudstones are generally covered by soil and colluvium and occupy topographic lows. The mudstones are rarely exposed in outcrops except in road cuts, streambanks, or where exposed from landslide scarps. Minor colluvial soil also mantles the abutments. Quaternary alluvial deposits cover bedrock in the stream channel to depths of about 5 feet. Quaternary terrace deposits also border the channel and have a thickness of about 20 feet. They are composed of sand, silt, and gravel, mantled by a clayey soil.

Plates 1 through 3 present the geologic mapping along with geologic cross sections and profiles, core logs, water pressure testing values, and minimum/maximum water levels at the site. Detailed logging and photodocumentation of the drill core is presented in Technical Memorandum A. Details of the water pressure testing are presented in Technical Memorandum B. Details of the piezometer construction and water levels are presented in Technical Memorandum C.

Bedrock Units

The proposed Sites Dam foundation consists of interlayered beds of Upper Cretaceous sandstone, siltstone, mudstone, and very minor conglomerate of the Boxer and Cortina Formations. Mudstone of the Boxer comprises about 50 percent of the foundation mainly upstream of the axis, with sandstone, siltstone, and minor conglomerate of the Cortina comprising the downstream 50 percent of the total footprint of the dam. This is detailed on Plate 2, Engineering Geology of the Sites Dam Site map.

These bedrock units were differentiated into mappable units (see Plates 1 through 3) as follows:

- KCVs - predominantly silty sandstone (70 to 100 percent) of the Venado member of the Cortina Formation with mudstone beds (0 to 30 percent) up to 5 feet in thickness.

DRAFT

- KCVsm - interbedded mudstones (30 to 70 percent) and silty sandstones (30 to 70 percent) of the Venado member of the Cortina Formation

- KBm - predominantly mudstone (70 to 100 percent) of the Boxer Formation with silty sandstone intervals (0 to 30 percent) up to 5 feet in thickness

The sandstone unit is the most resistant rock type at the site. Fresh sandstone is light to medium olive gray in color but yellowish brown when weathered. It is mostly very fine-to-medium grained, well-sorted, arkosic sandstone with a silt to clay matrix. Bedding is mostly massive to cross-bedded and ranges from less than a foot to tens of feet in thickness. It contains thin interbeds of siltstone and mudstone that range from laminar up to 5 feet in thickness. It is typically weathered at the surface to a depth of at least 15 feet. When fresh it shows no slaking. It is moderately to well indurated, moderately to slightly fractured, moderately hard to very hard, and moderately strong to strong. Internal structure is well developed in the areas of cross-bedding and vague where massive The fractures are commonly healed with calcite, and also have some pyritization.

The mudstone unit is the least resistant rock type in the area. It is low to moderately hard, weak to moderately strong, and is dark gray to black where fresh, and tan where weathered. Bedding is thinly laminar with thin sandstone and siltstone interbeds. It is brittle and slakes rapidly in outcrop when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak, and closely fractured.

A thin conglomerate unit outcrops just downstream of the left abutment. It is not exposed within the proposed footprint of the dam. Clasts range in size from coarse gravel to cobble. They are well-rounded and consist of chert, volcanic, and plutonic rocks. The clasts are hard and strong. The matrix is argillaceous. Some marine fossils are also associated with this unit. These have yet to be identified but appear to be pelecypod, coral, and gastropod fragments.

Unconsolidated Deposits

Unconsolidated deposits at the dam foundation consist of Quaternary stream channel deposits of sand and gravel, stream terraces, colluvium, and landslides.

Quaternary Alluvium (Qal) is the active stream channel of Stone Corral Creek and consists mainly of lean clay, silt, sand, gravel, cobbles, and boulders. It occurs along the channel sides and as discontinuous deposits in the channel. Deposits are estimated to range up to 5 feet in thickness.

Two terrace deposits (Qt1 and Qt2) border the active stream channel both upstream and downstream of the dam axis. They are flat and discontinuous and are elevated 15 to 25 feet above the stream channel. They range from about 30 feet in width at the downstream toe of the footprint to over 300 feet just upstream of the footprint. Qt1 is the youngest. Soil development is moderate. The upper part of this terrace is clayey silt with increasing clay content downward. Occasional gravel lenses are exposed along the sides of the incised stream channel and encountered in several of the drill and auger holes. In places there is a clay bed at the base of the observable deposit. The color of the upper 3 feet is very dark grayish brown, grading lighter with depth. These terraces may be correlative with the Modesto Formation as mapped by Helley and Harwood (Calif., Sacramento Valley 1982).

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular cobble and boulder rock fragments. This deposit ranges from 2 to 5 feet in thickness.

Twelve areas of potential zones of instability, including landslides, have been mapped at or near the proposed dam axis. Eight of these occur within the dam footprint, with an additional four located just upstream of both abutments. Three of these may be associated with the S-2 fault that crosses the upstream end of the right abutment, then bisecting the channel and crossing the left abutment downstream of the dam footprint. Two shallow debris slides occur about 500 feet downstream of the dam axis on the right abutment and channel. Both would be removed during the stripping for the foundation excavation. The remainder of the landslides occur mostly within the mudstone unit of the Boxer Formation, just upstream of the dam axis on both abutments near the formational contact between the Boxer and Cortina as shown on Plate 2. Most of these are earth flows and debris slides; however, several rockfall talus deposits occur, especially along the base of the ridge-forming Venado sandstone. These upstream zones of instability and landslides comprise about 30 percent of the surficial area within the dam footprint.

Structure

The primary structural feature at the Sites Dam site is the northerly striking, easterly dipping homoclinal bedding of the Great Valley sequence. Local bedding attitudes mostly strike from N10°W to N10°E and mostly dip from 45 to 55 degrees east. These are consistent with the regional trend in the Great Valley sequence.

Faults and Folds

Fault S-2 was mapped by USGS (Calif., Glenn and Colusa Counties 1961) as a northeast-trending right lateral tear fault (Photo 3). It extends from near the town of Sites and trends about N70°E across the right abutment just above the dam crest, crossing the channel just downstream of the toe of the footprint, trending more northerly on a bearing of about N40°E (see Plate 2). This right lateral fault has an apparent offset of about 120 feet.

Although it is unrecognized by USBR mapping, the Salt Lake fault or associated deformation may intersect the proposed dam footprint, according to DWR. The Salt Lake fault was mapped by William Lettis and Associates (WLA 1997) along the eastern edge of Antelope Valley about a half mile upstream of the proposed dam axis. There is some indirect evidence suggestive of faulting upstream of the dam axis on the left abutment and in the channel. This includes high angle normal slickensides in outcrop, a broad area of slickensided float upslope of this outcrop, several landslides on the left abutment, and some shearing encountered in DWR and USBR channel drill holes. However, these features by themselves could not justify placement of a discrete fault trace.

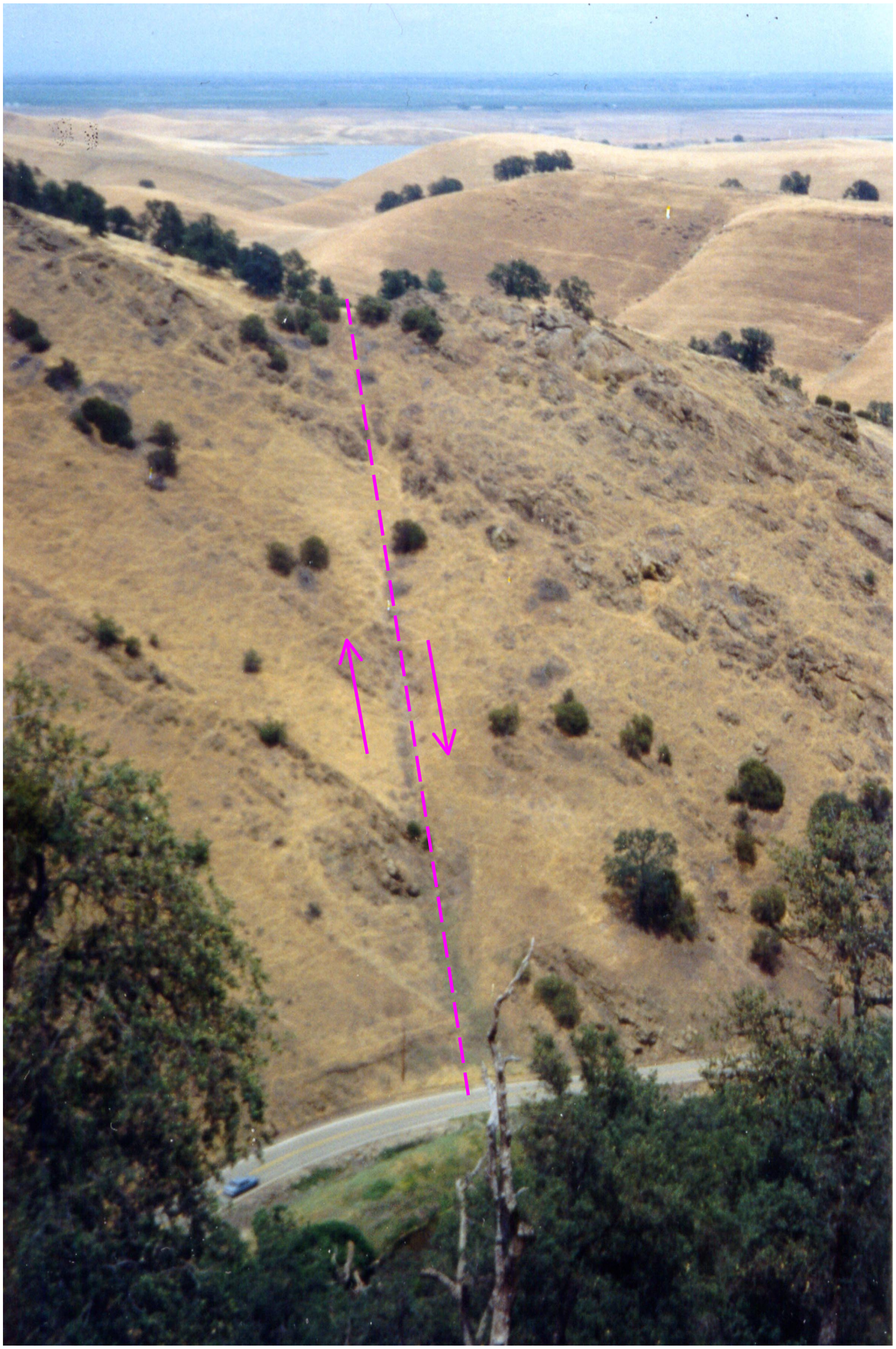


Photo 3. NE view of S-2 fault downstream of proposed Sites Dam footprint. (Note Funks Reservoir in the background)

Joints

At least two separate joint sets have been mapped in the area of the dam site. The primary and most distinctive jointing strikes NE and northwesterly dips ranging from 50 degrees to near vertical. This jointing is expressed on the left abutment, where intersections of these joints with the 175-foot-thick ridge-forming massive Venado sandstone has governed drainage off the ridge as steep gullies to the southwest. Secondary jointing exists at about N70°W with a wide range of dips. This is noted on the left abutment but becomes more apparent on the right abutment.

Foundation Conditions and Exploration

The rock at Sites Dam site should provide a good foundation for the proposed dam with moderate clearing and stripping. We have verified the existence of at least one fault in the right abutment, and our investigation suggests that another may exist in the channel and the left abutment. Also, both abutments contain zones of instability, including landslides that may require a moderate degree of excavation. Table 2 summarizes the foundation conditions.

