STATE OF CALIFORNIA
The Resources Agency
DEPARTMENT OF WATER RESOURCES
DIVISION OF ENGINEERING

GEOLOGIC FEASIBILITY REPORT

SITES RESERVOIR PROJECT

APPENDIX TO ENGINEERING FEASIBILITY REPORT

PROJECT GEOLOGY REPORT No. 94-30-02

JULY 2003

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

JULY 2003
DIVISION OF ENGINEERING

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The vast majority of the faulting and seismicity hazards investigation was performed by Jeff Unruh and staff at William Lettis and Associates.

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

JULY 2003
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Some of the organizational chart and position classifications shown here for the Division of Local Assistance are how they were when the report was prepared in May 2002.

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
DIVISION OF ENGINEERING

GEOLOGIC FEASIBILITY REPORT
SITES RESERVOIR PROJECT

PROJECT GEOLOGY REPORT No. 94-30-02
JULY 2003

ENGINEERING GEOLOGY CERTIFICATION

This report has been prepared under my direction as the professional geologist in direct responsible charge of the work, in accordance with the provisions of the Geologist Act of the State of California.

Several portions of this report, such as the drill hole logs, geologic mapping and geologic sections were prepared in the Northern District. Those work activities and associated products were performed under the direction of licensed engineering geologists in their office.

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Date ______________________________

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1.0 Executive Summary

This report summarizes and brings together all of the geologic information developed to date for the proposed Sites Project in Glenn and Colusa Counties, California. In total, the information demonstrates that **the proposed project is geologically feasible**. Although **significant additional exploration and studies will be required** during the design phases of the project, there have been **no "geologic fatal flaws" discovered**. In fact, the proposed Golden Gate Dam site, Sites Dam site, all of the saddle dam sites, the pumping plant site, tunnel alignment, and all other appurtenant structures appear to be well located from a geologic point of view.

To determine the geologic feasibility of this project, the Northern District of the Division of Planning and Local Assistance **conducted extensive exploration and studies** beginning in July of 1997. With the assistance of Department geologists from other district offices, the Division of Engineering's Project Geology Section, and the private consulting firm of William Lettis and Associates, the largest geologic exploration program for a dam site the Department has seen in decades was accomplished. Field work commenced in May 1998 and concluded in June 2001. **Drill hole exploration** consisted of drilling 45 core holes totaling 9,513 feet and about 16 auger holes totaling 267 feet. Twelve **seismic refraction surveys** were conducted only at the Golden Gate Dam site. **Detailed geologic field mapping** was accomplished mostly at scales of 1 inch = 100 and 200 feet. Also, a large **borrow study** was included with the investigations. Significant **laboratory testing** was performed as part of the investigations. Previous geologic studies for similar projects in this vicinity date back to 1957.

The **foundation materials** for all of the proposed dams and appurtenant structures will be sedimentary rocks consisting mainly of sandstone and mudstone. Most of the proposed connecting channels will be in various alluvial deposits. At the dam sites, **stripping** of unsuitable materials and **grouting** of foundation rock will be required.

Geologic hazards such as landslides are present in the project area but they are not significant enough to preclude the project from being built. Northern District geologists and William Lettis and Associates performed two phases of **faulting and seismicity studies** over a three-year period. Those studies cost nearly one million dollars and included extensive research, mapping, trenching, and analysis. The results of those studies show that the project is located in an area with active and "conditionally active" faults, and is therefore subject to ground shaking. Surface displacement may occur on several of the fault traces as sympathetic movement related to deeper movement on the Coast Ranges – Sierran Block Boundary Zone (CRSBZ), also known as the Great Valley fault. To be conservative, it will be assumed that such surface displacement (up to

16 inches) may occur on the Salt Lake fault which trends through Saddle Dam site No. 2. Although sediments at least 10,000 years old have not been displaced, the informally named GG-1, GG-2, GG-3 and S-2 faults, all of which pass directly through or near the proposed Sites and Golden Gate Dam sites, will also be assumed to be active. Surface displacement on these “tear faults” could be approximately three inches. Ground motion analysis has determined that a peak ground acceleration (PGA) of 0.8g would be generated from an MCE of M_w 6.8 on the Bear Valley segment of the Great Valley fault. Proper dam design will accommodate ground accelerations and any possible movement along these faults.

Groundwater is present at some of the structure sites but it will not cause a significant problem.

The Department of Water Resources has investigated the availability of **construction materials** for the Sites Reservoir Project with emphasis on the material requirements for the proposed embankment dams. The studies show that a surplus of impervious material exists within or near the project. The best available source of clean rockfill material within the project area is the fresh Venado sandstone. Sufficient quantities of Venado sandstone are available at the proposed quarry areas, foundation excavations, and tunnel excavations for construction of the embankment sections currently under consideration. Abundant quantities of random material are available. Sufficient deposits of sand and gravel are probably not available in the project area; therefore, crushed, fresh Venado sandstone was tested for use as filter, drain, and transition materials for the embankment dams and concrete aggregate. Laboratory testing indicates that crushed, fresh Venado sandstone may be suitable for these materials but additional testing and evaluation is required. Therefore, the current studies have assumed that these materials will be imported from an offsite sand and gravel source.

2.0 Introduction

In July of 1997 the California Department of Water Resources, Division of Planning and Local Assistance, Northern District, Geology Section began conducting geologic feasibility studies for both the Sites and Colusa Reservoir Projects. These two projects are in the Stone Corral, Funks, Hunters, and Logan Creek watersheds located on the west side of the Sacramento Valley (Plate 1). The current design for the Sites Reservoir Project consists of two major dams; nine smaller saddle dams, a pumping plant, and an inlet/outlet works tunnel that are illustrated on Figure 1). This Sites 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 storage to the north, increasing the reservoir capacity to 3.1 million acre-feet. This would be accomplished by adding two additional major dams, seven smaller saddle dams, and replacing the nine saddle dams associated with the Sites Reservoir along the ridge between the two components with a canal or tunnel; thereby joining the two. The outlet works would remain at the same location. These reservoirs would store water for agricultural, environmental, and municipal use; provide water-related recreation and some flood control. Although the initial study included both the Sites and Colusa Reservoir Projects, this report focuses only on work associated with the Sites Reservoir Project. This report is a final of the December 2002 draft report submitted as a portion of the package to the Consulting Board for the January 15-16, 2003 meeting.

2.1 Purpose and Scope

The purpose of this feasibility level of investigation was to determine the geologic foundation conditions for the proposed structures thereby providing the design engineers with geologic data to further develop conceptual designs and reasonably accurate estimates for the cost of construction. The program included both foundation drilling and geologic mapping for the two main dams and appurtenant structures; most of the nine saddle dams, a contracted faulting and seismicity study, and a study to determine the general availability of construction materials. The geologic studies were based on the assumption that the dams would be zoned embankments with some consideration for roller compacted concrete (RCC). It should be noted that the geologic study to date is considered preliminary and that additional detailed work in the future will be required for final design.

Geologic field studies were conducted by the Division of Planning and Local Assistance (DPLA) Northern District's, Geologic Investigation Section with assistance from the Division of Engineering's, Project Geology Section. Field work commenced in May 1998 and concluded in June 2001. Drill hole exploration consisted of drilling 45 core holes totaling 9,513 feet and about 16 auger holes totaling 267 feet. Twelve seismic refraction surveys were conducted only at the Golden Gate Dam site. Geologic field mapping was accomplished mostly at scales of 1 inch = 100 and 200 feet.

Locations of the Sites Reservoir Project features are shown on Figure 2 and the geologic exploration on Plates 3, 7, 9, and 13. Drill hole logs, drill core photographs, and drilling chronologies can be found in Appendix 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 Appendix B. Piezometers were installed in most of the drill and auger holes to monitor groundwater fluctuations with the groundwater levels read monthly. Well completion forms and hydrographs of these water levels are summarized in this report and presented in detail in Appendix C. The seismic refraction surveys that were performed at the Golden Gate Dam site and inlet/outlet works provided seismic velocities to assist in estimating stripping and rippability of the foundation bedrock. These results are summarized in this report. The Appendices are separate documents to this report.

2.2 Project Description

The proposed Sites Reservoir Project is located about 10 miles west of the town of Maxwell on the western edge of the Sacramento Valley, roughly halfway between Sacramento and Red Bluff (Plate 1). Initially, three reservoir capacities were considered by the Department of Water Resources: a 1.2 million acre-foot (maf) smaller Sites Reservoir, a 1.8 maf larger Sites Reservoir with a maximum water surface elevation of 520 feet, and a 3.1 maf Colusa Reservoir that included the Colusa cell to the north.

This report focuses on the larger Sites Reservoir. It would consist of two main dams: the operational Golden Gate Dam on Funks Creek and Sites Dam on Stone Corral Creek. The larger operational Golden Gate Dam has a proposed height of 310 feet, a crest length of 2,250 feet and a crest elevation of 540 feet. It would be an embankment structure having a volume of about 10,590,000 cubic yards (yds^3). The Sites Dam has a proposed height of 290 feet, a crest length of 850 feet, and a crest elevation of 540 feet. It also would be an embankment structure having a volume of about 3,836,000 yds^3. The Golden Gate inlet/outlet works tunnel would both be located immediately south of the right abutment for Golden Gate Dam (Figure 2). The proposed tunnel would be approximately 4,000-foot long and 30 feet in diameter. A 400-foot vertical access shaft for the tunnel gates would extend from the ridge top to tunnel invert. An additional nine saddle dams would be constructed along the northern rim of the reservoir, with Saddle Dam No. 3 requiring nearly the same volume as Sites Dam. The source water for Sites Reservoir would be from the Sacramento River conveyed via the Tehama-Colusa Canal, Glenn-Colusa Canal, and/or possibly a new conveyance facility from the Sacramento River to the existing U.S. Bureau of Reclamation's Funks Reservoir, which would act both as a forebay and afterbay. Water would be pumped into the proposed reservoir via the Golden Gate Pumping Plant.

2.3 Project Chronology

Initially, topographic base maps were generated to perform geologic mapping at the specific dam sites and appurtenant structures. Geologic mapping performed by the Department and the incorporation of previous mapping by others assisted in determining drill hole locations. Drilling for the Sites Reservoir Project was conducted primarily during two periods, May 1998 through August 1999, and July 2000 through June 2001.

Site specific drilling began on May 11, 1998 at the Sites Dam site. A total of four angle core holes (LC-1, -2, -3, and -4) ranging in depths from 130 to 250 feet were drilled, two upstream of the dam axis and two near the downstream toe. Drilling was not performed on the abutments at Sites because the USBR had drilled three holes, one on each abutment and one in the channel, in 1979 and 1980. In addition, three shallow auger holes were drilled. See Sites Dam site geologic and exploration maps (Plate 7, Sheets 1 and 2) for drill/auger hole locations.

Drilling moved to the Golden Gate Dam site in June 1998 and a total of eight core holes, including one angle hole, and three auger holes were drilled during the two aforementioned periods. Four holes (RC-1, LC-1, LA-1, RA-1) were drilled near the initial downstream straight axis and later four holes (GGC-RC1, GGC-RC2, GGC-LA1, GGC-RA1) were drilled at the present curved axis. The eight holes ranged in depth from 135 to 343 feet. In addition, three shallow auger holes were drilled. Drilling at the dam site ended in November 2000. See Golden Gate Dam site geologic and exploration maps (Plate 3, Sheets 1 and 2) for drill/auger hole locations.

Five core holes were drilled along the inlet/outlet tunnel alignment. Two of the holes (DHT-1 and DHT-4) were drilled in June/July 1999 to respective depths of 224 and 199 feet. Three additional holes were drilled in October/November 2000. They were DHT-3 (329'), -5 (499'), and -6 (599'). One drill hole, DHPP-1, was drilled at the proposed pumping plant in June 1999 to a depth of 200 feet. Seven auger holes ranging in depths from 6 to 36 feet were drilled at the various intake facilities. Three core holes were drilled at the original proposed spillway sites. DHS-1 was drilled at the initial southernmost spillway location in July 1999 to a depth of 199 feet. Drill holes DHS-3 and DHS-4 were drilled at the northernmost spillway in September 2000 and July 1999 respectively to depths of 189 and 199 feet. One shallow auger hole was drilled near DHS-1 in July 1999. For the drill/auger hole locations see Plate 3, Sheets 3-10.

Current design does not include a spillway structure at the Golden Gate Dam site and discussion of geologic exploration conducted during this feasibility level of study is not included in this report.

The drilling at the nine Sites Saddle Dam sites consisted of a total of 16 core holes and three auger holes. Three core holes, SSD3-1 (160'), SSD3-2 (265'), and SSD6-1 (119') along with three auger holes were all drilled in June/July 1999. Between July 2000 and June 2001 thirteen core holes were drilled at Saddle Dam Sites 3, 5, 8, and 9. These holes ranged in depth from 121 to 231 feet. The drill/auger hole locations can be found on the geologic and exploration maps Plate 9, Sheets 1-4. In 1979 the USBR drilled a total of 13 core holes (DH-100 through DH-112) generally along the same saddle dam alignments. These logs can be found in Appendix A.

One test core hole (SQ-1) was drilled at one of the proposed Sites Reservoir Project quarries to a depth of 45 feet in May 2000. Three east reservoir rim holes were drilled in May and June 2001 to assist in evaluating potential reservoir seepage problem areas. These holes were SS-1 (134'), SS-2 (194'), and SS-2A (221').

Four core holes were drilled in August and October 1998 as part of the larger Colusa Reservoir Project. They were drilled at Hunters Dam site and ranged in depth from 203 to 252 feet for a total footage of 908 feet. The drill hole information and associated geology for this portion of the project can be found in Appendix Q, (2/01) and will not be discussed in any more detail within this report.

All drill/auger hole information discussed in this section of the report can be found in Tables 1 and 2. Details of the drill hole logs can be found in Appendix A.

2.4 Previous Investigations and Reports

Various proposed Sites and Colusa Reservoir Projects have been studied in the past 40 years. In 1957 a 48,000 acre-foot reservoir was proposed by the Department of Water Resources on Stone Corral and Funks Creeks as part of Bulletin No. 3, *The California Water Plan 1957* (DWR 1957). The then proposed Tehama-Colusa Canal would have been the source water. This project was again proposed by DWR in 1964 in Bulletin 109, *Colusa Basin Investigation* (DWR1964). This project was partly for flood control measures on Stone Corral and Funks Creeks.

The U.S. Bureau of Reclamation (USBR) first considered larger projects associated with Sites in 1964 as part of its *West Sacramento Canal Unit Report* (DOI-USBR1964*).* This reconnaissance level study report included some geologic mapping at or near the current proposed axes for the Sites and Golden Gate Dam sites. No drilling was performed at the dam sites.

In 1969 the USBR identified four potential borrow areas for impervious materials within the proposed Sites Reservoir and three potential borrow areas for riprap, rock fill, and bedding materials outside of the reservoir area. Twenty-five bucket auger holes were drilled and two test pits excavated as part of a feasibility construction materials investigation.

In 1980 the USBR performed additional feasibility level studies at the project area and examined a larger Sites Reservoir design with a capacity of 1.2 maf. The study included detailed geologic surface mapping and exploration drill holes at both the Sites and Golden Gate Dam sites and the saddle dam sites. This study has become the basis for the Sites Reservoir Project evaluated in this investigation.

Since 1980 additional proposals for the Sites Reservoir have been mentioned in various USBR and DWR reports. These include:

- *Enlarging Shasta Lake Feasibility Study - Descriptions of Alternative Storage Facilities* (DOI-USBR 1982)
- *Enlarging Shasta Lake Feasibility - Progress Report* (DOI-USBR 1983a)
- *Assessment of Bureau of Reclamation Planning Activities Involving New Water Supplies* (DOI-USBR 1983)
- *Least-Cost CVP Yield Increase Plan - Appendix 6, Surface Storage and Conveyance* (DOI-USBR 1995)
- *California Water Plan Update,* Bulletin 160-93 (DWR 1993)

In 1990 the engineering consulting firm CH2M Hill prepared a long-range plan for the Glenn-Colusa Irrigation District that included an 870,000 acre-foot configuration of Sites Reservoir based on the 1964 USBR report. CH2M Hill followed this with the more general 1993 report *Meeting California's Water Needs in the 21st Century.*

3.0 Regional Geology and Structure

The project area is located in the northwestern part of the Sacramento Valley in the foothills bordering the eastern Coast Ranges geomorphic province. (Figure 2). Project features will be founded almost entirely on Cretaceous sedimentary rocks and some Tertiary sedimentary deposits. The Sites and Golden Gate Dam sites are located in stream-cut watergaps predominantly within the Venado sandstone member of the Upper Cretaceous Cortina Formation. The Upper Cretaceous Boxer Formation is upstream (west) of the Golden Gate Dam site and falls within the footprint of the Sites Dam site (Figure 1). Plio-Pleistocene deposits of the fluvial Tehama Formation cap some of the ridges. The watergaps are occupied by Stone Corral Creek and Funks Creek that drain easterly to the Central Valley. Quaternary older alluvium (terrace deposits), Holocene (recent) alluvium, colluvium, and some landslide deposits are present in and adjacent to the stream channels and hillsides.

The Cretaceous sedimentary rocks are a thick sequence of marine strata that are part of an east-dipping homocline that has been uplifted, faulted, and eroded to form a series of north-south trending ridges. Directly west of the dam sites, these rocks are folded about the axes of the north-trending Sites anticline and the Fruto Syncline.

3.1 General Geology and Structure

The Sites Reservoir Project will be founded on the Upper Cretaceous Cortina and Boxer Formations. The Golden Gate Dam site and appurtenant structures will be founded almost entirely on the Venado member of the Cortina with the pump/generator plant and the intake channel being founded on the Yolo member of the Cortina (Figure 1). Both the Venado and Yolo members are comprised of sandstone with mudstone interbeds. The Sites Dam site is founded on about 50% Cortina, downstream of the axis, and 50% Boxer, upstream of the axis. All nine saddle dam sites will be founded entirely on the Boxer Formation. The Boxer is primarily composed of mudstones with sandstone interbeds and some conglomerate.

The proposed Sites Reservoir and dams have moderate topographic relief with ridge to stream channel elevation changes of about 500 feet. The geologic structure is readily reflected in the topographic expression of the region. The Cretaceous bedrock units at the Golden Gate and Sites Dam sites form parallel, northerly trending ridges and valleys that have formed an intricate trellis drainage pattern. The most prominent structural geologic features are the trend of the bedding associated with folding, jointing, and faulting.

Folding consists of two primary ones: the Fruto syncline and the associated adjacent Sites anticline. The Sites anticline (Kirby 1943) and the Fruto syncline (Chuber 1961) are flexure structures extending northwest from the general area of Sites to about 40 miles north to Newville, and possibly as far as Paskenta. The anticline is a tight fold with steeply dipping and locally overturned strata on both limbs. Based on analysis of seismic reflection data, William Lettis & Associates (WLA 2002) has interpreted that the Fruto syncline, Sites anticline, Salt Lake fault and other surface faults in the Sites Project area have developed from the blind, west-dipping Great Valley thrust fault (WLA, Figure 3-2). The fault trends mostly north-south and is located only in the subsurface about 5 kilometers below the Sites Project dam sites. The Salt Lake fault is a high-angle thrust fault that developed adjacent to the axis of the doubly plunging Sites anticline (DWR 1978). It traverses through the reservoir and is defined by a series of salt-water springs and gas seeps that occur along the fault trace. The fault was trenched in several locations by WLA and determined to be active based on the Division of Dam Safety's criteria (See Faulting and Seismicity Section 10).

At the Golden Gate and Sites Dam sites, the bedding is most prominent in the resistant sandstone beds that are boldly exposed on the northerly trending ridges that comprise the abutments as illustrated in Photo 6. The bedding strikes mostly N-S and dips to the east (downstream) about 50º. Jointing is pervasive and the most dominant set strikes mostly E-W (nearly normal to the bedding) and dips steeply to the north or south. There are two secondary sets that roughly strike N-S with one dipping in a broad range to the NE and the other dipping to the SW. Northeast trending faults exposed at the ground surface have been mapped at both Golden Gate and Sites Dam sites. Some traverse through the footprints of the dams and are considered active but not seismic sources (See Faulting and Seismicity Section 10).

Bedding at the saddle dam sites strikes mostly N-S and dips variably (10-70º) to the west depending on the proximity to the axis of the Fruto Syncline. Some of the saddle dams have the northeast trending faults traversing through their footprints (Plate 9, Sheets 3 & 4). In addition, the northerly trending, active, Salt Lake fault traverses through the left abutment of Saddle Dam site No. 2.

3.2 Coast Ranges and Great Valley Geomorphic Provinces

The Coast Ranges extend for 600 miles in a northwesterly direction from the Transverse Ranges in Southern California to north of the California-Oregon border. They are complex and consist of many types of rocks ranging in age from Jurassic to Tertiary. Here graywacke, metagraywacke, shale, argillite, chert, limestone, mafic, and ultramafic rocks have been intermingled by pervasive shearing and the formation of melanges. These rocks are part of the Franciscan complex, which represents the basement rocks of the Coast Ranges in the project area. Within the Franciscan, low- and high-grade metamorphic rocks may occur adjacent to sedimentary rocks in a single outcrop. The general structural trend is northwest (Figure 1).

At several localities in the Coast Ranges, Upper Jurassic beds grading downward into pillow lavas and pillow breccias that form the upper horizons of an ophiolite sequence (Bailey et al. l970). The Coast Range ophiolite is believed to represent pieces of oceanic crust and upper mantle that were severely dismembered and structurally dislocated when it was accreted onto the western margin of North America. It consists of sheared serpentinite and small blocks of metamorphosed and sheared gabbro and diabase. These blocks are considered to be fragments of oceanic crust and upper mantle contemporaneous to the Franciscan complex and Great Valley Sequence (GVS). Radiometric dates on gabbroic rocks indicate that the igneous rocks of the ophiolite are Late Jurassic in age (Lanphere l97l), the same age as the lower part of the GVS. In most places the ophiolite has also been severely dismembered and structurally dislocated in part by underthrusting of the Franciscan during the Mesozoic, and partly by reverse-faulting in the steep limbs of much younger Tertiary folds (Raymond l973). It crops out along the base of the GVS about 10 miles west of the dam sites and is almost entirely faulted out along the Coast Range thrust. It also continues at depth beneath the reservoir area (Figure E-2). In the project area, the geomorphic province includes Upper Jurassic to Cretaceous marine sedimentary rocks of the Great Valley Sequence; fluvial deposits of the Tehama Formation; and terrace and stream deposits of the Red Bluff, Riverbank, and Modesto Formations.

The Great Valley Geomorphic Province is a north-south trending intermontane basin of very low relief that nearly extends from the Tehachapi Mountains in the south to the Klamath Mountains in the north bounded by the Sierra Nevada mountain range on the east and the Coast Ranges to the west. This large elongate northwest-trending asymmetric structural trough has been filled with a tremendously thick accumulation of sediments eroded from the adjacent ancestral Sierra Nevada and Klamath Mountains ranges starting in the Jurassic continuing into the Present. It has a long stable eastern shelf supported by the subsurface continuation of the granitic Sierran slope and a short western flank expressed by the upturned edges of the basin sediments. The western edge is bordered by the Coast Ranges where erosion has formed a series of northwest-trending, eastward-dipping ridges composed of sandstone and some conglomerate separated by valleys underlain by mudstone with siltstone. Easterly erosion through these sandstone ridges by drainages such as Funks and Stone Corral Creeks has formed water gaps on which the proposed dams are sited. At the Sites Project the Great Valley geomorphic province is characterized by both older and younger Quaternary deposits.

3.3 Great Valley Sequence Rocks

All of the Sites Reservoir proposed structures, except the new conveyance and alternative conveyances, will be founded on rocks of the Great Valley Sequence (GVS). This sequence is one of the thickest and most complete Upper Mesozoic sections in North America. The section consists principally of clastic sedimentary rocks that occur in simple stratigraphic order, are folded and faulted locally, but not disrupted in detail, and only affected by some minor metamorphism. The GVS and the Franciscan are the same age. The structural position of the GVS above the Franciscan results from regional overthrusting. The Coast Ranges represent a variety of ocean floor and trough deposits dragged downward against, and added to, the continental margin by plate subduction. In mid-Tertiary time, subduction of the oceanic plate and this accretion of Coast Range materials ceased and right lateral faulting along the San Andreas fault began. More recently, as underthrusting along the trough ceased, geologically rapid uplift occurred (Silver l97l; Calif., Sacramento Valley l978). Since then, nonmarine deposition occurred in the Sacramento Valley (Hackel l966), indicating that the basin had been uplifted above sea level.

The thrust fault contact between the Coast Ranges and the GVS marks the former position of the subduction zone, and the Sierra Nevada batholith about l00 miles east of the project area represents the eroded plutonic base of a volcanic arc that stood landward of the trough. Some of the sedimentary material of the GVS was eroded from the volcanic arc and deposited as deep marine turbidites in a large elongate northwest-trending structural trough. This trough was floored with basaltic and ultramafic oceanic crust (Coast Range ophiolite). The sediment sources for the turbidites are thought to have been the Sierra Nevada batholith to the east and the Klamath Mountains to the north. Locally the turbidites include materials derived from the underlying oceanic crust. These turbidites were deposited by gravity flow mechanisms at different times and places along the margins of the trough. These deposits are, therefore, lenticular, fan-, or tongue-shaped units set in a continuum of fine-grained deposits. The individual sandstone and pebble conglomerate beds wedge out or grade into finer-grained material over distances of less than one-half mile, or as much as 40 miles (Ingersoll et al l977), and probably represent distributary channels in the mid-fan and outer fan environment of submarine valleys.

Turbidite lithologies consist of interbedded sedimentary rocks dominated by mudstone and siltstone, interlayered with thin to thick sequences of sandstone and conglomerate. All three rock types were deposited sub-horizontally to horizontally and have been uplifted and tilted to the east by thrust faulting during the Tertiary, striking roughly north-south. This tilting causes the topography in the area to be dominated by ridges of sandstone and conglomerate. The mudstone is very susceptible to weathering and therefore, not a prominent ridge-former. In nearly all cases, the ridges pinch out along strike because of fault termination or some other structural phenomena.

The Golden Gate and Sites Dam sites are located on the eastern flank of the ridge near the contact between the Cretaceous Cortina Formation and the underlying siltstones and mudstones of the Cretaceous Boxer Formation. This contact is generally considered to be the lowest major sandstone unit.

The Boxer Formation consists of thin-bedded mudstones with scattered thin- to medium-bedded sandstones representing basin-plain deposits of distal turbidites (Ingersoll and others 1977). The basal member includes the Salt Creek Conglomerate. The Boxer Formation is less resistant to weathering and erosion and seldom is exposed in outcrop.

The Cortina Formation consists of a greater proportion of sandstone, with moderate to thick mudstone interbeds. The basal member of the Cortina Formation is the Venado sandstone (Photo 7). Near the base, the sandstone is primarily fine- to medium-grained and hard, occurring chiefly in 1- to 10-foot thick interbeds. Petrographic studies indicate that the rock is cemented by carbonates with a silica-clay matrix. The Venado includes a lesser amount of well-indurated, crudely fissile, mudstones that occur as 1/8- to 6-inch thick beds. Mudstone constitutes about 5 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 about an equal amount of mudstone (DOI-USBR 1969). The bedded, more resistant sandstone forms the series of ridges that constitute the abutments for the proposed Golden Gate Dam.

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.

Exposures of the Sites sandstone can be found about 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 sequence of mudstone about 8 miles south of the southern edge of the reservoir boundary.

In the project area, outcrops of sandstone beds are mostly brown, moderately strong, and range from thinly laminated to massive. In the drill core, fresh sandstones are mostly light green to gray and hard. They could be classified as graywackes because of the percentage of fine-grained interstitial material. Commonly they are interbedded with conglomerates, siltstones, and mudstones. Massive sandstones are well-indurated and hard with widely spaced joints, forming the backbone of most of the ridges.

In the project area, mudstones typically underlie the valleys and some west-facing ridges and are not found in outcrop due to their closely spaced fracturing and minimal resistance to weathering and erosion. Exposed mudstone units tend to readily slake. In the drill core, fresh mudstones are mostly dark gray to black, thinly laminated, moderately hard, and closely spaced due to pervasive jointing.

The interbedded conglomerates consist of lenticular and discontinuous beds that vary in thickness from several feet to more than 100 feet. These conglomerates, commonly cemented, are similar to the sandstone in hardness and jointing. Clasts in the conglomerate range in size from pebbles to boulders but are mostly gravel-sized. The clasts are composed primarily of cherty volcanic rocks, granitic rocks, and sandstones set in a matrix of cemented sand and clay. In Colusa County, a persistent conglomerate, the Salt Creek Conglomerate, marks the base of the Upper Cretaceous. Similar, though discontinuous, conglomerates are found more or less at the same stratigraphic level in the north end of the valley. These conglomerates contain reworked Lower Cretaceous clasts, which may indicate a period of local uplift and erosion at that time.

3.4 Tertiary Sedimentary Deposits

Tertiary and Quaternary fluvial sedimentary deposits unconformably overlie the Great Valley Sequence. In the study area, these belong to the Plio-Pleistocene Tehama Formation. Thin, discontinuous, and deeply weathered fluvial fan deposits were derived from the erosion of the Coast Ranges and Klamath Mountains. Eastward, the deposits thicken and coalesce, forming a broad, thick, fluvial outwash plain that contains pale green to tan semi consolidated sand, tuffaceous sand, and silt with lenses of gravel. The Nomlaki

Tuff Member occurs near the base of the Tehama Formation and has been age-dated at about 3.3 million years. It consists of white, tan, or pink dacite pumice tuff and lapilli tuff that is about 30 feet thick along the west side of the valley. Most of the tuff appears to have been deposited as an ash fall from a major volcanic eruption.

In places east of the project area, the distinctively red clayey gravel of the Red Bluff Formation caps the Tehama Formation. The Red Bluff remnants represent an extensive Pleistocene peneplain that once covered much of the northern Sacramento Valley.

3.5 Quaternary Deposits

Erosion of the Great Valley Sequence rocks has deposited sediments Holocene to mid-Pleistocene in age. These deposits include stream terraces, floodplain sediments of clay and silt, colluvium, landslides, and active stream channel deposits of sand and gravel. Helley and Harwood mapped these units in detail in the project area in 1985 (Calif., Sacramento Valley 1985).

Stream terraces (Older Alluvium, Qoal) form flat benches adjacent to and above the active stream channel (Recent Alluvium, Qal). Up to nine different stream terrace levels have been identified in the project area (WLA 2002). Terrace deposits consist of several to 10 feet or more of clay, silt, and sand overlying a basal layer of coarser alluvium containing sand, gravel, cobbles and boulders. USGS has given four terrace levels formational names. These are the Upper Modesto, Lower Modesto, Upper Riverbank, and the Lower Riverbank Formations. These formations range in age from 10,000 to several hundred thousand years old.

The Modesto Formation consists of 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 up to about 8 feet thick overlying older alluvial deposits. The surface preserves the original fluvial morphology with relief of 3 to 6 feet. 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 more extensive than on 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 because its terraces are topographically higher and exhibits a more developed soil profile. The upper member is unconsolidated but compact dark brown to red alluvium and forms the lower of the Riverbank terraces by about 10 feet but can be up to

15 feet above the lower Modesto terrace. The lower member is a red semi consolidated gravel, sand, and silt. Its surface is higher and more dissected than the upper member and has a stronger soil profile.

Alluvium consists of clay, silt, sand, gravel, cobbles, and boulders found in recent stream channels and clay, silt, and sand found on floodplains. Quaternary alluvium is generally loose deposits of soil, rock, clay, silt, sand, gravel, and boulders occasionally cemented.

Colluvium, or slope wash, occurs both on the ground surface of a hill and at its base. It consists mostly of soil, but contains a sizable fraction of angular rock fragments and some organic material.

Landslide deposits are similar to colluvium but more defined and generally deeper. Landslides occur along the reservoir rim or steep west-facing ridges but are generally small, shallow debris or earth flows. These could activate or enlarge in the event of a rapid drawdown of the reservoir. Rock fall deposits are present within the reservoir, especially on the backside of dip slope sandstone ridges and in some of the water gaps.

4.0 Site Exploration

Geologic exploration techniques used for investigation at the Sites Reservoir Project consisted of geologic mapping, drilling and water pressure testing, seismic refraction surveys, trenching and test pits, and laboratory testing. Discussed in detail below are the individual exploration techniques.

4.1 Geologic Mapping

Numerous sources of geologic mapping were utilized in developing site maps for individual features of the Sites Reservoir Project. The primary source of geologic mapping that covers the entire project area is the USGS Oil and Gas Investigations Map OM-210. It is entitled, “Geologic Map of the Lodoga Quadrangle, Glenn and Colusa Counties, California”. Mapping was performed by R.D. Brown and E. I. Rich in 1961 at a scale of 1:48,000. This mapping was the first attempt at delineating geologic units associated with the Cortina and Boxer Formations. This detailed regional geologic mapping covers the entire reservoir area and has been the geologic base map for all of the studies performed by the USBR and DWR since 1963.