The site was mapped on a regional scale initially by USGS in 1961, later by USBR in 1980, then modified by DWR-ND with assistance from DWR-DOE. In general, the lithology consists of upturned Upper Cretaceous sedimentary rocks consisting of dominant sandstone, mudstone, and minor conglomerate. The units strike roughly north-south, parallel to the axis, and dip downstream 45 to 55 degrees to the east. The foundation bedrock consists of about 50 percent sandstone and 50 percent mudstone interbeds (Figure 4). However, these percentages vary. The relative percentages of sandstone increases markedly in the main ridge, with a 160-foot thick sandstone layer in the Venado member of the Cortina Formation underlying the proposed dam axis. The Boxer Formation is immediately adjacent upstream. This has a predominant mudstone percentage of up to 70 percent, with secondary sandstone and siltstone interlayers to 30 percent, the reverse of the Cortina Formation. The channel between the abutments contains about 21 percent alluvium, 66 percent terrace deposits, and 13 percent landslide deposits.

In 1979-80 USBR drilled and water pressure-tested three diamond core holes along the proposed axis on both abutments and in the channel. Accordingly, our drilling concentrated on evaluating existing faults in the foundation. In the spring of 1998 we contracted with All -Terrain Drilling to provide drilling and testing services. An all-terrain CME-850 track mounted rig mobilized and started work at the site. Four diamond core holes were drilled totaling 740.4 feet; and three auger holes totaling 41.4 feet (Table 3). All four of the core holes were angle holes oriented to intercept the northeast-trending tear fault, and/or to explore the possibility of an extension of the Salt Lake fault or associated deformation intercepting the proposed dam footprint.

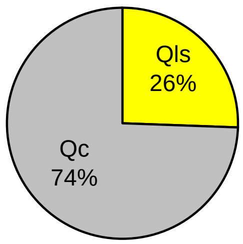
TABLE 2 – Sites Reservoir Project, Sites Dam Site Foundation Conditions (total area of Dam site footprint = 1,117,800 feet^2)

FEATURE	SURFICIAL/BEDROCK GEOLOGY (by area in feet^2)*	CLEARING ESTIMATES	STRIPPING ESTIMATES	WATER LEVELS	GROUTING ESTIMATES	STRUCTURAL REMARKVS
Left Abutment Axis Length = 365 feet. Max Footprint Length = 1,571 feet Min Elev. = 255 feet Max Elev. = 540 feet USBR Drill holes = 60 degree angle drill hole DH-302 (placed 280 feet. north of channel 180 feet. up the left abutment just downstream of the dam axis) No DWR Drill holes. No seismic done.	Surficial Qls = 100,100 feet^2 (26%) Qc = 291,700 feet^2 (74%) Total Area = 391,800 feet^2 Bedrock KCVs = 107,700 feet^2 (28 %) KCVsm = 130,600 feet^2 (33%) KBm = 153,500 feet^2 (39 %) Total Area = 391,800 feet^2 Therefore: Ss = from 114,600 feet^2 (29%) to 306,600 feet^2 (78%) Ms = from 85,200 feet^2 (22%) to 277,200 feet^2 (71%)	Light: Scattered grasses interspersed between open sandstone outcrops. A few oaks in south draining gully.	The upper foot of soil, colluvium, landslide deposits, and intensely weathered rock can be stripped with common methods. An additional 14 feet of moderately weathered rock may need to be excavated.	USBR drill hole not measured.	USBR Drill Hole DH-302 Shows that this hole is in predominately impervious sandstone except where it is semi-pervious in the range of 28 to 38 feet in moderately weathered ss and in the 47 to 56 feet. where there are some thin beds of mudstone.	The north-south trending Salt Lake thrust fault (S-1) is mapped about 1/2-mile northwest of the damsite. It or associated deformation may intercept upstream end of dam footprint. Several earth and debris flows, rockfall off Ss ridge, exist upstream of dam axis. Total area of Qls = 102,100 feet^2, or about 26% of the abutment. USBR drill hole DH-302 shows little or no fracturing except between 3 to 15 feet where there is some moderate fracturing.
Channel Section Axis Length = 146 feet Max Footprint Length = 1,614 feet. Min Elev. = 250 feet Max Elev. =295 feet USBR Drill holes =DH-301 (Placed left of channel along dam axis). DWR Drill holes LC-2, LC-4, AUG-1, and AUG-2 are located 350, 450, 405, and 975 feet, respectively upstream of the dam axis. DWR Drill holes LC-1, LC-3, and AUG-3 are located 820, 770 and 710 feet respectively down steam of the dam axis. AUG-2 is the only hole located outside of footprint. No seismic done.	Surficial Qls = 38,700 feet^2 (13%) Qal = 63,700 feet^2 (21%) Qt_1 = 205,000 feet^2 (66%) Total Area = 307,400 feet^2 Bedrock KCVs = 29,100 feet^2 (9 %) KCVsm = 42,200 feet^2 (14 %) KBm = 236,100 feet^2 (77 %) Total Area = 307,400 feet^2 Therefore: Ss = from 33,000 feet^2 (11%) to 223,900 feet^2 (73%) Ms = from 83,500 feet^2 (27%) to 274,400 feet^2 (89%)	Light: Light riparian bordering stream = grasses, cotton-wood, fig trees, poison oak; grasses on terrace deposits	The upper 4 to 20 feet of alluvium terrace deposits, and intensely weathered rock can be stripped with common methods. An additional 3 feet of moderately weathered rock may need to be excavated.	In Dec. 1979 DH-301 varied from 10-10.2 feet below surface. In Summer, 1998, DWR holes = 9.5 feet below surface, then constant till Summer, 1999 = 11.5 feet below surface. Changed in Nov. 1999 to 10 feet. below surface.	DWR Drill Hole LC-3: Moderate grout takes at 79 to 88 feet in fractured Ss/Ms. Low grout takes at 71 to 79, and 88 to 95 feet in fractured Ss/Ms. Rest of hole little grouting. DWR Drill Hole LC-4 (upstream of dam axis): High grout takes at 18 to 35 feet, 69 to 93 feet in fractured Ms/Ss. Moderate grout takes at 35 to 44 feet in fractured Ss/Ms. Low grout takes at 44 to 58 feet 62 to 69 feet, 93 to 100 feet, and 117 to 126 feet. in fractured Ms/Ss. The rest requires little grouting.	Mapped Fault (S-2) trends through channel just at downstream toe of footprint, then continues at N42^{o}E, dips >80^0 SE. Apparent right lateral offset = 120 feet. USBR drill hole DH-301 intercepts zones of very intense Fx from 19 to 20 feet and with shears containing slicks and gouge at 78 to 80 feet, 88.6 to 89.4 feet and 104 to 107 feet DWR drill hole LC-1 did not intercept any shears. Drill hole LC-2 intersects slicks and gouge 40 feet and from 194 to 195 feet, with intense Fx from 112 to 121 feet. Drill hole LC-3 intercepted closely to intense Fx and slicks from 24 to 29 feet and from 76 to 80 feet. Drill hole LC-4 intercepted closely to intense Fx and slicks at 60 to 61 feet., 101 feet.,104 feet., 136 to 138 feet, 177 feet., and 194 to 195 feet Note: Angle depths for the DWR holes.
Right Abutment Axis Length = 415 feet. Max Footprint Length = 1,601 feet. Min Elev. = 250 feet. Max Elev. = 540 feet. USBR Drill holes = DH-303 (placed 520 feet. south of channel 240 feet. up the right abutment along the dam axis) No DWR Drill holes. No seismic done.	Surficial Qls = 180,400 feet^2 (43%) Qc = 238,200 feet^2 (57%) Total Area = 418,600 feet^2 Bedrock KCVs = 109,837 feet^2 (27%) KCVsm = 89,600 feet^2 (21%) KBm = 219,200 feet^2 (52%) Total Area = 418,600 feet^2 Therefore: Ss = from 103,800 feet^2 (25%) to 326,000 feet^2 (78%) Ms = from 92,700 feet^2 (22%) to 314,900 feet^2 (75%)	Moderate: Heavier than left abutment due to abundant oak trees and poison oak, especially upstream of axis on old landslide deposit.	The upper 9 feet of soil, colluvium, landslide deposits, and intensely weathered rock can be stripped with common methods. An additional 40 feet of moderately weathered rock may need to be excavated.	DH-303 varied during drilling Feb. 1980, from dry to 125 feet below ground surface to dry again. This USBR drill hole has not measured since.	USBR Drill Hole DH-303 Shows that this hole is predominately impervious sandstone some thin and laminated beds of mudstone except where it is semi-pervious in the range of 31 to 86 feet it is lightly moderately weathered and in the 132 to 141 feet range where it corresponds to some very intense fracturing.	Mapped Fault (S-2) trends at N72^{o}E along southern edge of footprint, dips >80^0 SE. Apparent right lateral offset = 120 feet. USBR drill hole DH-303 shows little to intense fracturing with a zone of very intense fracturing 108.9-109.6 feet and 155.7-155.9 feet Note: these are angle depths.

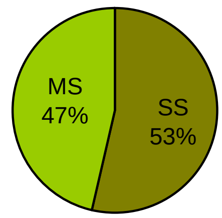
Ss = Sandstone Ms = Mudstone Cgl = Conglomerate Qal = Quaternary Alluvium Qc = Quaternary Colluvium Qt_1 = Quaternary Terrace (lower) Qt_2 = Quaternary Terrace (upper) Fx = fracturing
***Total Foundation Area of Damsite Footprint = 1,117,800 feet^2, therefore total Ss = from 251,400 feet^2 (22%)to 856,500 feet^2 (77%); total Ms = from 261,400 feet^2 (23%) to 856,500 feet^2(78%)**

FIGURE 4: Sites Dam Site Surficial and Bedrock Lithology By Percentage

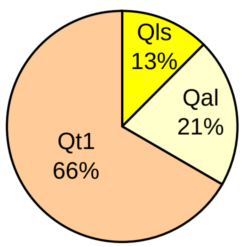
Areal Surficial Lithology of the Left Abutment



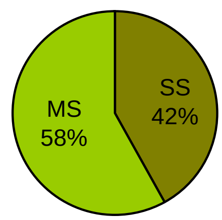
Areal Bedrock Lithology of the Left Abutment--Average Proportion of Sandstone and Mudstone



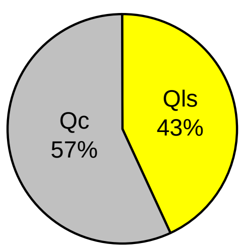
Areal Surficial Lithology of the Channel Section



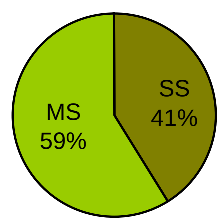
Areal Bedrock Lithology of the Channel Section--Average Proportion of Sandstone and Mudstone



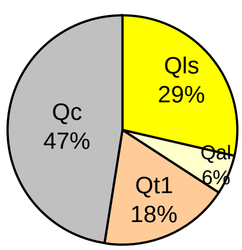
Areal Surficial Lithology of the Right Abutment



Areal Bedrock Lithology of the Right Abutment--Average Proportion of Sandstone and Mudstone



Areal Surficial Lithology of the Damsite Footprint



Areal Bedrock Lithology of the Damsite Footprint--Average Proportion of Sandstone and Mudstone

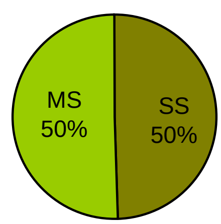


Table 3. DWR drilling footage of Sites Dam site

Drill site	Drill hole	Date started	Date completed	Drilled footage (feet)
Sites Dam site	LC–2	May 11, 1998	May 20, 1998	202.2
	LC-1	MAY 22, 1998	May 28, 1998	140.6
	LC-3	June 01, 1998	June 05, 1998	198.0
	LC-4	JUN 10, 1998	JUN 16, 1998	199.6
Total HQ Diamond Drill Footage				740.4
	AUG-1	MAY 21, 1998	MAY 21, 1998	10.5
	AUG-2	MAY 22, 1998	MAY 22, 1998	16.9
	AUG-3	MAY 22, 1998	MAY 22, 1998	14.0
Total Auger Footage				41.4
Total footage				781.8

LA = Left abutment drill hole
LC = Left channel drill hole
RC = Right channel drill hole
RA = Right abutment drill hole
DHPP = Drill hole power plant
DHS = Drill hole spillway
DHT = Drill hole tunnel
SSD = Sites saddle dams
AUG = Auger hole

Water pressure testing was also performed on two of these holes, LC-2 and LC-4, to determine the permeability of the Boxer Formation upstream of the dam axis and the presence of any faults, associated shearing, and/or fracturing (see Plates 2, 3, and Technical Memorandum C). Three holes were augered through the terrace and alluvial deposits to bedrock.