In December 1963, USBR geologist Louis R. Frei mapped the Golden Gate and Sites Dam sites to feasibility level at a scale of 1 inch = 200 feet. The tailrace channel for the Sites Pumping-Generating plant was mapped in March 1968 by USBR geologist Gerald D. Burk. In April and May of 1969, USBR geologist David W. Carpenter mapped the proposed dike sites and the general geology of the reservoir.

The USBR performed additional feasibility level geologic mapping at Golden Gate, Sites, and the saddle dam sites in 1979 and 1980. USBR geologists June Worthington and Joel Sturm delineated outcrop patterns to assist in the development of the site specific geologic maps. Mapping was performed utilizing the metric system including the topography. The Bureau's geologic mapping and topography was the basis for the Department's initial maps for the Sites Reservoir Project. In July 1997, the Division of Planning and Local Assistance, Northern District (DPLA, ND) digitized the Bureau's geologic maps and topography.

The Division of Land and Right of Way produced new topography from a November 1998 1:7,200 aerial flight. Contours were developed at two-foot intervals and project site maps were generated in 2000 and 2001. This is the current topographic base that most of the geologic maps for the project are utilizing. The Sites Reservoir Project geologic mapping that has occurred since 1997 has been performed at various scales from numerous sources. Northern District, Geologic Investigations Section geologists Dave Forwalter, Jon Mulder, Kelly Staton, and Bruce Ross have mapped at the Golden Gate and Sites Dam sites with contributions from the Division of Engineering, Project Geology Section geologist Tim Todd. Geologic mapping of the saddle dam sites were performed by DPLA, ND geologist Jon Mulder and Project Geology Section geologist Jeff Van Gilder. Additional mapping at the saddle dam sites was performed by DPLA, San Joaquin District geologist Al Steele. Reservoir geology mapping in the vicinity of the Salt Lake fault was performed by DPLA, Southern District geologist Bob Pierotti with contributions from Al Steele.

4.2 Drilling and Water Pressure Testing

Most all of the exploration drilling was accomplished with a truck-mounted, all-terrain, CME-850 (Photo 3) drill rig and occasionally a CME-750. A CS-1000 skid rig was used to drill the abutment holes at the curved axis site. The diamond core holes used a HQ wireline core barrel that produces 2 ½"-diameter core. At Golden Gate Dam site holes were drilled about two-thirds of the way up each abutment and one hole drilled on either side of the channel or in the channel proper. At Sites Dam site angle holes were drilled in lieu of vertical holes because the USBR had drilled vertical ones on the left abutment and in the channel. The angle holes at Sites were drilled upstream and downstream of the axis to investigate the presence of both mapped and unmapped faults/shears to determine their thickness and associated characteristics including fracturing and permeability.

Exploration drilling by DWR at the saddle dam sites consisted mostly of vertical holes complementing the previous USBR holes. The holes were drilled along the alignments near the abutments, occasionally in the channel, and four angle holes for faults/shears.

Augering was performed at all of the dam sites with hollow stem flight augers mostly to determine depth to bedrock, water levels, and soil characteristics. The drill and auger hole logs with accompanying core photographs can be found in Appendix A.

Upon completion of most of the diamond drill holes each hole was double packer water pressure tested. This double packer test consists of placing the 19-foot long by 1.25-inch diameter packer assembly at the bottom test interval of the drill hole. The length of the test interval is equal to the separation distance between the two packers. Water is then pumped into the test interval through the perforated pipe at a set pressure over a given time. The amount of water taken into the formation is then read from a flow meter and recorded in gallons per minute (gpm). This procedure is repeated at continuous intervals throughout the depth of the hole to ensure complete coverage. The water takes were used to calculate permeability values as outlined by USBR (1973) and modified lugeon values as outlined by Houlsby (1976). A full review of both permeability and Lugeon calculations is presented in Technical Memorandum B (Appendix B).

After each drill hole was water pressure tested, slotted 2-inch PVC pipe piezometers were set to 60 feet below ground surface in each drill hole. Periodic water level measurements are being made to monitor the depth to groundwater below the ground surface. Each hole was capped with a lockable steel monument and set in concrete. Details of the construction of the piezometers and associated hydrographs of the water levels can be found in Appendix C.

4.3 Seismic Refraction Surveys

Thirteen seismic refraction surveys totaling about 1,600 feet in length were performed at the Golden Gate Dam site and appurtenant structures in January 1998 and June 1999. Locations of the surveys, discussions of results, and summary tables (Table 9) can be found in the Golden Gate Dam site Section 5.0. The seismic refraction surveys were conducted primarily to determine the depth of bedrock and seismic velocities of the bedrock formations associated with foundations of the appropriate engineering structures. The velocities also assist in determining the rippability of the bedrock.

4.4 Trenching and Test Pits

No exploration dozer trenches were excavated during this level of study. Some access roads for drill hole setups at Golden Gate and Sites Dam sites were excavated but with minimal exposure of the bedrock formations. Numerous trenches were excavated by William Lettis and Associates in and around the Sites Reservoir Project area. These trenches were excavated for fault studies and their locations can be found in WLA’s report appendixed to this report as a CD. In addition, selected figures from WLA’s report identifying fault trench locations can be found appendixed to this report. In addition, the USBR excavated two backhoe trenches at Golden Gate Dam site in association with their 1979 work. These two trenches were also for fault studies.

Both the USBR and the DWR excavated test pits within the proposed Sites Reservoir as part of the construction materials investigation. The Bureau excavated two test pits, TP-1 and TP-2. The DWR excavated eight test pits, GG-1 through GG-8 near the Golden Gate Dam site and ten test pits, SC-1 through SC-10, near the Sites Dam site. Locations of these test pits can be found on Figures 3 and 4 in the DOE Sites Reservoir Feasibility Study: Materials Investigation, Testing, and Evaluation Program Report, June 2002.

4.5 Laboratory Testing

Numerous rock and soil samples were tested, primarily for construction materials use, in this feasibility phase of investigation by the DWR. Additional rock and soil testing has been conducted in the past by the USBR and the USACE. A whole suite of tests has been conducted on both rock and soil samples.

Tests on rock samples included specific gravity, absorption values, compressive, shear, and tensile strengths. The rock samples originated from drill core and the existing Sites Sandstone Quarry. The sandstone quarry samples were cut into various dimensions for testing and some crushed to 1 ½-inch minus. In addition, some fresh, drill core sandstone samples were crushed and tested for Los Angeles abrasion losses. The Venado sandstone is an on-site source that would be used for rockfill and riprap and potentially for filter, drain, and transition materials. Testing results are available in the June 2002 DOE report referenced in Section 4.4.

The USACE performed petrographic analyses of weathered and fresh samples of Venado sandstone in 1962 and 1972. The USACE was considering using the sandstone as a source for potential riprap as slope protection on Sacramento River projects. The analyses revealed that the rock was an argillaceous, arkosic graywacke composed of angular to subangular grains of quartz, mica, feldspar, and rock fragments in a chlorite-clay matrix.

Soil samples from test pits were analyzed predominantly for use as impervious materials. Tests performed were classification, density, permeability, and CUE triaxial testing from which shear strengths were determined. In addition, soil samples from the auger holes drilled along the new conveyance alignment were tested for resistivity, sulfates, and chlorides.

All testing of soil and rock samples were performed by the Department's Chemical and Concrete and Soils Bryte Laboratories in West Sacramento.

5.0 Golden Gate Dam Site

The Golden Gate Dam site is in a narrow, V-shaped water gap on Funks Creek about a mile west of Funks Reservoir and 8 miles west of the town of Maxwell in Colusa County. There are two parallel sandstone ridges at the site that the dam could be keyed into. These sandstone ridges are a northern extension of the same ridges that the Sites Dam would be keyed into. At least four different dam locations and designs have been considered. These are: 1) a straight dam axis straddling the furthest upstream sandstone ridge; 2) a straight dam axis along the west side of the furthest upstream sandstone ridge; 3) a straight dam axis on the downstream sandstone ridge; and 4) the current curved alignment keyed into the west side of the downstream sandstone ridge (Photo 1). The downstream straight alignment was explored and evaluated in 1998 and reported in the August 2000 *"North of the Delta Offstream Storage Investigation: Appendix Q, Foundation Studies*". The curved alignment is the current design and the primary focus in this section of this report.

5.1 Site Geology

The Golden Gate Dam would be founded on Cretaceous sedimentary rocks of the Cortina Formation that are upturned to form a series of northerly-trending homoclinal ridges that dip about 50 degrees downstream to the east. The sandstones, which transitionally grade into siltstone, constitute the ridges and the mudstones occupy the subtle, topographically low, valleys between the ridges. The ridges are commonly marked by bold sandstone outcrops with minimal soil cover, where the mudstones generally are covered by soil and colluvium. Recent alluvial deposits cover most of the bedrock in Funks Creek to depths of about four feet. Older alluvium (terrace deposits) borders the creek channel and attains a thickness of up to about 25 feet. Some minor landslides and surficial slumps are present within the footprint of the proposed dam site.

The proposed curved axis was investigated by drilling four exploration holes: GGC-LA1, GGC-RC1, GGC-RC2, and GGC-RA1. See Plate 3, Sheets 1 and 2 for location of drill holes and Table 1 for footages. The discussion of the geology for the curved axis dam site is split up into three sections: the left abutment, the channel, and the right abutment.

The proposed Golden Gate Dam curved axis would be founded on three bedrock units that were differentiated into mappable units as follows:

- Kcvs - predominantly (> 70%) silty sandstone of the Venado member of the Cortina Formation with (< 30%) mudstone interbeds up to 5-feet thick.

- Kcvsm – approximate equal amounts of interbedded silty sandstones and mudstones of the Venado member of the Cortina Formation.

- Kcvm - predominantly (>70%) mudstone of the Venado member of the Cortina Formation with (< 30%) silty sandstone interbeds up to 5-feet thick.

For discussion purposes, the remainder of this report will refer to the two rock types, siltstone and sandstone, as only sandstone because they have very similar geologic characteristics and engineering properties. These geologic units at the Golden Gate Dam site are described on Plate 2 and are illustrated on Plate 3, Sheets 1 and 2 of 10. The current curved axis dam footprint will be underlain by about 50% sandstone (Kcvs) and 50% interbedded sandstone and mudstone (Kcvsm).

5.1.1 Left Abutment

The left abutment ranges in elevation from a high of about 650 feet to a low of about 260 feet near the channel of Funks Creek. It is characterized by moderately steep slopes ranging from about 1.5:1 reverse dip slopes to about 2:1 dip slopes and flattening out approaching the Funks Creek channel (Photo 2). The abutment is underlain by sandstones (Kcvs) and interbedded sandstones and mudstones (Kcvsm) that trend mostly N-S or slightly askew to the curved axis dipping to the east or downstream about 50º as illustrated on Plate 3, Sheet 1. Exploration drill holes GGC-LA1 and LA-1 represent geologic conditions on the left abutment and indicate that colluvium on the slopes ranges in thickness from about one to five feet (See Appendix A for drill hole logs and photographs). Upstream of the axis near the toe, the colluvium likely exceeds five feet in thickness in or adjacent to some shallow landslides. Exploration drill hole GC-LA1 was drilled about 70 feet downstream of the curved dam axis and drill hole LA-1 was drilled about 400 feet downstream of the current curved axis site at the straight axis site but encountered the same interbedded sandstones and mudstones.

The sandstone (Kcvs) is the resistant rock type at the site and is mostly yellowish brown in color when weathered and is light to medium olive gray in color when fresh. The sand is very fine to medium grained, angular to subangular, and poorly sorted. The matrix is predominately calcareous clay. Bedding in the sandstone ranges from thin-bedded to very thick-bedded, less than a foot to tens of feet in thickness, as evidenced in the drill core and in outcrops. It contains thin interbeds of mudstone that range from laminar up to five feet in thickness. The sandstone is moderately to well indurated. Drill hole information and surface exposures indicate that the sandstone is intensely to moderately weathered at the surface and to a depth of about 25 feet. In the drill holes, slightly weathered rock was encountered to depths ranging from 38 to 95 feet with the top of fresh rock as shallow as 38 feet in LA-1 and as deep as 95 feet in GGC-LA1. Weathered sandstone is mostly moderately hard, moderately strong, and closely to moderately fractured. The slightly weathered and fresh sandstone is mostly hard (occasionally very hard where locally cemented), strong, and moderately to slightly fractured with some massive.

In the drill core, fractures in the sandstone are most commonly associated with jointing and occasionally bedding. The joint fractures observed in the drill core are mostly healed with calcite and minor pyrite. Some bedding fractures also contained some calcite healing. The calcite healing ranges in thickness from 1/32 of an inch up to 0.1 feet but mostly about 1/16 of an inch. Some minor leaching of the calcite was noted throughout the drill core. Internal structure is well developed where bedding exists and not discernable where massive.

The mudstone is the least resistant rock type at the site and consequently is rarely exposed in outcrops except in fresh road cuts and the streambed or scars from recent landslide movements. It is mostly tan in the weathered state and dark gray to black where fresh. Preliminary geologic surface mapping did not reveal any individual mudstone (Kcvm) units within the footprint of the curved axis site. Rather the mudstone is most prevalent as an interbedded unit with sandstone (Kcvsm). A relatively thick mudstone unit was mapped downstream of the curved axis footprint on the south side of fault GG-2 (See Plate 3, Sheet 1). Bedding thickness ranges from thinly-laminated (.08 in.) to very thin-bedded (2 in.) with thin sandstone interbeds. The mudstone is mostly moderately indurated. When exposed in outcrop, it is friable to low hardness, mostly weak, and closely fractured. It is brittle and due to its close fracturing the mudstone is susceptible to slaking when exposed to air and moisture. Fresh mudstone in the drill core is mostly moderately hard and moderately strong, slaking only slightly after prolonged exposure to air. Continual wetting and drying accelerates the slaking. Bedding plane fractures are most prevalent in the mudstone and joint fractures are relatively short and discontinuous.

Bedrock shears encountered in exploration drill holes GGC-LA1 and LA-1 were generally very thin, between ¼ inch and 0.2 feet, mostly associated with bedding. The shears commonly contained only about 10% clay gouge with a variable percentage of calcite healing. Drill hole LA-1 encountered a bedding plane shear zone at a depth of 125.1 to 128.8 feet. It contained about 70% mudstone fragments and about 30% clay gouge (See drill hole log in Appendix A for details). In the drill core, bedding plane fractures in the mudstone commonly exhibit some plastic deformation in the form of slickensides or internal shearing.

This appears to be characteristic of the mudstone unit and does not indicate an actual shear or shear zone.

Geologic surface mapping identified two primary joint sets at the Golden Gate Dam site. The most prevalent one, Set A, ranges in strike from N68ºE to N86ºE and dips steeply from 67ºN to 75ºS. Joint Set A trends nearly normal to the ridges and the bedding trend. There is a joint set that is parallel to subparallel to the bedding trend, Set B. It ranges in strike from N-S to N25ºW, and varies in dip between 53º and 79ºE. A minor joint set, Set C, ranges in strike from N48º to 58ºW, dipping 54º to 74ºS. See Plate 3, Sheets 1 through 10 for the joint rose depicting joint Sets A, B, and C.

There are two near vertical, northeast-trending faults, GG-1 and GG-2, that are located in the vicinity of the left abutment (See Photo 2 and Plate 3, Sheet 1). Fault GG-1 is located 150 to 400 feet upstream of the curved axis footprint. It is expressed on aerial photographs as a series of well-defined topographic and vegetation lineaments that coincide with truncated and/or offset north striking sandstone and mudstone beds of the Cortina and Boxer Formations. Correlation of displaced sandstone and mudstone beds suggests a maximum right-lateral separation across the GG-1 fault of about 250 feet (WLA, 02).

Fault GG-2 is located about 650 feet southeast (downstream) of the top of the left abutment and intersects the downstream toe near the transition of the lower left abutment and the channel. It is highly visible on aerial photographs as a well-defined lineament that truncates north-striking sandstone and mudstone beds of the Cortina Formation. Based on offset of sandstone marker beds within the Cortina, a maximum right-lateral separation of about 1300 feet is associated with the GG-2 fault (WLA, 02).

Additional discussions of the GG-1 and GG-2 faults can be found in Section 10 on Faulting and Seismicity with detailed discussions in the September 2002 WLA Report which is an appendix as a CD to this report.

Only minor landslides or surficial colluvial slumps are present on the left abutment. They are shallow seated and the smaller ones commonly form on the reverse dip slopes of the ridges as illustrated on Plate 3, Sheet 1.

There is a 200 x 100 feet shallow seated landslide located about 500 feet upstream of the curved axis on the lower left abutment just above the Funks Creek channel. This slide would not pose any construction problems and should be easily removed. There is an area about 200 feet upstream of the axis high on the left abutment that is located on the reverse dip side of a slope. This area, 200 x 150 feet, appears to be a minor rock fall that has an accumulation of talus at the toe of the slope. This area is illustrated on Plate 3, Sheet 1 and it does not pose any construction problems.

5.1.2 Channel Area

The channel area in the vicinity of the dam axis is about 250 feet wide, but the width varies between about 170 feet near the upstream toe to almost 500 feet near the downstream toe. The channel area ranges between elevations 230 and 260 feet, where the abutments topographically transition from the ridges into the Funks Creek channel (See Plate 3, Sheets 1 and 2). It contains deposits comprised of recent (Qal) and older (Qoal) alluvium. The Qal deposits are confined to the Funks Creek channel. They are comprised of mostly silty and poorly graded sands with gravel layers up to three inches thick and cobbles and boulders. The Qal deposits range in thickness from a few feet up to about 17 feet. The Qoal deposits flank the creek channel in the form of benches or terraces. They generally are composed of mostly sandy and lean clays with varying percentages of gravel and, within the footprint of the dam, range in thickness from about 13 to 25 feet. Where the axis crosses the channel, there is a resistant, exposed sandstone (Kcvs) unit about 100 feet wide. This exposed, resistant bedrock unit has apparently caused Funks Creek to change its flow direction from mostly E-W to almost N-S.

Including two USBR drill holes, DH-201 and DH-205, a total of five drill holes and two auger holes were drilled in the channel area at the Golden Gate Dam site that encountered either Qal or Qoal alluvial deposits. Drill hole GGC-RC2 did not encounter any alluvial deposits and will be discussed as a right abutment hole. The two auger holes, GG-AUG4 and –AUG6, were drilled downstream beyond the dam footprint and encountered 21.0 and 29.0 feet respectively of Qoal deposits. DWR drill holes GGC-RC1, LC-1, and RC-1 encountered Qoal deposits to respective depths of 12.1, 15.0, and 22.9 feet. See Plate 3, Sheets 1 and 2 for drill hole locations and Appendix A for drill hole logs and details.

The bedrock encountered in four of the five channel holes was mostly comprised of about 70% sandstone and 30% mudstone (Kcvsm) with variable percentages of the two rock types at depth. One exception was drill hole DH-201 that was drilled just inside the upstream toe. It was drilled within the Boxer Formation and encountered mostly mudstone (Kbm). The bedrock has the same hardness and strength as described above. It mostly exhibited shallow weathering below the alluvial deposits, averaging only about 11 feet to fresh rock.

Bedding in the channel is consistent with the abutment exposures striking mostly N-S and dipping easterly (downstream) about 50º (See Plate 3, Sheets 1 and 2). Jointing is also consistent with the joint sets depicted on the joint rose on Plate 3. Bedrock shears encountered in the drill holes were minimal and predominantly associated with bedding. Drill hole GGC-RC1, which was drilled about 100 feet downstream of the curved axis, encountered an apparent bedding plane shear at a depth of 150.3 to 154.0 that contained 0.2 feet of gouge and associated intensely fractured mudstone.

Drill hole RC-1, about 350 feet downstream of the curved axis, was drilled along the earlier downstream straight axis at an angle of 45º. It was drilled nearly normal to the trend of Fault GG-2 in an attempt to encounter it below ground surface verifying its presence and in-situ condition. Assuming a near-vertical dip, GG-2 was recovered in drill hole RC-1 as an approximate 2.3-foot thick zone of highly sheared mudstone with about 10% clay gouge and an approximate 10 to 15 feet of associated intensely fractured, internally sheared mudstone (See Appendix A for drill hole log details). GG-2 trends about N50ºE passing under the downstream footprint and traversing across the upper right abutment as shown on Plate 3, Sheet 2. In trenches excavated by WLA, GG-2 was expressed as a discrete, well-defined narrow zone of faulting between 2 and 3-feet thick with minor secondary shears in the adjacent predominant sandstone bedrock. The width of GG-2 appears to vary considerably depending on whether the fault is located in sandstone or mudstone.

5.1.3 Right Abutment

The right abutment ranges in elevation from a high of about 600 feet to a low of about 270 feet near the channel of Funks Creek. Within the footprint of the dam most of the right abutment is characterized by moderately steep slopes of about 1.75:1 for both reverse and dip slopes. One exception is near the downstream toe where the slope steepens to about 1.25:1 in the vicinity of a massive sandstone (Kcvs) outcrop. Drill hole data and geologic surface mapping indicate that most of the right abutment within the footprint of the dam will be founded on sandstone (Kcvs) with about 25% of the interbedded sandstone and mudstone unit (Kcvsm). These units mostly trend N-S or nearly parallel to the curved axis dipping downstream about 50º as illustrated on Plate 3, Sheets 1 and 2.

Three drill holes, which represent the geologic conditions for the right abutment, were drilled on or in the vicinity of the abutment. Drill hole GGC-RC2, which has a channel designation, but is located on the lower right abutment, was drilled along the curved axis. Drill hole RA-1, which was drilled along the earlier downstream axis, was drilled about 400 feet downstream of the curved axis. Drill hole GGC-RA1 was drilled about 50 feet upstream of the curved axis. Drill hole locations can be found on Plate 3, Sheet 2. Most of the drill hole data indicates that the majority of the right abutment is covered by a relatively shallow thickness, about five feet, of colluvium. Locally, the colluvium is absent or less than a few inches thick where the sandstone unit (Kcvs) is present. Also the colluvium may be thicker in or adjacent to some shallow landslides that have been mapped in the lower right abutment as shown on Plate 3, Sheet 2.

Weathering on the right abutment is variable. Drill hole GGC-RC2, lower right abutment, encountered fresh sandstone at a depth of only 14.2 feet. Based on drill hole logs for RA-1 and GGC-RA1, the depth of weathered rock is 44.9 and 26.8 feet respectively. The upper 34.7 feet of GGC-RA1 encountered about 90% moderately weathered mudstone to 25.4 feet and below 34.7 feet to a depth of 136.5 feet, 90% sandstone was encountered. Drill hole RA-1, downstream and outside of the footprint, showed moderately weathered sandstone from 14.2 to 30.6 feet. Hardness and strength for the weathered and fresh sandstones and mudstones are consistent with the description for the left abutment. The sandstones encountered in the three drill holes are generally closely to moderately fractured near the surface and moderately to slightly fractured, often massive at depth. The mudstones encountered in drilling indicate that they are mostly intensely to closely fractured near the surface and closely to moderately fractured at depth (See drill hole logs and photographs in Appendix A for details). As noted in the left abutment drill core, fractures are commonly healed with calcite.

Shears within the bedrock encountered in the drill holes were minimal and commonly where present are almost entirely associated with bedding. The shears are very thin, generally less than 0.1 feet and often are partially healed with calcite. Bedding fractures in the mudstone drill core commonly exhibit some plastic deformation represented by slickensides along dip. This appears to be characteristic of the mudstone unit and does not indicate an actual shear or shear zone.

Fault GG-2 is the primary geologic structure on the right abutment that is evident on the ground surface and depicted on Plate 3, Sheet 2. It is illustrated as truncating or offsetting geologic units in a right-lateral sense. The fault is not exposed in any road or stream cuts on the abutment nor was it encountered in any exploration drill hole on the abutment. There are some subtle geomorphic features on the right abutment associated with GG-2. They include some subtle breaks in slope and some linear northeast-trending swales that WLA had noted in their study (WLA, 02). Further discussions of GG-2 can be found in Section 10 on Faulting and Seismicity with detailed discussions in the September 2002 WLA Report, an appendixed CD to this report.

There are two minor landslides, numerous small colluvial slumps, and some minor rock falls associated with older quarry operations. The two landslides and rock falls are located on the lower right abutment adjacent to Funks Creek. The majority of the colluvial slumps form on the reverse dip slope ridge and coincidentally along the surface trace of Fault GG-2 as illustrated on Plate 3, Sheet 2. The two landslides appear as shallow seated features and are located at the toe of the primary ridge that the right abutment is keyed into. The dimensions are about 200 feet long by about 150 feet wide at the toe. These slides should not pose any construction problems and would likely be removed in the foundation shaping.

5.2 Clearing and Stripping

Clearing is expected to be minimal as the only vegetation is light grass pastureland, a few oaks, shrubs, and other trees scattered throughout the footprint of the dam located along the Funks Creek channel and secondary drainages (See Plate 3, Sheets 1 and 2). The abutments will require stripping of the colluvial material overlying the underlying bedrock. The colluvium ranges in thickness from a few inches up to about five feet, but locally it may be up to 10 feet thick. Some minor amounts of talus are located in the secondary drainage at the base of the reverse dip slope of the left abutment and associated with the minor rock falls on the lower right abutment. Both the recent (Qal) and older (Qoal) alluvium associated with Funks Creek will require stripping. Within the footprint of the dam the alluvial materials range in thickness from a few feet up to 25 feet.

5.3 Excavation Characteristics, Rock Strength, and Cutslopes

5.3.1 Excavation Characteristics

At the Golden Gate Dam site, the sandstone unit (Kcvs) is the hardest of the rock types with the interbedded sandstones and mudstones unit (Kcvsm), less harder, and the mudstone unit (Kcvm), the least hardest, of the three rock units. Based on the drill core recovered from the exploration drill holes and limited surface exposures, the three rock units in their weathered states can be excavated by common methods. Some blasting will be required to achieve the required foundation shaping or the cutoff trench excavation depth where the harder, slightly weathered to fresh sandstone unit (Kcvs) is encountered on the abutments and in the channel.

Six seismic refraction survey lines were performed at the Golden Gate Dam site. They are located near the downstream toe adjacent to the Funks Creek channel and are illustrated on Plate 3, Sheets 1 and 2. Their locations are close to the original downstream axis. Seismic velocities in this area range from a low of 3,200 ft/sec. (likely intensely weathered mudstone) to a high of 13,700 ft/sec. (likely massive, slightly weathered or fresh sandstone). The average velocity for the six seismic lines in the area is about 7,200 ft/sec., which correlates to rippable rock by a D9R with a single or multiple shank rippers (See Table 9).

Rock quality designation (RQD) values were determined from logging of the drill core from the exploration holes. The RQD method of determining rock quality is a diagnostic description intended primarily for evaluating problems with rock excavations or tunnels. Most contractors are interested in RQD as a measure of blasting performance, rippability, and stability. RQD values are listed as a percent as shown on Table 3 and an indicator of the overall compressive strength of rock and can represent ease of excavation. Even relatively strong rock may be routinely rippable with RQD's less than about 50 to 60 percent. RQD can be closely correlated with rock weathering and fracturing. Generally the more weathered and fractured the rock is the lower the RQD value. Commonly RQD values increase with depth as the quality and competence of the rock does.

Both USBR and DWR used RQD as an indicator of the competence of rock as shown in Table 3. Logging of the core indicates that, generally, rock competence ranges from very poor near the surface to excellent at depth. RQD values generally indicate that the left abutment, along the axis, has very poor rock quality from the ground surface to a depth of 38 feet, poor to good from 38 to 118 feet, and fair to good from 118 to 263 feet with an exception of very poor rock quality from 118 to 128 feet. Rock quality in the channel underlying the older alluvium is very poor to good from 12.1 (top of rock) to 34 feet and excellent from 34 to 249 feet with an exception of fair quality from 94 to 154 feet. Rock quality at the base of the right abutment along the proposed axis is very poor from 4.2 (top of rock) to 15 feet and excellent from 15 to 250 feet with an exception of a fair quality from 55 to 80 feet. The mid to upper right abutment along the axis has very poor rock quality from about 18 (top? of rock) to 28 feet, fair from 28 to 63 feet, and good to excellent from 63 to 343 feet with an exception of fair quality from 298 to 313 feet.

5.3.2 Rock Strength

Numerous one-foot long core samples of sandstone and mudstone were taken from the exploration holes and submitted for testing at the DWR Soils and Concrete Lab in Bryte. Some samples were submitted in April 1999 from drill holes associated with the downstream straight axis, and some in May 2001 associated with the curved axis (Table 8). Five sandstone core samples from the left abutment drill holes had an average specific gravity (SPG) of 2.54 and an average absorption of 3.23. Two of these samples, from depths of 27.8 and 75.8 feet, have dry unconfined compressive strengths (UCS) that average 10,698 psi. Their wet UCS average was 5,214 psi. One fresh mudstone sample has a SPG of 2.51 and absorption of 4.63.

Six sandstone core samples from the channel drill holes had an average specific gravity of 2.54 and an average absorption of 2.67. Two of these sandstone samples have an average UCS of 13,320 psi. One sample has a wet UCS value of 4,693 psi. Four mudstone samples were collected between the depths of 23.2 and 200.3 feet. Two of these have an average specific gravity of 2.54 and an average absorption of 4.10. Two fresh mudstone samples have an average dry UCS of 4,685 psi. One slightly weathered mudstone sample has a dry UCS of 1,180 psi.

One fresh sandstone core sample from drill hole GGC-RA1 on the right abutment at a depth of 59.9 to 61.0 feet had a specific gravity of 2.55 and an absorption of 2.64. It has a dry UCS of 9,997 psi and a wet UCS of 4,810 psi. One fresh mudstone sample from the same drill hole at a depth of 146.3 feet has a dry UCS of 2,184 psi. Additional lab results from Golden Gate Dam site drill core samples can be found in Table 9.

5.3.3 Cutslopes

Drill hole logs from exploration hole GGC-LA1 indicates that along the axis below the approximate one to five feet of colluvium, about 30 feet of intensely to closely fractured, moderately weathered mudstone with sandstone interbeds (Kcvsm) will need to be excavated from the upper to mid-lower left abutment. Current feasibility design with the curved axis configuration keying into the left abutment requires about 40 feet of rock below ground surface (bgs) be excavated near dam centerline to 80 feet bgs near the downstream catch point of the 1:1 slope. The 1:1 feasibility design slopes for the foundation excavation in this area will be acceptable with only minor stability problems. The upstream 1:1 cut may experience some minor instability associated with bedding planes having an apparent dip slightly less than or about the same angle (45º) as the cut. Conversely, the downstream 1:1 cut may experience some minor instability associated with toppling of the steeper (60 to 70º) bedding planes. In addition, joint sets A and C may have a tendency to create overhangs in the less weathered rock or in combination with bedding, cause minor wedge failures.

From the lower left abutment to the channel, and up to the lower right abutment, drill hole logs from exploration holes GGC-RC1, GGC-RC2, and DH-205 indicate that in the vicinity of the axis below the older and younger alluvium, about 80% sandstone with mudstone interbeds is present. Current feasibility design requires about 40 to 50 feet of rock to be excavated within the impervious core footprint. The aforementioned logs also indicate that at this depth the excavation would encounter mostly fresh, hard rock that likely would require blasting in the lower 10 to 20 feet. The 1:1 feasibility design slopes for the foundation excavation in this area will be acceptable with minor stability problems associated with bedding and minor wedge failures similar to the ones described above on the left abutment. Bedding trends slightly askew to the axis in this area with an apparent dip of about 45º or steeper.

From the lower right to the upper right abutment, the drill hole logs for exploration holes GGC-RA1 and RA-1 indicates that in the vicinity of the axis below the mostly shallow colluvial cover, a predominant sandstone unit (Kcvs) and interbedded sandstone and mudstone (Kcvsm) is present. Current feasibility design with the curved axis configuration keying into the right abutment requires a significant cut within the impervious core footprint of between 80 feet at dam centerline and a maximum of 95 feet at the downstream catch point of the 1:1 cut. The aforementioned logs also indicate that at this depth the excavation would encounter fresh, hard rock that likely would require blasting in the lower 30 feet or so. The 1:1 feasibility design slopes will be acceptable with some minor slope stability problems associated with bedding and minor wedge failures as described above. Bedding trends nearly parallel to the axis and dips about 50 to 60º, or slightly steeper than the upstream cutslope of 1:1. The intersection of joint set A with a northerly dip and bedding could cause minor wedge failures. In addition Fault GG-2 traverses askew to the axis crossing the upper right abutment as shown on Plate 3, Sheet 2. The current feasibility design has a bend in the footprint where it cuts across the nose of the right abutment ridge at about elevation 450 feet. This portion of the footprint is only about 50 feet from the surface trace of Fault GG-2. The fractured rock associated with GG-2 may create some instability at this locale.

Overall the Cretaceous bedrock units at the Golden Gate Dam site are very competent as foundation rocks. They can mostly be excavated by common methods except where the downstream toe cuts for the left and right abutments encounter fresh, hard sandstone below 50 feet or so. These areas will likely require blasting. The feasibility design cutslopes appear to be acceptable with only minor instability associated with the trend of bedding and the combination of jointing creating some minor wedge failures. Slope stability analyses associated with the combination of bedding and jointing will be refined during design exploration.

5.4 Water Pressure Testing, Grouting, and Foundation Treatment

Water pressure testing in the exploration drill holes indicate that the abutments at the Golden Gate Dam curved alignment site will require significantly more grouting than in the channel area. Details of how the water pressure testing was conducted can be found in Section 4.2. The abutment holes indicated that permeabilities in the sandstone near the surface are at least an order of magnitude greater than for the underlying mudstone. This is likely associated with weathering and fracturing of the rock near the ground surface rather than intrinsic differences in the lithology.

Left Abutment

The rock encountered in exploration drill hole GGC-LA1 from 1.0 to 34.0 feet is mudstone with interbedded sandstone that is intensely weathered from 1.0 to 3.5 feet and moderately weathered from 3.5 to 34.0 feet. From 34.0 to 115.4 feet, mostly sandstone was encountered that is moderately weathered from 34.0 to 35.8 feet, slightly weathered from 35.8 to 95.5 feet, and fresh below 95.5 feet. Below 115.4 to the BOH of 263.0 feet, the hole encountered mostly (85%) fresh mudstone with interbedded sandstone (See Appendix A, geologic logs and photos for details).

To a depth of 61.0 feet, permeability values range from 0.3 to 5 ft/day, averaging 3.7 ft /day. Representative corresponding Lugeon values range between 26 and 82 (4.2 to 19.3 feet), averaging about 48 for this interval. If the

4.2 to 19.3-foot interval is omitted, because it would likely fall within the depth of excavation, then the average would be about 33. These values indicate that the grouting requirement to a depth of 61.0 feet in this portion of the left abutment will likely be mostly moderate with some local high intervals. The interval between 61.0 and 108.9 feet had permeability values ranging from 0.3 to 0.9 ft/day, averaging 0.7 ft/day. Representative corresponding Lugeon values range from 3 to 18, averaging about 12 indicating that low to moderate grout takes may be expected at this depth in this portion of the left abutment. From 108.9 feet to 257.9 feet (depth of final test interval), all permeability and lugeon values are 0 indicating this interval is tight and no grouting will be required in this portion of the left abutment. Additional exploration drilling and water pressure testing for preliminary design and final design studies will further characterize the permeability values and perspective grouting requirements for the left abutment.

Channel

Exploration drill holes GGC-RC1 and GGC-RC 2 (actually lower right abutment) were drilled in or near the channel through Quaternary terrace deposits and colluvium encountering mostly (~80%) sandstone with interbedded mudstone. The sandstone encountered in GGC-RC1 is intensely weathered from 12.1 to 12.4 feet, moderately weathered 12.4 to 26.9 feet, slightly weathered from 26.9 to 30.5 feet, and fresh below 30.5 feet. The sandstone encountered in GGC-RC2 is mostly intensely weathered from 4.2 to 10.0 feet, moderately weathered from 10.0 to 11.8 feet, slightly weathered from 11.8 to 14.2 feet, and fresh below 14.2 feet (See Appendix A, geologic logs and photos for details).

In GGC-RC1, three water test intervals between from 13.7 and 43.7 feet had permeabilities ranging from 0.4 to 0.55 ft/day, averaging 0.48 ft/day. Their representative corresponding Lugeon values range between 1 and 10, averaging about 7 indicating that to a depth of about 45 feet anticipated grout takes should be low. Below about 45 feet the water pressure tests indicate that the rock is tight with permeabilities up to 0.1 ft/day and corresponding Lugeon values of mostly less than 1. It is anticipated that grout takes will be minimal. In GGC-RC2 (actually the lower right abutment) the rock is very tight, with permeability averaging 0.002 feet/day with corresponding Lugeon values of mostly less than 1. This indicates that the rock in this portion of the channel and the lower right abutment will require no grout or minimal grout take. Additional exploration drilling and water pressure testing for preliminary design and final design studies will further characterize the permeability values and perspective grouting requirements for the channel area and the lower right abutment in the vicinity of exploration hole GGC-RC2.

Right Abutment

The rock encountered in exploration drill hole GGC-RA1 from about 18.0 to 34.7 feet is mostly (90%) mudstone that is moderately weathered from 18.0 to 25.4 feet, slightly weathered from 25.4 to 26.8 feet, and fresh below 26.8 feet. From 34.7 to a depth of 136.5 feet the rock is mostly (95%) fresh, hard sandstone. Below 136.5 feet to a depth of 343.0 feet (BOH) the rock is mostly (80%) fresh mudstone.

The lugeon values in the interval tested from 14.8 to 25.4 feet are greater than 7, indicating potential low grout takes. It is likely that the rock within this interval will be removed during the foundation excavation. From 25.4 to 110.2 feet, permeability values ranged from 0 to 1.1 ft/day, averaging 0.32 ft/day. Representative corresponding Lugeon values ranged from 0 to 17, averaging about 4 indicating that grout takes are anticipated to be low to moderate with some local zones of high takes, especially in the intervals from 40.5 to 57.2 feet and 93.5 to 110.2 feet. The water tests for the remainder of the hole from 110.2 to 343.0 feet indicate that the rock is tight except for a zone from 135.9 ft to 146.5 ft. It had a permeability of 0.2 ft/day with a lugeon value of 4.

While conducting water pressure tests in exploration drill hole RA-1, located near the earlier explored downstream straight axis, some minor springs located at the lower right abutment (Plate 3, Sheet2), showed an increase in flow. Drill hole RA-1 is located about 400 feet east (downstream) of the curved axis and about 250 feet downstream of the footprint. There appears to be a direct hydraulic connection here indicating that there are likely open fractures in the abutment that could act as potential conduits for seepage. One possibility is that blasting from the small quarry operation, located at the lower right abutment, may have opened existing joints and/or fractures. Additional exploration drilling and water pressure testing for preliminary design and final design studies will further characterize the permeability values and perspective grouting requirements for the right abutment.

In general, water pressure testing in the exploration drill holes at the Golden Gate Dam site indicate that overall the slightly weathered and fresh foundation bedrock is fairly tight with some local zones of potential high hydraulic conductivity near the ground surface. Some intervals of high water take occurred in the upper portions of some drill holes to depths of up to 80 feet below the proposed excavated foundation surface. About 80% of the water pressure tested intervals within the anticipated grout depth range were characterized as tight.

The construction of a multiple row grout curtain to a minimum depth of 100 feet or one half the height of the dam should significantly reduce seepage through the foundation. Water pressure testing in the exploration drill holes generally indicated that hydraulic conductivity decreases with depth. For feasibility estimates grout takes in the foundation bedrock are estimated to be between 0.1 and 0.3 sacks of cement per lineal foot of grout hole. This estimate will be further refined in the later stages of design. A grout cap should be constructed in the foundation to cover areas where fractured, jointed, or sheared rocks are exposed and to assist in the prevention of surface grout leakage during the upper grout stages. This feasibility phase of exploration presently indicates that grout takes are anticipated to be minimal to low in the channel area and low to moderate with local intervals of high on the abutments.

Faults/shears and open fractures exposed in the foundation may require some dental work prior to the placement of embankment. These discontinuities could be potential seepage paths through the foundation and will require grouting. Feasibility mapping indicates that fault GG-2 is a continuous geologic structure traversing diagonally across the right abutment and through the channel near the downstream toe for about 1500 feet. This feature will likely require some type of dental work to cutoff this potential seepage path. Blanket grouting should be considered to seal surface fractures and joints.

5.5 Groundwater and Springs

Groundwater is present at the site. It is near the ground surface in the channel area and some 50 feet or deeper on the abutments. Ten exploration drill holes and three auger holes were drilled at the Golden Gate Dam site. These holes were retained as observation wells and the depth to water below the existing ground surface (bgs) and their corresponding elevations have been monitored up until August 10, 2001 (last reading). The water level measurements are presented in Appendix C. Their locations can be found on Plate 3, Sheets 1 and 2. Drill holes DH-201 through DH-205 were drilled by the USBR in 1979 as part of their investigation of the proposed upstream alignment. Only DH-203 and DH-205 have been monitored by DWR during this feasibility study. DWR drill holes LA-1, GGC-LA1, LC-1, RC-1, GGC-RC1, GGC-RC2, RA-1, and GGC-RA1 were drilled as part of the investigation for both the straight downstream alignment and the current curved axis alignment. In addition three auger holes, AUG-4, -5, and –6, were drilled in the alluvial deposits downstream of the dam. Depth to water measurements have been monitored in these auger holes but groundwater in the vicinity of these holes is irrelevant to the dam site excavation. All depth to water elevations in piezometers that are illustrated on the geologic profile or sections only reflect the last reading taken on August 10, 2001.

The depth to water near the top of the left abutment in GGC-LA1 averaged about 75 feet bgs (elev. 357). The depth to water in LA-1, which is about 100 feet downstream of the curved axis footprint, averaged about 60 feet bgs (elev. 382). The current design for the curved axis would encounter groundwater in the left abutment downstream of the dam centerline because portions of the impervious core excavation in this area will be between 70 to 80 feet below original ground. This indicates that dewatering may be required if any enclosed excavations are designed, otherwise groundwater could be directed down the abutment and into the channel.

There are five observation wells that represent the depth to water in the channel area of the dam site. They are in order from left abutment to right abutment: LC-1, GGC-RC1, DH-205, RC-1, and GGC-RC2. As discussed earlier GGC-RC2 actually represents conditions and groundwater for the lower right abutment. It is located adjacent to a secondary drainage that the axis crosses on the lower right abutment. It has had an artesian flow rate of about 0.1 gpm since the hole was completed in November 2000 up until the last measurement in August 2001.

The depth to water in LC-1 averaged about 15 feet bgs (elev. 231). The depth to water in GGC-RC1 averaged about 13 feet bgs (elev. 254). The depth of water in DH-205 averaged about 25 feet bgs (elev. 235). The depth to water in RC-1 averaged about 22 feet bgs (elev. 238). The four piezometers are all located on the terraces above the channel of Funks Creek, which is a perennial creek. Water levels in LC-1, GGC-RC1, DH-205, and RC-31 for the most part reflect the groundwater elevation associated with the creek channel. Current design shows that the excavation in the channel at dam centerline for the impervious core to be about 40 feet below original ground indicating that groundwater will be encountered and dewatering will be required.

The depth to water near the top of the right abutment in GGC-RA1 averaged about 43 feet bgs (elev. 437). The depth to water in RA-1, some 200 feet downstream of the curved axis toe, showed erratic fluctuations in measurements but in general averaged about 70 feet bgs (elev. 392). The current design for the curved axis would encounter groundwater in the right abutment downstream of the dam centerline because portions of the impervious core excavation in this area will be vary from 80 to 95 feet below original ground. This indicates that dewatering may be required if any enclosed excavations occur, otherwise groundwater could be directed down the abutment and into the channel.

Some minor perennial springs are located near the toe of the right abutment about 100 feet north of the downstream toe (See Plate 3, Sheet 2). No historic record is available as to the amount of their flow but collectively it is likely less than one gallon per minute. As discussed in Section 5.4, water pressure testing in RA-1 showed an increase in the flow of these springs. This indicates that there is an apparent hydraulic connection between open fractures in the right abutment and these springs. Coincidentally these springs are located some 30 feet east (downstream) of Fault GG-2 as shown on Plate 3, Sheet 2. GG-2 may be acting as a groundwater barrier and these springs are a surface expression of the groundwater exiting downgradient of the fault. No other springs have been noted at the Golden Gate Dam site.

5.6 Pumping Plant and Approach Channel

The proposed pumping plant is located on the eastern side of the primary ridge that the right abutment for Golden Gate Dam is keyed into some 2,500 feet to the southeast. The curved approach channel extends about 5,000 feet east into Funks Reservoir (See Plate 3, Sheets 6, 7, and 8). Sandstone with interbedded mudstone of the Cortina Formation (Kcvsm) would comprise the foundations. The strike of the bedding is generally N-S with a dip of about 50^o E. Jointing trends mostly E-W with near vertical dips. The sandstone and interbedded mudstone is anticipated to be fresh and hard at invert and should provide excellent bearing capacity for the support of the structures. The older alluvium (Qoal) and recent alluvium (Qal) along the alignment for the approach channel ranges in depth from as shallow as 6.3 feet to the east at Funks Reservoir to at 35.3 feet at the west end. The soils are primarily lean clay and silt with some gravel interbeds.

The pumping plant foundation excavation would encompass an area of about 1,400-feet long by 1,200-feet wide. Current design shows a maximum depth of excavation to invert of the plant at 116 feet (elev.144). Only one exploration drill hole was drilled at the pumping plant during this feasibility study. The drill hole was DHPP-1 and it was drilled to a depth of 199.6 feet. See Plate 3, Sheet 6 for its location.

The hole encountered 5.3 feet of colluvium. The rock encountered was 85 percent sandstone with 15 percent mudstone interbeds. It was intensely weathered from 5.3 to10.3 feet, moderately weathered to 20.3 feet, slightly weathered to 26.5 feet, and fresh below 26.5 feet. The rock was mostly closely fractured to a depth of about 35 feet. Below 35 feet, the rock is almost entirely sandstone (95%) that is hard and strong and mostly slightly fractured to massive (See Appendix A for drill hole log and photos). RQD values for the rock encountered in DHPP-1 were very poor (avg. 25%) to a depth of 35 feet and excellent (98%) below 35 feet. The hardness and strength along with the excellent RQD values for the sandstone indicate that, below a depth of about 50 feet to 116 feet (invert grade), blasting will be required.

Cutslopes in the weathered and fractured rock from 5.3 feet to a depth of about 30 feet should be stable at 1:1 and below 30 feet, the fresh, hard sandstone should be stable at ½:1. The west end of the plant excavation may encounter some instability associated with bedding because it would be a dip slope cut.

Water pressure testing of drill hole DHPP-1 indicates that below about 40 feet the rock is very tight with some local zones (79.4 to 111.3 feet) of high permeability. Representative Lugeon values within this approximate 30-foot interval ranged from 82 to >100. The core photos show 100% sandstone that is mostly massive within this interval making the water tests highly suspect.

The depth to groundwater below the ground surface averages about 13 feet indicating that the pumping plant excavation will require dewatering. The most recent water level is illustrated on Plate 6, Sheet 2.

Auger holes AUG-1 through AUG-3 were augered along the straight alignment for the approach channel. The locations of these auger holes and the curved approach channel are illustrated on Plate 3, Sheets 6, 8, and 10. They were augered to determine the thickness of the older alluvial deposits (Qoal) and the depth to the top of bedrock. No diamond drill core samples were taken but some drive samples were driven into the intensely weathered sandstone or mudstone. (See Appendix A for logs). AUG-1 encountered lean clay from 0.0 to 6.3 feet and intensely weathered sandstone from 6.3 to 11.0 feet (refusal). AUG-2 encountered lean clay and silt from 0.0 to 11.2 feet and intensely weathered sandstone from 11.2 to 13.5 feet (refusal). AUG-3 encountered lean clay and silt with interbedded gravel layers up to 0.7 feet thick from 0.0 to 35.4 feet and intensely weathered mudstone from 35.4 to 36.3 feet (refusal).

Fault GG-3 trends (~ N30ºE) diagonally across the approach channel about 450 feet west of the pumping plant as shown on Plate 3, Sheet 6. It is visible on aerial photographs as a series of well-defined lineaments that extend from northwest of Funks Reservoir southwest to the town of Sites. Based on offset of a prominent sandstone marker bed, WLA estimates a maximum right-lateral separation of about 1600 feet. Fault trenches excavated by WLA indicate that the “GG-3 fault is a narrow (less than 2-ft wide), sub-vertical bedrock shear zone” (WLA, 2002). GG-3 is covered by alluvium in the approach channel but trends through the hillside on the right side of the approach channel. GG-3 would likely act as a groundwater barrier in the bedrock exposed in the approach channel.

The current design has an approach channel invert elevation of 170 feet, which means that about 35 to 50 feet of interbedded sandstone and mudstone will be encountered in the excavation. Seismic velocities generated from seismic lines SL-10 and SL-11 in the vicinity of the approach channel ranged between 8000 and 9000 ft/sec. These velocities indicate that the bedrock is marginally rippable. Assuming about 30 feet of weathered bedrock is present, then it could be excavated by common methods. Some blasting in the lower 5 to 15 feet of the excavation may be required in the harder, fresh sandstone to achieve the invert elevation of 170 feet.

The alluvial soils should be stable at 2:1 slopes, weathered bedrock at 1:1, and fresh rock at ½:1 along the approach channel.

Groundwater will be encountered in the excavation for the approach channel that will require dewatering. Only auger hole AUG-3 has a piezometer installed and the depth to water below the ground surface is about 25 feet.

Clearing will be minimal at the pumping plant and along the approach channel, as the only vegetation is light grasses and scattered pockets of riparian growth in the Funks Creek channel.

5.7 Inlet/Outlet Works Tunnel

Current design considerations consist of two alignments from essentially the same pumping plant location. The two alignments are referred to as the Long Tunnel (~ 4000 ft.) and Short Tunnel (~ 2500 ft.), both with a gate shaft option or multi-level outlet works option. Both the Long and Short Tunnels are currently designed to be 30 feet in diameter. The Long Tunnel alignment is located about 2500 feet south of the right abutment for Golden Gate Dam. The Short Tunnel alignment is located about 660 feet south of the right abutment. The Long Tunnel alignment along with the gate shaft option was initially the primary consideration because it avoided the intersection of Fault GG-2 in the tunnel and only encountering it in the intake channel in the reservoir. Geologic investigations were conducted only along the Long Tunnel alignment with the gate shaft option as illustrated on Plate 3, Sheets 3, 4, 5, and 9. The geologic profile along this alignment is illustrated on Plate 6, Sheets 1 and 2. The Short Tunnel alignment encounters Fault GG-2 about 600 feet downstream of the intake tower. During this phase of feasibility study no drill holes were drilled along the Short Tunnel alignment.

The proposed 30-foot diameter concrete-lined tunnel for both the Long and Short Tunnel alignments will encounter the Cortina and Boxer Formations characterized by interbedded sandstones and mudstones. Maximum cover for the Short Tunnel alignment is about 400 feet and 550 feet for the Long Tunnel alignment. Geologic mapping indicates that the current Short Tunnel alignment would encounter at tunnel invert about 500 feet, approximately 20%, of the Boxer Formation, which consists of mostly (~70%) mudstone. The remainder 2,000 feet or 80% of the alignment would encounter the Cortina Formation, predominantly (~70%) sandstone with interbedded mudstone. Based on preliminary drill hole information, tunneling conditions through these sedimentary rocks are not expected to encounter difficult conditions.

Strike of the bedding is roughly N-S, nearly normal to the tunnel alignment, with an average dip of about 50º E. A prominent joint set, Set A, trends about E-W with near vertical dips. The Boxer Formation consists of dominantly laminated to thinly-bedded mudstone with very-thinly to thickly-bedded sandstone interbeds. The Cortina Formation consists of very thinly- to very thick-bedded sandstone with laminated to thinly-bedded mudstone.

The sandstone is generally hard and strong and the mudstone is moderately hard and moderately strong. A total of eleven sandstone and mudstone core samples from tunnel drill holes, DHT-1, -3, -4, -5, and –6, were submitted for testing (Table 9). Five of the seven sandstone samples are representative of fresh, hard sandstone from tunnel grade. These five tunnel samples had dry Unconfined Compressive Strengths (UCS) ranging from a low of 4,600 to a high of 11,988 psi with an average of 8,665 psi. Three of the four samples had wet UCS values ranged between 4,548 and 7,740 psi with an average of 6,011 psi. One sandstone sample had a dry tensile strength of 2,795 psi. Three other sandstone samples had wet tensile strengths ranging from 1,467 to 1,776 psi with an average of 1,648 psi. The sandstone has an average specific gravity (SPG) of 2.49 and an average absorption value of 3.19.

Three of the four mudstone samples are representative of fresh mudstone from tunnel grade. These three mudstone samples have dry UCS values that range between 2,816 and 3,856 psi with an average of 3,070 psi. Their dry tensile strengths range between 649 and 1,393 psi with an average of 988 psi. The fresh mudstone samples had an average SPG of 2.57 and an average absorption value of 3.86.

The five tunnel exploration drill holes indicate that the Rock Quality Designation (RQD) values for the sandstone and mudstone at tunnel grade range from good (84%) in the two portal drill holes, DHT-1 and -4, to excellent (99%) in the other three drill holes, DHT-3, -5, and-6, which represents the remainder of the tunnel alignment (See Table 3). Drill hole logs for DHT-1 and DHT-4 indicate that some steeply-dipping (70^o) shears are present at tunnel grade (See Appendix A for drill hole log details and photos).

Some instability or minor overbreak may occur in the crown associated with laminated bedding of the mudstone. Moderate overbreak may occur along the tunnel walls where shears and associated fractured rock are present. RQD values indicate that tunnel support requirements are anticipated to utilize light to moderate weight steel sets on about 4-foot centers. Local areas of fractured rock associated with shearing may require heavier steel sets and/or closer spacing.

All five of the tunnel exploration drill holes showed groundwater levels well above tunnel grade indicating that groundwater will be encountered during tunnel excavation. Groundwater levels are illustrated in the drill holes on Plate 6, Sheets 1 and 2. Drill hole DHT-3 encountered artesian flows estimated to be about 10 gpm indicating that some isolated, confined, high groundwater flows will be encountered during the tunnel excavation.

In addition, water pressure testing was performed in the tunnel drill holes. The testing was used to estimate permeabilities for the tilted strata, especially where they intersect the tunnel alignment. Water pressure tests at tunnel grade in the five exploration holes showed no water losses indicating that the rock in the tunnel at these locations is tight. Water pressure tests in the same holes above tunnel grade showed isolated intervals with water losses and associated

Lugeon values >7. For details of the water pressure testing of the tunnel exploration drill holes see Appendix C.

5.8 Conclusions and Recommendations

The Cretaceous rock units of the Cortina Formation and part of the Boxer Formation at the Golden Gate Dam site and appurtenant structures are adequate for the current proposed design foundations. Water pressure testing indicates that grout takes will be mostly low to moderate with some isolated intervals of high to depths of up to 80 feet below the estimated depth of foundation excavation on the abutments. The channel will be mostly low. The fresh rock at depth is mostly tight. Most of the excavations can be accomplished by common methods with some blasting required in the fresh, hard and strong sandstone. Fault GG-2 will likely require some treatment in the foundation excavation.

Additional work that needs to be addressed is:

- Excavation of dozer trenches on the abutments to help delineate the rock units and more accurately define the bedrock structure.
- Additional exploration drilling and water testing to better define foundation conditions.
- Determining the bedrock conditions of Fault GG-2 on the right abutment by exploration dozer trenches.
- Further refining of the potential open fractures on the right abutment that were identified from the apparent communication between water testing at the springs at the lower right abutment by drilling and water pressure testing.
- Continue to monitor water levels, preferably quarterly, in the existing observation wells, especially regarding artesian conditions associated with drill hole GGC-RC2.
- Perform additional drilling and water testing along the short tunnel alignment if this option is still a design consideration.
- Perform additional seismic refraction surveys on the abutments to better define velocities of the Cortina Formation.
- Perform additional borrow and quarry investigations.

6.0 SITES DAM SITE

The Sites Dam site, like Golden Gate Dam site, is in a narrow, V-shaped water gap on Stone Corral Creek. The site is about 2.5 miles south of Golden Gate Dam site and about 8 miles west of the town of Maxwell in Colusa County. There is a prominent N-S trending ridge that Sites Dam would be keyed into and it is the southern extension of a portion of the same ridge that the Golden Gate Dam site will founded on. This dam site is the same location that the USBR investigated during their 1979-80 study.

6.1 Site Geology

The Sites Dam would be founded on Cretaceous sedimentary rocks of the Cortina and Boxer Formations that are upturned to form a series of northerly-trending homoclinal ridges that dip about 50 degrees downstream to the east. The sandstones, which transitionally grade into siltstone, constitute the main topographically high ridge and the mudstones occupy the subtle, topographically lower unit to the west. The main ridge is marked by a bold sandstone outcrop at the axis (See Photo 8). The sandstone units at the site have no soil cover or only a thin veneer, where the mudstones generally are covered by a topsoil and/or colluvium from a depth of a few feet up to about 10 feet. Recent alluvial deposits cover most of the bedrock in Stone Corral Creek to a depth of a few feet. Older alluvial deposits border the creek channel and attain a thickness of up to about 15 feet. Some minor landslides or surficial slumps in the Cortina Formation are present within the footprint of the proposed dam site. The Boxer Formation within the footprint of the dam is more susceptible to landsliding and contains slides of various sizes and shapes mainly upstream of the dam axis.

During this feasibility study, the proposed Sites Dam site was investigated by drilling four angle exploration drill holes, two near the upstream toe and two near the downstream toe: LC-1, LC-2, LC-3, and LC-4. In addition three auger holes were augered in the channel: AUG-1, AUG-2, and AUG-3. Previous investigation by the USBR in 1979-80 included two vertical and one angle exploration drill holes: DH-301, DH-302, and DH-303 (angle) that were drilled along the axis. See Photo 6 and Plate 7, Sheets 1 and 2 for location of drill holes and Table 1 for footages. The discussion of the geology for the dam site is split up into three sections: the left abutment, the channel, and the right abutment.

The proposed Sites Dam would be founded on three bedrock units that were differentiated into mappable units as follows:

- Kcvs - predominantly (> 70%) silty sandstone of the Venado member of the Cortina Formation with (< 30%) mudstone interbeds up to 5-feet thick.

- Kcvsm – approximate equal amounts of interbedded silty sandstones and mudstones of the Venado member of the Cortina Formation.

- Kbm - predominantly (>70%) mudstone of the Boxer Formation with (< 30%) silty sandstone interbeds up to 5-feet thick.

6.1.1 Left Abutment

The left abutment ranges in elevation from a high of about 700 feet to a low of about 250 feet in the channel of Stone Corral Creek. It is characterized by moderately steep slopes ranging from about 1.25:1 reverse dip slopes to about 2:1 dip slopes retaining their steepness all the way to Stone Corral Creek channel. About 50% of the left abutment is underlain by sandstones (Kcvs) and interbedded sandstones and mudstones (Kcvsm) of the Cortina Formation. The other 50% of the abutment is underlain by mostly mudstones (Kbm) of the Boxer Formation. The rock units trend mostly N-S or nearly parallel to the axis dipping to the east or downstream about 50^{o} as illustrated on Plate 7, Sheet 1. Only USBR exploration drill hole DH-302 represents geologic conditions for the portion of the left abutment in the Cortina Formation. DWR exploration drill holes LC-2 and LC-4, while drilled in the channel, would likely represent similar conditions of the Boxer mudstone for the portion of the left abutment that is underlain by the Boxer. Drill hole DH-302 encountered only less than a foot of colluvium overlying the sandstone (Kcvs) at this location. Colluvium overlying the Boxer mudstones in the vicinity of the left abutment is likely to be between one and five feet thick.

The sandstone (Kcvs), like at Golden Gate Dam site, is the resistant rock type at the site and commonly is exposed as bold outcrops, especially along the axis where a 100-foot plus sandstone unit is exposed (Photo 8). It is mostly yellowish brown in color when weathered and fresh, it is light to medium olive gray in color. Bedding in the sandstone ranges from thin-bedded to very thick-bedded, less than a foot to tens of feet in thickness, as evidenced in the drill core and in outcrops. It contains thin interbeds of mudstone that range from laminar up to five feet in thickness. The sandstone is moderately to well indurated. Drill hole information from DH-302 and surface exposures indicate that the sandstone is intensely to moderately weathered at the surface and to a depth of about 10 feet. In DH-302, slightly weathered rock was encountered to a depth of about 15 feet and fresh rock below 15 feet. Weathered sandstone is mostly moderately hard, moderately strong, and closely to moderately fractured. In DH-302 the slightly weathered and fresh sandstone is mostly hard (occasionally very hard where locally cemented), strong, and slightly fractured to massive. It is noted in the drill hole log for DH-302 that the fresh sandstone was recovered mostly as single core lengths (~5 feet) broken only by mechanical breaks. Some mudstone interbeds were encountered between the depths of 47.7 and 53.8 feet.

As previously mentioned no drilling was performed in the Boxer Formation that comprises the left abutment. Angle exploration drill holes LC-2 and LC-4 were drilled in the channel 400 and 500 feet respectively upstream of the dam axis. These two holes encountered the Boxer, which varies in composition of 60 to 80% mudstone and about 20 to 40% interbedded sandstone. The geologic units encountered in these two drill holes would project out of the channel and up onto the left abutment and likely represent what the Boxer is comprised of on the left abutment. The mudstone encountered in the drill holes was moderately hard, moderately strong, closely to moderately fractured, and very thin- (2in. to 1/2in.) to thinly- (2ft. to 2in.) bedded. Some minor to moderate air slaking was noted in the mudstone drill core within a few days and up to a few weeks.

Drill holes LC-2 and LC-4 indicate that weathering in the Boxer Formation at the channel drill hole locations is about three feet of moderate, five to eight feet of slightly, and fresh below about eight or ten feet. Weathering in the Boxer on the left abutment is anticipated to be deeper because the bedrock surface is exposed to the elements and it is likely there will be about five feet of intensely weathered rock. Due to its close fracturing, in outcrop the mudstone is susceptible to slaking from air and moisture.

In the drill core, fractures in the sandstone are most commonly associated with jointing and occasionally bedding. Fractures in the mudstone are most commonly associated with bedding. The joint fractures observed in the sandstone core are mostly healed with calcite and minor pyrite. Some bedding fractures occasionally contained calcite healing. The calcite healing ranges in thickness from 1/32 of an inch up to 0.1 feet but mostly about 1/16 of an inch. Some minor leaching of the calcite in the sandstone was noted throughout the drill core. Internal structure is well developed where bedding exists and not discernable where massive.

No bedrock shears were encountered in exploration hole DH-302. It was drilled to a depth of 132 feet and entirely within the Cortina Formation. Shearing encountered in channel holes LC-2 and LC-4 were few and appear to be associated with bedding. In LC-2, a zone of intense to closely fractured mudstone was encountered between the depths of 111.7 and 121.1 feet. This may be associated with a zone of shearing but only minor gouge was noted with some calcite healing. In LC-4, one notable shear was encountered between the depths of 39.6 and 44.6 feet. It contained about 10% clay gouge and may be a bedding plane shear (See Appendix A for drill hole details). The thicker shears encountered in LC-2 and LC-4 may be continuous from the channel into the upstream portion of the left abutment. Additional exploration during design may confirm their possible correlation. In the drill core, bedding plane fractures in the mudstone commonly exhibit some plastic deformation in the form of slickensides or internal shearing. This appears to be characteristic of the mudstone unit and does not indicate an actual shear or shear zone.

Geologic surface mapping identified two primary joint sets at the Sites Dam site. The most prevalent one, Set A, ranges in strike from N57ºE to N80ºE and dips steeply from 69º to 80º N. Joint Set A trends nearly normal to the ridges and the bedding trend. Joint Set B ranges in strike from N72ºW to N86ºW and dips steeply from 78ºN to 83ºS. Joint Set C is an isolated set that strikes about N74ºE and dips about 45ºN. See Plate 7, Sheets 1 and 2 for the joint rose depicting joint Sets A, B, and C.

Fault S-2 is another of the northeast trending tear faults like the GG-1, GG-2, and GG-3 faults at the Golden Gate Dam site. It is continuous for some 2.5 miles between Funks Reservoir and the town of Sites. In the vicinity of the Sites Dam site, Fault S-2 " is primarily distinguished by the presence of juxtaposed bedrock types, fractured bedrock, and sidehill benches and topographic saddles" (WLA, 2002). Based on correlation of offset bedding near the northeastern end of the S-2 fault, "maximum right-lateral separation is about 550 feet" (WLA, 2002). WLA fault trenches revealed that the S-2 fault is a narrow (less than 2-ft wide) sub-vertical bedrock shear zone. Fault S-2 is located about 900 feet downstream from the axis on the left abutment where it is trending about N40ºE as illustrated on Plate 7, Sheet 1. S-2 would not fall within the excavation for the abutment. Additional details on the S-2 fault can be found in Section 10, Faulting and Seismicity and the September 2002 WLA report appendixed as a CD to this report.

There are two landslides (Qls) on the left abutment located within the footprint of the dam. They have been mapped in the Boxer Formation upstream of the axis and are shown on Plate 7, Sheet 1. The smaller of the two slides is about 200 feet upstream of the axis and appears to be a shallow seated feature that would likely be removed in the left abutment excavation. The larger slide is about 400 feet upstream adjacent to the smaller one. It is about 250 feet wide and about 400 feet long. It was exposed in the access road to drill holes LC-2 and LC-4. It is comprised of colluvium and slumped Boxer mudstone. The approximate thickness should not exceed 30 feet in depth and would be removed during the excavation of the abutment. No other instability on the left abutment was recognized during this phase of feasibility mapping.