Angle drill hole LC-2 was drilled to evaluate the possible existence of the Salt Lake fault or associated deformation in the upstream footprint of the proposed dam axis (Photo 4). It was oriented cross-channel at S62°W to also explore the possibility of a "blind" or hidden fault under the alluvium that trends nearly parallel with Stone Corral Creek. It was drilled to a total depth of 202.2 feet. The upper 0.0 to 20.5 feet are composed of terrace deposits consisting of a mostly lean clay. From 20.5 to 39.0 feet, the hole drilled through 80 percent mudstone with 20 percent siltstone interbeds. From 39.0 to 50.7 feet, the hole drilled through 50 percent mudstone and 50 percent siltstone interbeds. From 50.7 to 72.0 feet, it intersected 80 percent sandstone with 20 percent mudstone interbeds. From 72.0 to 202.2 feet, the hole drilled through 80 percent mudstone with 20 percent sandy siltstone interbeds. It also intersected minor shears from 39.7 to 39.9 feet, 194.2 to 194.7 feet, and a shear zone from 111.7 to 121.0 feet. These zones contained slickensides and fracturing that may be related to the S-2 fault (Photo 5).

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Photo 4. CME - 850 drill rig at Sites Dam site drill hole LC–2

Angle drill hole LC-4 was drilled roughly 100 feet southwest of LC-2 at S86°W to further evaluate the Boxer Formation underlying the upstream portion of the dam footprint, and to explore the possibility that more shears may parallel the ones found in LC-2. The upper 0.0 to 18.3 feet of the hole drilled through a terrace deposit consisting of a sandy clay. From 18.3 to 44.6 feet, it drilled through 70 percent mudstone with 30 percent siltstone interbeds. From 44.6 to 60.1 feet, it intersected 50 percent mudstone and 50 percent siltstone interbeds. From 60.1 to 76.5 feet, the hole contains 90 percent mudstone with 10 percent siltstone interbeds. From 76.5 to 169.6 feet, the hole contains 60 percent mudstone with 40 percent siltstone interbeds. From 169.6 to 174.3 feet, it hit a 100 percent sandstone layer.

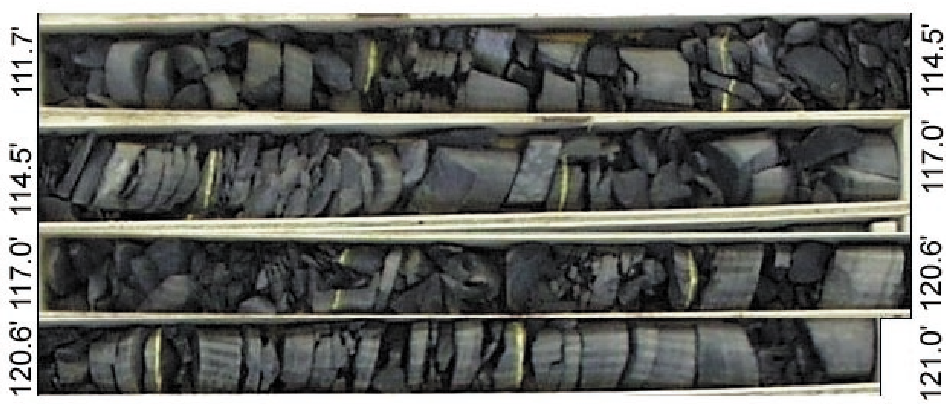

Photo 5. Intense fracturing from 111.7 to 121.0 feet in drill hole LC-2

From 174.3 to 199.6 feet, the hole is composed of 60 percent mudstone with 40 percent siltstone interbeds. It also intersected slickensides and intense fracturing from 60.3 to 61.1 feet, 101.1 to 101.6 feet, at 104.0 feet, and from 136.2 to 136.6 feet, 137.4 to 137.7 feet, 176.7 to 177.1 feet, and 194.0 to 194.9 feet. The hole did not encounter any significant shearing, although minor slickensides were encountered throughout the hole.

Angle hole LC-1 was drilled to intercept the S-2 fault as mapped and to explore the possibility that a buried or hidden fault trends beneath Stone Corral Creek. It drilled through lean clay terrace deposits to 21.0 feet. The rest of the hole to 140.6 feet intercepted about 95 percent sandstone with 5 percent thin mudstone interlayers. No fault was encountered, so the drill rig was moved to drill hole LC-3.

Angle hole LC-3 was oriented nearly perpendicular to the mapped trend of S-2 fault. It drilled through sandy clay terrace deposits to a depth of 7.1 feet. No core was recovered from 7.1 to 18.9 feet. From 18.9 to 198.0 feet, the hole encountered 95 percent sandstone with 5 percent thin mudstone interlayers. It also encountered a zone of close fracturing of rock and slickensides from 24.0 to 28.5 feet and a zone of fractured rock and slickensides from 76.3 to 80.0 feet. These are probably related to the S-2 fault but are probably not the main zone of shearing.

USBR drilled vertical drill hole DH-301 in 1979 at the proposed dam axis about 380 feet downstream of LC-2. It encountered very intense fracturing from 19.1 to 20.0 feet and slickensides and gouge from 78.3 to 80.0 feet, 88.6 to 89.4 feet, and 103.9 to 106.7 feet. Although not correlative with the shearing in LC-2 and LC-4, these features may also represent deformation associated with the Salt Lake fault, or the contact between the Boxer and Cortina Formations.

Auger holes AUG-1, AUG-2, and AUG-3 were drilled to determine the composition and thickness of the terrace deposits in the channel. Bag samples were taken every 5 feet. The terraces are composed mostly of clayey silts with minor gravels and range in thickness from 10.5 to 16.9 feet.

On June 10 the drill rig was moved north to explore the Golden Gate Dam site.

Rock Strength

Logging of the core indicates that the rock strength of the sandstone ranges from moderate to hard. Rock quality designation (RQD) was used by both USBR and DWR in logging of the core (see Table 4 and Plate 3). This

Table 4. Rock quality designation in drill holes at Sites Dam site

Agency	Drill Hole	Vertical Depth Interval (feet)	Minimum RQD*	Maximum RQD*	Average RQD*	Description
DWR	LC-1	25–100	84	100	96	Excellent
DWR	LC-2	25–37	16	78	41	Poor
DWR	LC-2	38–51	77	100	89	Good
DWR	LC-2	52–86	22	86	55	Fair
DWR	LC-2	87–143	68	94	85	Good
DWR	LC-3	25–55	95	100	98	Excellent
DWR	LC-3	56–57	0	0	0	Very Poor
DWR	LC-3	58–94	76	100	92	Excellent
DWR	LC-3	95–112	58	100	82	Good
DWR	LC-3	113–140	86	100	93	Excellent
DWR	LC-4	25–74	0	72	32	Poor
DWR	LC-4	75–117	38	100	76	Good
DWR	LC-4	118–142	20	88	59	Fair
USBR	DH-301	10–23	0	35	9	Very Poor
USBR	DH-301	24–59	64	100	82	Good
USBR	DH-301	60–61	9	9	9	Very Poor
USBR	DH-301	62–108	20	100	77	Good
USBR	DH-302	25–130	88	100	99	Excellent
USBR	DH-303	10–28	0	30	12	Very Poor
USBR	DH-303	29–63	33	87	54	Fair
USBR	DH-303	64–76	80	100	87	Good
USBR	DH-303	77–90	35	47	39	Poor
USBR	DH-303	91–128	62	100	85	Good
USBR	DH-303	129–133	28	28	28	Poor
USBR	DH-303	134–180	81	100	98	Excellent
USBR	DH-303	181–193	41	80	61	Fair
USBR	DH-303	194–206	86	100	95	Excellent

parameter is often used as an indicator of the competence of rock. In general, calculation of RQD indicates that the left abutment along the Sites Dam site axis has excellent rock quality deeper than 25 feet. Also, quality in the channel upstream of the axis in the Boxer Formation is fair to good below 75 feet. Quality in the channel along the axis is good below 62 feet. Quality in the channel downstream of the axis in the Venado sandstone is good to excellent below 58 feet. Quality on the right abutment along the axis is fair to excellent below about 90 feet in depth.

Bryte Laboratory tested several fresh samples of sandstone core from drill hole LC-2. A sample from 53.5 to 54.5 feet was tested wet and had a specific gravity of 2.55, a 1.6 percent loss, and unconfined compressive strength (UCS) of 17,868 pounds per square inch (psi). Sandstone samples were also taken from Sites Quarry about 2,000 feet downstream of the dam site and tested. Three fresh sandstone samples had a UCS of 9,568 psi when dry, 6,983 psi when wet. Three moderately weathered sandstone samples averaged a UCS of 4,998 psi when dry, 3,589 psi when wet.

Water Pressure Testing

Water pressure tests were performed by DWR in angle drill holes LC-3 and LC-4. These holes generally had minimal water losses, but there were several intervals in which high losses were recorded. High losses occurred in drill hole LC-4 in the zones from 50 to 65 feet, and from 75 to 90 feet. Water losses were relatively low below these depths. About one psi per foot of overburden was used for water testing.

Grouting and Foundation Treatment

Grouting requirements focus on LC-4 to the west, where secondary fracturing of the predominately mudstone formation is associated with high Lugeon values. Average permeability for the mudstone in this hole is 0.26 feet per day, with grouting necessary throughout the top 140 feet of the hole. The remainder of the hole will require moderate to no grouting. The eastern-most drill hole, LC-3, is composed mainly of sandstone, with an average permeability of 0.04 feet per day. Grouting in this hole will center on the fractured zone encountered between 100 feet and 135 feet, with the balance of the hole requiring moderate to low grouting. This hole has an average Lugeon value of 1, which is significantly lower than the mudstone of LC-4 (average Lugeon value of 6). LC-1 and LC-2 were not water pressure tested due to problems with the packers.

Faults uncovered in the foundation may require some cleaning and excavation of weakened and sheared rock before the embankment is constructed. These faults/shears, bedding, and jointing are potential seepage paths through the abutments and will undoubtedly require grouting. Therefore, for estimating purposes, blanket grouting should be considered to seal near-surface fractures and joints.

Water Levels

Piezometers were installed in drill holes LC-2, LC-3, and LC-4 at the Sites Dam site. Water levels have been monitored since the summer of 1998. The water level in the channel holes was roughly 9.5 feet deep just after drilling in the summer of 1998, then remained fairly constant until the summer of 1999 when it dropped to about 11.5 feet deep. It then rose to about 10 feet deep by the winter. The water level on the right abutment was 125 feet deep when measured in DH-303 by USBR in February 1980.