6.1.2 Channel Area

The channel area in the vicinity of the dam axis is about 140 feet wide. The width within the footprint varies between about 450 feet near the upstream toe, narrowing to only about 40 feet (330 feet downstream of the axis), and about

150 feet wide near the downstream toe. The channel area ranges between elevations 230 and 260 feet, where the abutments topographically transition from the ridges into the Stone Corral Creek channel (See Photo 7 and Plate 7, Sheets 1 and 2). It contains deposits comprised of recent (Qal) and older (Qoal) alluvium. The Qal deposits are confined to the Stone Corral Creek channel. They are comprised of mostly silty and poorly graded sands and gravels with cobbles and scattered boulders. The Qal deposits range in thickness from a few inches to a few feet. The Qoal deposits flank the creek channel in the form of benches or terraces. They generally are comprised mostly of sandy and lean clays and silts with gravel underlain by silty and clayey gravels. Within the footprint of the dam, the alluvial deposits range in thickness from about 10 to 20 feet.

Including USBR drill hole DH-301, a total of five drill holes and three auger holes were drilled in the channel area at the Sites Dam site that encountered either Qal or Qoal alluvial deposits. Only auger hole AUG-1, drilled about 450 feet upstream of the axis, falls within the footprint of the dam. Auger holes AUG-2 and AUG-3 were drilled about 300 feet upstream and about 200 feet downstream respectively of the dam footprint (See Plate 7, Sheet 1).

Auger hole AUG-1, drilled adjacent to exploration drill holes LC-2 and LC-4, encountered a sandy to lean clay from the ground surface to a depth of 6.8 feet underlain by a clayey gravel from 6.8 to about 10 feet where weathered mudstone fragments were encountered to a refusal depth of 10.5 feet. Auger holes AUG-2 and -3 encountered 16.0 and 14.0 feet respectively of Qoal deposits. USBR drill hole DH-301 and DWR drill holes LC-1, -2, -3, and -4 encountered Qoal deposits to respective depths of 19.1, 14.9, 14.5, 13.4, and 13.0 feet. See Plate 7, Sheets 1 and 2 for drill hole locations and Appendix A for drill hole logs and details.

Only USBR drill hole DH-301 was drilled near (~50 feet upstream) the current dam axis. DH-301 encountered about 90% mudstone with 10% interbedded sandstone of the Boxer Formation. Being that DH-301 was drilled as a vertical hole, it best represents the bedrock channel conditions in the Boxer Formation. It was drilled to a depth of 108.3 feet and encountered 90% mudstone with 10% interbedded sandstone. The drill hole log indicates that only about one foot of intense to moderately weathered rock overlies fresh mudstone at a depth of 20.0 feet. The mudstone is described as mostly low to moderately hard, weak to moderately strong, and laminated (1/2 in. to .08 in.) to thin-bedded (2 ft. to 2 in.). It was noted that the mudstone is susceptible to air slaking and upon wetting and drying the slaking intensified. Three shears were encountered at depths of about 79, 89, and 105 feet. Two appear to be bedding shears and the other had an unknown dip.

DWR exploration drill holes LC-1 and LC-3 were drilled 150 and 270 feet downstream of the toe. These two holes were angle holes that were drilled to explore the presence of Fault S-2. Both holes encountered about 90% sandstone with 10% interbedded mudstone of the Cortina Formation. Although these two holes are located outside the footprint of the dam, they are likely representative of the channel bedrock conditions for the Cortina Formation. The sandstone is mostly hard and strong, thick-bedded (4ft. to 2ft.), and mostly moderately to slightly fractured with some massive. In LC-3 there is a zone of intensely to closely fractured sandstone with slickensides between155.5 and 158.0 feet that appears to correlate with Fault S-2 at this location in the channel. Apparently S-2 was not encountered in LC-1 due to the bearing it was drilled.

No bedrock outcrops were mapped in the channel but bedding is assumed to be consistent with the abutments trending generally N-S and dipping 50^{o}E or downstream. Angle exploration drill holes LC-2 and LC-4 were drilled in the channel 400 and 500 feet respectively upstream of the dam axis. These two holes encountered the Boxer Formation, which is comprised of 60 to 80% mudstone and about 20 to 40% interbedded sandstone. The mudstone encountered in the drill holes was moderately hard, moderately strong, closely to moderately fractured, and very thin- (2in. to 1/2in.) to thinly- (2ft. to 2in.) bedded. Some minor to moderate air slaking was noted in the mudstone drill core within a few days and up to a few weeks. Drill holes LC-2 and LC-4 indicate that weathering in the Boxer Formation at the channel drill hole locations is about three feet of moderate, five to eight feet of slightly, and fresh below about eight or ten feet.

Bedrock shears in the channel area appear to be mostly associated with the Boxer mudstone upstream of the axis. Shears encountered in channel holes LC-2 and LC-4 were few and appear to be associated with bedding. In LC-2, a zone of intense to closely fractured mudstone was encountered between the depths of 111.7 and 121.1 feet. This may be associated with a zone of shearing but only minor gouge was noted with some calcite healing. In LC-4, one notable shear was encountered between the depths of 39.6 and 44.6 feet. It contained about 10% clay gouge and may be a bedding plane shear (See Appendix A for drill hole details).

6.1.3 Right Abutment

The right abutment ranges in elevation from a high of about 750 feet to a low of about 250 feet near the channel of Stone Corral Creek. Within the footprint of the dam about 50% of the right abutment (mainly downstream of the axis) will be founded on the Cortina Formation and it is characterized by moderately steep slopes ranging from 1.25:1 down the abutment to about 1.75:1 for both reverse and dip slopes. The steepness of the slopes continues down the abutment all the way to the channel. The upstream 50% of the right abutment is located in the Boxer Formation and it generally has more subdued slopes ranging between 2:1 and 2.5:1. Unlike the slopes in the Cortina, slopes in the Boxer flatten as they approach the channel. Drill hole data and geologic surface mapping indicate that the 50% portion of the right abutment in the Cortina is comprised of sandstone (Kcvs) and interbedded sandstone and mudstone (Kcvsm). The other 50% portion of the right abutment in the Boxer is comprised of mostly (~75%) mudstone with interbedded sandstone. These units mostly trend N-S or nearly parallel to the axis dipping downstream about 50^o as illustrated on Plate 7, Sheet 2. Only USBR exploration drill hole DH-303 represents geologic conditions for the portion of the right abutment in the Cortina Formation. It was drilled at an angle of 60^o and slightly askew to the trend of bedding (See Plate 7, Sheet 2). DWR exploration drill holes LC-2 and LC-4, while drilled in the channel, would likely represent similar conditions of the Boxer mudstone for the portion of the right abutment that is underlain by the Boxer. Drill hole DH-303 encountered about eight feet of colluvium overlying the interbedded sandstone and mudstone (Kcvsm) at this location. Because the right abutment is mostly a north-facing slope, it is likely that thicker accumulations of colluvium overlie the Boxer than the Cortina in the vicinity of the right abutment dam footprint. This thicker colluvium is likely due to the lack of outcrops and presence of tree growth in the Boxer.

The same 100-foot plus thick, bold sandstone outcrop (Kcvs) exposed on the left abutment at the axis is also on the right abutment along the axis (See Plate 7, Sheet 2). The sandstone is the resistant rock type at the site. It is mostly yellowish brown in color when weathered and fresh, it is light to medium olive gray in color. Bedding in the sandstone ranges from thin-bedded to very thick-bedded, less than a foot to tens of feet in thickness, as evidenced in the drill core and in outcrops. It contains thin interbeds of mudstone that range from laminar up to five feet in thickness. The sandstone is moderately to well indurated.

Drill hole information from DH-303 and surface exposures indicate that the sandstone (Kcvs) and the sandstone with interbedded mudstone (Kcvsm) is mostly intensely to moderately weathered at the surface and to a depth of about 30 feet. The rock is moderately to slightly weathered from 30 to 55 feet, and slightly weathered from 55 to a depth of about 130 feet. Although there is only subsurface information from one drill hole, DH-303, this indicates that the depth of weathering in the Cortina Formation is much more pronounced on the right abutment compared to the left abutment. The same is true in the Boxer Formation. Weathered sandstone is low to moderately hard, weak to moderately strong, and closely to moderately fractured. In DH-303 the slightly weathered sandstone is mostly moderately hard, moderately strong, and mostly moderately to slightly fractured. Weathered mudstone in DH-303 has low hardness, weak, and intensely to closely fractured. It is laminated to thin-bedded. The drill hole log indicates that the weathered mudstone core is quite susceptible to air slaking and often breaks with handling into angular fragments. The slightly weathered mudstone in DH-303 is low to moderately hard, weak to moderately strong, and mostly closely fractured.

In the drill core, fractures in the sandstone are most commonly associated with jointing and occasionally bedding. Fractures in the mudstone are most commonly associated with bedding. The joint fractures observed in the sandstone core are mostly healed with calcite and minor pyrite. Some bedding fractures occasionally contained calcite healing. Internal structure is well developed where bedding exists and not discernable where massive.

As previously mentioned no drilling was performed in the Boxer Formation that comprises the right abutment. Angle exploration drill holes LC-2 and LC-4 were drilled in the channel 400 and 500 feet respectively upstream of the dam axis. These two holes encountered the Boxer, which varies in composition of 60 to 80% mudstone and about 20 to 40% interbedded sandstone. The geologic units encountered in these two drill holes would project out of the channel and up onto the right abutment and likely represent what the Boxer is comprised of on the right abutment. The mudstone encountered in the channel drill holes was moderately hard, moderately strong, closely to moderately fractured, and very thin- (2in. to 1/2in.) to thinly- (2ft. to 2in.) bedded. Some minor to moderate air slaking was noted in the mudstone channel drill core within a few days and up to a few weeks.

Drill holes LC-2 and LC-4 indicate that weathering in the Boxer Formation at the channel drill hole locations is about three feet of moderate, five to eight feet of slightly, and fresh below about eight or ten feet. Weathering in the Boxer on the right abutment is anticipated to be deeper than the left abutment and the channel due to the north facing slope and the bedrock surface is exposed to the elements. It is likely that the depth of intensely weathered rock in the Boxer mudstone on the right abutment may exceed 10 feet. Due to its close fracturing, in outcrop the mudstone is susceptible to slaking from air and moisture.

No bedrock shears were encountered in exploration hole DH-303. It was drilled to a depth of 206.3 feet and entirely within the Cortina Formation. The mapped surface projection of Fault S-2 that trends across the right abutment indicates that S-2 passes through the lower part of DH-303. The drill hole log for DH-303 does not describe any shears that were encountered. Shearing encountered in channel holes LC-2 and LC-4 were few and appear to be associated with bedding. The thicker shears encountered in LC-2 and LC-4 may be continuous from the channel into the right abutment. Additional exploration during design may confirm their possible correlation. In the drill core, bedding plane fractures in the mudstone commonly exhibit some plastic deformation in the form of slickensides or internal shearing. This appears to be characteristic of the mudstone unit and does not indicate an actual shear or shear zone.

Geologic surface mapping identified two primary joint sets at the Sites Dam site. They are present on both abutments. The most prevalent one, Set A, ranges in strike from N57^{o}E to N80^{o}E and dips steeply from 69^{o} to 80^{o} N. Joint Set A trends nearly normal to the ridges and the bedding trend. Joint Set B ranges in strike from N72ºW to N86ºW and dips steeply from 78ºN to 83ºS. Joint Set C is an isolated set that strikes about N74ºE and dips about 45ºN. See Plate 7, Sheets 1 and 2 for the joint rose depicting joint Sets A, B, and C.

Fault S-2 is located about 700 feet downstream from the axis and about 100 feet downstream of the toe on the right abutment where it is trending about N60ºE as illustrated on Plate 7, Sheet 2. S-2 changes trend to about N70ºE midway up the right abutment. Current design would encounter S-2 at the top of the right abutment near the dam axis. S-2 was not observed in outcrop or described during field mapping for this feasibility study.

There are two minor landslides (Qls) that were mapped at the downstream toe on the lower right abutment. The larger of the two is about 100 by 100 feet. They are both located in the Cortina Formation as shown on Plate 7, Sheet 2. There is a fairly sizable slide (550 x 450 ft.) located about 600 feet upstream of the axis that current design encounters within the very upstream portion of the footprint (See Plate 7, Sheet 2). The western edge of the slide has a well-defined toe bulge of about 3 feet (See Photo 4). The eastern edge (inside the footprint) of the slide has very subtle features with no detectable toe bulge. There are two minor depressions that vary in depth from one to six feet located at the crown of the slide. The topography associated with the Boxer Formation above the slide is quite subdued as seen in Photo 5. The maximum depth of the slide is estimated to be about 35 feet. No other instability on the right abutment was recognized during this phase of feasibility mapping.

6.2 Clearing and Stripping

Clearing is expected to be minimal in the Cortina Formation, which comprises about 50% of the footprint downstream of the axis. The left abutment in the Cortina is covered with light grass, scattered oaks (especially on the dip slope), and shrubs. The north facing right abutment slope in the Cortina contains more oak trees than the left abutment. The Boxer Formation, which comprises the upstream 50% of the dam footprint, will require more clearing than the Cortina area of the footprint. In particular, the right abutment is mostly covered by numerous scrub oaks, light grass, and scattered shrubs. In the Stone Corral Creek channel there are scattered trees and grasses.

The abutments will require stripping of the colluvial material overlying the underlying bedrock. The colluvium ranges in thickness from a few inches up to about eight feet overlying the Cortina. The colluvium overlying the Boxer may exceed depths of 10 feet and locally it may be thicker where it is associated with the landslides near the upstream toe of the footprint (See Plate 7, Sheets 1 and 2). Both the recent (Qal) and older (Qoal) alluvium associated with Stone Corral Creek will require stripping. Within the footprint of the dam the alluvial materials range in thickness from a few feet up to about 20 feet.

6.3 Excavation Characteristics, Rock Strength, and Cutslopes

6.3.1 Excavation Characteristics

At the Sites Dam site, the sandstone unit (Kcvs) of the Cortina Formation is the hardest of the rock types with the interbedded sandstones and mudstones unit (Kcvsm), less harder, and the mudstone unit (Kbm) of the Boxer Formation, the least hardest, of the three rock units. Based on the drill core recovered from the exploration drill holes and surface exposures, the three rock units in their weathered states can likely be excavated by common methods. An exception might be the 100-foot thick massive sandstone unit exposed along the axis on both abutments. Some blasting will be required to achieve the required foundation shaping or the cutoff trench excavation depth where the harder, slightly weathered to fresh sandstone unit (Kcvs) is encountered on the abutments and in the channel.

No seismic refraction survey lines were performed at the Sites Dam site. Seismic velocities determined from the refraction survey lines conducted at the Golden Gate Dam site would likely be similar at Sites because the same geologic formations with their associated rock units are present. Seismic velocities at the Golden Gate Dam site ranged from a low of 3200 ft/sec. (likely intensely weathered mudstone) to a high of 13700 ft/sec. (likely massive, slightly weathered or fresh sandstone). The average velocity for the six seismic lines in the area is about 7200 ft/sec., which correlates to rippable rock by a D9R with a single or multiple shank rippers.

Like at Golden Gate Dam site, rock quality designation (RQD) values were also determined from logging of the drill core from the exploration holes at Sites Dam site (See Table 5). The RQD method of determining rock quality is a diagnostic description intended primarily for evaluating problems with rock excavations or tunnels. Most contractors are interested in RQD as a measure of blasting performance, rippability, and stability. RQD values are listed as a percent and an indicator of the overall compressive strength of rock and can represent ease of excavation. Even relatively strong rock may be routinely rippable with RQD’s less than about 50 to 60 percent. RQD can be closely correlated with rock weathering and fracturing. Generally the more weathered and fractured the rock is the lower the RQD value. Commonly RQD values increase with depth as the quality and competence of the rock does.

Both USBR and DWR used RQD as an indicator of the competence of rock at Sites Dam site as shown in Table 5. Logging of the core indicates that, generally, rock competence ranges from very poor near the surface to excellent at depth. RQD values from USBR drill hole DH-302 indicate that the left abutment, along the axis, has excellent quality from about 3 feet to a depth of 132 feet with an exception of fair from 12.5 to 15.7 feet. The RQD values range between 88 and 100 with an average of 99. This drill hole was drilled entirely within the 100-foot plus thick Cortina sandstone unit (Kcvs), hence the high rock quality values.

In channel USBR drill hole DH-301, along the axis, rock quality for the Boxer underlying the older alluvium is good from 19.1 (top of rock) to 108 feet ranging from a low of 20 to a high of 100 and averaging about 77. There is a very poor exception of 9 between 58 and 61 feet. DWR channel holes LC-2 and LC-4 were 45^{o} angle holes drilled upstream of the axis in the Boxer Formation (See Plate 7, Sheet 2). Rock quality in LC-2 ranged from poor at 14.5 (top of rock) to a depth of about 37 feet to mostly good from 37 to 143 with a fair exception from 53 to 86 feet. Rock quality in LC-4 was similar to LC-2. These two holes were generally oriented normal to bedding and the drill core exhibited fracturing along bedding indicating for the most part a lower rock quality.

Rock quality in USBR drill hole DH-303 along the axis at the top of the right abutment ranges from very poor to good. The quality is very poor from 10 to about 28 feet with an average RQD of 12. The quality is fair from 28 to 91 feet with values ranging between 33 and 100 but an average of just 58. From 91 to 206 feet the quality is good ranging from a low of 28 to high of 100 but averaging 85. As discussed earlier this is an angle hole drilled at 60^{o} down on a bearing paralleling the topography. While the hole had a total depth of 206 feet, the bottom of the hole finished only about 130 feet below the ground surface.

6.3.2 Rock Strength

Several fresh, sandstone drill core samples from drill hole LC-2 were submitted to the DWR Concrete and Soils lab in Bryte for testing. A sample from 53.5 to 54.5 feet was tested wet and had a specific gravity of 2.55 and an unconfined compressive strength (UCS) of 17,868 pounds per square inch (psi). Sandstone samples were also submitted for testing from Sites Quarry located about 2,000 feet downstream of the dam site. Three of the Sites Quarry fresh sandstone samples had a UCS value of 9,568 psi when dry and 6,983 psi when wet. Three moderately weathered sandstone samples that were tested had an average UCS value of 4,998 psi when dry and 3,589 psi when wet.

6.3.3 Cutslopes

Drill hole log from USBR exploration hole DH-302 indicates that along the axis below the one foot of colluvial cover, about 15 feet of moderately to slightly fractured and moderately to slightly weathered sandstone (Kcvs) will be encountered for most of the left abutment. Below about 15 feet along the axis, mostly slightly fractured, fresh sandstone is present. Current feasibility design for the Sites Dam axis requires about 70 feet of rock be excavated for the impervious core near dam centerline transitioning down to 50 feet near the downstream catch point of the 1:1 slope. The lower 35 to 50 feet of the sandstone will likely require blasting. The 1:1 feasibility design slopes for the foundation excavation in this area will be acceptable with only minor stability problems. The upstream 1:1 cut may experience some minor instability associated with degradation of the Boxer mudstone due to slaking. In addition, some instability may occur because bedding planes will dip out of the slope at about the same angle (45º) as the cut. Conversely, the downstream 1:1 cut may experience some minor instability associated with toppling of the steeper (60 to 70º) bedding planes. In addition, joint sets A and B may have a tendency to create overhangs depending how continuous they are, especially in the fresh rock or in combination with bedding, cause minor wedge failures.

From near the toe of the lower left abutment, across the channel, and up to the lower right abutment, USBR exploration drill hole log DH-301 indicates that in the vicinity of the axis Boxer Formation is present. Underlying the older and younger alluvium, the Boxer at this location is comprised of about 90% mudstone with 10% sandstone interbeds. Current feasibility design requires about 35 feet of rock to be excavated within the impervious core. The Boxer likely can be excavated by common methods, but the hard, fresh sandstone of the Cortina, which in the channel is only about 50 feet downstream of the axis, will likely require blasting in the lower 20 feet. The 1:1 feasibility design slopes for the foundation excavation in this area will be acceptable with minor stability problems associated with degradation of the Boxer mudstone along with bedding and minor wedge failures similar to the ones described above on the left abutment. Bedding trends slightly askew to the axis in this area with an apparent dip of about 45º or steeper.

From the lower right to the upper right abutment, the drill hole log for USBR angle exploration hole DH-303 indicates that in the vicinity of the axis below the mostly shallow colluvial cover, a predominant sandstone unit (Kcvs) and interbedded sandstones and mudstones (Kcvsm) are present. Current feasibility design requires a significant cut for the impervious core of between 60 feet at dam centerline to a maximum of about 70 feet at the upstream catch point of the 1:1 to cut. The aforementioned log indicates that at this location weathering is deeper in the Cortina on the right abutment than on the left abutment. Slightly weathered rock is present from a depth of 53 to 130 feet. The lower 10 feet may require blasting if weathering is indeed as deep as the drill hole indicates. Further refinement of the depth of weathering on the right abutment will occur in design exploration. The 1:1 feasibility design slopes will be acceptable with some minor slope stability problems associated with bedding and minor wedge failures as described above. Bedding trends nearly parallel to the axis and dips about 50º, or slightly steeper than the upstream cutslope of 1:1, which would be in the Boxer Formation mudstone that will likely experience degradation associated with slaking. The intersection of joint set A with a northerly dip in combination with bedding could cause minor wedge failures. The southerly dipping B joints may create local overhangs.

Overall the Cretaceous bedrock units at the Sites Dam site are very competent as foundation rocks. They can mostly be excavated by common methods except where the downstream toe cuts for the left abutment and the channel excavations encounter fresh, hard sandstone below 50 and 20 feet respectively. These areas will likely require blasting. The preliminary design cutslopes appear to be acceptable with only minor instability associated with the trend of bedding and the combination of jointing creating some minor wedge failures. Slope stability analyses associated with the combination of bedding and jointing will be refined during design exploration.

6.4 Water Pressure Testing, Grouting, and Foundation Treatment

Water pressure testing in the exploration drill holes indicate that at the Sites Dam site the abutments in the Cortina Formation will require less grouting than the Boxer Formation in the channel area. Details of how the water pressure testing was conducted in the DWR exploration drill holes can be found in Section 4.2. Other than the existing drill hole logs, no further details of the USBR water pressure testing are available. The abutment holes indicated that permeabilities in the Cortina sandstone near the surface are at least an order of magnitude less than the channel Boxer mudstone. Water pressure testing was conducted by the USBR in their exploration drill holes DH-301, -302, and –303, which are located near the current axis. Water pressure testing was performed on two of the DWR exploration holes, upstream hole LC-4 and downstream hole LC-3. No water pressure tests were performed in the downstream DWR exploration hole LC-1 or upstream hole LC-3. USBR drill hole DH-302, drilled on the left abutment along the axis, appears to offer the best representative permeability values for the Cortina sandstone unit (Kcvs). USBR drill hole DH-301, drilled in the channel along the axis, appears to offer the best representative permeability values for the Boxer mudstone unit (Kbm). DWR angle exploration drill hole LC-3 was drilled downstream of the footprint nearly subparallel to bedding and the water pressure test results do not reflect true vertical permeability values. The upstream DWR angle hole LC-4 was drilled nearly normal to the trend of bedding and its water pressure test results also do not reflect true vertical permeability values.

Left Abutment

USBR exploration drill hole DH-302 was drilled in the massive Cortina sandstone unit (Kcvs) present on the left abutment. Between the depths of about 28 and 132 feet, ten water pressure tests were performed with six showing no water takes indicating that the sandstone is tight. Only the initial test interval from 28 to about 38 feet showed an elevated permeability value of 3.68 ft/day. This interval will likely fall within the depth of excavation for the left abutment core trench according to the current feasibility design. The next two tests, 37 to 47 and 46 to 56 feet had permeability values of 0.4 and 1.1 ft/day respectively. These two test intervals also likely fall within the left abutment core trench excavation. Below the depth of 56 feet only one other water pressure test, 84 to 94 feet, showed any take and it had a permeability value of 0.23 ft/day. No corresponding Lugeon values were calculated from the permeability values in the USBR drill holes.

Channel

USBR exploration drill hole DH-301 was drilled in the Boxer mudstone unit (Kbm) present in the channel. Between the depths of about 28 (top of rock is about 19 feet bgs) and 108 feet, nine water pressure tests were performed with water takes noted in every test indicating that the mudstone in the channel near the axis is permeable. Four water pressure tests were performed between the depths of about 28 and 65 feet. Permeability values ranged from a low of 0.61 to a high of 4.20 ft/day with an average of 2.55 ft/day. Current feasibility design shows about 40 feet of excavation for the core trench in the channel leaving about 25 feet of highly permeable mudstone. Between the depths of about 65 and 85 feet the permeability value for the mudstone has an average of 0.73 ft/day indicating that at depth the mudstone is becoming tighter. Between the depths of 85 and 108 feet the average permeability value is 0.24 ft/day.

Right Abutment

USBR exploration drill hole DH-303 is the only drill hole that represents any permeability values for the right abutment. As discussed in Section 6.1.3 this is an angle hole drilled askew to bedding. It was drilled entirely within the Cortina Formation and has a total drilled depth of 206.3 feet but the bottom of the hole finishes only about 130 feet below the existing ground surface. While this hole does not provide true vertical permeability values for the right abutment, it shows permeability values ranging from 0.95 to 4.48 ft/day with an average of 2.95 ft/day to a depth below the ground surface (bgs) of about 60 feet. From about 60 to 130 feet bgs the permeability values range from 0.03 to 1.01 ft/day with an average of 0.27 ft/day.

In general, water pressure testing in the exploration drill holes at the Sites Dam site indicate that overall the slightly weathered and fresh foundation bedrock is fairly tight with some local zones of potentially higher hydraulic conductivity closer to the ground surface. High water takes generally occurred to depths of 40 to 60 feet below the proposed excavated foundation surface. Below this depth range the rock was mostly tight.

The construction of a multiple row grout curtain to a minimum depth of 100 feet or one half the height of the dam should significantly reduce seepage through the foundation. Water pressure testing in the exploration drill holes generally indicated that hydraulic conductivity decreases with depth. For feasibility estimates, grout takes in the foundation bedrock are estimated to be between 0.1 and 0.25 sacks of cement per lineal foot of grout hole. This estimate will be further refined in the later stages of design. A grout cap should be constructed in the foundation to cover areas where fractured, jointed, or sheared rocks are exposed and to assist in the prevention of surface grout leakage during the upper grout stages. This feasibility phase of exploration presently indicates that grout takes are anticipated to be minimal to low on the abutments in the predominate Cortina sandstone and low to moderate with local intervals of high grout takes in the channel Boxer mudstone.

Faults/shears and open fractures exposed in the foundation may require some dental work prior to the placement of embankment. These discontinuities could be potential seepage paths through the foundation and will require grouting. Feasibility mapping indicates that Fault S-2 is a continuous geologic structure traversing diagonally across the right abutment and crossing the channel about 250 feet downstream of the toe. Current design may encounter this feature crossing the axis near the extreme upper right abutment. If this feature is encountered in the foundation it will likely require some type of dental work to cutoff this potential seepage path. Blanket grouting should be considered to seal surface fractures and joints.

6.5 Groundwater and Springs

Groundwater is present at the site. It is near the ground surface in the channel area and some 80 feet deep on the abutments. Seven exploration drill holes, three USBR and four DWR, along with three auger holes were drilled at the Sites Dam site. Drill holes LC-2, LC-3, LC-4, DH-301, DH-302, and DH-303 were retained as observation wells. DH-301, a USBR channel hole drilled in December 1979, has since been destroyed or covered and no depth to water readings are available. The auger holes were not retained as monitoring wells. The depth to water below the existing ground surface (bgs) and their corresponding elevations have been monitored up until August 10, 2001 (last reading). The water level measurements are presented in Appendix C. Their locations can be found on Plate 7, Sheets 1 and 2.

All depth to water elevations in the observation wells, that are illustrated on the geologic profile or sections, only reflect the last reading taken on August 10, 2001.

The depth to water at about mid-left abutment in DH-302 averaged about 81 feet bgs (elev. 343). The current design for Sites would encounter groundwater in the left abutment at the drill hole location because the depth of excavation for the impervious core in this area will be between 70 and 80 feet below original ground. This indicates that dewatering may be required if any enclosed excavations are designed, otherwise groundwater could be directed down the abutment and into the channel.

There are three observation wells that represent the depth to water in the channel area of the dam site. They are in order from upstream to downstream: LC-4, LC-2, and LC-3. Depth to water measurements along with their corresponding elevations have been taken from July 1998 to August 2001. The three piezometers are all located on the terraces above the channel of Stone Corral Creek, which is a perennial creek. Water levels in LC-4, LC-2, and LC-3 for the most part reflect the groundwater elevation associated with the creek channel. Current design shows that the excavation in the channel at dam centerline for the impervious core to be about 40 feet below original ground indicating that groundwater will be encountered and dewatering will be required.

The depth to water in USBR drill hole DH-303, located at the top of the right abutment, averaged about 80 feet bgs (~elev. 450). The current design for Sites shows that the excavation for the impervious core in this area will be between 60 and 70 feet below original ground. This indicates that groundwater will not be encountered in the excavation. Additional drilling of vertical exploration drill holes during design studies will assist in defining the depth to groundwater on the right abutment.

During this feasibility study no springs have been noted at the Sites Dam site.

6.5.1 Conclusions and Recommendations

The Cretaceous rock units of the Cortina Formation and the Boxer Formation at the Sites Dam site are adequate for the current proposed design foundation. Water pressure testing indicates that grout takes will be mostly low to moderate with some isolated intervals of high to depths of 40 to 60 feet below the estimated depth of foundation excavation on the abutments. The channel will be mostly low. The fresh rock at depth is mostly tight. Most of the excavations can be accomplished by common methods with some blasting required in the fresh, hard and strong 100-foot thick sandstone unit that is present on the abutments and the channel. Fault S-2 will likely require some treatment in the upper right abutment excavation.

Additional work that needs to be addressed is:

- Excavation of dozer trenches on the abutments to help delineate the rock units and more accurately define the bedrock structure.
- Perform additional exploration drilling and water testing to better define foundation conditions, especially on the right abutment.
- Continue to monitor water levels, preferably quarterly, in the existing observation wells.

- Determining the bedrock conditions of Fault S-2 on the right abutment by exploration dozer trenches.

- Perform seismic refraction surveys on the abutments and the channel to better define velocities of the Cortina and Boxer Formations.

- Determine the depth and size of the landslide present on the upstream right abutment by excavating dozer trenches and drilling.

- Perform additional borrow and quarry investigations

7.0 SITES RESERVOIR SADDLE DAMS

The Sites Reservoir nine saddle dam sites are located in the northern part of the reservoir. Saddle Dam (SSD) #1 (closest) and #9 (farthest) are located about three miles north and six miles northwest respectively from the Golden Gate Dam site (See Figure 1). These nine saddle dams would total about 15,000 feet in length and would be built along about a 4-1/2-mile long reach that will constitute the northern reservoir rim of the proposed Sites Reservoir. The saddle dams range in crest lengths from as short as 270 feet (SSD-4) to as long as 3,810 feet (SSD-3). They range in height above streambed from 40 feet (SSD-4) to 130 feet (SSD-3). Work was performed by the USBR in 1979-80 and by DWR from 1998 to 2001. The USBR referred to their sites as Dikes L-1 through L-11 and the current DWR alignments are at about the same locations but with slightly different configurations. No geologic plan maps were published for SSD-1, SSD-2, SSD-6, and SSD-7. The USBR drilled 12 exploration drill holes at the sites and the DWR drilled an additional 13 exploration drill holes. The drill hole logs and core photos (except USBR) can be found in Appendix A and the footages on Table 2. Results of the water pressure testing can be found in Appendix B and the depth to water level measurements are presented in Appendix C.

7.1 General Geology and Structure

The proposed saddle dams will be constructed on Cretaceous sedimentary rocks of the Boxer Formation. The geologic units consist of interbedded mudstone, sandstone, and some conglomerate commonly overlain by a variable thickness of lean to fat clay. In general, the Boxer is comprised of about 70% mudstone, about 25% sandstone, and about 5% massive conglomerate. The primary structural features, in the vicinity of the saddle dams, are the Salt Lake fault, which trends through SSD-2, and the Fruto syncline. In addition some of the northeast trending tear faults traverse through some of the saddle dam sites (See Plate 9, Sheets 3 and 4)). Further details of the Salt Lake fault can be found in Section 8, Reservoir Geology, and Section 10, Faulting and Seismicity.

Generally, outcrops at the saddle dam sites are scarce making it difficult to obtain geologic attitudes and therefore determining the lateral extent of the rock units. Only the massive, thickly-bedded conglomerate unit and discontinuous sandstone beds provides the best outcrops. The more resistant tilted conglomerates and sandstones form ridges that dominate the subtle topography. A north-south trending conglomerate unit comprises the abutments at SSD-6, the western edge of SSD-5, and the ridge just east of SSD-7 (See Figure 3). Colluvial (Qc) cover depth of up to five feet is present on the ridges and up to 20 feet in the low-lying areas. Colluvial (Qc) cover depth of up to five feet is present on the ridges and up to 25 feet in the low-lying areas. The geologic rock units strike roughly N-S with a dip that ranges from west to east depending on the location of the saddle dam with respect to the axis of the Fruto syncline, which trends just west of SSD-9. Bedding associated with the eastern limb of the syncline dips at about 20ºW at SSD-8 and nearly horizontal, about 5ºW, at SSD-9. The dip direction gradually changes from west to east close to intersection of the Salt Lake fault and possibly the northern extension of the Sites anticline in the vicinity of SSD-1 and SSD-2.

The proposed saddle dam sites would be founded on four bedrock units that were differentiated into mappable units as follows:

- Kbm - predominantly (> 70%) mudstone of the Boxer Formation with (< 30%) sandstone interbeds up to 5-feet thick.

- Kbsm – approximate equal amounts of interbedded silty sandstones and mudstones of the Boxer Formation.

- Kbs - predominantly (>70%) sandstone of the Boxer Formation with (< 30%) mudstone interbeds up to 5-feet thick.

- Kbcgl – predominantly (>95%) conglomerate with minor sandstone interbeds.

These geologic units at the saddle dam sites are described on Plate 2 and are illustrated on Plate 9, Sheets 1 through 4.

7.2 Saddle Dam #1

SSD-1 is located about three miles north of the Golden Gate Dam site and is only about 50 feet high with a crest length of about 500 feet. This small structure trends nearly east-west and sits astride a narrow saddle separating southerly and northerly trending drainages (See Plate 9, Sheet 1). The site is underlain by mostly Boxer mudstone (Kbm) with some minor sandstone interbeds (Kbs and Kbsm).

USBR exploration drill hole DH-100 was drilled near the maximum section of the dam to a depth of 34.1 feet. It encountered 25.7 feet of colluvium (Qc) composed mostly of lean clay with sand overlying about 80% mudstone with 20% interbedded sandstone. Bedding in the drill hole dips about 60º. The mudstone is decomposed from 25.7 to 27.3 feet, intensely weathered from 27.3 to 29.2 feet, and slightly weathered from 29.2 to 34.1 feet. It is mostly intensely fractured, thin-bedded (2ft. to 2 in.), low hardness, and weak. The sandstone interbeds are mostly thin-bedded but averaging only about three inches thick. Three minor (1.5 in. to 0.4 ft) shears in the mudstone were encountered between the depths of 29.2 and 33.9 feet. Two had dips between 10 and 20º and were subparallel to bedding and one was a bedding plane shear with a dip of about 60º. No groundwater was encountered to a depth of 34.1 feet. One water pressure test was performed in the approximate nine feet of mudstone encountered. The permeability value was 0.09 ft/day. Current design requires about stripping to an approximate depth correlating with the top of intensely weathered rock and additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations can be accomplished by conventional methods. It does not include foundation grouting since a large portion of this saddle dam is freeboard. Foundation seepage was not considered to be significant for SSD-1 due to relatively low head and a long flow path below the core trench.

A geologic plan map for SSD-1 was not published by DWR Northern District, but some geologic reconnaissance of the site was performed during this feasibility study. Short, discontinuous sandstone interbeds exposed on the left abutment indicate that the bedding trends about N20ºW and dips about 65ºE. The dam axis would trend normal to bedding indicating that it would dip out of the left abutment and into the right abutment. Some minor surficial soil slumps are present on the right abutment. An area of instability containing some surficial landslides is located about 300 feet upstream of the left abutment.

7.3 Saddle Dam #2

SSD-2 is located about three miles northwest of the Golden Gate Dam site, some 2000 feet due west of SSD-1. It is about 80 feet high with a crest length of about 420 feet. This small structure trends nearly east-west and sits astride a narrow saddle separating southerly and northerly trending drainages (See Plate 9, Sheet 1). The site is underlain by mostly Boxer sandstone (Kbs) with minor mudstone interbeds (Kbsm).

USBR exploration drill hole DH-101 was drilled about 400 feet downstream of the axis to a depth of 31.7 feet. It encountered 17.6 feet of colluvium (Qc) composed mostly of lean to fat clay with sand overlying about 95% sandstone with 5% interbedded mudstone. Bedding in the drill hole is vague but dips about 70º. The sandstone is decomposed from 17.6 to 18.3 feet and intensely weathered from 18.3 to 31.7 feet. It is mostly intensely fractured, thick- to very thick-bedded, low hardness, and weak. No shears were noted but joints in the core were noted as being slightly rough and open 1 to 2mm and occasionally containing the same thickness of clay or carbonate filling. Groundwater was encountered at about 6 feet when the hole was drilled in November 1979. No water pressure testing was performed. Current design requires stripping to the top of intensely weathered rock and additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations can be accomplished by conventional methods. It does not include foundation grouting since a large portion of this saddle dam is freeboard. Foundation seepage was not considered to be significant for this small saddle dam due to relatively low head and a long flow path below the core trench.

A portion of the left abutment for SSD-2 would have about 270 feet of embankment that would only be about 2 feet in height. It would require a large amount of excavation for a relatively small embankment volume. Therefore, the typical saddle dam section will be replaced at this location with a small homogeneous impervious embankment and a 5-foot wide by 270-foot long, 40-foot deep bentonite slurry wall to provide foundation seepage control. In addition the slurry wall acts as a defense measure against potential displacements associated with an event along the Salt Lake fault.

A geologic plan map for SSD-2 was not published by the DWR Northern District, but some geologic reconnaissance of the site was performed during this feasibility study. Short, discontinuous sandstone interbeds exposed on the abutments indicate that the bedding trends between N20^{o}E and N20^{o}W and dips about 70^{o}E. The axis would trend normal to bedding indicating that it would dip out of the left abutment and into the right abutment.

The primary geologic feature in the vicinity of SSD-2 is the bedding-parallel Salt Lake thrust fault. The Salt Lake fault is considered active and is capable of generating up to 16 inches of reverse movement in a single ground rupturing event (WLA 2002). Although the Salt Lake fault is projected through the left abutment, it has not been trenched here and its exact location is unknown. Currently the projection of the Salt Lake fault trends through the slurry wall extension of the left abutment (See Plate 9, Sheet 1). Additional trenching during design exploration will verify the exact location of the Salt Lake fault at the SSD-2 site. No signs of instability at the site were noted during the geologic reconnaissance mapping.

7.4 Saddle Dam #3

SSD-3 is located about three and three quarter miles northwest of the Golden Gate Dam site, some 4000 feet almost due north of SSD-2. It is the longest, highest, and largest of the nine saddle dams. It has a crest length of about 4400 feet (including about 600 feet of a small homogeneous embankment with slurry wall). It is about 130 feet in height, and has a volume of about

3,600,000 cubic yards. This large structure trends mostly north-south and sits astride an 800-foot wide broad, alluvial channel (See Plate 9, Sheet 2). The site is underlain by mostly Boxer mudstone (Kbm) with minor sandstone interbeds (Kbsm & Kbs). Photo 10 is an aerial view of SSD-3 showing the location of exploration.

Exploration at SSD-3 consisted of drilling eight core holes (including two by the USBR in 1979) and three auger holes. The core holes from the left abutment to the right abutment are: SSD3-4, DH-103, SSD3-3, DH-102, SSD3-2, SSD3-1, SSD3-5, and SSD3-6. The three auger holes, AUG-1, -2, and –3 were drilled in the vicinity of the channel. Although the reference is made to a channel, there is no defined drainage that occupies the channel. For the location of these exploration drill holes see Plate 9, Sheet 2. The colluvium (Qc) on the abutments and in the channel area varies in thickness from about one foot up to as thick as 21.2 feet. The colluvium is predominantly fine-grained soils composed of mostly sandy lean clays and fat clays with sand. The colluvium is underlain by varying percentages of mudstones (Kbm), interbedded sandstones and mudstones (Kbsm), and sandstones (Kbs) of the Boxer Formation. Bedrock outcrops on the abutments consist of mostly discontinuous sandstone interbeds that strike between N-S to N20^{o}W and vary in dip from 54 to 70^{o}W. SSD-3 is located on the east limb of the Fruto syncline. At least two northeast trending shear zones referred to as lineaments LSSD3-1 and LSSD3-2 trend nearly normal to the axis on the left abutment and maybe one, LSSD3-3 on the lower right abutment. These structures are inferred by the subtle changes in vegetation, subtle breaks in slopes, and lineaments in the topography, an abundance of white calcareous float in the soil, and offsets mapped in a conglomerate ridge to the west.

Left Abutment

The left abutment ranges in elevation from a high of about 560 feet to a low of about 420 feet near the channel. It is characterized by very subtle slopes. Exploration drill hole SSD3-4 was drilled on the axis near the top of the left abutment (See Plate 9, Sheet 2). It was drilled to a depth of 181.0 feet to evaluate foundation conditions at this portion of the left abutment. Underlying the 2.0 feet of the lean to fat clay colluvium (Qc) the hole encountered about 90% mudstone with 10% sandstone interbeds. The rock is decomposed to intensely weathered from 2.0 to 9.2 feet, intensely weathered from 9.2 to 16.9 feet, moderately weathered from 16.9 to 56.4 feet, slightly weathered from 56.4 to 74.2 feet, and fresh below 74.2 feet.

The thinly-bedded to laminar mudstone contains a few thickly-bedded sandstone interbeds and is intensely to moderately fractured to a depth of 56.4 feet, and intensely to slightly fractured (mostly moderately) to 181.0 feet. The mudstone is friable to low hardness and friable to weak with the sandstone being mostly low hardness and weak to 56.4 feet, then both are mostly moderately hard and moderately strong to 181.0 feet. The mudstone exhibits numerous intrinsic slickensides along bedding planes and mechanical fractures.

From 96.0 to 164.4 feet is an interval consisting of numerous shears with intensely but up to moderately fractured rock with variable percentages of gouge associated with individual shears. This interval also contains breccia fragments up to ½", slickensides, bedding offsets, and associated pyritization along with calcite and clay healing. Individual shears are separated by intervals of relatively unsheared rock that are mostly closely to moderately fractured.

USBR exploration drill hole DH-103 was drilled on the axis at about mid-left abutment to a depth of 51.4 feet. It encountered only about one foot of colluvium underlain by about 60% sandstone with about 40% interbedded mudstone (Kbsm). The rock is intensely weathered to a depth of about 47 feet and then slightly weathered from 47 to 51.4 feet.

The sandstone is mostly thin-bedded with intervals of thick-bedded and the mudstone is very thin- to thin-bedded. Bedding dips 55 to 60º. The rock is mostly closely fractured (90% bedding) with zones of intense. The mudstone is friable to low hardness and friable to weak with the sandstone being mostly low hardness and weak. The mudstone exhibits numerous intrinsic slickensides along bedding planes and mechanical fractures.

Two shears about 0.3 of a foot were encountered between the depths of 15.2 to 15.6 and 34.4 to 34.6 feet. The shallowest shear is a bedding plane shear with a dip of 50º. Both shears exhibit slickensides.

Exploration drill hole SSD3-3 was drilled on the axis near the lower left abutment as shown on Plate 9, Sheet 2. It was drilled to a depth of 131.0 feet and encountered 4.0 feet of colluvium underlain by variable percentages of interbedded mudstones and sandstones. From 4.0 to 19.5 feet, the Boxer unit (Kbs) consisting of about 80% sandstone with 20% mudstone interbeds was encountered. From 19.5 to 97.0, feet the unit (Kbm) consisting of about 80% mudstone with 20% sandstone interbeds was encountered and from 97.0 to 131.0 feet the unit (Kbsm) with about 50% mudstone and 50% sandstone was encountered (See Appendix A for details of the drill hole log and core photos).

The rock is decomposed from 4.0 to 5.8 feet, intensely to moderately weathered from 5.8 to 32.0 feet, moderately to slightly weathered from 32.0 to 56.0 feet, slightly weathered from 56.0 to 74.2 feet, and fresh below 74.2 feet. The sandstone is mostly thin-bedded with intervals of thick-bedded and the mudstone ranges from laminated to thin-bedded. The mudstone is friable to low hardness and friable to weak with the sandstone being mostly low hardness and weak to a depth of about 32.0 feet. From 32.0 to about 97.0 feet, the sandstone is mostly moderately hard and moderately strong and the mudstone mostly low hardness and weak. Below 97.0 feet the sandstone is mostly hard and strong and the mudstone is moderately hard and moderately strong. The mudstone exhibits numerous intrinsic slickensides along bedding planes and mechanical fractures throughout the hole. Bedding dips range between 40 and 69º. The rock is mostly intensely fractured from 4.0 to about 32.0 feet, closely with some (20%) moderately fractured from 32.0 to 97.0 feet, and mostly moderately fractured below 97.0 feet.

The intensely fractured rock between 4.0 and 32.0 feet appears to be associated with shearing. The rock exhibits extensive shearing with variable percentages of gouge throughout the interval. There are intervals of unsheared rock up to 1.5 feet in length. Due to the intense fracturing, the dip could not be determined. The rock contains numerous zones of calcium carbonate healing to a depth of 27.0 feet. In the Kbm unit between 19.5 and 97.0 feet the mudstone contains numerous (~seven) shears that vary in thickness from 0.3 feet up to about three feet. Often the mudstone exhibits internal shearing in the body of the rock but no gouge.

Both the USBR and DWR used rock quality designation (RQD) as an indicator of the competence of rock (Table 6). RQD values from the drill core indicate that the rock competence at SSD-3 ranges from very poor near the surface to good at depth. In general, RQD values indicate that the upper left abutment along the axis is very poor to 76 feet, good to 116 feet, and very poor from 116 to 181 feet. No RQD values were determined in the USBR drill hole at the mid-left abutment but the log indicates the rock is mostly intensely fractured and it would be of poor quality at best. Rock quality underlying the lower left abutment along the axis is very poor to 55 feet, poor to 92 feet, and good from 92 to 131 feet. One mudstone sample from a depth of 140.0 to 141.0 feet from drill hole SSD3-4 was tested by DWR-Bryte Labs. It had a specific gravity of 2.40 and an absorption rate of 8.4. Compressive and tensile strengths were not determined because the sample was too weak and broke apart during testing.

Water pressure testing was performed in the three drill holes for the left abutment. The rock in drill hole SSD3-4 near the top of the left abutment between 16.9 feet and 56.4 feet had permeability averages of 1.03 feet/day with a corresponding Lugeon average of about 40. Below 56.4 feet to a depth of 181 feet the rock is very tight with a permeability value averaging 0.0031 feet/day with a corresponding Lugeon average of less than 1. In USBR drill hole DH-103, near the mid-left abutment, the entire hole (5.0 to 51.4 feet) was water tested as one interval with a permeability value of 0.005 ft/day. A separate test interval between the depths of 41.8 and 51.4 feet had a permeability value of 0.08 ft/day. In drill hole SSD3-3, near the lower left abutment, the test interval between about 4 and 20 feet showed a permeability average of 0.11 feet/day and a corresponding lugeon average of 3. The interval from 56 to 127 feet had an average permeability of 0.07 ft/day and an average Lugeon value of 1. One exception is the zone between 85 and 112 feet. This interval has an average permeability of 1.1 ft/day and an average Lugeon value of 37.

Water levels measured in the three drill holes that were drilled in the left abutment indicate that groundwater is about 35 feet below the ground surface (bgs). In drill hole SSD3-4, the last measurement in August 2001 showed that groundwater was 44 feet bgs. In drill hole DH-103, the last measurement in April 2000 showed that groundwater was 27 feet bgs. In drill hole SSD3-3, the last measurement in August 2001 showed that groundwater was 41 feet bgs.

Channel

The channel ranges in elevation from about 410 near the downstream toe to about 420 feet upstream of the axis. Along the axis, the channel is about 800 feet in width and is mostly flat with no real defined thalweg. Four exploration drill holes and three auger holes were drilled in the channel area.
See Plate 9, Sheet 2 for location of drill/auger holes.

USBR exploration drill hole DH-102 was drilled about 100 feet upstream of the axis. It was drilled to a depth of 81.8 feet to determine the depth to bedrock and evaluate the foundation conditions in the vicinity of the maximum section. Underlying the 13.0 feet of lean to fat clay with sand colluvium (Qc) the hole encountered mostly mudstone (Kbm) from 13.0 to 24.3 feet. Below 24.3 feet and to the bottom depth of 81.8 feet the rock unit (Kbsm) composed of about 60% mudstone with 40% sandstone interbeds was encountered. The rock is described in the drill hole log as being decomposed from 13.0 to 24.3 feet and fresh below 24.3 feet.

In drill hole DH-102, the Kbm mudstone is laminar to thin-bedded. The sandstone is mostly very thin- to thin-bedded. Bedding dips 49 to 60º. The rock is intensely to closely fractured from 13.0 to 24.3 feet and closely to moderately fractured (60% bedding) from 24.3 to 50.8 feet. From 50.8 to 81.8 feet the rock is closely fractured with about 30% moderate. The mudstone has soil-like characteristics and is mostly friable from 13.0 to 24.3 feet. From 24.3 to 81.8 feet the mudstone is friable to low hardness and friable to weak with the sandstone being mostly low hardness and weak. The mudstone exhibits soil-like characteristics and commonly is internally slickensided along bedding planes and mechanical fractures throughout the hole.

Three shears and/or shear zones were encountered in drill hole DH-102 at 63.8 to 64.5, 68.4 to 70.8, and 73.2 to 74.2 feet. They are all within the mudstone and appear to dip between about 15 and 30º with variable percentages (30-70%) of clay gouge.

About 400 feet south of drill hole DH-102, two DWR drill holes, SSD3-1 and SSD3-2 were drilled at 45-degree angles in a downstream direction to determine foundation conditions of the Boxer Formation. In addition, the holes were oriented to explore whether or not the northeast-trending lineament

LSSD3-3 exists on the right side of the channel near the lower right abutment (See Plate 9, Sheet 2). Drill holes SSD3-1 and SSD3-2 were drilled to respective depths of 160.5 and 265.0 feet. Both holes encountered less than five feet of colluvial soil overburden and about 60 percent sandstone with 40 percent mudstone interbeds. No significant shearing that could be correlated with the lineament was encountered in drill hole SSD3-1 but in drill hole SSD3-2 a series of shears or shear zones, approximately seven, were encountered between the depths of about 155.0 and 263.5 that may correlate with the lineament. The drill hole log indicates that an approximate 9.5-foot thick shear zone encountered between the depths of 250.0 and 263.5 feet may be associated with the lineament (See Appendix A for details). RQD values for both holes showed that in general, the rock has very poor quality in about the upper 50 feet to fair quality below about 50 feet. Neither hole was water pressure tested because of the angle of the holes and the associated poor rock quality.

Exploration drill hole SSD3-5 was drilled on the extreme right side of the channel near the base of the right abutment (See Plate 9, Sheet 2). It was drilled to a depth of 199.0 feet and underlying the 4.0 feet of clayey colluvium (Qc), it encountered from 4.0 to 60.0 feet the rock unit (Kbm) comprised of about 70% mudstone with 30% sandstone interbeds. From 60.0 to 72.0 feet, the rock unit (Kbs) with 95% sandstone and 5% mudstone interbeds was encountered. From 72.0 to 199.0 feet, the hole encountered about 80% mudstone with 20% sandstone interbeds (See Appendix A for details of the drill hole log and core photos).

The rock is decomposed to intensely weathered from 4.0 to 17.6 feet, moderately weathered from 17.6 to 22.0 feet, slightly weathered from 22.0 to 24.2 feet, and fresh below 24.2 feet. The mudstone is laminar to thinly-bedded and the sandstone interbeds are thinly- to thickly- bedded. Bedding dips from 45 to 60º. The mudstone is friable to low hardness and mostly weak from 4.0 to 17.6, mostly low hardness and weak from 17.6 to 22.0, and moderately hard and moderately strong below 22.0 feet. The sandstone has similar hardness and strength as the mudstone to a depth of 22.0 feet but is moderately hard to hard and moderately strong to strong below 22.0 feet. Locally the sandstone can be cemented with calcium carbonate and where fresh it will be hard and strong to very strong. The rock is mostly intensely fractured from 4.0 to 17.6 feet and below 17.6 feet the rock is closely to moderately fractured with isolated zones of intense associated with shears. The mudstone exhibits numerous intrinsic slickensides along bedding planes and mechanical fractures.

Shears encountered in SSD3-5 are minor and range in thickness between 0.2 and 0.6 of a foot. One shear zone that was logged between 9.0 and 15.9 feet was recovered as mostly intensely fractured rock exhibiting brecciated mudstone fragments in a clayey gouge matrix. The zone contains calcite veins up to 5/8 of an inch thick. This shear zone will fall within the current as-excavated zone for the foundation. The core exhibits calcite veinlets and calcite healed fractures throughout the hole.

Water pressure testing was performed in both USBR drill hole DH-102 and DWR drill hole SSD3-5 to determine permeability values in the channel foundation area. DH-102 had one test that was conducted between the depths of 29.5 and 81.8 feet and it had a permeability value of just 0.03 ft/day. Within this interval an isolated test was conducted from 62.5 to 81.8 feet with similar results of 0.05 ft/day. Water pressure testing in drill hole SSD3-5 commenced at a depth of 24.3 feet and continued to 192.0 feet. Permeability averages about 0.10 feet/day with corresponding average lugeon values of about 3. An exception is three tests that were performed in the interval from 78 to 108 feet. They had an average permeability of 0.42 ft/day with an average corresponding Lugeon value of 15.

Auger holes SSD3-AUG1, -AUG2, and -AUG3 were augered in the channel primarily to determine the depth to bedrock and the soil types comprising the colluvium (Qc). The depth to bedrock was shallow, 7.5 and 5.4 feet respectively, in auger holes AUG-1 and AUG-2. AUG-3 encountered 21.2 feet of colluvium. The channel colluvium consists of mostly grayish-brown lean clay with sand that is mostly of low plasticity, medium toughness, and medium dry strength.

Water levels measured in the two channel drill holes, DH-102 (left side of channel) and SSD3-5 (right side of channel) indicate that groundwater can be as shallow as only about a foot bgs in the spring as evidenced by a measurement of 0.7 feet bgs in DH-102 in April 2000. In SSD3-5 the depth to groundwater was about 10 feet bgs with the last measurement in August of 2001 showing 10.3 bgs. Based on the drilling and the depth to water bgs, the deepest portion of the colluvium filled channel and the corresponding shallowest depth to groundwater appears to be the left side.

Right Abutment

Exploration drill hole SSD3-6 was drilled near the top of the right abutment (See Plate 9, Sheet 2). It was drilled to a depth of 231.0 feet to determine the foundation conditions of the underlying sandstones and mudstones. The hole encountered 4.0 feet of clayey colluvium (Qc) and decomposed bedrock with sandstone clasts eroded from the scattered thin sandstone outcrops. Overall the hole encountered an average of about 70% mudstone with about 30% sandstone interbeds.

The rock is mostly intensely weathered with 20% moderate from 4.0 to 24.0 feet, moderate to slightly weathered from 24.0 to 43.0 feet, and fresh below 43.0 feet. This laminar to thin-bedded mudstone and thinly- to very-thickly bedded sandstone are rock units of the Boxer Formation. The mudstone is friable to low hardness and weak from and the sandstone is mostly low hardness and weak 4.0 to 14.3 feet. Below 14.3 feet the mudstone is mostly low to moderately hard and moderately strong with the sandstone being moderately hard to hard and mostly strong. The rock is intensely fractured from 4.0 to 14.3 feet, intensely to closely fractured from 14.3 to 24.0 feet, closely fractured from 24.0 to 43.0 feet, and mostly closely to moderately fractured below 43.0 feet with 15% slightly (sandstone). An exception is most of the rock in the bottom 60 feet (169.0 to 231.0 feet) of the hole is intensely to closely fractured apparently associated with numerous shears and shear zones. The mudstone exhibits few intrinsic slickensides along bedding planes and fractures from 4.0 to 86.9 feet, but many from 93.2 to 114.4 feet.

Shears and shear zones encountered in SSD3-6 range in thickness from as thin as ½ inch up to 5 feet. From 52.0 to 53.0 feet is a bedding plane shear consisting of intensely fractured rock with sandstone breccia fragments up to 1/4" in a clayey gouge matrix and calcite healing. The core exhibits calcite veinlets and calcite healed fractures throughout the hole.

From 70.5 to 73.9 is an interval that contains numerous small bedding plane shears with clay gouge and breccia fragments. From 97.8 to 98.0 feet is another bedding shear associated with intensely fractured rock. There are a series of bedding plane shears (six) that comprise a shear zone from 109.6 to 114.4 feet along with numerous incipient fractures.

The interval from 169.0 to 231.0 feet the hole encountered rock that is intensely to closely fractured. Within this interval the mudstone exhibits internal shearing with abundant intrinsic slickensides along fractures. The interval includes shear zones with numerous individual shears ranging from 0.1 to 12.0-feet thick (mostly about 1 foot) characterized by intensely fractured rock with clayey gouge, calcite healing, and slickensides. Some shears also have sandstone breccia fragments up to ¼ " in diameter in a clayey gouge matrix. Commonly the shears are separated by intervals of up to 10 feet of intensely fractured rock. The rock has prominent calcite healing throughout this interval.

The rock quality (RQD) value for the underlying mudstones and sandstones is very poor from 4.0 to 49.0 feet, fair from 49.0 to 154.0 feet, and very poor to poor below 154.0 feet.

Water pressure testing in SSD3-6 showed relatively low permeability values with an average of about 0.03 ft/day and a corresponding Lugeon value of about 1.0 between 22.0 and 55.0 feet. Permeability values from 55.0 to 224.0 feet averages 0.07 ft/day with corresponding Lugeon values of 1.0.

Current design calls for stripping to the top of intensely weathered rock with additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations can be accomplished by conventional methods. An extension of the left abutment for SSD-3 would include about a 600-foot long, 20-foot deep slurry bentonite wall and a homogeneous embankment that would replace construction of a 5-foot high section of dam embankment to provide foundation seepage control. Curtain grouting was included for SSD-3 to reduce seepage through the foundation. Foundation grouting will consist of a 2 row vertical grout curtain spaced 10 feet apart parallel to the dam centerline and a depth of 0.5 the height of the dam or 30 foot minimum. The grout program will also include a 20-foot wide by 3-foot thick grout cap, where feasible, to prevent surface leakage of grout during grouting of the upper stage of the hole. In addition, tertiary holes may be required to meet grout closure criteria. Water pressure testing in the exploration holes at SSD-3 indicates that generally the Boxer Formation is relatively impermeable with some areas of higher hydraulic conductivity. Feasibility estimates for grout takes range between 0.1 and 0.2 sacks of cement per lineal foot of grout hole. These estimates will be further refined in the later stages of design investigations.

The depth to water bgs in SSD3-6 is about 20 feet. The last measurement showed groundwater at 22.9 feet bgs in August 2001.

7.5 Saddle Dam #4

SSD-4 is located about 4.5 miles northwest of the Golden Gate Dam site, some 1500 feet northwest of SSD-3. It is the smallest of the nine saddle dams at about 40 feet height and a crest length of about 270 feet. This small structure trends about S60^{o}E and sits astride a narrow saddle above a northeast trending drainage (See Plate 9, Sheet 3). The site is underlain by mostly Boxer silty sandstone (Kbs) with minor (15%) mudstone interbeds (Kbsm).

USBR exploration drill hole DH-104, located near the maximum section, was drilled to a depth of only 11.8 feet. It encountered 2.6 feet of fat clay (CH) colluvium (Qc) overlying about 85% sandstone with 15% interbedded mudstone. Bedding in the drill hole dips between about 40 and 60^{o}. The sandstone is decomposed from 2.6 to 5.5 feet and intensely weathered from 5.5 to 11.8 feet. It is mostly intensely fractured (80% bedding), thin-bedded, low hardness, and weak. No shears were noted but discontinuity fractures in the core were noted as being heavily oxidized. One water pressure test was performed between the depths of 5 and 10.8 feet with no water loss at this shallow depth. Groundwater was not encountered in the hole when it was drilled in November 1979.

A geologic plan map for SSD-4 was published by DWR Northern District and some geologic reconnaissance of the site was performed during this feasibility study. The site is void of outcrops so no trend of bedding was observed but locally the bedding trends mostly N-S and dips westerly about 50^{o}. A northeast trending tear structure is projected through the center of the saddle dam but no trenching has been performed to verify its presence.

Current design requires about five feet of stripping to the top of intensely weathered rock and an additional 20 feet of excavation for the cutoff trench. All excavations can be accomplished by conventional methods. It does not include foundation grouting since a large portion of this saddle dam is freeboard. Foundation seepage was not considered to be significant for SSD-4 due to relatively low head and a long flow path below the core trench.

7.6 Saddle Dam #5

SSD-5 is located about 4.6 miles northwest of the Golden Gate Dam site, some 500 feet northwest of SSD-4. It is the third largest of the nine saddle dams with a crest height of 100 feet and a crest length of about 2300 feet, including 240 feet of slurry wall. The right abutment for SSD-5 shares the same knoll that the left abutment for SSD-4 keys into. The initial axis that Northern District (ND) investigated had multiple bends. The current axis design by the Division of Engineering (DOE) has a straight axis on a bearing of about S55ºE and crosses two minor northeast trending drainages separated by a subtle center abutment (See Plate 9, Sheet 3). The site is underlain by mostly (~70%) Boxer mudstone (Kbm), interbedded mudstone and sandstone (Kbsm) with minor amounts of sandstone (Kbs), and conglomerate (Kbcgl).

Exploration at SSD-5 consisted of drilling six core holes, including two by the USBR in 1979. The core holes from the left abutment to the right abutment are: SSD5-1, SSD5-2, SSD5-3, DH-106, SSD5-4, and DH-105. The exploration drill holes were drilled along the initial ND axis. Although the drill holes for the most part are close to the DOE axis some are located upstream and some downstream. These drill holes still represent similar geologic foundation conditions that would be encountered at the DOE straight axis. For the location of these exploration drill holes see Plate 9, Sheet 3.

The colluvium (Qc) on the abutments and in the channels varies in thickness from none overlying the conglomerate up to 12 feet in the channel closest to the right abutment. The colluvium is predominantly composed of fat clays with sand. The colluvium is underlain by varying percentages of mudstones (Kbm), interbedded sandstones and mudstones (Kbsm), minor sandstones (Kbs), and conglomerate (Kbcgl) of the Boxer Formation. Bedrock outcrops on the abutments consist of a prominent conglomerate bed at the end of the left abutment and minor discontinuous sandstone interbeds that strike between N10ºE to N10ºW and vary in dip from 40 to 60ºW. At least two northeast trending shear zones referred to as lineaments LSSD5-4 and LSSD5-3 are projected as trending slightly askew to the axis. LSSD5-4 trends through about the middle of the axis and LSSD5-3 trends through the slurry wall. These structures are inferred by subtle vegetation changes, subtle breaks in slopes, lineaments in the topography, an abundance of white calcareous float in the soil, and offsets mapped in the conglomerate ridge that comprises part of the left abutment.

Left Abutment

The left abutment ranges in elevation from a high of about 550 feet to a low of about 450 feet near the channel. It is characterized by a gentle slope of about 4:1. Exploration drill hole SSD5-1 was drilled about 50 feet west of the slurry wall outside of the dam footprint (See Plate 9, Sheet 3). It was drilled on a bearing of S40ºE at a 45º angle to a depth of 176.0 feet to determine the base of the conglomerate and the presence of a northeast trending lineament, LSSD5-3. The hole started on the surface in conglomerate and continued in this unit to a depth of 27.5 feet. From 27.5 to 107.9 feet the hole encountered about 90% sandstone with 10% mudstone interbeds (Kbs) and from 107.9 to 176.0 feet the hole encountered 95% mudstone with 5% sandstone interbeds (Kbm).

The rock is intensely weathered from 0.0 to 24.0 feet, moderately weathered from 24.0 to 27.5 feet, slightly weathered from 27.5 to 71.5 feet, and fresh below 71.5 feet. The conglomerate is mostly low hardness and weak, it contains 45% sandstone and 5% mudstone interbeds, and is intensely to closely fractured. The underlying sandstone to a depth of 107.9 feet is thinly- to thickly-bedded, moderately hard to hard and mostly moderately strong. It is closely to moderately fractured with a zone of intensely fractured rock from about 39.0 to 45.2 feet. The mudstone below 107.9 feet is laminated to thinly-bedded, mostly moderately hard and weak to moderately strong.

The drill hole log indicates that only four shears ranging in thickness from 0.2 to 0.4 feet contain some clay gouge and calcite healing up to ½ inch thick. Only one shear, 172.4 to 172.6 feet, appears to be a bedding plane shear. No shearing that could be correlated with lineament SSD5-3 was encountered. Drill hole SSD5-1 was probably not drilled deep enough to encounter the lineament.

Rock quality (RQD) values for SSD5-1 are very poor from 0.0 to 61.0 feet and good with an average RQD value of 79% below 61.0 feet. Water pressure testing was performed in the hole below a depth of 35.7 feet and to the bottom of the hole at 176.0 feet. Testing indicates that the rock at this location has, on the average, fairly high permeability. Permeability rates average about 1.1 ft/day with corresponding Lugeon values ranging from 3 to >100 averaging about 45.

The depth to water is about 50 feet bgs. The last measurement in August 2001 was 50.3 feet.