Clearing and Stripping

Photo 6. Sites Dam site left abutment

Left Abutment

The left abutment is moderately steep adjacent to the channel section. It has a slope ranging from 1:1 at the base, then lessening to 0.75:1 towards the crest. (Photo 6). The sandstone forms the topographic highs often void of soil cover. Mudstone is mostly subdued in topographic expression and develops a colluvial soil overburden. These beds strike nearly north-south and dip about 50 degrees downstream toward the east. Most joint fractures strike nearly east-west with a dip between 70 degrees south to 70 degrees north. Vegetation is light on the left abutment, consisting mostly of grass with a few scattered oaks, especially in the south-draining gullies upstream of the axis.

The unconsolidated deposits on the left abutment consist of about 74 percent colluvial soil and 26 percent landslide deposits. This is underlain on average by about 55 percent sandstone and siltstone, with 45 percent mudstone interlayers.

Foundation preparation should include the removal of at least the upper foot of colluvial soil, landslide material, and heavily weathered bedrock using common methods, with another 14 feet of moderately weathered bedrock that may have to be excavated. The material removed from the foundation stripping probably can be used as random fill. The upper 1-foot of soil, colluvium, and intensely weathered bedrock on the left abutment can be stripped using common methods.

Channel

Photo 7. Downstream view of the channel at Sites Dam site

The channel varies in width from about 75 to 450 feet in the footprint, and averages about 150 feet at the dam axis (Photo 7).

Alluvial cover is superficial with about 4 to 10 feet of poorly to well-graded sand and gravel. No bedrock was observed in the channel of Stone Corral Creek within the footprint of the dam. The creek has perennial flows, so a creek diversion or impoundment will be necessary. The flow in the summer and fall is generally minimal, and dewatering will not be a serious problem.

The channel has a fairly light riparian zone with scattered pockets of grasses, cottonwoods, fig trees, and poison oak. This is thicker in the channel along the dam axis where the channel narrows.

Stream channel deposits consisting of an areal proportion of 21 percent alluvium, 66 percent terrace deposits, and 13 percent landslide deposits overlie the channel. The underlying bedrock is estimated at about 42 percent sandstone and 58 percent mudstone.

Foundation preparation should include the removal of 4 to 20 feet of alluvium, terrace deposits, and intensely weathered bedrock using common methods, with at least another 9 feet of moderately weathered bedrock that may have to be excavated. In addition, the oversteepened slopes adjacent to and cut by the creek will require shaping.

Right Abutment

The right abutment is moderately steep with a natural slope of about 0.75 to 1 (Photo 8). The mudstone units mostly upstream of the dam axis are mostly covered by soil creep and/or colluvium and are generally only seen exposed in creek beds, roadcuts, and drill core. The sandstone can generally be observed as outcrops exposed as topographic highs with little or no soil cover. Minimal amount of colluvium and slope wash covers the mid to lower right abutment

Vegetation is much heavier on the right abutment than that on the left abutment. Oak trees cover much of the footprint and are especially dense just upstream of the dam axis on the Boxer Formation. This is associated soil development on the mudstones and a northern slope exposure along with an old extensive landslide deposit.

There are thicker soil and colluvial deposits on the Boxer Formation than on the Cortina because the Boxer contains a greater relative percentage of more erodible mudstone. The unconsolidated deposits on the right abutment consist of about 57 percent colluvial soil and 43 percent landslide deposits. This is underlain on average by about 40 percent sandstone and siltstone, with 60 percent mudstone interlayers.

Foundation preparation should include the removal of at least 9 feet of topsoil, colluvium, heavily weathered bedrock, and landslide and rock debris. In some locations intensely weathered bedrock can be excavated using common methods, with at least another 40 feet of moderately weathered bedrock that may have to be excavated. A reconnaissance-level investigation of Sites Dam site states, "Depth to groutable rock on the left abutment will average three feet. Deep slopewash accumulations on the right abutment will neccessitate 10- to 15-foot excavations to reach groutable rocks. Depths to groutable rock in the channel section will vary from five to eighteen feet. Temporary slopes of 1:1 on the abutments and 1.5:1 in the channel section are recommended." (DOI-USBR 1969) The material removed by foundation stripping can probably be salvaged for use as random fill

Photo 8. Sites Dam site right abutment

Conclusions and Recommendations

DWR's Northern District Geology Section concludes that the foundation drilled appears to be suitable for the proposed structures. Table 2 summarizes the foundation conditions in the footprint for the proposed dam site. More conclusions follow:

- Mapped S-2 fault on Plate 2 is a near vertical linear feature that trends about N70°E on the upper right abutment along the southern edge of the footprint. It turns more northerly near the channel, trending N45°E downstream of the dam axis. This feature has an apparent right lateral offset of about 160 feet. USBR located angle drill hole DH-303 about 100 feet upslope of this fault and did not intercept it. DWR angle drill hole LC-3 drilled through slickensides and intense fracturing from 24.0 to 28.5 feet,and from 76.3 to 80.0 feet. These are probably related to the S-2 fault, but are probably not the main zone of shearing. The consulting firm of William Lettis and Associates concluded that there is no evidence of Quaternary fault movement along the S-2 fault where trenched to the northeast of the dam site. It is likely that this is also true in the footprint of the Sites Dam site.

- The Salt Lake fault was mapped by William Lettis and Associates (WLA 1997) along the eastern edge of Antelope Valley about a half mile upstream of the proposed dam axis. The fault or associated deformation may extend into the proposed dam footprint. This is indirectly supported by high angle normal slickensides in outcrop on the left abutment, a broad area of slickensided float upslope of this outcrop, several landslides on the left abutment, and some shearing encountered in DWR and USBR channel drill holes. However these features by themselves could not justify placement of a discrete fault trace. DWR 45-degree angle DH LC-2 and LC-4 were drilled to determine whether this fault exists in the footprint. DH LC-2 was oriented at S62oW. It intersected slickensides and gouge from 39.7 to 39.9 feet and 194.2 to 194.7 feet and a zone of intense fracturing from 111.7 to 121.0 feet. LC-4 was drilled roughly 100 feet southwest of LC-2 at S86oW to continue this exploration. It intersected slickensides and intense fracturing from 60.3 to 61.1 feet, 101.1 to 101.6 feet, at 104.0 feet, and from 136.2 to 136.6 feet, 137.4 to 137.7 feet, 176.7 to 177.1 feet, and 194.0 to 194.9 feet. Also USBR's vertical DH-301 was placed in the left channel about 380 feet away at the proposed dam axis. It encountered very intense fracturing from 19.1 to 20.0 feet; and slickensides and gouge from 78.3 to 80.0 feet, 88.6 to 89.4 feet, and 103.9 to 106.7 feet. In the author's opinion these features may indicate deformation associated with the Salt Lake fault or may be related to the contact between the Boxer and Cortina Formations.

- In addition to the mapped fault traces, drill core data indicate that other minor faults and shears exist. The mapped fault traces and the minor faults and shears should not pose any unusual construction difficulties.

- The rock strengths should be adequate for the dam foundations as proposed.

- In general, the mudstone has the highest average permeability at 0.26 feet per day, followed by sandstone at 0.04 feet per day. Overall, the rocks have little primary permeability. Instead, zones of high water take are associated with the development of secondary permeability through weathering, extensive fractures, or jointing. This is most common in the sandstone.

- Grout takes were calculated for the proposed dam foundation in the channel from a Lugeon analysis of the water pressure testing (Technical Memorandum B). Estimates for the abutments were based on USBR's permeability values obtained during its drilling program. The grout takes on the left abutment in DH-302 are expected to be low except for moderate grout takes from 28 to 38 feet and 47 to 56 feet, and moderate grout takes from 50 to 62 feet in angle drill hole DH-303 on the right abutment. Additional exploration is warranted prior to construction to better evaluate where the S-2 fault intersects the right abutment. The takes in the channel downstream of the axis are also expected to be low except for moderate grout takes from 31 to 86 feet in moderately weathered sandstone and mudstone, and from 132 to 141 feet in fractured sandstone and mudstone. A grout curtain to 100 feet under the foundation with 10- to 20-foot centers should be sufficient to control foundation seepage.

- Water levels were measured in the channel over the past two years with a minimum depth of 10 feet and a maximum depth of 12 feet. Depth to water on the right abutment is at least 125 feet. Depth on the left abutment is undetermined.

- There should not be a significant problem with clearing vegetation from the foundation. The heaviest vegetation growth is on the right abutment where oak trees are fairly dense, especially upstream of the dam axis. There are only scattered oaks on the left abutment and light riparian growth in the channel.

- Additional foundation preparation would include the removal of about 10 feet of colluvium, soil, and intensely weathered bedrock from the left abutment; 15 feet from the channel; and 10 feet from the right abutment. An additional 10 feet of fractured and moderately weathered rock may have to be excavated from the left abutment, 3 to 10 feet from the channel, and 10 feet from the right abutment.

Additional work prior to final design and construction should include:

- Performing seismic refraction surveys on the terrace deposits to determine rippability estimates of the foundation bedrock.

- Further evaluating the extent and depth of the landslide deposits upstream of the axis on the left and right abutments.

- Having DWR's Bryte Laboratory test representative mudstone and sandstone samples from the core for both dry and wet unconfined compressive strength.

- Specific grouting requirements will require additional drilling.

Attachment A: Observed and Potentially Occurring Mammal Species of the Proposed Alternatives and Surrounding Areas

		Status	Sites	Colusa	Thomes-Newville	Red Bank
Order Marsupialia						
Family Didelphidae						
Didelphis marsupialis	Virginia opossum	CDFG-H	O	P	O	P
Order Insectivora						
Family Soricidae						
Sorex trowbridgii	Trowbridge shrew		P	P	O	P
Sorex vagrans	vagrant shrew		O	O		P
Sorex ornatus	ornate shrew		O	P	P	P
Family Talpidae						
Neurotrichus gibbsii	shrew-mole			P	P	
Scapanus latimanus	broad-footed mole		P	P	P	O
Order Chiroptera						
Family Vespertilionidae						
Myotis lucifugus	little brown myotis		O	P	P	P
Myotis yumanensis	Yuma myotis	USFWS-SC, CDFG-SC	O	P	O	O
Myotis evotis	long-eared myotis	USFWS-SC	P	P	P	P
Myotis thysanodes	fringed myotis	USFWS-SC	P	P	P	P
Myotis volans	long-legged myotis	USFWS-SC	P	P	P	P
Myotis californicus	California myotis		P	P	P	P
Myotis ciliolabrum	small-footed myotis	USFWS-SC	P	P	P	P
Lasionycteris noctivagens	silver haired bat				P	P
Pipistrellus hesperus	Western pipistrelle		O	O	O	O
Eptesicus fuscus	big brown bat		P	P	O	O
Lasiurus blossevilli	Western red bat	USFS-S	O	P	P	O
Lasiurus cinereus	hoary bat		P	P	P	O
Euderma maculatum	spotted bat	USFWS-SC, CDFG-SC	P	P	P	P
Corynorhinus townsendii townsendii	Townsend's western Big-eared bat	USFWS-SC, CDFG-SC, USFS-S	P	P	P	P
Corynorhinus townsendii pallescens	Pale big-eared bat	USFWS-SC, CDFG-SC, USFS-S	P	P	P	P
Antrozous pallidus	pallid bat	CDFG-SC, USFS-SC	O	O	P	O

Attachment A: Observed and Potentially Occurring Mammal Species of the Proposed Alternatives and Surrounding Areas