Exploration drill hole SSD5-2 was drilled about 150 feet upstream from the top of the left abutment as illustrated on Plate 9, Sheet 3. The hole was drilled to a depth of 152.0 feet and encountered mostly (90%) mudstone (Kbm) with sandstone interbeds. The rock is intensely weathered from 4.5 to 21.0 feet, moderately weathered from 21.0 to 57.3 feet, and fresh below 57.3 feet. The mudstone is mostly friable and weak to 57.3 feet and low to moderately hard and weak to moderately strong below 57.3 feet. The mudstone is laminated to thinly-bedded. The interbedded sandstone to a depth of 57.3 feet is mostly thinly-bedded, low to moderately hard and mostly moderately strong. Below 57.3 feet the sandstone is mostly hard and strong. The rock is mostly intensely fractured to 21.0 feet and intensely to closely fractured from 21.0 to 83.0 feet (See Appendix A for core photos). Below 83.0 feet, the rock is mostly moderately fractured with some (10%) closely and some (10%) slightly fractured.

The fractured rock between 4.5 and 78.4 feet is associated with shearing. Within this interval numerous (~20) individual shears occur that range in thickness from 0.1 up to 2.7 feet but mostly about 0.2 feet. The shears commonly contain clay gouge, brecciated fragments, and occasional calcite healing. Due to the fractured state of the rock it is difficult to determine the dip of the shears although some dips between 40 and 60^{o}, consistent with bedding, are noted. Below 78.4 feet and to 152.0 feet only four shears were noted ranging in thickness from 0.1 to 1.1 feet.

Rock quality (RQD) values for SSD5-2 are very poor from 0.0 to 62.0 feet, poor from 62.0 to 100.0 feet with an average RQD of 49%, and excellent below 100.0 feet. Water pressure testing was performed in the hole below a depth of 33.5 feet and to a bottom depth of 143.6 feet. Besides the initial water test from 33.5 to 49.2 feet with a Lugeon value of greater than 100, the remainder of the tests indicates that the rock at this location has, on the average, fairly low permeability. Lugeon values below 50 feet average about 3.

The depth to water in SSD5-2 is about 40 feet bgs. The last measurement in August 2001 was 40.5 feet bgs.

Channel 1

Due to the length of the DOE axis for SSD-5 it crosses two channel areas. The first channel is about 250 feet wide and is at about 450-foot elevation. Two exploration drill holes were drilled in the vicinity of Channel 1. Drill hole SSD5-3 was drilled about 50 feet upstream of the current axis and USBR drill hole DH-106 was drilled about 70 feet downstream. See Plate 9, Sheet 3 for drill hole locations.

Drill hole SSD5-3 was drilled on a bearing of N90^{o}E at an angle of 45^{o} to a depth of 181.0 feet. The hole was drilled nearly normal to the channel to determine if a northeast trending fault is present. Underlying the 3.2 feet of fat clay colluvium the hole encountered mostly (80%) sandstone (Kbs) with 20% mudstone interbeds from 4.5 to 120.3 feet.

The rock is decomposed from 4.5 to 6.0 feet, intensely weathered from 6.0 to 10.0 feet, mostly moderately weathered from 10.0 to 36.5 feet, and fresh below 36.5 feet. The sandstone is mostly friable and weak to 6.0 feet, moderately hard and moderately strong below 6.0 to 36.5 feet, and hard and strong below 36.5 feet. The interbedded mudstone is mostly low hardness and weak to 36.5 feet and moderately hard and moderately strong below 36.5 feet. The sandstone is thinly- to thickly-bedded and the mudstone is laminated to thinly-bedded. The rock is intensely to closely fractured to 18.7 feet, closely fractured from 18.7 to 32.7 feet, and mostly moderately to slightly fractured from 32.7 to 120.3 feet. From 120.3 to 139.4 feet, the hole encountered 100% sandstone (Kbs) that is hard and strong to very strong. It is very thick-bedded and mostly massive. From 139.4 to 171.0 feet, the hole encountered about 50% sandstone and 50% mudstone (Kbsm). Below 171.0 feet, 95% sandstone (Kbs) with 5% interbedded mudstone was encountered. The sandstone is partially cemented with calcium carbonate throughout the hole as most of the bedding and jointing fractures in the sandstone are.

The drill hole log indicates that no shears were encountered. The hole was only drilled to a depth of 181.0. The width of Channel 1 is 250 feet and if a northeast trending fault is present then it would have to be located on the right side of the channel.

RQD values for SSD5-3 show that the rock is very poor to a depth of about 30 feet and excellent below 30 feet.

USBR drill hole DH-106 was drilled in about the center of Channel 1 to a depth of 53.6 feet. It encountered 3.5 feet of mostly lean to fat clay colluvium overlying about 95% sandstone (Kbs) with 5% mudstone interbeds. The rock is intensely weathered from 3.5 to 12.9 feet, moderately weathered from 12.9 to 21.2 feet, slightly weathered from 21.2 to 26.5 feet, and fresh below 26.5 feet. The sandstone is thinly- to thickly-bedded and the minor mudstone interbeds are laminated to thinly-bedded. The rock is intensely to closely fractured from 3.5 to 21.2 feet, closely to moderately fractured with 15% intense from 21.2 to 26.5 feet, and mostly slightly fractured with 15% intense below 26.5 feet. No shearing was noted in the drill hole log.

One water pressure test was conducted in DH-106 between the depths of 37.3 and 53.6 feet (fresh rock). The permeability value for this interval was 0.24 ft/day. Water testing in SSD5-3 began at a drill depth of 26 feet. From 26 to 108 feet, the average permeability was 1.15 ft/day with corresponding Lugeon values ranging from 12 to >100. These values for this interval may be erroneous because the RQD values, the nearly 100% core recovery, and the core photos indicate that the sandstone appears tight. Below 108 feet the rock is tight with permeability values ranging between 0 and 0.05 ft/day with corresponding Lugeon values ranging from 0 to 2.

The depth to water in DH-106 is about 10 feet bgs, ranging from a high of 9.1 feet to a low of 12.4 feet. The last depth to groundwater measurement in August 2001 was 11.0 feet bgs. The depth to water in SSD5-3 is about 20 feet bgs. The last depth to groundwater measurement in August 2001 was 17.5 feet bgs.

Center Abutment

This portion of the alignment separates Channel 1 and Channel 2. The center abutment ranges in elevation from a high of about 490 feet to a low of about 450 feet near the two channels (See Plate 9, Sheet 3). One exploration drill hole, SSD5-4 was drilled in the vicinity of the center abutment. SSD5-4 was drilled on top of the knoll some 350 feet downstream of the axis to a depth of 151.0 feet. Underlying the 1.0 feet of fat clay colluvium, the hole encountered about 95% sandstone (Kbs) with 5% mudstone interbeds from 1.0 to 41.0 feet. From 41.0 to 77.8 feet, the hole encountered 90% mudstone (Kbm) with 10% sandstone interbeds. From 77.8 to 131.0 feet 90% sandstone with 10% mudstone interbeds were encountered and below 131.0 feet 50% mudstone and 50% sandstone (Kbsm) were encountered.

The rock is moderately weathered with about 10% intense from 1.0 to 41.5 feet, slightly weathered from 41.5 to 57.0 feet, and fresh below 57.0 feet with a slightly weathered exception from 97.5 to about 106.0 feet. The sandstone is mostly moderately hard to hard and moderately strong to strong. The mudstone is mostly low to moderately hard and weak to moderately hard. The sandstone is thickly-bedded to massive to a depth of 41.0 feet and thinly- to thickly-bedded below 41.0 feet. The mudstone is laminated to thinly-bedded. Bedding dips between 50 and 60º. The rock is mostly closely fractured to 26.0 feet, intensely to closely fractured from 26.0 to 41.8 feet, and closely to moderately fractured with about 10% slight below 41.8 feet. The interval between 24.2 and 41.5 feet is heavily calcified throughout containing calcite veinlets up to ½ inch thick.

In SSD5-4, a zone of fractured rock associated with shearing was encountered between about 23.5 and 77.8 feet. This interval has numerous individual shears with zones of consolidated gouge that is comprised of mostly sheared mudstone that can be easily gouged with a knife (See Appendix A for core photos). This interval includes the aforementioned zone of heavily calcified sandstone. This zone of shearing may correlate with lineament LSSD5-4, which is projected through the saddle dam adjacent to this drill hole as shown on Plate 9, Sheet 3. Below 77.8 feet, only two shears were noted on the drill log. One bedding plane shear dipping 55º was encountered from 97.6 to 98.6. The other was encountered at a depth of 137.8 to 138.3 feet.

RQD values for SSD5-4 show that the rock is mostly very poor to a depth of about 90 feet, excellent from 90 to 121 feet, poor from 121 to 136 feet, and good below 126 feet. Water testing in SSD5-4 began at a depth of 7.2 feet and ended at a bottom depth of 136.4. From 7.2 to 16.2 feet, high permeability values are indicated based on a Lugeon value of >100. From 24.2 to 33.2 feet, the rock tested tight and from 34.2 to 92.5 feet water testing indicated that the rock has mostly moderate permeability with Lugeon values ranging from 28 to >100. The interval from 95.7 to 104.4 tested tight but from 106.7 to 136.4 feet the Lugeon values ranged from 19 to 60 (washout) indicating that the rock has moderate permeability. The core recovery, RQD values, and the core photos indicate that the rock is tight from 106.7 to 136.4 feet.

The depth to water in SSD5-4 is about 90 feet bgs. The last groundwater measurement in August 2001 was 90.5 feet bgs.

Channel 2

Due to the length of the DOE axis for SSD-5 it crosses two channel areas. The second channel, near the right abutment, is about 200 feet wide and is mostly at about 450-foot elevation but reaches a low of 440 feet at the thalweg of the channel. One exploration drill hole was drilled in the vicinity of Channel 2. USBR drill hole DH-105 was drilled about 150 feet downstream of the current axis. See Plate 9, Sheet 3 for the drill hole location.

Drill hole DH-105 was drilled to a depth of 61.0 feet. The hole encountered 12.1 feet of fat clay with sand colluvium underlain by about 70% mudstone (Kbm) with 30% sandstone interbeds from 12.1 to 32.3 feet. From 32.3 to 61.0 feet is about 85% silty sandstone (Kbm) with 15% interbedded mudstone.

The rock is decomposed from 12.1 to 13.8 feet, intensely weathered from 13.8 to 19.8 feet, moderately weathered from 19.8 to 31.1 feet, slightly weathered from 31.1 to 32.3, and fresh below 32.3 feet. The mudstone is mostly friable to low hardness and weak to 19.8 feet, mostly low hardness and weak to moderately strong from 19.8 to 32.3 feet. The interbedded sandstone from 12.1 to 32.3 feet is mostly low to moderately hard and weak to moderately strong. The sandstone below 32.3 feet is mostly moderately hard and moderately strong except locally where it is cemented with calcium carbonate it is hard and strong. The mudstone is very thin- to thin-bedded, mostly one to six inches thick and the sandstone is thin- to thick-bedded, ranging from four inches to 3.3 feet thick. The rock is mostly intensely fractured from 12.1 to 32.3 feet and closely to moderately fractured below 32.3 feet. The drill hole log indicates that the mudstone has a slight reaction to HCl but the sandstone has a strong reaction. The drill hole log for DH-105 states that mudstone encountered in the hole air slaked from 1/8 to ¾ inch angular fragments within one or two days of exposure.

Only one water test was conducted in DH-105 at a depth of 32.7 to 54.6 feet. The permeability value for the rock within this interval is 0.29 ft/day. The depth to water in DH-105 when last measured by the USBR in 1979 was at 8.2 feet bgs. Numerous attempts were made by DWR to get an up to date reading during this study phase but hole was dry and blocked at a depth of 14.7 feet.

Right Abutment

The right abutment ranges in elevation from a high of about 560 feet to a low of about 450 feet near the channel and is only about 150 foot in length. It is characterized by a slightly steeper slope than the left abutment but still a relatively gentle slope of about 3:1. No exploration drilling was performed on the right abutment. The geologic plan map, Plate 9, Sheet 3, indicates that the abutment contains mostly interbedded sandstones and mudstones (Kbsm). Short, discontinuous sandstone (Kbs) interbeds that trend mostly N-S and dip steeply, 78°W or out of the abutment and towards channel 2.

Current design calls for stripping to the top of intensely weathered rock with additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations at SSD-5 can be accomplished by conventional methods. An extension of the left abutment for SSD-5 would include about a 240-foot long, 20-feet deep slurry bentonite wall and a homogeneous embankment that would replace construction of a 10-foot high section of zoned dam embankment. Curtain grouting was included for SSD-5 to reduce seepage through the foundation. Foundation grouting will consist of a 2 row vertical grout curtain spaced 10 feet apart parallel to the dam centerline and a depth of 0.5 the height of the dam or 30 foot minimum. The grout program will also include a 20-foot wide by 3-foot thick grout cap, where feasible, to prevent surface leakage of grout during grouting of the upper stage of the hole. In addition, tertiary holes may be required to meet grout closure criteria. Water pressure testing in the exploration holes at SSD-5 indicates that the Boxer Formation permeability varies from low to moderate with some local high intervals. Feasibility estimates for grout takes range between 0.1 and 0.2 sacks of cement per lineal foot of grout hole. These estimates will be further refined in the later stages of design investigations.

The primary geologic structure that needs to be confirmed by further investigation is the presence of the northeast trending lineament LDDS5-4 because it trends through about the center of the saddle dam site as illustrated on Plate 9, Sheet 3. Special treatment of this feature was not included in the feasibility level design since the proposed embankment section includes a broad impervious core of plastic materials and significant core trench excavation possibly to moderately weathered rock.

7.7 Saddle Dam #6

SSD-6 is located about 5.5 miles northwest of the Golden Gate Dam site, some 3500 feet northwest of SSD-5. It is about 70 feet in height and has a crest length of about 530 feet. The structure trends N-S and sits at the head of a narrow easterly trending drainage (See Plate 9, Sheet 3). The site is underlain by mostly Boxer conglomerate (Kbcgl) with sandstone (Kbs) interbeds on the abutments and mudstone (Kbm) with interbedded sandstone in the channel.

Exploration at SSD-6 consisted of drilling two core holes, one by the USBR, DH-107, in 1979 and one by DWR, SSD6-1, in 1999. USBR exploration drill hole DH-107 was drilled in the channel along the axis. DWR exploration drill hole SSD6-1 was drilled about 100 feet upstream of the lower right abutment for the current DOE axis. The initial ND axis was a curved axis located slightly upstream of the DOE straight axis. The DOE straight axis was selected to simplify construction and provide favorable abutment contacts while locating the centerline as far upstream as practicable to minimize projection of the downstream slope into the drainage. For the location of these exploration drill holes see Plate 9, Sheet 3. A geologic plan map for SSD-6 was not published by the DWR Northern District, but some geologic reconnaissance of the site was performed during this feasibility study.

Left Abutment

The left abutment ranges in elevation from a high of about 550 feet to a low of about 480 feet near the channel. It is characterized by a gentle slope of about 3:1. No exploration drilling was performed on the left abutment. The left abutment is part of a northerly-trending ridge of exposed bedrock composed of Boxer conglomerate (Kbcgl) with interbedded sandstone. Bedding ranges in strike from N10ºE to N30ºW and dips 20 to 36ºW. Most of the abutment has no colluvial cover until the slope approaches the channel where some colluvium starts to mantle the conglomerate and the underlying mudstone.

Channel

The channel at SSD-6 is about 110-feet wide and mostly at about elevation 480 feet. USBR drill hole DH-107 was drilled on the left side of the channel along the axis to a depth of 40.8 feet (See Plate 9, Sheet 3). The hole encountered 4.8 feet of colluvium/alluvium that is comprised of fat clay with sand. Underlying the colluvium from 4.8 to 29.2 feet the hole encountered about 75% mudstone (Kbm) with about 25% interbedded sandstone. Below 29.2 feet the hole encountered about 60% sandstone and 40% interbedded mudstone (Kbsm).

The rock is decomposed from 4.8 to 12.8 feet, intensely weathered from 12.8 to 14.4 feet, moderately weathered from 14.4 to 25.6 feet, slightly weathered from 25.6 to 29.2 feet, and fresh below 29.2 feet. The mudstone is friable to low hardness and weak from 4.8 to 14.4 feet and low to moderately hard and weak to moderately strong from 14.4 to 29.2. The sandstone from 29.2 to 40.8 feet is mostly moderately hard and moderately strong. The mudstone throughout the hole is laminar to very thin-bedded. The sandstone is mostly thinly-bedded with some thickly-bedded intervals. Bedding dips about

30º. The rock is mostly intensely fractured to 29.2 feet and mostly closely fractured below 29.2 feet. It was noted in the drill hole log that fractures in the weathered mudstone above 18.9 feet are commonly filled with a thin coating of white carbonate. It is also noted that the interbedded sandstone below 18.9 feet has a strong reaction to HCl. No shears were noted in the core throughout the hole.

No water pressure tests were performed in DH-107 possibly due to caving conditions from about 27 to 41 feet. The depth to water measured last in November 1979 was 8.3 feet bgs.

Right Abutment

The right abutment ranges in elevation from a high of about 550 feet to a low of about 480 feet near the channel. It is characterized by a gentle slope of about 3:1. DWR exploration drill hole SSD6-1 was drilled on the lower right abutment about 100 feet upstream of the axis to a depth of 119.0 feet (See Plate 9, Sheet 3). The right abutment is part of a northerly-trending ridge of exposed bedrock composed of Boxer conglomerate (Kbcgl) with interbedded sandstone. Bedding ranges in strike from N10ºE to N30ºW and dips 20 to 36ºW. Most of the abutment has no colluvial cover until the slope approaches the channel where some colluvium starts to mantle the conglomerate and the underlying mudstone. At the drill hole location, the lean clay colluvial cover is 9.2 feet thick.

In drill hole SSD6-1, underlying the 9.2 feet of colluvium the hole encountered about 70% conglomerate (Kbcgl) with about 30% interbedded sandstone. The rock is moderately weathered from 9.2 to 16.1 feet, slightly weathered from 16.1 to 16.5 feet, and fresh below 16.5 feet. The conglomerate is mostly hard to very hard and strong. The interbedded sandstone from 9.2 to 16.1 feet is mostly moderately hard and moderately strong with the remainder of the sandstone interbeds being hard and strong. The conglomerate is very thick-bedded and the sandstone is thick- to very thick-bedded. Bedding dips about 30º. The rock is closely fractured from 9.2 to 16.1 feet and closely to moderately fractured with 15% slightly (sandstone interbeds) below 16.1 feet. It is noted that the interbedded sandstone contains calcite healed fractures up to ¼-inch thick. The conglomerate has a sight reaction to HCl. No shears were noted in the core throughout the hole.

Rock quality (RQD) values for SSD6-1 are poor from 14.0 to 19.0 feet and excellent below 19 feet. Three conglomerate samples from drill hole SSD6-1 were submitted to the Bryte Lab for testing. The three samples were from depths of 31.6 to 32.0, 71.6 to 73.7, and 111.8 to 113.2 feet with respective dry compressive strengths of 6400, 3400, and 5600 psi. Water pressure testing was conducted from 6.0 to 115.0 feet. The initial test was from 6.0 to 16.9 feet and exceeded 50 Lugeons. This test interval included the lower three feet of colluvium and the fractured sandstone interbed overlying the conglomerate. The second test interval from 11.0 to 21.9 feet had a Lugeon value of about 10. Below 22.0 feet the nine water pressure test intervals all tested tight.

Current design calls for stripping to the top of intensely weathered rock with additional excavation to the top of moderately weathered rock for the cutoff trench. Excavations at SSD-6 in the channel where the Boxer mudstone (Kbm) is present can be accomplished by conventional methods. Excavations on the abutments in the conglomerate can be accomplished by conventional methods for the stripping of the intensely weathered rock but some of the moderately weathered conglomerate for the cutoff trench excavation will require some heavy ripping and maybe even some light blasting. Curtain grouting was included for SSD-6 to reduce seepage through the foundation. Foundation grouting will consist of a 2 row vertical grout curtain spaced 10 feet apart parallel to the dam centerline and a depth of 0.5 the height of the dam or 30 foot minimum. The grout program will also include a 20-foot wide by 3-foot thick grout cap, where feasible, to prevent surface leakage of grout during grouting of the upper stage of the hole. In addition, tertiary holes may be required to meet grout closure criteria. Since water pressure testing in exploration hole SSD6-1 indicates that the Boxer Formation conglomerate permeability below about 20 feet is low. Feasibility estimates for grout takes in the conglomerate are about 0.1 sacks of cement per lineal foot of grout hole. These estimates will be further refined in the later stages of design investigations.

The depth to water in drill hole SSD6-1 averaged about 15 feet bgs. The last depth to groundwater measurement was 16.3 feet bgs in August 2001.

7.8 Saddle Dam #7

SSD-7 is located about 5.5 miles northwest of the Golden Gate Dam site, some 3500 feet northwest of SSD-5. It is about 75 feet in height and has a crest length of about 1040 feet. The structure trends S85ºE and sits astride a northerly trending drainage, a subtle near-center knoll, and a subtle saddle between the center knoll and the right abutment (See Plate 9, Sheet 4). A geologic plan map for SSD-7 was not published by the DWR Northern District, but some geologic reconnaissance of the site was performed during this feasibility study. Since the topography at this location does not lend itself towards one preferred alignment, the alignment for SSD-7 was primarily selected to provide continuity with SSD-8. The site is underlain by mostly Boxer mudstone (Kbm) with sandstone (Kbs).

Exploration at SSD-7 consisted of two core holes drilled by the USBR in 1979. The core holes are DH-108 and DH-109. DH-109 was drilled near the top of the left abutment about 40 feet downstream of the DOE axis. DH-108 was drilled in the subtle saddle area about 150 feet upstream of the axis. For the location of these exploration drill holes see Plate 9, Sheet 4. Bedding trends generally N-S and dips about 40ºW out of the right abutment and flattening to

30°W into the left abutment as the axis nears the Fruto syncline just west of SSD-9.

Left Abutment

The left abutment ranges in elevation from a high of about 540 feet to a low of about 490 feet near the channel. The abutment has a very gentle slope and is void of outcrops. Exploration drill hole DH-109 was drilled to a depth of 31.4 feet about 40 feet downstream of the axis (See Plate 9, Sheet 4). The hole encountered 8.1 feet of fat clay colluvium underlain by mudstone.

The rock is decomposed to intensely weathered from 8.1 to 23.5 feet and intensely to moderately weathered from 23.5 to 31.4 feet. The mudstone is mostly friable to low hardness and weak that was recovered as mostly intensely fractured. The mudstone is laminated to thin-bedded. It is noted in the drill hole log that discontinuities are heavily oxidized. One water pressure test was performed in DH-109 between the depth of 16.4 and 31.4 feet. It had a permeability rate of 0.6 ft/day. Upon completion of drilling the hole was dry.

Channel

The channel area is about 150-feet wide and mostly at about elevation 490 feet. No drilling was performed in the area and no outcrops were mapped. It is assumed that the channel is mostly underlain by Boxer mudstone (Kbm).

Center Abutment

The center abutment is about 300 feet wide and varies from about a low elevation of 490 feet on the left side to about 530 feet on top. No drilling was performed in this area and no outcrops were mapped. Due to the presence of the knoll it is likely that is underlain by Boxer sandstone (Kbs) with interbedded mudstone.

Saddle

The saddle is about 200 feet wide and mostly at about elevation 520 feet but reaches a low of 510 feet immediately downstream of the axis. No outcrops were mapped in this area. USBR drill hole DH-108 was drilled in the saddle area about 150 feet upstream of the axis and outside the current DOE footprint (See Plate 9, Sheet 4). It was drilled to a depth of only 15.3 feet and encountered 4.9 feet of fat clay colluvium underlain by interbedded mudstone and sandstone (Kbsm).

The rock is decomposed to intensely weathered from 4.9 to 11.8 feet and intensely from 11.8 to 15.3 feet. The mudstone is mostly friable to low hardness and weak that was recovered as mostly intensely fractured (~50% bedding).

Bedding in the drill hole dips about 30°. Bedding attitudes in a minor drainage some 250 feet downstream of the axis in this area shows dips of 41 and 43°. The mudstone is very thin- to thin-bedded. It is noted in the drill hole log that discontinuities are heavily oxidized. No water pressure test was performed in DH-108. Upon completion of drilling the hole was dry.

Right Abutment

The right abutment ranges in elevation from a high of about 580 feet to a low of about 520 feet near the saddle. The abutment has a very gentle slope and is void of outcrops. No drilling was performed on the right abutment. It is likely underlain by Boxer mudstone (Kbm) with interbedded sandstone.

Current design calls for stripping to the top of intensely weathered rock with additional excavation to the top of moderately weathered rock for the cutoff trench. Excavations at SSD-7 in Boxer mudstone (Kbm) and sandstone (Kbsm) can be accomplished by conventional methods. Curtain grouting was included for SSD-7 to reduce seepage through the foundation. Foundation grouting will consist of a 2 row vertical grout curtain spaced 10 feet apart parallel to the dam centerline and a depth of 0.5 the height of the dam or 30 foot minimum. The grout program will also include a 20-foot wide by 3-foot thick grout cap, where feasible, to prevent surface leakage of grout during grouting of the upper stage of the hole. In addition, tertiary holes may be required to meet grout closure criteria. Only one water pressure test was performed in USBR exploration hole DH-109 indicating that the Boxer Formation mudstone and interbedded sandstone at this location and depth (16 to 30 feet) has low permeability. Feasibility estimates for grout takes in the conglomerate are about 0.1 sacks of cement per lineal foot of grout hole. These estimates will be further refined in the later stages of design investigations.

7.9 Saddle Dam #8

SSD-8 is located about 5.8 miles northwest of the Golden Gate Dam site, only 200 feet west of SSD-7. The right abutment for SSD-8 shares the same knoll as the left abutment for SSD-7. SSD-8 is the second highest and second longest of the nine saddle dams. It is about 105 feet in height and has a crest length of about 3000 feet. The straight axis trends S83°E and crosses two "channel" areas separated by a subtle center abutment (See Plate 9, Sheet 4). The ND alignment had multiple bends and was located some 100 to 300 feet upstream of the DOE straight axis. The DOE alignment was selected to position the dam embankment between the hills near the center of the dam to ensure development of conservative cost estimates considering the relatively flat dip of the bedding in this area. The site is underlain by mostly Boxer mudstone (Kbm) with interbedded sandstone and about 15% interbedded sandstone and mudstone (Kbsm). Rock outcrops are scarce in the area. Bedding ranges in strike from about N-S to N23°W and dips from 5 to 35°W with the steeper dips near the right abutment and the flatter dips near the left abutment as the alignment approaches the axis of the Fruto syncline just west of SSD-9.

Exploration at SSD-8 consisted of drilling six core holes, including two by the USBR in 1979. The core holes from the left abutment to the right abutment are: DH-111, SSD8-3, SSD8-2, SSD8-5, DH-110, and SSD8-1. The exploration drill holes were drilled along the initial ND axis and, with the exception of SSD8-1, are located some 200 to 300 feet upstream or south of the DOE axis. These drill holes still represent similar geologic foundation conditions that would be encountered at the DOE straight axis. For the location of these exploration drill holes see (See Plate 9, Sheet 4).

Left Abutment

The left abutment ranges in elevation from a high of about 560 feet to a low of about 480 feet near Channel 1. The left abutment has a very gentle slope. No exploration drilling was performed on the left abutment for the DOE axis and no outcrops are present. Geologic reconnaissance mapping indicates that the left abutment is underlain by Boxer mudstone (Kbm).

Channel 1

Due to the length of the DOE axis for SSD-8 it crosses two channel areas. Channel 1 along the axis is about 300 feet wide and mostly at about 480-foot elevation. One exploration drill hole, USBR DH-111, was drilled in the vicinity of Channel 1. Drill hole DH-111 was drilled about 200 feet upstream of the current DOE axis. See Plate 9, Sheet 4 for drill hole locations.

Drill hole DH-111 was drilled to a depth of 38.2 feet. The hole encountered 21.0 feet of mostly lean and sandy clay colluvium with a 3.0-foot thick fat clay topsoil overlying the colluvium. The hole encountered mostly (95%) mudstone (Kbm) with 5% silty sandstone interbeds from 21.0 to 38.2 feet.

The rock is intensely weathered from 21.0 to 21.7 feet, moderately weathered from 21.7 to 24.6 feet, slightly weathered from 24.6 to 28.7 feet, and fresh below 28.7 feet. The mudstone is mostly friable to low hardness and weak to 24.6 feet and mostly low to moderately hard and weak to moderately strong below 24.6 feet. The sandstone is mostly low to moderately hard and weak to moderately strong. The mudstone is laminated to thin-bedded. The sandstone is mostly thin-bedded. Bedding dips between 0 and 15^{o} but mostly 10^{o}. The rock is mostly intensely fractured to 24.6 feet, closely fractured from 24.6 to 28.7 feet, and moderately fractured below 28.7 feet. The fracturing is almost entirely associated with bedding. No shears were noted in the drill hole log.

One water pressure test was performed in the hole between the depths of 27.5 feet and the bottom depth of 38.2 feet. It had a permeability rate of

0.07 ft/day. The depth to water bgs ranged from a high of 1.7 feet in April 2000 to a low of 9.0 feet in September 2000. The last measurement to the depth of groundwater was 6.8 feet in August 2001.

Center Abutment

This portion of the alignment separates Channel 1 and Channel 2. The center abutment ranges in elevation from a high of about 505 feet to a low of about 450 feet near the left side of Channel 2 (See Plate 9, Sheet4). Two DWR exploration drill holes, SSD8-3 and SSD8-2, were drilled to respective depths of 121.0 and 151.0 feet in the vicinity of the center abutment some 250 and 300 feet respectively upstream of the DOE axis. Underlying about 1.5 feet of lean to fat clay colluvium, drill hole SSD8-3 encountered about 70% sandstone (Kbs) with 30% mudstone interbeds from about 1.5 to 21.4 feet and below 21.4 feet to the bottom of the hole it encountered about 70% mudstone (Kbm) with 30% sandstone interbeds. Underlying about 2.0 feet of colluvium, drill hole SSD8-2 encountered 70% sandstone (Kbs) with 30% mudstone interbeds from 2.0 to 44.3 feet, interbedded mudstone and sandstone (Kbsm) from 44.3 to 66.2 feet, and 70% mudstone with 30% interbedded sandstone (Kbm) below 66.2 feet.

In drill hole SSD8-3 the rock is decomposed to intensely weathered from 1.5 to 11.0 feet, moderately weathered from 11.0 to 24.0 feet, slightly weathered from 24.0 to 71.4 feet, and fresh below 71.4 feet. The sandstone has mostly low hardness and is weak from 1.5 to 21.4 feet and hard and strong below 36.8 feet. The mudstone is mostly low hardness and weak from 21.4 to 24.0 feet, low to moderately hard and moderately strong from 24.0 to 31.0 feet, and mostly hard and moderately strong below 31.0 feet. The sandstone is thin- to thick-bedded to 21.4 feet and mostly very thick-bedded as interbeds in the Kbm unit below 21.4 feet. The mudstone is laminated to thin-bedded. Bedding dips between 14 and 18º. The rock is intensely to moderately fractured from 1.5 to 11.0 feet, moderately fractured from 11.0 to 24.0 feet, and moderately to slightly fractured below 24.0 feet. A few minor shears up to 0.1 feet thick were noted throughout the hole. Fractures are commonly healed with calcite up to ¼-inch thick.

In drill hole SSD8-2 the rock is decomposed to intensely weathered from 2.0 to 11.0 feet, moderately weathered from 11.0 to 44.8 feet, slightly weathered from 44.8 to 48.2 feet, and fresh below 48.2 feet. The sandstone has mostly low hardness and is weak from 2.0 to about 20 feet and moderately hard to hard and mostly moderately strong from about 20 to 44.3 feet. The interbedded mudstone is mostly low hardness and weak from 2.0 to 48.2 feet and moderately hard and moderately strong below 48.2 feet. The sandstone is mostly thin- to thick-bedded throughout the hole. The mudstone is laminated to thin-bedded. Bedding dips between 11 and 18º. The rock is intensely to closely fractured from 2.0 to 23.5 feet, closely to moderately fractured from 23.5 to 51.3 feet, and mostly moderately fractured with about 10% isolated closely fractured zones throughout below 51.3 feet. No shearing was noted in the drill hole log.

Fractures are commonly healed with calcite up to ¼-inch thick and some pyrite is present.

Rock quality (RQD) values for SSD8-3 are very poor from 1.5 to 41.0 feet, poor from 41.0 to 76.0, and excellent below 76.0 feet. Rock quality (RQD) values for SSD8-2 are very poor from 2.0 to 41.0 feet and good from 41.0 to 151.0 feet. Water pressure testing was conducted in SSD8-3 from 8.4 to 117.7 feet. From 8.4 to 75.4 feet, the rock has high permeability with an average of 5.1 ft/day with all but one of the seven test intervals exceeding 100 Lugeons. Below 75.4 feet, the rock had low permeability with values ranging from 0 to 8 Lugeons. Water pressure testing was conducted in SSD8-2 from 6.2 to 147.4 feet. The rock from 6.2 to 137.4 feet has high permeability with the 13 tests intervals averaging 2.2 ft/day and corresponding Lugeon values ranging from 15 to >100. Below 137.4 feet the rock is tight.