		Status	Sites	Colusa	Thomes-Newville	Red Bank
Family Molossidae						
Tadarida brasiliensis	Mexican free-tailed bat		O	O	O	O
Eumops perotis californicus	Greater western mastiff bat	USFWS-SC, CDFG-SC	P	P	P	P
Order Lagomorpha						
Family Leporidae						
Lepus californicus	black-tailed hare	CDFG-H	O	O	O	O
Sylvilagus audubonii	desert cottontail	CDFG-H	O	O	O	P
Sylvilagus bachmani	brush rabbit	CDFG-H	P	P	P	P
Order Rodentia						
Suborder Sciuromorpha						
Family Sciuridae						
Spermophilus beecheyi	California ground squirrel	CDFG-H	O	O	O	O
Eutamias amoenus	yellow pine chipmunk					O
Eutamias sonomae	Sonoma chipmunk				P	P
Sciurus griseus	Western gray squirrel	CDFG-H	P	P	P	O
Tamiasciurus douglasii	Douglas' tree squirrel	CDFG-H			P	P
Glaucomys sabrinus	Northern flying squirrel					P
Family Geomyidae						
Thomomys bottae	Botta's pocket gopher		O	O	O	P
Family Heteromyidae						
Perognathus inornatus inornatus	San Joaquin pocket mouse	USFWS-SC, CDFG-SC	P	P	O	P
Dipodomys californicus	California kangaroo rat		O	O	O	O
Family Heteromyidae						
Castor canadensis	beaver		CDFG-H		P	P
Suborder Myomorpha						
Family Cricetidae						
Reithrodontomys megalotis	Western harvest mouse		O	O	O	O
Peromyscus maniculatus	deer mouse		O	O	O	O
Peromyscus boylii	brush mouse		O	O	O	O
Peromyscus truei	Pinon mouse		O	P	P	O

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Attachment A: Observed and Potentially Occurring Mammal Species of the Proposed Alternatives and Surrounding Areas

		Status	Sites	Colusa	Thomes-Newville	Red Bank
Neotoma fuscipes	dusky-footed woodrat		P	P	O	O
Neotoma cinerea	bushy-tailed woodrat					O
Microtis californicus	California vole		O	O	O	O
Microtus longicaudus	long-tailed vole					P
Microtus oregoni	creeping vole					P
Ondatra zibethicus	muskrat		P	P	P	P
Family Muridae						
Rattus norvegicus	Norway rat		P	P	P	P
Rattus rattus	black rat		O	P	P	P
Mus musculus	house mouse		O	O	O	P
Family Zapodidae						
Zapus princeps	Western jumping mouse					P
Suborder Hystricomorpha						
Family Erethizontidae						
Erethizon dorsatum	porcupine				O	P
Order Carnivora						
Family Canidae						
Canis latrans	coyote	CDFG-H	O	O	O	O
Vulpes vulpes	red fox		P	P	O	P
Urocyon cinereoargenteus	gray fox	CDFG-H	P	P	O	O
Family Ursidae						
Ursus americanus	black bear	CDFG-H	O	P	O	O
Family Procyonidae						
Bassariscus astutus	ringtail	CDFG-P	O	P	O	P
Procyon lotor	raccoon	CDFG-H	O	O	O	O
Family Mustelidae						
Martes americana	Pine marten	USFS-S			P	
Martes pennanti	Pacific fisher	USFWS-SC, CDFG-SC, USFS-S				P

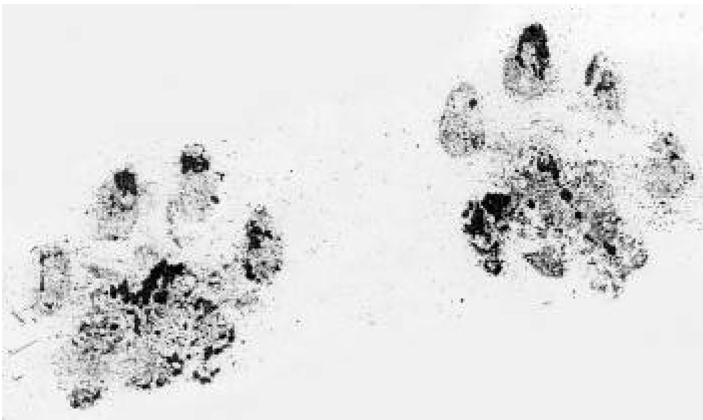
Attachment A: Observed and Potentially Occurring Mammal Species of the Proposed Alternatives and Surrounding Areas

		Status	Sites	Colusa	Thomes-Newville	Red Bank
Mustela ermina	ermine	CDFG-H			P	P
Mustela frenata	long-tailed weasel	CDFG-H	P	P	P	O
Mustela vison	mink	CDFG-H			P	P
Taxidea taxus	American badger	CDFG-SC	O	O	O	P
Spilogale gracilis	Western spotted skunk	CDFG-H	P	P	P	O
Mephitis mephitis	Western striped skunk	CDFG-H	O	P	O	O
Lutra canadensis	river otter		P	P	P	P
Family Felidae						
Puma concolor	mountain lion		O	P	O	O
Felis domesticus	feral cat		O	P	O	P
Lynx rufus	bobcat	CDFG-H	O	P	O	O
Order Arteriodactyla						
Family Suidae						
Sus scrofa	feral pig	CDFG-H	O	O	O	O
Family Cervidae						
Odocoileus hemionus columbianus	black-tailed mule deer	CDFG-H	O	O	O	O

Legend

USFWS-SC U.S. Fish and Wildlife Service "Federal Special Concern Species"
CDFG-SC California Department of Fish and Game "California Species of Special Concern"
USFS-S U.S. Forest Service "Sensitive Species"
CDFG-P California Department of Fish and Game "Fully Protected Species"
CDFG-H California Department of Fish and Game "Harvested Species"
O Observed in the project area
P Potentially occurring species in the project area

Attachment B: Representative Track Samples from the Track Plate Efforts



Bobcat

Domestic Cat

Striped Skunk

Fore Foot

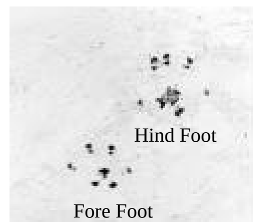
Hind Foot

Fore Foot

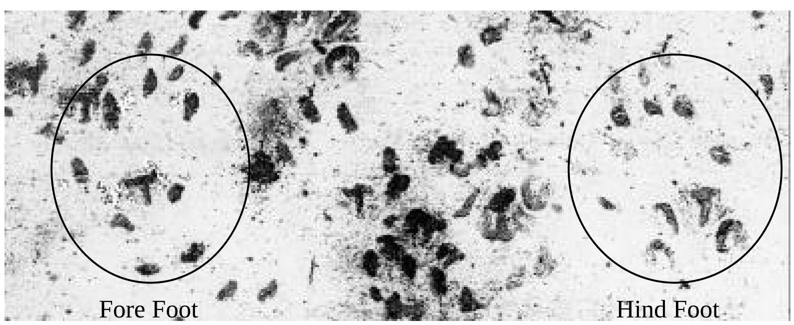
Hind Foot

Raccoon

Mouse



Dusky-footed Woodrat



California Ground Squirrel

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Attachment C: Representative Photographs from the Photo Stations Efforts

Cattle

Raccoon

Coyote

Feral pigs

Gray fox

Black bear

Black-tailed deer

Western striped skunk

Golden eagle

Western gray squirrel

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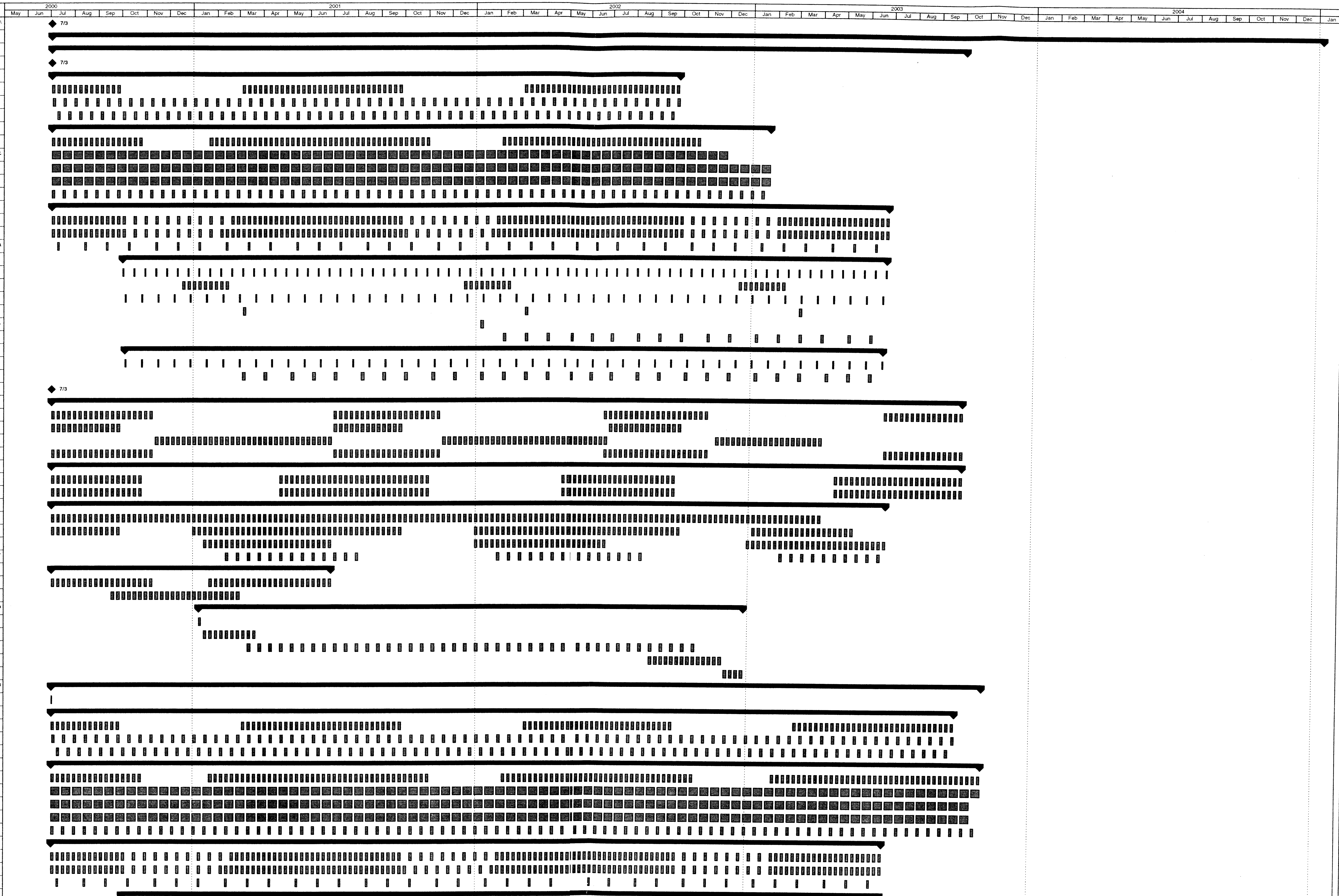
Attachment D: Proposed Timeline for Completion of Environmental Studies

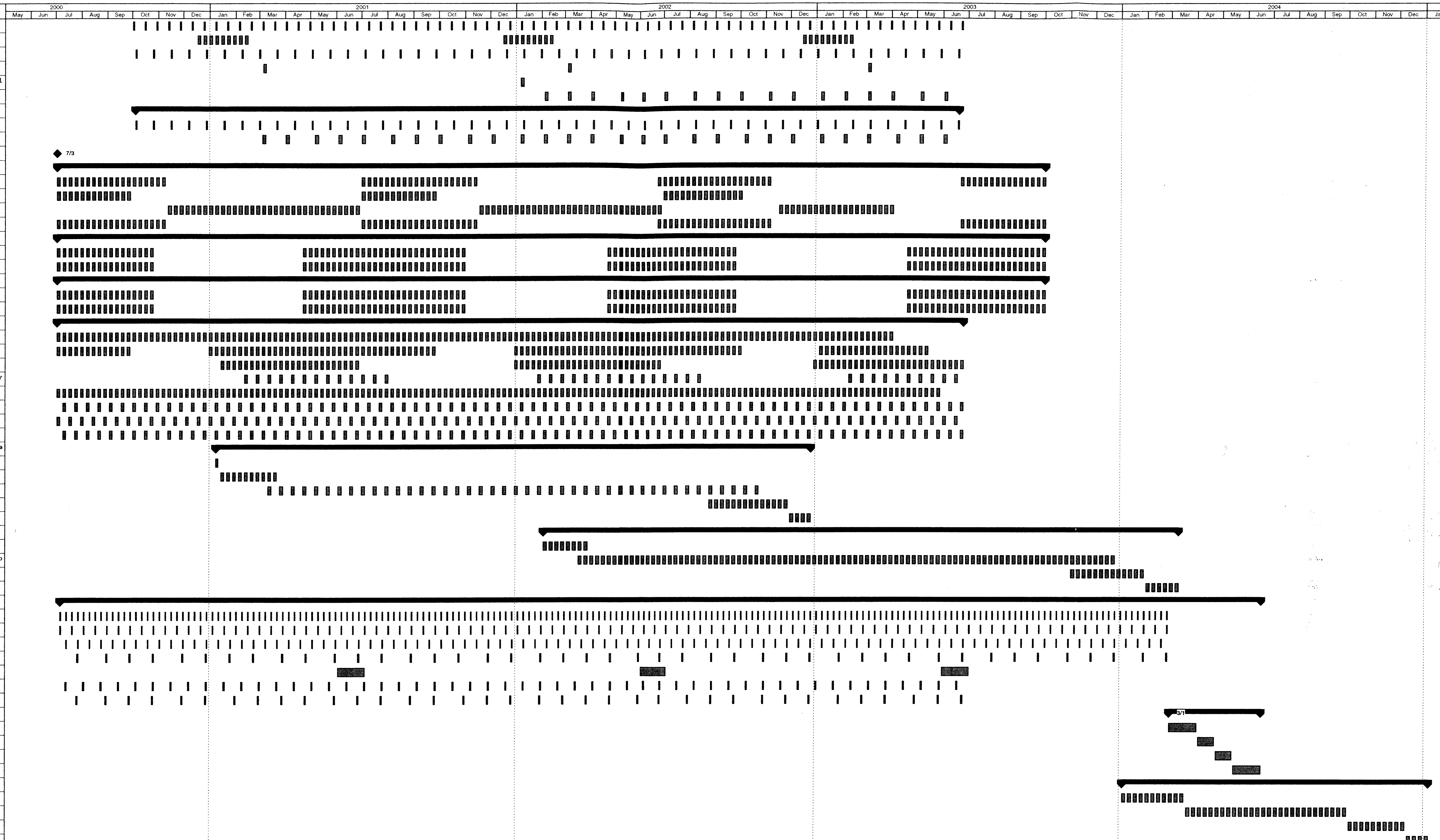
ID	Task Name
1	Off Stream Storage Feasability Stu
2	Project Management
3	Sites-Colusa Project Studies
4	Mammals
5	Small Mammals
6	Trapping
80	Walking transects
140	Driving transects
199	Medium Mammals
200	Trapping
297	Track plates and scent st
361	Photo stations
429	Video surveillance
497	Spotlighting
565	Bat surveys
566	Acoustical surveys
695	Mist netting
826	Roost and hibernacula sea
863	Deer surveys
864	Pellet group counts
937	Herd composition counts
965	Ground counts
1014	Aerial surveys
1018	Capture and radio collari
1020	Telemetry surveys
1038	Other Game Species
1039	Ground counts
1088	Habitat assessment
1117	Fish - Tributaries
1118	Salmon and Steelhead
1119	Electroshocking
1194	Diving
1235	Fyke traps
1321	Seining
1396	Other fish
1397	Electroshocking
1490	Seining
1583	Reptiles and Amphibians
1584	Searching
1729	Vocalization surveys
1841	Egg mass surveys
1918	Larval and tadpole survey
1957	Colusa Basin Drain
1958	Fyke traps
2001	Hook and line
2026	Habitat Evaluation Procedure
2027	Develop HEP Team
2029	HSI Model Selection
2040	Data Collection
2084	Data Analysis
2099	Develop HEP Report
2104	Thomes/Newville Project Studies
2105	Mammals
2106	Small Mammals
2107	Trapping
2211	Walking transects
2297	Driving transects
2382	Medium Mammals
2383	Trapping
2519	Track plates and scent st
2607	Photo stations
2694	Video surveillance
2781	Spotlighting
2869	Bat surveys
2870	Acoustical surveys
2999	Mist netting
3130	Roost and hibernacula sea
3167	Deer surveys



Project: Northern District Feasibility Stuc
Date: Mon 3/20/00

Task | Split | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Split | Rolled Up Milestone | Rolled Up Progress | External Tasks | Project Summary

ID	Task Name
3168	Pellet group counts
3241	Herd composition counts
3269	Ground counts
3318	Aerial surveys
3322	Capture and radio collari
3324	Telemetry surveys
3342	Other Game Species
3343	Ground counts
3392	Habitat assessment
3421	Fish - Tributaries
3422	Salmon and Steelhead
3423	Electroshocking
3498	Diving
3539	Fyke traps
3625	Seining
3700	Other fish
3701	Electroshocking
3794	Seining
3887	Fish - Ponds
3888	Electroshocking
3981	Seining
4074	Reptiles and Amphibians
4075	Searching
4220	Vocalization surveys
4332	Egg mass surveys
4409	Larval and tadpole survey
4448	Night Driving surveys
4601	Seining
4680	Dip Netting
4759	Spotlighting
4838	Habitat Evaluation Procedure
4839	Develop HEP Team
4841	HSI Model Selection
4852	Data Collection
4896	Data Analysis
4911	Develop HEP Report
4916	Mitigation Evaluation
4917	Develop Mitigation Needs
4926	Evaluate Potential Mitigatio
5020	Data Analysis
5034	Develop Mitigation Report
5041	Data Management and Reports
5042	Field data entry
5234	Data Quality Assurance
5331	Bi-weekly Status Report
5427	Monthly Status Report
5472	Annual status report
5476	GPS Data Processing
5529	Data Analysis
5566	Summary Report preperation
5567	Draft Report
5568	Review Period
5569	Incorporate comments
5570	Final Report
5571	Environmental Impact Report
5572	Write Chapters (DRAFT)
5584	Draft Review
5613	Incorporate Comments
5624	Final EIR Chapter



Project: Northern Distridt Feasibility Stu Date: Mon 3/20/00	Task · Split · Progress · Milestone · Summary · Rolled Up Task · Rolled Up Split · Rolled Up Milestone · Rolled Up Progress · External Tasks · Project Summary

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Attachment E: Proposed Budget for Completion of the Environmental Documentation. Northern District Budget

	00/01	01/02	02/03	03/04	04/05
Project management	$267,600.00	$267,600.00	$267,600.00	$267,700.00	$156,100.00
Sites-Colusa Project					
small mammals	$52,200.00	$52,200.00	$52,200.00		
medium mammals	$52,200.00	$52,200.00	$52,200.00		
bats	$26,100.00	$26,100.00	$26,100.00		
deer	$55,500.00	$80,940.00	$67,940.00		
other game	$48,300.00	$60,360.00	$57,610.00		
fish - tributaries					
salmon and steelhead	$60,840.00	$52,200.00	$52,200.00	$13,050.00	
resident fish	$56,520.00	$52,200.00	$52,200.00	$13,050.00	
reptiles and amphibians	$60,840.00	$52,200.00	$52,200.00		
Colusa Basin Drain	$46,470.00				
HEP		$33,820.00	$67,640.00	$37,030.00	
Thomes/Newville Project					
small mammals	$72,260.00	$80,520.00	$24,050.00	$13,050.00	
medium mammals	$67,940.00	$81,570.00	$30,900.00	$17,400.00	
bats	$65,420.00	$84,420.00	$68,670.00		
deer	$42,150.00	$42,150.00	$42,150.00		
other game	$42,150.00	$42,150.00	$42,150.00		
fish - tributaries					
salmon and steelhead	$52,200.00	$52,200.00	$52,200.00	$13,050.00	
resident fish	$52,200.00	$52,200.00	$52,200.00	$13,050.00	
fish - ponds					
resident fish	$52,200.00	$52,200.00	$52,200.00	$13,050.00	
reptiles and amphibians	$104,400.00	$104,400.00	$104,400.00	$26,100.00	
HEP		$26,100.00	$52,200.00	$26,100.00	
Mitigation evaluation		$34,600.00	$83,080.00	$62,400.00	
Data management/reports	$87,860.00	$81,420.00	$87,860.00	$87,860.00	
EIR				$43,650.00	$121,880.00
Mammal Operating	$176,000.00	$352,000.00	$120,000.00	$70,400.00	$35,200.00
Fish/herp Operating	$58,650.00	$58,650.00	$58,650.00	$35,200.00	
TOTAL	**$1,600,000.00**	**$1,874,400.00**	**$1,618,600.00**	**$752,140.00**	**$313,180.00**
Mammal proposed budget	$877,950.00	$1,206,340.00	$923,080.00	$416,610.00	$235,130.00
Fish/herps proposed budget	$722,050.00	$668,060.00	$695,520.00	$335,530.00	$78,050.00

State of California, Gray Davis, Governor
The Resources Agency, Mary D. Nichols, Secretary for Resources
Department of Water Resources, Thomas M. Hannigan, Director

Steve Macaulay, Chief Deputy Director
Raymond D. Hart, Deputy Director
L. Lucinda Chipponeri, Assistant Director for Legislation
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North of the Delta
Offstream Storage Investigation

Progress Report

Appendix S: Mammal Surveys

January 2001

Integrated
Storage
Investigations

CALFED
BAY-DELTA
PROGRAM

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North of the Delta
Offstream Storage Investigation

Progress Report

Appendix S: Mammal Surveys

This report was prepared by the California Department of Fish and Game under the supervision of

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Scientific Aide

January 2001

Integrated
Storage
Investigations

CALFED
BAY-DELTA
PROGRAM

Contents

Tables

Figures

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1.0 Introduction

1.1 History and Background

Water availability and use in California has been the topic of many debates throughout the State's history. The latest of these has led to the current State and federal agency investigations of future water demands, quality, and availability for California under a 1994 "Framework Agreement." This Agreement provides for increased coordination and communication for environmental protection and water supply dependability, which led to the formation of CALFED and the development of the CALFED Program.

CALFED is a cooperative interagency effort involving State and federal agencies with management and regulatory responsibilities in the Bay-Delta Estuary. The program is responsible for developing a long-term solution to fish and wildlife, water supply reliability, flood control, and water quality problems in the Bay-Delta.