The depth to water bgs in SSD8-3 is about 50 feet and the last measurement to the depth of groundwater was 55.5 feet in August 2001. The depth to water bgs in SSD8-2 is about 80 feet and the last measurement to the depth of groundwater was 78.1 feet in August 2001.

Channel 2

Due to the length of the DOE axis for SSD-8 it crosses two channel areas and Channel 2 along the axis is about 600 feet wide and mostly at about 440-foot elevation. Two exploration drill holes, DWR SSD8-5 and USBR DH-110, were drilled in the vicinity of Channel 2. Drill hole SSD8-5 was drilled about 250 feet upstream of the current DOE axis and DH-110 was drilled about 200 feet upstream of the axis. See Plate 9, Sheet 4 for drill hole locations.

Drill hole SSD8-5 was drilled to a depth of 151.0 feet and DH-110 was drilled to a depth of 66.4 feet. SSD8-5 encountered 16.8 feet of fat clay colluvium and DH-110 encountered 16.6 feet of colluvium comprised mostly of lean to fat clay with some clayey sand interbeds. SSD8-5 encountered about 80% mudstone (Kbm) with 20% sandstone interbeds. DH-110 encountered about 85% mudstone (Kbm) with 15% sandstone interbeds.

In drill hole SSD8-5 the rock is decomposed to intensely weathered from 16.8 to 22.5 feet, moderately weathered from 22.5 to 32.0 feet, slightly weathered from 32.0 to 52.0 feet, and fresh below 52.0 feet. The mudstone is friable to low hardness and friable to weak from 16.8 to 22.5 feet and low to moderately hard and weak to moderately strong from about 22.5 to 52.0 feet, and moderately hard and moderately strong below 52.0 feet. The interbedded sandstone is low to moderately hard and weak to moderately strong. The mudstone is laminated to thin-bedded and the sandstone is mostly thin-bedded throughout the hole. Bedding dips between 15 and 30°. The rock is intensely fractured from 16.8 to 36.0 feet, mostly closely fractured from 36.0 to 107.5 feet, and closely to moderately fractured below 107.5 feet. No shearing was noted in the drill hole log. It was noted that the mudstone has no reaction to HCl but the sandstone has a strong reaction.

In drill hole DH-110 the rock is decomposed to intensely weathered from 16.6 to 26.8 feet, moderately weathered from 26.8 to 33.6 feet, slightly weathered from 33.6 to 44.4 feet, and fresh below 44.4 feet. The mudstone is friable to low hardness and friable to weak from 16.6 to about 26.8 feet and low to moderately hard and weak to moderately strong from about 26.8 to 66.4 feet. The interbedded sandstone is low to moderately hard and weak to moderately strong. The mudstone is laminated to thin-bedded and the sandstone is mostly thin-bedded throughout the hole. Bedding dips about 25º. The rock is intensely fractured from 16.6 to 33.6 feet and closely to moderately fractured below 33.6 feet. No shearing was noted in the drill hole log. It was noted that the mudstone has no reaction to HCl but the sandstone has a strong reaction.

Rock quality (RQD) values for SSD8-5 are very poor from 16.8 to 81.0 feet and excellent below 81.0 feet. Water pressure testing in SSD8-5 began at a depth of 22.9 feet. The initial test from 22.9 to 31.9 feet exceeded 100 Lugeons. The test interval from 32.9 to41.9 feet had a Lugeon value of about three. The two test intervals between 42.3 feet and 62.9 feet had Lugeon values of about 30. Below 64.9 feet to a depth of 146.9 feet the rock is mostly tight having an average permeability of 0.02 ft/day. One exception is the interval between 106.9 and 115.9 feet, which had a Lugeon value of about 11.

The depth to water bgs in SSD8-5 is about 20 feet and the last measurement to the depth of groundwater was 20.4 feet in August 2001. The depth to water bgs in DH-110 is also about 20 feet and the last measurement to the depth of groundwater was 18.8 feet in August 2001.

Right Abutment

The right abutment ranges in elevation from a high of about 540 feet to a low of about 450 feet near Channel 2. The right abutment has a very gentle slope and shares the same knoll that the left abutment for SSD-7 does. One exploration drill hole, SSD8-1, was drilled at the top of the right abutment to a depth of 151.0 feet (See Plate 9, Sheet 4). It encountered 2.0 feet of lean to fat clay colluvium. Underlying the colluvium the drill hole encountered about 50% mudstone and 50% sandstone (Kbsm). An approximate 100-foot thick Kbsm unit trends through the mid-abutment providing good control for the determination of bedding trend. Bedding ranges in strike from N20ºW to N7ºE and dips between 17 and 30ºW. The remainder of the right abutment is underlain by the Kbm rock unit.

In drill hole SSD8-1 the rock is decomposed to intensely weathered from 2.0 to 7.4 feet, moderately weathered from 7.4 to 23.2, slightly weathered from

23.2 to 56.0 feet, and fresh below 56.0 feet. The rock is mostly friable to low hardness and weak from 2.0 to 7.4 feet, low hardness and weak from about 7.4 to 23.2 feet, and moderately hard to hard and mostly moderately strong with some strong in individual sandstone beds below 23.2 feet. The mudstone is laminated to thin-bedded and the sandstone is mostly thin-bedded throughout the hole. Bedding dips between 30 and 35º. The rock is intensely fractured from 2.0 to 11.0 feet, intensely to closely fractured from 11.0 to 28.5 feet, closely fractured from 28.5 to 56.5 feet, and closely to moderately fractured below 56.5 feet. Most fracturing is associated with bedding. Two minor shears were noted in the drill hole log at depths of 120.4 to 120.7 and 132.0 to 132.6 feet. Both appear to be bedding plane shears and both have clay gouge with calcite healing up to ¾-inch thick.

A minor slide, 100 by 100 feet, was mapped at about the mid-right abutment and located mostly in the (Kbsm) unit that trends through the abutment. The slide is parallel to bedding and is likely shallow seated.

Rock quality (RQD) values for SSD8-1 are very poor from 2.0 to 51.0 feet and good below 51.0 feet. Water pressure testing in SSD8-1 began at a depth of 15.2 feet. The rock from 15.2 to 32.2 feet has high permeability associated with fracturing that average 1.4ft/day with corresponding Lugeon values averaging about 50. The rock between 32.2 and about 75.0 feet tested mostly tight. From 75.0 to 105.2 the testing indicates that the rock has high permeability with a permeability rate of 0.75 ft/day with corresponding Lugeon values ranging from 28 to >100. Below 105.2 feet the rock is tight. The depth to water bgs in SSD8-1 is about 60 feet and the last measurement to the depth of groundwater was 61.8 feet bgs in August 2001.

Current design calls for stripping to the top of intensely weathered rock with additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations at SSD-8 can be accomplished by conventional methods. Curtain grouting was included for SSD-8 to reduce seepage through the foundation. Foundation grouting will consist of a 2 row vertical grout curtain spaced 10 feet apart parallel to the dam centerline and a depth of 0.5 the height of the dam or 30 foot minimum. The grout program will also include a 20-foot wide by 3-foot thick grout cap, where feasible, to prevent surface leakage of grout during grouting of the upper stage of the hole. In addition, tertiary holes may be required to meet grout closure criteria. Since water pressure testing in the exploration holes at SSD-8 indicates that the Boxer Formation permeability varies from low to high. Feasibility estimates for grout takes range between 0.15 and 0.25 sacks of cement per lineal foot of grout hole. These estimates will be further refined in the later stages of design investigations.

7.10 Saddle Dam #9

SSD-9 is the last and furthest saddle dam located in the northwest corner of the reservoir about 6.5 miles northwest of the Golden Gate Dam site, and only about 200 feet west of SSD-8. It is the second smallest at 40 feet in height and has a crest length of about 340 feet. The structure trends S57ºE and sits astride a northerly trending drainage (See Plate 9, Sheet 4). The DOE alignment is some 500 feet north of the ND alignment. The DOE alignment was selected to provide favorable abutment contacts while providing continuity with SSD-8. The abutments have very gentle slopes with the right abutment being slightly steeper than the left. The right abutment shares the same knoll that the left abutment for SSD-8 does. The site is underlain by mostly Boxer mudstone (Kbm) with sandstone interbeds.

Exploration at SSD-9 consisted of drilling two core holes, SSD9-1 drilled by DWR, and DH-112 drilled by the USBR in 1979. The two core holes were drilled near the ND alignment. SSD9-1 was drilled to a depth of 150.4 feet and is located about 900 feet upstream of the DOE axis. DH-112 was drilled to a depth of only 19.5 feet and it is located about 600 feet upstream of the DOE axis. SSD9-1 was drilled on the left abutment of the ND axis and DH-112 was drilled in the colluvium near the lower right abutment of the ND axis. For the location of these exploration drill holes see Plate 9, Sheet 4. Even though the holes are some 600 to 900 feet upstream of the DOE axis they represent similar geologic conditions that exist at the current axis. Drill hole SSD9-1 encountered about 75% mudstone (Kbm) with 25% sandstone interbeds and drill hole DH-112 encountered about 50% mudstone and 50% sandstone (Kbsm). Bedding trends generally N-S and dips about 5 to 10ºW out of the right abutment and into the left abutment near the Fruto syncline just west of SSD-9.

Drill hole SSD9-1 encountered about 0.5 feet of lean to fat clay colluvium. The rock is decomposed to intensely weathered from 0.5 to 5.4 feet, intensely weathered from 5.4 to 14.8 feet, moderately weathered with 20% slight from 14.8 to 37.0 feet, and fresh below 37.0 feet. The rock is mostly friable and weak from 0.5 to 5.4 feet, low to moderately hard and weak to moderately strong from about 5.4 to 37.0 feet, and moderately hard to hard and mostly moderately strong with some strong in individual sandstone beds below 37.0 feet. The mudstone is laminated to thin-bedded and the sandstone is mostly thin-bedded throughout the hole. Bedding dips between 0 and 10º. The rock is mostly intensely fractured from 0.5 to 13.5 feet, closely fractured from 13.5 to 37.0 feet, and closely to moderately fractured from 37.0 to 150.4 feet with a zone of intense to closely fractured rock from 122.3 to 133.8 feet. Most fracturing is associated with bedding. Some minor bedding plane shears were noted in the drill hole log. The aforementioned fractured rock from 122.3 to 133.8 feet is associated with a shear zone composed of crushed and sheared mudstone with minor gouge and laced with calcite throughout the interval. The dip was indeterminate. It is not likely that this shear is continuous some 900 feet to the north at SSD-9. Numerous fractures through out the core are calcite healed up to ¾-inch thick but mostly 1/8-inch thick.

Rock quality (RQD) values for SSD9-1 are very poor from 0.5 to 35.4 feet, good from 35.4 to 120.6 feet, very poor from 120.6 to 135.6 feet, and fair below 135.6 feet. Water pressure testing in SSD9-1 began at a depth of 11.6 feet. The rock from 11.6 to 31.6 feet has high permeability associated with fracturing that average about 0.7ft/day with corresponding Lugeon values averaging about 70. The rock between 31.6 and about 116.0 feet tested tight to low permeability of 0.0 to 0.1 ft/day with. The aforementioned shear zone with associated fractured rock was tested from about 116.0 to about 137.0 feet and is permeable with Lugeon values ranging from about 8 to 14. While these permeability values are representative for the Boxer Formation at this drill hole location, additional drilling and water testing at the DOE SSD-9 axis will provide better site location values. The depth to water bgs in SSD9-1 is about 40 feet and the last measurement to the depth of groundwater was 43.5 feet bgs in August 2001.

USBR drill hole DH-112 encountered about 8.7 feet of lean clay colluvium. The rock underlying the colluvium is decomposed from 8.7 to 11.3 feet and intensely weathered from 11.3 to 19.5 feet except for a slightly weathered, carbonate cemented sandstone interbed from 13.1 to 13.7 feet. The rock is mostly friable and weak from 8.7 to 11.3 feet, low hardness and mostly weak below 11.3 feet except hard and strong in the sandstone interbed at about 13.5 feet. The mudstone is laminated to thin-bedded and the sandstone is mostly thin-bedded throughout the hole. Bedding dips between 0 and 10^{o}. The rock is mostly intensely fractured from 8.7 to 11.3 feet and closely fractured from 11.3 to 19.5 feet. Most fracturing is associated with bedding. No shears were noted in the drill hole log.

One water test was performed in DH-112 between the depths of 10.2 and 19.5 feet. It had a permeability value of 0.04 ft/day. The hole was dry during drilling and the hole caved from 18.6 to 19.5 feet before conversion into an observation well. Current design requires stripping to the top of intensely weathered rock and additional excavation to the top of moderately weathered rock for the cutoff trench. All excavations can be accomplished by conventional methods. It does not include foundation grouting since a large portion of this saddle dam is freeboard. Foundation seepage was not considered to be significant for SSD-9 due to relatively low head and a long flow path below the core trench.

7.11 Conclusions and Recommendations

Rock units of the Boxer Formation at the proposed foundations for the Sites Saddle Dam sites are acceptable. The current design depths of excavation for the abutments and cutoff trenches at the sites can be accomplished by conventional methods with possibly some light blasting where the conglomerate rock unit is present.

Some issues that will require additional studies are:

- Unlike the Golden Gate and Sites Dam sites rock outcrops at the saddle dams are scarce at the proposed sites. Dozer and/or backhoe trenches to expose the rock units will be required.

- Some of the DOE dam axes have a different location than the ND axes and consequently will require additional exploration drilling for final design to define foundation conditions and associated permeability values.

- The locations of the northeast trending lineaments or faults at the saddle dam sites need to be verified. The Salt Lake fault at SSD-2 needs to be trenched to determine its exact location.

- Additional geologic mapping at some of the smaller saddle dam sites needs to be accomplished.

- Continue to monitor water levels, preferably quarterly, in the existing observation wells.

- Perform additional borrow and quarry investigations.

8.0 SITES RESERVOIR GEOLOGY

Sites Reservoir would inundate Antelope Valley. Except for a small area upstream of Golden Gate Dam site, the reservoir would lie entirely over the Boxer Formation (See Figure 1). The Boxer Formation rock units consist mainly of mudstone (Kbm), interbedded sandstone and mudstone (Kbsm), and minor sandstone (Kbs), and conglomerate (Kbcgl). Except for minor outcrops of discontinuous sandstone interbeds and the bold conglomerate outcrops, the main units, Kbm and Kbsm, are mostly not exposed. The reservoir area in Antelope Valley is characterized by a gentle sloping valley with some subtle rounded knolls mainly in the vicinity of the saddle dams. It is drained primarily by easterly flowing Funks and Stone Corral Creeks with some minor northeasterly flowing drainages in the northwest part of the reservoir.

The topography is mostly subdued with the steeper slopes located in the vicinity of the Golden Gate and Sites dam sites. The geologic mapping performed during this feasibility study did not reveal any large massive landslide complexes that would create reservoir instability during filling. The landslides that have been mapped are mostly surficial slumps and mostly shallow seated (< 20 feet thick).

The primary geologic structures that trend through the reservoir are the Salt Lake fault, Sites anticline, Fruto syncline, and the northeast trending tear faults such as GG-1, GG-2, GG-3, and S-2 (See Figure 1). The Salt Lake fault is a bedding parallel, north-striking, high-angle thrust fault that can be traced confidently for about 12 miles from north of Logan Creek and south to Stone Corral Creek near the town of Sites (WLA 2002). Near the southern end of the fault, the northeast-trending tear fault GG-2 offsets the Salt Lake fault some 500 feet in a right-lateral sense (WLA 2002). The fault flattens at depth and is interpreted to terminate down dip against the gently west-dipping flat of the underlying blind thrust. It is located about 1.5 and 1.7 miles respectively west of the Sites and Golden Gate Dam sites. It is projected as trending through the left abutment of Saddle Dam site 2. Further discussions of the Salt Lake fault and its activity can be found in Section 10, Faulting and Seismicity.

The Sites anticline is located immediately west of the Salt Lake fault some 1000 to 2000 feet. It is a doubly plunging anticline about three miles in length within the reservoir dying out slightly south of the town of Sites. The anticline is interpreted to be a west-vergent fault-propagation fold developed above a blind, east-dipping thrust fault that is rooted in the flat of the Funks segment of the Great Valley fault (WLA 2001). The anticline is a tight fold with steeply dipping and overturned strata on both limbs. East of the anticline axis, strata dips to the east like the bedding does at Golden Gate and Sites Dam sites. West of the anticline axis strata dips to the west steeply adjacent to the axis and flattening to the west as it approaches the west limb of the Fruto syncline.

The Fruto syncline is located about one mile west of the Sites anticline near the west side of the reservoir (See Figure 1). It is continuous for some nine miles within the reservoir area and plunges out slightly south of the town of Sites. WLA interprets the western limb of the syncline to be the forelimb of a large, east-vergent fault propagation fold above the ramp in the Funks segment of the Great Valley fault. Strata west of the syncline axis dip flatly to the west and steepening to the east.

In addition, Brown and Rich (1961) mapped a bedding-parallel, north-striking, thrust fault about 0.75 miles southwest of the Sites Dam site. It is similar to the Salt Lake fault and it terminates against the northeast-trending S-2 tear fault southwest of Sites Dam site.

The northeast-striking, high-angle, tear faults GG-1, GG-2, GG-3, and S-2 trend through the reservoir and traverse either through or near the Golden Gate and Sites Dam sites (See Figure 2). Some of the shorter tear faults trend through some of the saddle dam sites (See Figure 3). These tear faults obliquely cut across the north-striking bedrock units, and consistently displace stratigraphic contacts in a right later sense. WLA believes that the tear faults are confined to the hanging wall block of the Funks segment and accommodate differential northeast-directed shortening across the segment boundary.

Three drill holes were drilled, two at the same location, as part of the initial Sites Reservoir eastern rim seepage study. They are SS-1, SS-2, and SS-2A. Drill hole SS-1 was drilled about one mile south of Saddle Dam site 1. Drill holes SS-2 and SS-2A were drilled about 1.5 miles south of Golden Gate Dam site and about one mile north of Sites Dam site. The three holes are not located on a reservoir map.

Drill hole SS-1 was drilled to a depth of 134.0 feet at about elevation 580 feet in the Cortina Formation. It encountered variable percentages of mudstone and sandstone rock units (Kcvm, Kcvsm, and Kcvs). Water pressure tests were performed but were not finalized and published by ND. Below a depth of about 15 feet the drill hole log indicates that the RQD ratings were good to excellent.

Drill hole SS-2 was drilled to a depth of 194.0 feet at about elevation 650 feet. It encountered Cortina Formation interbedded sandstone and mudstone (Kcvsm) to a depth of about 34 feet and 100% sandstone (Kcvs) from about 40 to 132 feet. From about 132 to 194 feet the hole encountered Boxer Formation comprised of 80 % mudstone and 20% interbedded sandstone (Kbm). Water pressure tests were performed but not finalized and published by ND. The drill hole log indicates that the RQD ratings in the upper 34 feet range mostly from very poor to fair and from 34 to 132 feet mostly good to excellent with some isolated intervals of poor to fair. The Boxer Formation ranges from very poor to excellent but averages about 65% (fair). A companion hole, SS-2A, was drilled at a 45^{o} angle on a bearing of S19^{o}W to encounter the northeast trending tear fault GG-3. It did encounter a zone between a drilled depth of 152.2 to 161.7 feet that in the drill hole log indicates it correlates with GG-3. The zone is described as highly deformed beds of sandstone and mudstone in a clay gouge matrix. The rock from about 150 to 176 feet has a very poor RQD rating, apparently associated with fault GG-3. In the upper part of the hole, the rock has a RQD rating of very poor to a depth of about 30 feet. From about 30 to 150 feet the rock has a RQD rating of mostly good to excellent with about 15 % poor to fair. From about 176 to 196 feet the rock has a RQD rating of very poor to poor and below 196 feet excellent.

Further analysis of the reservoir rim stability and seepage potential will be conducted during the design phase of exploration.

Eight exploration gas wells were drilled in the reservoir. Two were drilled about 500 feet west of Saddle Dam site 3, one west of Sites, and six near Salt Lake. These exploration wells are assumed to have been abandoned in their proper manner but further research is required to verify this prior to reservoir filling.

9.0 FUNKS RESERVOIR MODIFICATION AND NEW CONVEYANCE

9.1 Funks Reservoir

The Funks Reservoir enlargement would provide additional storage capacity as a forebay/afterbay. Material generated from the enlargement would provide about 5 million cubic yards of construction material that may potentially be used as impervious or random embankment materials for Golden Gate Dam. Besides the source from Funks Reservoir, the enlargement would include the excavation of the older alluvium (Qoal) associated with the terrace deposits located along Funks Creek between Funks Reservoir and the pumping plant. This potential borrow source area is closer to Golden Gate Dam site than other sources. Enlarging Funks Reservoir would accomplish the following:

- Provide increased afterbay/forebay reservoir capacity. Sizes currently under consideration range from 1,340 to 5,290 acre-feet.

- Increased afterbay/forebay operational flexibility by improving water conveyance between the afterbay/forebay and the pumping plant.

Geologic investigation included drilling auger holes GGO AUG-1, -2, and -3, and seismic refraction lines SL-8, SL-10 and SL-11. This work was completed during the summer of 2000. Nine additional auger holes, FR-AUG-1,-2,-3,-4,-5,-6,-7,-8, and –9, were drilled during the spring of 2001. The locations of auger holes and seismic lines are shown on Plate 3, Sheets 6-10. The drill hole logs are included in Appendix A. The holes were drilled with a CME 750 drill rig with 8-inch hollow stem augers. Standard Penetration Tests (SPTs) were conducted at five foot intervals using a modified California sampler, with the number of blows (N-values) recorded every 6-inches. One sample tube was collected for each interval. Two bulk samples of the cuttings were also collected from each auger hole. Sample laboratory analyses were tested only on auger holes FR-AUG-7,-8,-9 with results listed in Figure 6.

Deposits near Funks Reservoir are saturated below lake level, depending on the time of the year. The saturated soils may be undesirable because of the problem with moisture control and the effort that is required to dry the material out. The reservoir likely will require draining prior to enlargement.

The older alluvium (Qoal) that make up the terrace deposits along Funks Creek downstream of Golden Gate are 25 to 35 feet thick as observed in the auger holes, fault trenches, and along the seismic lines. Assuming an average depth of about 27 feet, there is approximately 3 million cubic yards of mostly impervious material available. The field classification of these deposits range from CL to ML.

Auger holes FR-AUG-1,-2,-3,-4,-5, and-6 were drilled along the south and west edges of Funks Reservoir. They encountered weathered bedrock, interbedded sandstone and mudstone, at depths ranging from as shallow as 2.0 feet in auger hole FR-AUG-1 (located at the south edge) to as deep as 25.0 feet in auger holes FR-AUG-5 and –6 (located at the northwest corner of Funks Reservoir). The auger logs for these holes indicate that underlying the lean clay and silt and overlying the bedrock are alluvial (Qal) deposits ranging in thickness from about 3 to 10 feet and comprised of mostly silty and clayey gravels with some silty and clayey sands. The alluvial (Qal) material would not be suitable for use as impervious material in Golden Gate Dam.

New Conveyance

The proposed New Conveyance alignment extends for about 13 miles from the Sacramento River just south of Princeton to Funks Reservoir. Preliminary design looked at using an open channel canal. This design would have required an additional pump station. It also would have required a 30-foot high embankment to prevent overtopping in flood events associated with the Colusa Basin, which covers more than half of the total length of the alignment. Current design has three alternatives all with a 12-foot diameter pipelines and a pump station. Ten auger holes were drilled along the proposed alignment. The canal traverses through a number of mostly geologic soil units as shown on Plate 13, Sheets 1-3. The auger hole logs are located in Appendix A. No mechanical analyses have been completed on the samples collected but some samples from near pipeline invert were submitted for sulfate and chloride analyses to determine resistivity values and potential sulfate attack on concrete pipe.

Geologic soil units that the new conveyance alignment traverses, from east to west, include Sacramento River channel deposits, Modesto Formation, basin deposits, the Riverbank Formation, the Tehama Formation, and the Red Bluff Formation. The auger holes were drilled using a CME-850 drill rig with eight-inch diameter hollow stem augers. A two-inch diameter Shelby tube was used to collect samples near the surface. Below about 10 feet, a California sampler was used in conjunction with a Standard Penetration Test. Blow counts (N-values) and sample intervals are recorded on the auger logs in Appendix A.

In the vicinity of the Sacramento River and Pump Station, auger holes NC-AUG-9 and –10 were both drilled to a depth of 51.5 feet and encountered Sacramento River deposits and the Lower Modesto Formation. Soils encountered in auger hole NC-AUG-10 consisted mostly of interbedded silt and lean clay with some silty sand. N-values achieved from utilizing the California

Modified sampler ranged between 7 and 18 with an average of 13 to a depth of 26.5 feet. Below 26.5 feet the five test intervals average N-value is 32. Soils encountered in auger hole NC-AUG-9 consists mostly of lean clay with silt interbeds. N-values achieved from utilizing the California Modified sampler were 8 and 9 respectively for the 10 and 15-foot test intervals. Below 15 feet, N-values ranged between 18 and 49 with an average of 32.

About half of the alignment (~7 miles) traverses through basin soil deposits that were encountered in auger holes NC-AUG-5,-6,-7, and –8. These soils consist of gray to brown lean clay with some silt interbeds and some silty sand and silty to clayey gravels. Holes closer the Sacramento River contained more silt, sand, and gravel. The basin deposits appear confined close to the ground surface and may be relatively thin, ranging from about 7 to 15 feet thick. Below the basin deposits are yellowish brown sediments that may be of Modesto age or older but because this was not confirmed, they are shown as basin deposits on the drill logs. The basin deposits appear to contain more organic material.

Soils encountered in auger hole NC-AUG-8, which was drilled to a depth of 51.5 feet, consist mostly of lean clay to a depth of 32.3 feet. Below a depth of 32.3 feet to 51.5 feet, clayey and well-graded gravels were encountered. N-values in the lean clay were between 13 and 27 with an average of 15. The gravel zone between 32.3 and 51.5 feet was noted on the log as unconsolidated yet had high N-values with 50 plus blows.

Soils encountered in auger hole NC-AUG-7, which was drilled to a depth of 51.5 feet, consist mostly of lean clay with some poorly graded sand to a depth of 25.5 feet. N-values for the upper 25.5 feet range between 13 and 36 with an average of 20. Below 25.5 feet to a depth of 40.7 feet the hole encountered poorly and well-graded sands with some well-graded gravel near the base of the sand unit. This coarse-grained unit had N-values of 22 to 55 for three test intervals with an average of 43. Below 40.7 feet and to a depth of 51.5 feet, lean clay was encountered with N-values ranging between 17 and 22 for three test intervals.

Soils encountered in auger hole NC-AUG-6, which was drilled to a depth of 51.5 feet, consist mostly of lean clay and silt to a depth of about 38 feet. Besides the N-value of 10 at 10 feet, N- values in the lean clay unit below 10 feet ranged from 20 to 32 with an average of 25 for three test intervals. The silt unit underlying the lean clay had N-values of 16 and 20 for the two test intervals. The dense silty sand unit between about 38 and 49 feet had N-values of 24 and 49 for two test intervals. The lower lean clay unit below about 49 feet had an N-value of 24.

Soils encountered in auger hole NC-AUG-5, which was drilled to a depth of 51.5 feet, consist entirely of lean clay. The initial SPT test at 10 feet had an

N-value of 14. Below 10 feet the N-values ranged between 23 and 37 with an average of 30.

About 4 miles of the alignment traverses through the Riverbank Formation. Auger holes NC-AUG-3, -3A, and –4 were drilled to depths of 51.5 feet, 119 feet, and 51.5 feet respectively. Soils encountered in the auger holes consist predominantly of dark yellowish-brown lean clays with interbedded silts and some silty and poorly graded sands. The Riverbank Formation is similar to the underlying Tehama Formation.

Soils encountered in NC-AUG-4 were comprised of lean clay with a poorly graded sand interbed from about 23 to 38 feet. N-values in the lean clay from 10 to about 23 feet range between 15 and 20 for the three test intervals. N-values in the poorly graded sand unit from about 23 to 38 feet range between 17 (top of the sand unit) and 33 (bottom of the sand unit) with an average of 25 indicating that the sand is denser at depth. The underlying lean clay unit has N-values that range between 17 (top) and 37 with an average of 29. Auger holes NC-AUG-3 and –3A were drilled adjacent to one another. SPT sampling was only achieved in NC-AUG-3. No samples were collected in the upper 50 feet of NC-AUG-3A and below 50 feet to 119.0 feet the soils were cored with a HQ diamond bit with core barrel. The hole encountered lean and sandy clays with a one-foot thick silty sand interbed at a depth of 79 feet. N-values in NC-AUG-3 indicate that the lean clays and silts in the upper 16.5 feet are very soft to soft with blows of 8 and 5 for the two tests performed in this interval. Below 16.5 feet, the interbedded lean clays and silts had N-values that range between 17 and 34 with an average of 24.

The last two miles of the alignment would encounter the Red Bluff and Tehama Formations. Auger holes NC-AUG-1 and –2 were drilled to depths of 51.5 feet encountering the Tehama and some bedrock. NC-AUG-1 drilled through about 16 feet of Tehama before encountering Cretaceous mudstone of the Cortina Formation. The weathered mudstone was augered from a depth of about 16 to 52 feet with some drive samples, suggesting that the mudstone is decomposed to intensely weathered and rippable to that depth.

Auger hole NC-AUG-2 encountered almost entirely lean clay with some sand and a minor clayey sand and silty sand unit at perspective depths of about 5 feet and 10 feet. The silty sand unit from 10.0 to 11.5 feet was very dense with an N-value of 61. The lean clay of the Tehama is mostly stiff to very stiff with N-values ranging from 34 to 53 with an average of 44. Most of the Tehama at this location appears acceptable as impervious core for Golden Gate Dam.

Auger hole NC-AUG-1 was drilled near the end of the alignment on the left (east) side of the Tehama-Colusa Canal (See Plate 13, Sheet 3). The auger hole log indicates that below about 16 feet, decomposed to intensely weathered mudstone was encountered. One SPT sample from 10.0 to 11.5 feet had an

N-value of 92 for 5 inches, which is likely mudstone. SPT samples in the mudstone commonly had N-values that ranged between 74 and 100, often for only 3 to 5 inches of penetration into the mudstone.

Groundwater was encountered in all of the auger holes at relatively shallow depths below the ground surface (bgs) ranging from only 5.5 feet in NC-AUG-3 to 13.0 feet in NC-AUG-6. Groundwater is only about 9 feet bgs in NC-AUG-10 located at the Sacramento Pump Station. The shallow depth to groundwater bgs indicates that the majority of the excavations will be saturated and will require extensive dewatering.

Temporary slopes in the saturated soils should be stable at 1.5 to 1 but may require laying back to 2 to 1 if instability is a problem. Additional work along the alignment will be required for future design.

10.0 FAULTING AND SEISMICITY

10.1 Introduction

The Department of Water Resources initiated the study and then entered into a three-year Faulting and Seismicity study from June 1999 to September 2002 contracted with William Lettis and Associates, Inc. (WLA) from Walnut Creek, California. The study incorporated two phases, Phase I by DWR and Phase II by WLA, which culminated with a major report released in October 2002 titled, "Seismotectonic Evaluation, Phase II Fault and Seismic Hazards Investigations, North of Delta Offstream Storage, DWR – Integrated Storage Investigations".

Northern District Geology Section performed extensive research and published the first phase of this study in September 1999 with a report entitled, "Phase I, Fault and Seismic Hazards Investigation". Phase I included a literature search and discussion of faulting and seismicity based on present available information. The literature search helped in identifying the location of faults both locally and regionally and their associated potential seismic sources, and the regional earthquake history. Information was obtained from published documents and no fieldwork was performed. Also included are preliminary estimates of a maximum credible earthquake and associated peak ground accelerations, surface rupture hazards, reservoir-induced seismicity and liquefaction.

Phase II presents the seismotectonic study of the regional area and included the results of field investigations to evaluate surface-faulting hazards and maximum levels of strong ground shaking that would affect the Sites Reservoir Project structures. The Phase II study involved an extensive aerial photo interpretation to determine location of faults and excavating trenches to determine their location and assessment of their activity. WLA incorporated the assistance of C. B. Crouse from URS Corp. in determining ground motion analysis. The Phase II report compiled by WLA contains information that will be suitable in final design. Due to the extensive volume of the WLA report a copy of the report on CD is included with this report.

10.2 Previous Studies

Of particular importance to this study is the mapping of bedrock stratigraphy and structure by Brown and Rich (1961). Their mapping identified several unnamed northeast-trending tear faults that traverse diagonally through the Golden Gate and Sites Dam sites. In addition, Brown and Rich identified and mapped the Sites anticline and Salt Lake fault in Antelope Valley within the reservoir west of the Golden Gate and Sites Dam sites. The Salt Lake fault traverses through the reservoir and is projected through Saddle Dam site 2. The Salt Lake fault and the northeast trending tear faults eventually became the focus of study in determining their activity, especially in Phase II. The U.S. Bureau of Reclamation (1963, 1969, and 1979-80) and DWR (1997-2000) performed subsequent geologic mapping, drilling, and trenching thereby providing additional documentation of these fault locations.