The CALFED Program has been developing and analyzing a series of conveyance opportunities, which are described in a report titled *CALFED Bay-Delta Program Storage and Conveyance Component Inventories*, dated March 7, 1997. These inventories led to a more refined list of components as reported in *CALFED Storage and Conveyance Components Refinement Process*, dated October 1997. Four of the surface storage facilities described in this report are the Sites, Colusa, Thomes-Newville, and Red Bank Projects.

The California Department of Water Resources' Northern District became the lead agency in investigating the potential feasibility of the four Offstream Storage Facilities north of the Sacramento-San Joaquin Delta. The California Department of Fish and Game's Central Valley Bay-Delta Branch was contracted in 1997 to conduct pre-feasibility field investigations for the presence of threatened, endangered, and special status mammal species on the sites. An additional task assigned to DFG was to collect some baseline information and begin planning efforts for conducting Habitat Evaluation Procedures for future efforts. Funding for the July 1997 through June 1998 field efforts was provided from money allocated from the passage of Proposition 204 — The Safe, Clean, Reliable Water Supply Act (1996) — and additional funds were made available by the State Legislature for July 1998 through present field efforts.

This report focuses primarily on the status of the DFG's ongoing mammal field surveys on the four proposed offstream storage reservoirs but includes a brief overview of the HEP process, its value as a potential tool for assisting future field studies, and compile a list of Habitat Suitability Index Models that are available for conducting a HEP. The majority of the report, however, focuses on the mammal field studies conducted by DFG. It outlines survey methodologies and summarizes results of field investigations that occurred from July 1997 to December 1999. DFG recommendations are also provided for future study needs necessary to support an adequate Environmental Impact Report/Environmental Impact Statement and consultation under the California

Environmental Quality Act, National Environmental Protection Act, and the State and federal Endangered Species Acts.

1.2 Project Description

The four alternatives range in storage capacity from approximately 350,000 to 3 million acre-feet of water. Each of the facilities would consist of a reservoir with associated diversion and conveyance facilities. The concept is to bank high-flow or floodwater from the tributaries associated with each alternative and from the Sacramento River for later use. Depending upon the operation criteria and management, a new reservoir could potentially reduce the need for Sacramento River diversions by the Tehama-Colusa Canal and the Glenn-Colusa Irrigation District. The operation of the facilities is still being investigated by DWR's Northern District staff; therefore, specific information is not available at this time.

The proposed alternatives have not been completely defined at this time, including determination of the size of each reservoir. For the purposes of this report the highest reservoir surface elevations are considered to be the projects and only the inundation zones were surveyed during this level of field investigations. Additionally, operational studies are not available at this time, therefore, it is impossible to accurately determine the feasibility of conveyance facilities, providing mitigation needs, or enhancement potentials for the projects.

1.3 Study Area

The alternatives are all located west of Interstate 5 in the western portion of the Northern Sacramento Valley (Figure 1). The Sites Reservoir Project area is primarily in western Colusa County approximately 8 miles west of the town of Maxwell. The Colusa Reservoir Project area is an enlarged, northern extension of Sites Reservoir. The Thomes-Newville Reservoir Project area is adjacent to Thomes Creek and located in southwest Tehama County and northwest Glenn County. The Red Bank Reservoir Project area is a complex of four small reservoirs along the South Fork of Cottonwood Creek and Red Bank Creek in western Tehama County.

1.3.1 Sites Reservoir

The proposed Sites Reservoir area (approximately 14,200 acres) is located in Antelope Valley, primarily in northwestern Colusa County and partially in southwestern Glenn County, approximately 8 miles west of the town of Maxwell (Figure 2). The site is predominantly non-native grassland and managed primarily for cattle grazing with some areas of dryland farming. Other habitats include northern clay hardpan vernal pools, swales, seasonal wetlands, alkaline wetlands, emergent wetlands, oak woodland, and riparian.

1.3.2 Colusa Reservoir

The proposed Colusa Reservoir area (approximately 27,900 acres) is also located in Antelope Valley in northwestern Colusa and southwestern Glenn

Figure 1. Location of the four proposed offstream storage reservoirs.

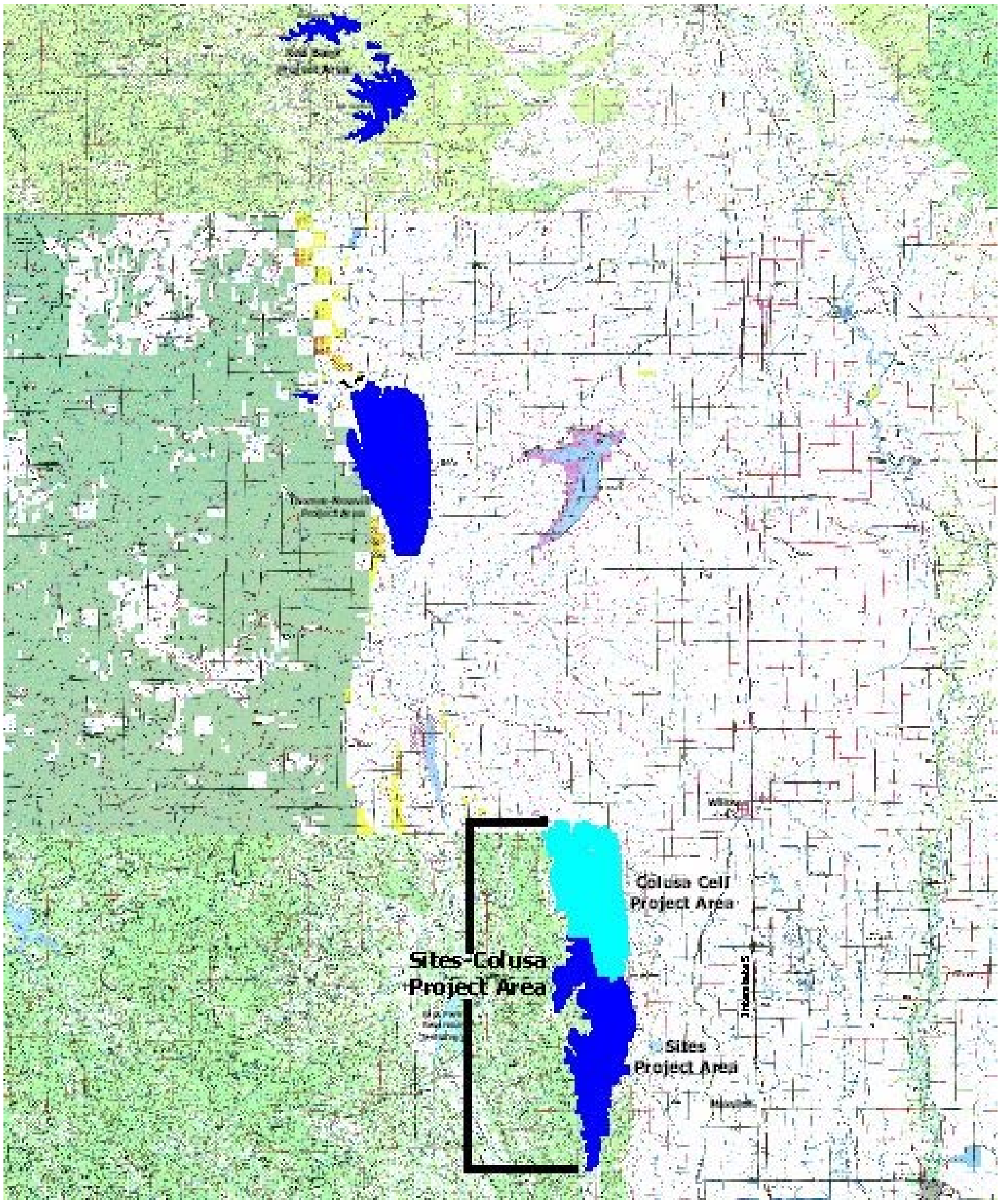
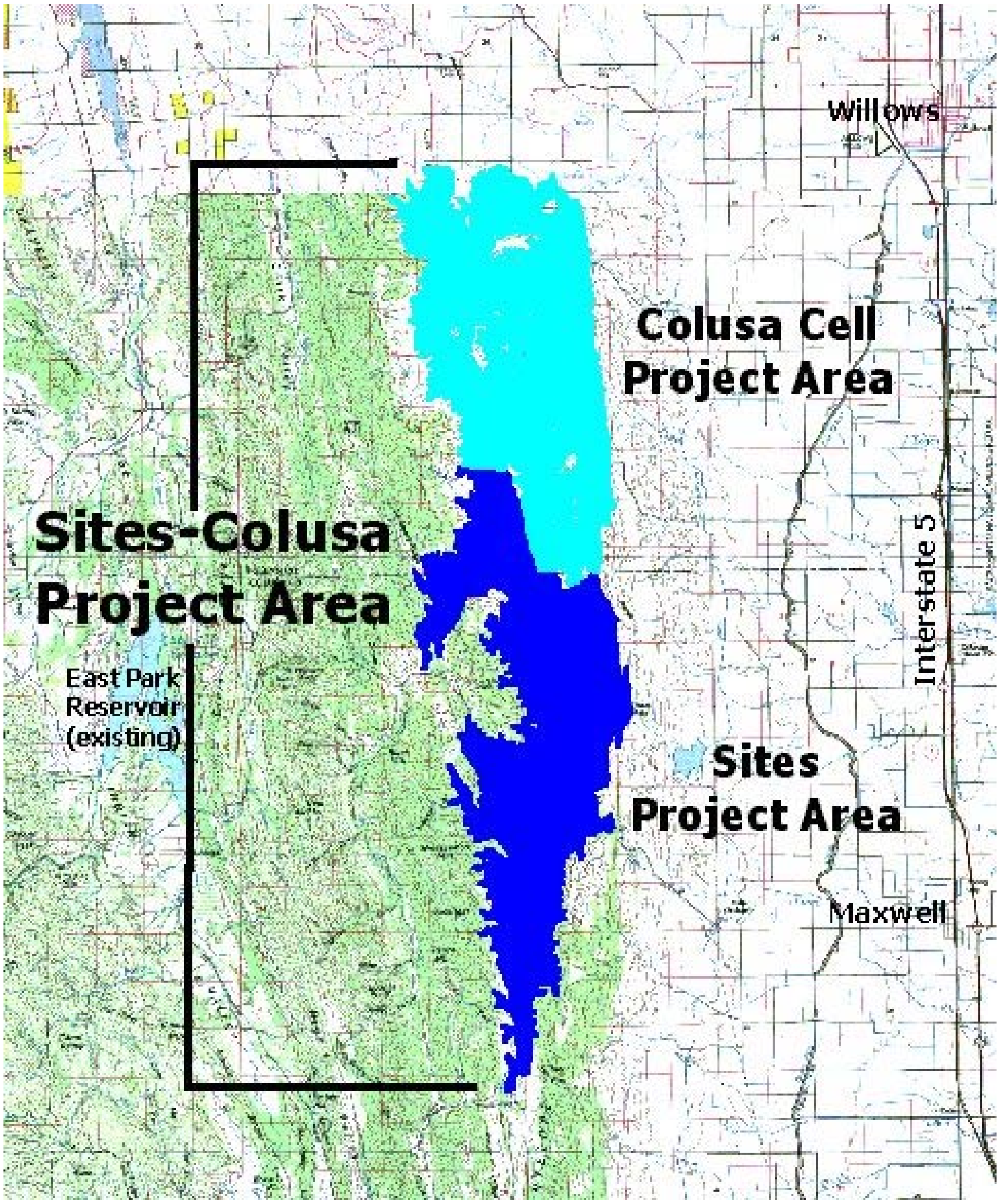


Figure 2. Location of the proposed Sites Reservoir and Colusa Cell Project areas in western Colusa and Glenn Counties.



Counties (Figure 2). It can best be described as an enlargement of the Sites Reservoir described above. The enlargement (an additional 13,700 acres of land to the north of the Sites Reservoir) would incorporate additional acreages of predominantly non-native grassland which is managed primarily for cattle grazing. Other habitats include northern clay hardpan vernal pools, swales, seasonal wetlands, alkaline wetlands, oak woodland, and riparian. For the purposes of this report, surveys and results will refer only to the northern extension of the Sites Reservoir, hereinafter referred to as the Colusa Cell.

1.3.3 Thomes-Newville Reservoir

The proposed Thomes-Newville Reservoir area (approximately 17,100 acres) is located adjacent and to the south of Thomes Creek in southwestern Tehama and northwestern Glenn Counties, upstream of the existing Black Butte Lake (Figure 3). It is located approximately 25 miles west of the town of Corning. The site is predominantly non-native grassland managed for cattle grazing. Other habitats include northern clay hardpan vernal pools, swales, seasonal wetlands, alkaline wetlands, emergent wetlands, oak woodland, and riparian.

1.3.4 Red Bank Reservoir

The proposed Red Bank Reservoir Project area (approximately 4,900 acres) is located in western Tehama County (Figure 4). This alternative is actually a series of four small reservoirs, or components, linked together. The components are Dippingvat, Lanyon, Bluedoor, and Schoenfield Reservoirs. The Dippingvat component is located along South Fork Cottonwood Creek. The Lanyon component is located to the southeast, just east of Jackass Canyon. The Bluedoor component is adjacent to the Lanyon component and is along North Fork Red Bank Creek. The Schoenfield component is just south of the Bluedoor component and includes Red Bank, Dry, and Grizzly Creeks. The predominant habitat types are blue oak woodland, foothill pine, and chaparral. Other habitats include riparian and seasonal wetlands.

1.4 Scope of Study

In 1997, DWR contracted with DFG to conduct field studies to inventory the special status mammal species that could occur in the project areas and assess the potential of any red flags. Red flags could be considered any species, habitat, or situation that, in and of itself, constitutes a project stopper. A project stopper would be something that might be considered unmitigatable by the regulatory agencies or have such high mitigation costs that the project proponent could no longer afford the project.

An additional task assigned to DFG was to conduct some preliminary planning efforts for a HEP. The primary objective was to compile a list of HSI Models available for conducting a HEP. Formal surveys for the HEP have not been conducted, nor are they scheduled at this time. The focus at this stage of field surveys was to compile species lists of the project areas and HSI Models available, which would assist with implementation of the HEP process in future survey efforts.

The scope of the field investigation by DFG was limited to the mammals directly impacted by construction of the reservoirs (within the footprint or inundation zone). The level of effort, however, has varied among the alternatives. Appurtenant facilities and right-of-way impacts in the immediate areas have not been included in the investigations because of the lack of access. Additionally, the scope of the investigation has not addressed nor has it included the potential impacts associated with conveyance to and from the project or use of the water stored by the project. These issues will be addressed in future studies of the alternatives.

1.4.1 Initial Study (1997-1998)

The initial purpose of this study was to document special status species' presence and distribution. Special status species are those species designated as threatened, endangered, sensitive, or fully protected by State and/or federal agencies. The direction was given by DWR to focus on special status species for each alternative. It was agreed that this would provide some comparable baseline information on each alternative, which could assist them in determining the potential feasibility of each alternative. The results of special status species surveys would also provide a better understanding of some of the potential mitigation needs. Field survey methods were relatively the same for each alternative because the list of potential species was the same or similar for each. The level of effort, however, varied among the alternatives because access varied in the alternatives.

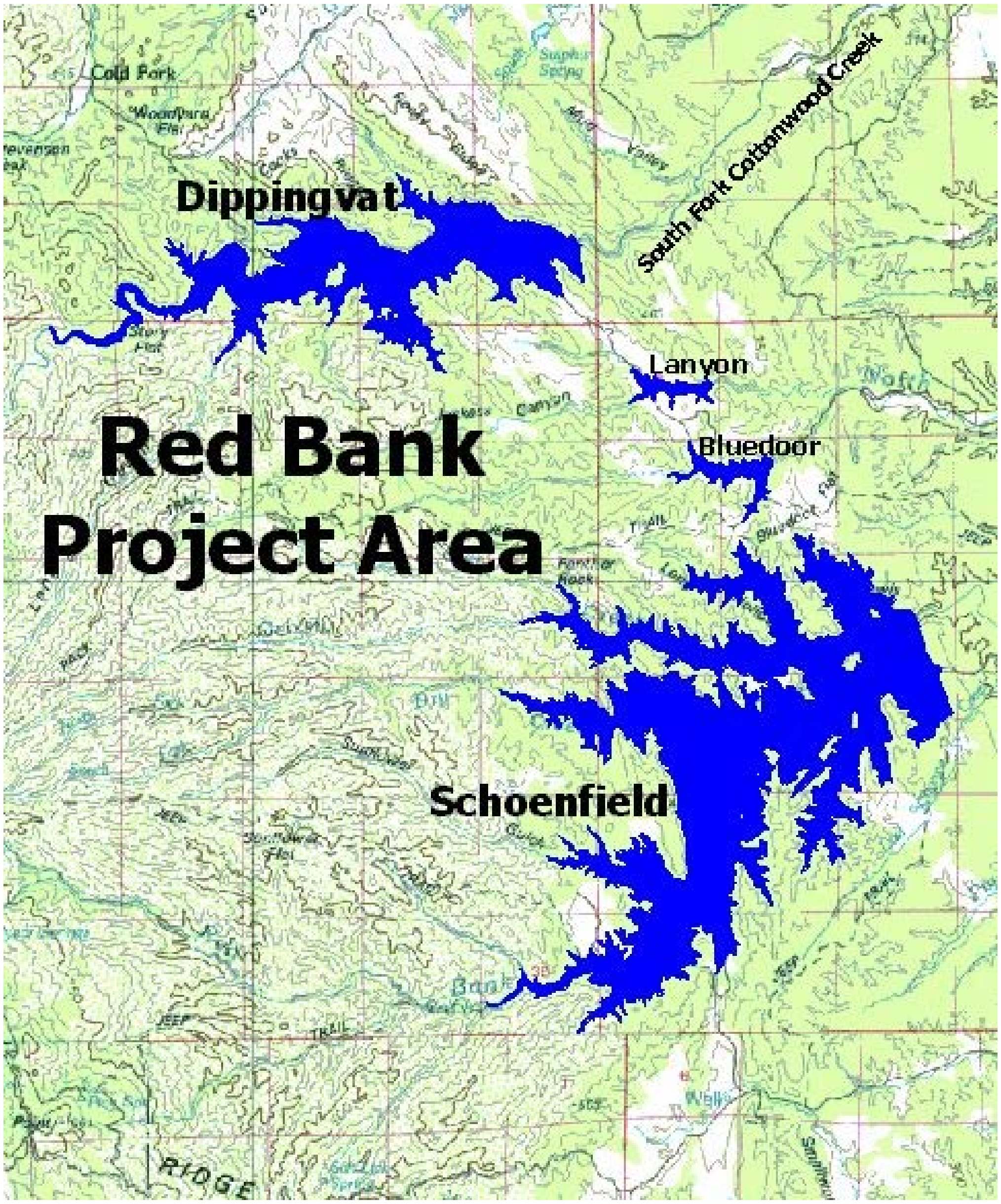
1.4.2 Current Effort (1998-1999)

During the second year of studies, field investigations were modified to address the presence, distribution, and, where possible, relative abundance of all mammal species in the project areas. These studies were designed to address the future compliance needs of the CEQA and NEPA as well as address the State and federal Endangered Species Acts. The current efforts are the first of multiple years of field investigations needed to evaluate the potential impacts associated with project construction.

In addition, staff has been researching the availability of HSI Models that could be used in future survey efforts to conduct a HEP. HEP is a valuable tool that will help with future investigations of the alternatives. It is a computerized method for use in habitat inventory, impact assessment, and mitigation studies. The method consists of a basic accounting procedure that combines habitat quality (defined as HSI) with habitat area to calculate Habitat Units. HUs are sensitive to changes in the amount and quality of available habitat. The basic accounting procedure enables comparisons of habitat availability at several sites (baseline studies) or of changes in habitat over time (impact assessment) for various sites or project alternatives. HEP output consists of quantitative information for each species or suite of species evaluated.

Figure 3. Location of the proposed Thomes-Newville Reservoir Project area in western Glenn and Tehama Counties.

Figure 4. Location of the proposed Red Bank Reservoir Project area and its four components in western Tehama County.



DRAFT

Proposition 204 Funding Allocated for North-of-the-Delta Offstream Storage

The North-of-the-Delta Offstream Storage investigation was allocated $5.6 million of the $10 million Proposition 204 Funding under the *Feasibility Projects Subaccount* to conduct reconnaissance-level study of four potential offstream storage reservoir sites in the Sacramento Valley, north of the Sacramento-San Joaquin Delta: (1) the Sites Project, (2) the Colusa Project, (3) the Thomes-Newville Project, and (4) the Red Bank Project. In 1997, DWR began the two-year reconnaissance-level study of the four potential offstream storage sites. The study included extensive field surveys of environmental resources; geological, seismic and foundation evaluations; potential environmental impacts; and preliminary engineering feasibility studies. Starting in FY1998-1999, DWR received General Funds to broaden the 1997 reconnaissance study to a North-of-the-Delta Offstream Storage Project. The attached table shows a list of reports that have been completed with funding provided mostly by Proposition 204. The reports and data developed with Proposition 204 funds, General Funds, and subsequent Proposition 50 Funds will be used in the development of the feasibility report and environmental impact report/environmental impact statement for the North-of-the-Delta Offstream Storage Project currently scheduled to be completed by the Fall of 2008.

List of Reports Completed with Funding Provided Mostly by Proposition 204

Final Draft North-of-the-Delta Offstream Storage Progress Report (see appendices below)	July 2000
• Draft Appendix A: Botanical Resources Report	January 2000
• Draft Appendix B: Wetland Delineation Field Studies Report	April 2000
• Draft Appendix C: Survey for the Valley Elderberry Longhorn Beetle at Four Proposed Offstream Storage Reservoir Locations	June 2000
• Draft Appendix D: Fish Survey Summary	September 2000
• Draft Appendix E: Amphibian and Reptile Survey Summary	April 2000
• Draft Appendix F: Sacramento River Diversion and Its Potential Impacts	June 2000
• Draft Appendix H: Water Exchange Element	April 2000
• Draft Appendix I: Road Relocation Studies	August 2000
• Draft Appendix J: Recreation Requirements and Opportunities: Sites Reservoir Alternative	April 2000
• Draft Appendix K: Survey for State and Federally Listed Avian Species at Four Proposed Offstream Storage Reservoir Locations	January 2000
• Draft Appendix L: Water Supply and Operation Studies	January 2001
• Draft Appendix M: Sites Offstream Storage Project, Power Cost Study	May 2000
• Draft Appendix N: Sites Reservoir Conveyance Study	May 2001
• Draft Appendix O: Phase I Fault and Seismic Hazards Investigation	July 2000
• Draft Appendix P: Sites and Colusa Reservoir Projects, Construction Materials Sampling and Testing	August 2000
• Draft Appendix Q: Sites and Colusa Reservoir Foundation Studies	February 2001
• Draft Appendix S: Offstream Storage Investigations Mammal Surveys	January 2001
Seismotectonic Evaluation – Phase II Fault and Seismic Hazards Investigations – North of Delta Offstream Storage	October 2001