WLA also reviewed 1:24,000 scale Quaternary geologic mapping of the Sacramento Valley by Helley and Harwood (1985). This mapping identified Quaternary deposits along Stone Corral Creek and Funks Creek in the vicinity of the Sites and Golden Gate dam sites. In addition, Steele (1980) identified, mapped and characterized terraces formed along major streams in the northern part of the study area at a scale of 1:62,500. Although this mapping does not cover the Sites and Golden Gate dam sites, terraces identified by Steele (1980) provide regionally correlative late Quaternary markers for assessing recent fault activity and deformation in the northwestern Sacramento Valley. WLA incorporated results from their recent seismic hazard assessment for East Park and Stony Gorge dams (WLA, 1997), which are located west and northwest, respectively, of the present study area. This previous work, performed for the U.S. Bureau of Reclamation, included a thorough review of the existing literature on the stratigraphy, structure, and seismotectonics of the northern Coast Ranges and western Sacramento Valley. This work included reconnaissance and detailed mapping of geomorphic surfaces in the project site region (see references cited in WLA, 1997).

In the Phase II report, WLA presented a discussion of the Department of Water Resources, Division of Safety of Dams (DSOD) criteria for the assessment of fault activity. Listed below are the following guidelines adopted by DSOD (1995; also, Fraser, 1997) defining three categories of seismic sources for dam design.

1) **Active Seismic Sources,** which include Holocene-active faults and late Pleistocene active faults;

2) **Inactive Seismic Sources;** and

3) **Conditionally Active Seismic Sources.**

Holocene-active faults are defined as faults on which surface or subsurface displacement has occurred within the last 11,000 years. Holocene activity is demonstrated by: displacement or deformation of Holocene stratigraphic units; geomorphic evidence of Holocene displacement; well-located zones of seismicity; or documented fault creep.

Latest Pleistocene-active faults are defined as faults with no Holocene displacement, but which have produced surface or subsurface displacement of units 11,000 to 35,000 years old or show geomorphic evidence of latest Pleistocene displacement.

Inactive faults are defined as faults which have had no surface or subsurface displacement within the last 35,000 years demonstrated by a confidently-located fault trace that is overlain by unbroken geologic materials 35,000 years or older.

Conditionally active faults are defined as faults with a displacement history during the last 35,000 years that is not known with sufficient certainty to consider the fault an active or inactive seismic source.

10.3 Regional Faults

In the Phase I report by ND and the Phase II by WLA, numerous regional faults were addressed. The primary ones include the lengthy San Andreas right lateral transform fault, the Cascadia Subduction Zone, and the Coast Ranges – Sierran Block Boundary Zone (CRSBZ), which WLA refers to as the Great Valley fault in their Phase II report. Other regional faults that both the Phase I and Phase II reports discuss are: the Maacama, Bartlett Springs, Stony Creek, Coast Range, Green Valley, Paskenta, Rumsey Hills, Sweitzer, Valley Side, Black Butte, and Corning faults. Discussions of these faults can be found in the WLA CD included with this report.

The following text on the San Andreas fault, Cascadia Subduction Zone, and the Great Valley fault along with references to Figures are extracted from the WLA report and can be found in the appendixed CD.

San Andreas Fault

The San Andreas fault is the most significant active fault in western California. The fault strikes northwest and can be traced as a continuous, well-defined geomorphic feature for approximately 650 miles (1,050 km) between the Gulf of California in southern California to Pt. Arena on the northern California coast (Figure 1-3). The San Andreas fault extends north of Pt. Arena in the offshore region and terminates in the vicinity of the Mendocino triple junction for a total length of approximately 700 miles (1,200 km). The San Andreas fault accommodates a large part of the approximately 39 mm/yr of distributed Pacific/Sierran plate motion in western California. Paleoseismic studies indicate that the slip rate on the San Andreas fault north of San Francisco is approximately 24 mm/yr (Niemi and Hall, 1992). Based on elastic dislocation modeling of geodetic data, Freymueller et al. (1999) inferred that the slip rate on the northern San Andreas fault is about 15 to 20.5 mm/yr. The closest approach of the San Andreas fault to the Sites and Golden Gate dam sites is 70 miles (113 km).

The San Andreas fault is the source of two M ˜8 historic earthquakes in California, the1857 Fort Tejon earthquake in southern California and the 1906 San Francisco earthquake). The 1906 earthquake ruptured approximately 270 miles (435 km) of the northern San Andreas fault between San Juan Batista to the south, and Shelter Cove to the north. The reach of the San Andreas fault that ruptured in 1906 currently is aseismic or nearly so (Hill et al., 1990). Workers generally interpret the relative lack of seismicity as evidence that the fault is "locked" and presumably accumulating strain for release in a future large-magnitude earthquake (Working Group on Northern California Earthquake Probabilities, 1996).

Based on paleoseismic evidence for repeated Holocene earthquakes and the occurrence of historic events such as the 1906 earthquakes, WLA concludes that the San Andreas fault is an active seismic source.

Cascadia Subduction Zone

This section characterizes two classes of potential seismic sources associated with the southern Cascadia subduction: (1) an “interplate” source, which is the subduction zone megathrust fault between the subducting Gorda plate and the overlying crust of the Sierran microplate; and (2) “intraplate” sources, which are seismogenic faults within the Gorda slab.

Interplate Sources

Geological investigations (Atwater et al., 1995; Nelson et al., 1995), geophysical modeling (Fluck et al., 1997; Hyndman and Wang, 1995), and historical tsunami records from Japan (Satake et al., 1996) provide the basis for the current scientific consensus that the Cascadia subduction zone (CSZ) has the potential to generate earthquakes that may rupture the entire 1,000-km length of the plate boundary. Geological evidence for repeated great earthquakes on the CSZ includes: (1) stratigraphic relations in estuaries that document repeated episodes of sudden submergence of forests and tidal marshes; (2) seismically triggered turbidites in submarine channels; (3) liquefaction caused by strong shaking; and (4) tsunamis generated by dislocation of the seafloor (Atwater et al., 1995) (Figure 3-60).

The most recent great earthquake on the Cascadia subduction zone is estimated to have occurred about 300 years ago, based on analyses of tree rings from fossil spruce and cedar trees at Cascadia estuaries, as well as radiocarbon dating of fossil trees and marsh herbs interpreted to have been killed by earthquake-induced subsidence (Jacoby et al., 1995; Nelson et al., 1995; Yamaguchi et al., 1997). These data are consistent with the interpretation of Satake et al. (1996) that a large tsunami, which struck Japan on the evening of 26 January 1700, was triggered by an earthquake that ruptured 560 to 621 miles (900-to-1000) km of the Cascadia plate boundary. Paleoseismic data indicate that earthquakes of this size may recur on average every 500 to 600 years (Atwater and Hemphill-Haley, 1997; Goldfinger et al., 2001). Therefore, on the basis of this evidence and upon geophysical modeling that supports a Mw 9 capability for the CSZ (Fluck et al., 1997; Hyndman and Wang, 1995), we conclude that the northern California portion of the CSZ will likely be involved in a future great plate-boundary earthquake (Figure 3-60).

The 1992 Mw 7 to 7.2 Cape Mendocino earthquake was the first well-recorded historical seismic event to release significant strain within the subduction complex of the Cascadia margin (Murray et al., 1996; Oppenheimer et al., 1993; Velasco et al., 1994). Based on observations of dead marine intertidal organisms above the normal elevation range of their habitats following the earthquake, the maximum coseismic uplift was estimated to be 4.6 feet (1.4 m) (Carver et al., 1994). The focal mechanism and aftershock distribution indicate rupture of a northeast-dipping thrust plane located 25 km southeast of Cape Mendocino at 10 km depth (Murray et al., 1996). Within uncertainty, the slip vector derived from inversion of geodetically determined coseismic surface displacements (16 feet, or 4.9 m, directed 250°±10°N) is parallel to the relative plate convergence direction between the North America and Juan de Fuca plates (240.6°N; Murray et al., 1996). Based on the shallow depth of the 1992 earthquake (about 8 km above the top of the Gorda-North America plate interface), Verdonck and Zandt (1994) suggested that the 1992 event was an intraplate earthquake caused by low-angle thrust faulting within the subduction complex of the upper plate, rather than rupture of the actual subduction zone megathrust fault. However, Oppenheimer (19993) interpreted the focal mechanism and distribution of aftershocks to be consistent with nearly pure reverse slip on the plate interface striking N10°W and dipping 13° to the east-northeast.

Evidence for repeated uplift of wave-cut platforms in the Cape Mendocino region indicates that the southern North America-Gorda plate boundary has produced large to great earthquakes over the last 7,000 years. Merritts (1996) evaluated the uplift and pattern of deformation of ancient marine strandlines along the southern CSZ and found evidence for larger amounts of incremental uplift (about 8.2 feet) (2.5 m) than the 1992 earthquake, suggesting that great earthquakes (Mw > 8) may have ruptured the southern portion of the plate boundary in the last 7000 years in addition to Cape Mendocino-type events.

To summarize, recent geologic studies have documented evidence for Holocene earthquakes that probably ruptured the full 560- to 621-mile (900- to 1000-km) length of the Cascadia subduction zone. WLA concludes that the subduction zone megathrust fault in northern California will be involved in future great earthquakes to rupture the Cascadia convergent margin. WLA also concludes that faults within the accretionary complex above the subduction zone also may be a source of large (MW 7 or greater) earthquakes, similar to the 1992 Cape Mendocino earthquake.

The closest approach of the potential Cascadia earthquake rupture plane to the Sites and Golden Gate dam sites is a function of: (1) the dip of the plate interface; (2) the down dip extent of the coseismic rupture surface; and (3) the position of the southern edge of the subducting Gorda plate (Figure 3-61). WLA calculates the closest approach from estimates of the minimum depth to coseismic rupture on the plate interface, as well as the horizontal distance to the southern edge of the Gorda plate. Beaudoin et al. (1996) estimate an ~11° dip for the Gorda slab from wide-angle reflection profiles acquired during the Mendocino triple junction seismic experiment. This estimate agrees well with the 10° to 14° dip of the Gorda plate estimated by Smith et al. (1993) based on seismicity (Figure 3-61). The down-dip extent of the seismic rupture surface has been estimated by Hyndman and Wang (1995) and Fluck et al. (1997) based on dislocation modeling of geodetic data and thermal constraints (Figure 3-61 and Figure 3-62). The three-dimensional dislocation model developed by Fluck et al. (1997) predicts a 35-km wide locked zone and a 21.7-mile- (35-km-) wide transition zone for the northern California portion of the CSZ based on geodetic data from central Oregon. The transition zone is down dip of the interseismic locked portion of the fault where maximum coseismic rupture is expected but above the free-slip portion of the fault where no coseismic displacement occurs. The lower limits of the locked and transition zones are constrained by maximum temperatures predicted by numerical thermal models of the fault of 350°C and 450°C, respectively (Hyndman and Wang, 1995). To estimate the maximum coseismic rupture area, Fluck et al. (1997) assumed that both the locked and transition zones are involved in the rupture. From these estimates of the dip of the subduction zone and depth range of brittle behavior, we therefore estimate that the minimum depth to the southeastern-most edge of the rupture zone is 12.4 miles (20 km).

The horizontal distance to the southern edge of the subducting Gorda plate is inferred from estimates of the plate geometry beneath northwestern California. Beaudoin et al. (1996) traced the Gorda slab 93 miles (150 km) eastward from the Cascadia margin based on seismic reflection and refraction data. Other studies have delineated the southern edge of the Gorda plate using gravity anomalies (Jachens and Griscom, 1983), the northern progression of late Cenozoic volcanic activity in the Coast Ranges (Wilson, 1989), local earthquake travel times (Verdonck and Zandt, 1994), and seismic profiling and gravity (Beaudoin et al., 1998) (Figure 3-63a). Beaudoin et al. (1998) located the southern edge of the Gorda slab from analyses of a 155-mile- (250-km-) long, north-south seismic refraction-reflection profile across a region in northwestern California presumed to have been modified by the passage of the Mendocino triple junction. WLA concludes that the data of Beaudoin et al. (1996; 1998) provide the highest resolution imaging available for the location and geometry of the southern boundary of the Gorda plate. To determine the source-to-site distance we located the point defined by the intersection between the down-dip limit of the transition zone derived by Fluck et al. (1997) and the southern edge of the Gorda plate as determined by Beaudoin et al. (1998) (Figure 3-61). From trigonometric relations, the depth to this point 12.4 miles (20 km) and the horizontal distance between this point and the two dam sites provide source-to-site distances of approximately 100 miles (160 km) (for Golden Gate and Sites) (Figure 3-63a).

Intraplate Sources

The Mendocino triple junction region is one of the most seismically active areas in the western United States. A large percentage of the seismic activity in the Mendocino region occurs in the subducting Gorda slab, which is shortening in a north-south direction in response to compression imposed by buttressing of the Pacific plate along the Mendocino fault (Figure 3-59). Evidence of S-curved magnetic anomalies and densely distributed seismicity in the Mendocino region led Silver (1971) and Wilson (1989) to argue that internal deformation of the southern edge of the Gorda plate is accommodated by northeast-southwest oriented left-lateral shearing subparallel to the spreading fabric. This hypothesis is consistent with the distribution of aftershocks and first motion studies following the 1980 Ms 7.2 Eureka earthquake that ruptured a 75-mile (120-km-) long left-lateral fault in the Gorda plate (Smith et al., 1993).

The largest instrumentally recorded intraplate earthquake in the Gorda plate is the 1980 Eureka earthquake. Surface-wave magnitude for this event was estimated at Ms 7.2 (Smith et al. 1993), and estimates of the maximum moment magnitude are Mw 7.3 to 7.4 (Dengler et al., 1992; Velasco et al., 1994). Two other large earthquakes, the July 13, 1991 Mw 6.8 and the August 17, 1991 Mw 7.1 events, also ruptured conjugate strike-slip faults accommodating north-south shortening in the internally deforming Gorda plate (Velasco et al., 1994). Following Dengler et al. (1992), WLA conservatively concludes that intraplate earthquakes in the subducting Gorda plate may be as large as Mw 7.5. Although the largest earthquakes appear to have strike-slip mechanisms and occur north and northwest of the Mendocino triple junction (Smith et al., 1993; Wang and Rogers, 1994), WLA cannot preclude Mw 7+ earthquakes in the Gorda slab at depths greater than 19 miles (>30 km), and as much as 93 miles (150 km) east of the subduction zone (Beaudoin et al., 1996). For example, Weaver and Shedlock (1996) estimated a 28-37 (45-60 km) source depth for Gorda slab events. WLA believes that large intraplate earthquakes at depths greater than 19 miles (30 km) are plausible in light of the February 28, 2001 Mw 6.8 Nisqually earthquake that occurred 32 miles (52 km) beneath Olympia, Washington within the subducting Juan de Fuca plate.

WLA calculates the closest distance between the DWR dam sites and seismic events in the slab from trigonometric relations between the horizontal distance to the southeastern corner of the Gorda plate, and depth to the slab. Based on seismic imaging by Beaudoin et al. (1996, 1998), the closest horizontal distance from the dam sites and southeasternmost edge of the subducted Gorda slab is approximately 40 miles (65 km) (Figure 3-60). The minimum estimated depth to the top of the slab, determined from data in Weaver and Shedlock (1996) and the results of new work performed for the Sites study (Chapter 4), is 28 miles (45 km). The closest straight-line distance through the crust between the dam sites and the southern edge of the subducted Gorda slab is thus 50 miles (80 km).

Great Valley Fault

As discussed in Section 2.3 of WLA's report they interpret that the western edge of the Sacramento Valley is underlain by a system of blind thrust faults that dip west beneath the Coast Ranges. These faults lie within a zone of contractional deformation that Wong and Ely (1983) and Wong et al. (1988) called the "Coast Ranges-Sierran Block Boundary Zone". Subsequent workers have referred to the system of blind thrust faults within this zone as the "Great Valley fault" (Working Group on Northern California Earthquake Potential, 1996; CDWR, 1999). For convenience, WLA adopts the latter term for this report, with the understanding that the "Great Valley fault" is a system of geometrically and structurally distinct thrust-fault segments rather than a single continuous fault (Wakabayashi and Smith, 1994; O'Connell and Unruh, 2001. A segment of the Great Valley fault beneath the Coalinga anticline in the western San Joaquin Valley was the source of the M6.5 1983 Coalinga earthquake (Wentworth and Zoback, 1989). Recent investigations by U.S. Bureau of Reclamation

(WLA, 1997; O'Connell and Unruh, 2000) have documented evidence for Quaternary activity of segments of the Great Valley fault in the western Sacramento Valley south of the Sites and Golden Gate dam sites. In particular, O'Connell and Unruh (2000) interpreted that the moderate-magnitude 1892 Winters-Vacaville earthquake sequence occurred on a structural segment of the Great Valley fault in the southwestern Sacramento Valley.

WLA recognizes at least five discrete geometric segments of the Great Valley fault system along the northwestern Sacramento Valley margin between the towns of Williams and Orland (Figure 3-54; see Appendix A for additional discussion). From south to north, the segments are informally designated as follows:

- Bear Valley Segment
- Funks Segment
- Willows Segment
- Elk Creek Segment
- Orland Segment

The Funks segment (Figure 3-54), which is the closest segment to the dam sites, exhibits a tectonic wedge geometry. That is, there is a ramp-flat transition beneath the Fruto syncline that has produced some fault-bend folding of the hanging wall block, and backthrusting has occurred along the Salt Lake fault to accommodate underthrusting of the hanging wall block beneath the western Sacramento Valley margin (Figure 3-2; Section 3.3). In contrast, the Bear Valley segment to the south, as well as the Willows, Elk Creek and Orland segments to the north are characterized by fault-propagation folding. This occurs as displacement on the thrust fault is consumed by folding of the hanging wall block, with no significant backthrusting or wedging at the thrust tip) (Appendix A). The Willows, Elk Creek, and Orland segments progressively steepen northward and the eastern limit of deformation steps abruptly eastward moving north of the boundary between the Elk Creek and Orland segments (Figure 3-54).

Funks Segment, Great Valley Thrust Fault

Length of the Funks Segment

The array of 2-D seismic reflection lines available for the Sites study (Appendix A) indicate that the northern termination of the Funks segment lies between Hunters and Logan Creeks (Figure 3-54) (Appendix A). The southern segment boundary underlies the S-2 fault (Section 3.2). The Funks segment steps down to the Bear Valley segment by about 1 mile (1.6 km) across the southern segment boundary. Total length of the Funks segment measured between its northern and southern terminations is about 11 mi (17km).

Activity of the Funks Segment

The Great Valley fault is a blind thrust fault, and is not exposed at the earth's surface. Standard paleoseismic methods of trenching the fault to assess recency and timing of surface-rupturing events cannot be used to evaluate the activity of the Great Valley fault. Consequently, we use indirect lines of evidence to assess activity, including trenching investigations of secondary faults like the Salt Lake fault that are genetically related to the Great Valley fault, and geomorphic studies of surface uplift and folding related to slip on the fault at depth. Indirect lines of evidence for activity or non-activity of the Funks segment are presented in the following sections. WLA's detailed analysis of the Late Quaternary incision of the Coast Ranges west of the Fruto syncline and deformation of fluvial terraces and morphology along Hunters Creek is evidence for progressive growth of the Sites anticline in mid (?) to late Quaternary time. WLA in turn interprets this as indirect evidence for mid- to late Quaternary activity on the underlying Funks segment of the Great Valley fault.

This analysis in conjunction with activity of the Salt Lake fault has led WLA to the following conclusions:

1) The Salt Lake fault has produced multiple late Quaternary surface ruptures (Section 3.4.2);

2) There is localized Quaternary uplift and fluvial incision of the eastern Coast Ranges and foothills region above the ramp in the Funks segment;

3) Mid (?) to late Quaternary fluvial terraces are folded about the axis of the Sites anticline; and

4) The modern channel of Hunters Creek shows evidence of being perturbed by growth of the Sites anticline, and possibly by movement on the Salt Lake fault.

Based on these observations, WLA concludes that the Funks segment of the Great Valley fault is an active seismic source. This interpretation is consistent with evidence for late Quaternary activity of segments of the Great Valley fault about 28 miles (45 km) south of the DWR dam sites (Unruh and Moores, 1992; Unruh et al., 1995). It is also consistent with the style and timing of deformation observed elsewhere in the Coast Ranges-Sierran Block Boundary Zone (Wong et al., 1988).

Bear Valley Segment, Great Valley Fault

The Bear Valley segment is the next discrete fault segment of the Great Valley fault south of the Funks segment. The fault is imaged in seismic line SV-12 as a west-dipping reflector south of the S-2 fault that juxtaposes east-dipping strata of the Great Valley Group above against a package of bright, west-dipping reflectors below (Appendix A). The Bear Valley segment flattens abruptly eastward beneath the western Sacramento Valley. The Bear Valley segment also is imaged on line 807 as a west-dipping feature that similarly juxtaposes oppositely dipping reflectors (Appendix A). From preparation of a structure contour map of the Great Valley fault system in the northwestern Sacramento Valley, WLA interprets that the strike of the Bear Valley segment is about due north-south (Figure 3-54).

Length of the Bear Valley Segment

The northern boundary of the Bear Valley segment is interpreted to coincide with the S-2 fault, and is imaged directly by seismic line SV-12 (Appendix A). The southern boundary probably lies south of line 807 and is not imaged directly by seismic reflection profiles acquired for the Sites study. From inspection of Shell line 806 (published in Constenius et al., 2000), which crosses the southern end of the Wilbur Springs anticline south of line 807, WLA interprets that the southern boundary of the Bear Valley segment lies between lines 807 and 806. The dip discordance that WLA interprets to be the thrust fault in line 806 cannot be correlated with the Bear Valley segment without significantly changing the strike of the fault between line 807 and 806. WLA thus infers that the thrust faults imaged in lines 807 and 806 are two different structures, and that the southern boundary of the Bear Valley segment is located between the two seismic lines near latitude N 39° 07'.

WLA interprets the location of the segment boundary by assessing variations in patterns of late Cenozoic uplift along the western Valley margin. Notable physiographic changes near latitude N 39° 07' include the northern termination of a range of low hills along the western Sacramento valley margin west-southwest of Williams that are underlain by uplifted and folded Tehama Formation strata, as well as the southern termination of Bear Valley and Antelope Valley. In particular, the abrupt northern termination of the late Cenozoic hills west-southwest of Williams indicates that an abrupt boundary is present at depth in the geologic structures responsible for their uplift. WLA interprets the northern termination of the hills, which coincides with east-draining Salt Creek, to be the surface expression of the southern Bear Valley segment boundary. WLA adopts a length of 14.4 miles (23 km) for the Bear Valley segment, which is the distance between the S-2 fault and the northern end of the hills.

Activity of the Bear Valley Segment

WLA did not perform detailed studies to evaluate activity of the Bear Valley segment of the Great Valley fault. WLA conservatively assumes that this segment is active because it lies between the active Funks segment to the north (Section 3.4.4.1), and the tectonically active Rumsey Hills region to the south (Unruh et al., 1995).

10.4 Project Site Faults

Two primary sets of surface faults are mapped in the vicinity of the dam sites:

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

2) North-striking faults that are generally parallel to bedding. The most laterally continuous example of these structures is the east-dipping Salt Lake thrust fault (Figure E-1), which is parallel to, and directly east of, the axis of the Sites anticline. The Salt Lake fault is approximately 0.9 miles (1.4 km) west of the Golden Gate Dam site and the southern end of the fault is approximately 0.7 miles (1.15 km) west of the Sites Dam site (Figure E-1). The fault trace is mapped through the proposed Saddle Dam site 2. Another example of a bedding-parallel fault is the informally named east-dipping S-3 fault, which is exposed in the Sites rock quarry just north of Sites road approximately 2000 feet (600 m) east of the Sites Dam site (Figure E-1).

Based on analysis of seismic reflection data and surface geologic relationships, WLA interprets that the Fruto syncline, Sites anticline, and surface faults described above are underlain by a blind, west-dipping thrust fault (Figure E-2). This structure is informally named the Funks segment of the Great Valley fault. The Funks segment is about 10.6 miles (17 km) long, dips about 27° toward the west beneath the Fruto syncline, and flattens eastward beneath the Sites anticline on seismic reflection profiles. At the latitude of the Sites and Golden Gate Dam sites, the Sites anticline is interpreted to be a fault-propagation fold developed above a blind, east-dipping thrust fault that splays upward from the low-angle Funks segment. This east-dipping blind thrust fault and the overlying Sites anticline accommodate shortening of the crustal block above the west-dipping Funks segment (Figure E-2). The Salt Lake fault also splays upward from the gently west-dipping part of the Funks segment. The intersection of the Salt Lake fault with the blind Funks segment forms an east-tapering underthrust tectonic wedge beneath the western valley margin. The S-3 fault is interpreted to be a bedding-parallel thrust fault that has accommodated shearing of the sedimentary rocks during uplift and eastward tilting along the valley margin (Figure E-2).

The northeast-striking GG-1, GG-2, GG-3 and S-2 faults are interpreted to be tear faults in the upper crust associated with the southern structural boundary of the Funks segment. Based on analysis of seismic reflection data, WLA interprets that another distinct segment of the Great Valley fault, here referred to as the Bear Valley segment, is present south of the Funks segment. The Bear Valley segment is about 14 miles (23 km) long and strikes almost due north-south. Based on available reflection seismic data, WLA interprets that the Bear Valley segment has a constant west dip, in contrast to the ramp-flat geometry of the Funks segment. The hanging wall of the Bear Valley segment appears to be deformed by simple fault-propagation folding rather than tectonic wedging because an east-dipping backthrust similar to the Salt Lake fault has not been recognized or mapped along the entire length of the segment (Brown and Rich, 1961; Rich, 1971).

Probability of Surface Rupture on Project Site Faults

Salt Lake Fault

The Salt Lake fault is mapped by Brown and Rich (1961) as passing through the proposed Saddle Dam site 2. Based on evidence for late Quaternary surface-rupturing events from paleoseismic trenching studies, WLA concludes that surface rupture may occur on the Salt Lake fault during earthquakes on the Funks segment of the Great Valley thrust fault system. Locations of trench sites for the Salt Lake fault are illustrated on Figures 3-34 and 3-35 appendixed to this report. Restoration of faulted contacts in late Quaternary deposits overlying the bedrock surface indicates that about 16 inches (40 cm) of reverse displacement may occur during a single surface rupturing event on the Salt Lake fault. The subsurface relationships conservatively can be interpreted as evidence that up to 43 inches (110 cm) of displacement has occurred during a single event, but WLA does not favor this interpretation because palinspastic restoration of stratigraphic and structural relations is more reasonably accomplished through a series of smaller displacements. Results from elastic dislocation modeling of triggered, aseismic slip on the Salt Lake fault associated with the maximum earthquake on the Funks segment suggest discrete displacements of about 4.5 inches (11 cm). WLA concludes that surface displacements on the Salt Lake fault during a moderate to large earthquake on the Funks segment of the Great Valley fault are likely to range from 4.5 inches to 16 inches (11 cm to 40 cm).

Northeast-Striking Dextral or Tear Faults

Locations of fault trenches, trench logs, and detailed discussions of fault trench analysis are available in the WLA report appendixed to this report as a CD. Some of WLA's figures showing fault trench locations have been reproduced and are appendixed to this report. Paleoseismic trench investigations for this study document no Holocene surface displacement on the GG-1, GG-2, GG-3 and S-2 faults. Locations of trench sites for the aforementioned tear faults are illustrated on Figures 3-9, 3-18, and 3-29 appendixed to this report. WLA's preferred kinematic model for the structural evolution of the area directly around the dam sites, however, postulates that movement on these faults may be related to movement at depth on the blind Funks segment of the Great Valley fault. Given this structural model, WLA's conclusion that the Funks segment is an active seismic source is in apparent contradiction with evidence for no activity of the northeast-striking dextral faults. This apparent contradiction arises in part from poor age constraints on the timing of late Quaternary events on the Funks segment and the northeast-striking faults.

Paleoseismic data provide indirect evidence for a minimum of three earthquakes on the Funks segment during the past 30,000 to 70,000 years. It is possible that the last Funks segment earthquake occurred in latest Pleistocene time (i.e., about 10,000 years ago), just prior to deposition of undeformed early Holocene sediments overlying the GG-1, GG-2, GG-3 and S-2 faults, which were exposed in trenches and documented during this investigation. Thus, the oldest deposits available for evaluating activity of the GG-1, GG-2, GG-3, and S-2 faults may post-date the last surface-faulting event on these structures. Alternatively, it is possible that the GG-1, GG-2, GG-3, and S-2 faults are not kinematically related to the Great Valley fault or, if they are that they are not reactivated during every earthquake on the Funks segment.

Given these uncertainties, WLA conservatively assumes that the GG-1, GG-2, GG-3 and S-2 faults may accommodate minor displacement during a moderate to large earthquake on a proximal segment of the Great Valley fault (i.e., the Funks and Bear Valley segments). To assess the potential magnitude of triggered surface displacement, WLA used three different approaches, which are described as follows:

a. Surface Displacement as a Fraction of Coseismic Slip on the Funks Segment

For this approach, WLA assumes that the ratio of incremental slip on the dextral faults to slip on the Funks segment of the Great Valley thrust system during an earthquake is the same as the ratio of total, cumulative slip on these structures. WLA estimated cumulative slip through analysis of seismic reflection data and map-scale geologic structure. WLA assumes that 3.3 feet (1 m) of slip may occur on the Funks segment during the maximum earthquake (Mw 6.6). This assumption is consistent with estimates of about 4 feet (1.3 m) for the average coseismic slip during the M 6.7 1994 Northridge earthquake (Wald et al., 1996), which occurred on a blind thrust fault in southern California. With these assumptions, the predicted surface displacements on the northeast-striking faults associated with 3.3 feet (1 m) of slip on the Funks segment are:

Fault GG-1: 0.4 inches + 0.12 inches (1 cm + 3 mm)

Fault GG-2: 2 inches + 0.2 inches (5 cm + 5 mm)

Fault GG-3: 2.4 inches + 0.12 inches (6 cm + 3 mm)

Fault S-2: 0.8 inches + 0.24 inches (2 cm + 6 mm)

A more conservative assumption is that the total dextral slip distributed over all of the faults in the previous example instead may be concentrated on a single northeast-striking fault during a given earthquake. The summed dextral displacement on the GG and S faults for 3.3 feet (1.0 m) of coseismic slip on the Funks segment in the previous example is 5.5 inches (14 cm), with a combined uncertainty of about 1 inch (+ 2 cm). WLA attaches a low likelihood to this scenario.

b. Magnitude Of Dextral Slip As A Function Of Tectonic Wedging

In this approach, WLA considers the possibility that dextral slip on the northeast-striking faults accommodates northeast propagation of the tectonic wedge structure created by the intersection of the Salt Lake fault with the blind Funks segment of the Great Valley fault (Figure 2). WLA assumes that the component of coseismic slip on the east-dipping Salt Lake fault, resolved in the horizontal plane, represents incremental propagation of the tectonic wedge during an earthquake. Dextral slip on the northeast-striking faults accommodates differential propagation of the wedge above the Funks and Bear Valley segments. Based on the analysis and discussion in the previous sections, WLA assumes that the range of likely displacement on the Salt Lake fault is about 4 to 16 inches (11 to 40 cm). WLA also assumes that the fault dips parallel to bedding. Mapping by Brown and Rich (1961) indicates that Upper Cretaceous strata adjacent to the Salt Lake fault dip about 60° to 80° in the vicinity of Hunters Creek. The horizontal component of motion accommodated by 4 to 16 inches (11 to 40 cm) of slip on a fault dipping 60° to 80° ranges from about 1 to 8 inches (2 to 20 cm).

This inferred horizontal displacement could be fully accommodated by dextral slip on a single fault, or it could be distributed across faults GG-1, GG-2, GG-3 and S-2. In the former scenario, the maximum displacement is 8 inches (20 cm). For the latter scenario, the simplest model is to assume that slip is distributed equally across the four dextral faults. With this assumption, coseismic slip on each of the four faults could range from about 0.25 inches to 2 inches (0.5 to 5 cm). Alternatively, the slip could be distributed among the four faults in the same proportions as the total dextral slip is distributed, similar to the model discussed in the previous section. For this model, 1 to 8 inches (2 to 20 cm) of total dextral shear is distributed among the faults as follows:

Fault GG-1: about 0.1 inches to 0.6 inches (0.2 to 1.4 cm)

Fault GG-2: about 0.7 inch to 3 inches (0.7 cm to 7 cm)

Fault GG-3: about 0.4 inches to 3.4 inches (0.9 cm to 8.6 cm)

Fault S-2: about 0.2 inches to 1.2 inches (0.3 cm to 3 cm)

The extreme range of surface displacement on the northeast-striking dextral faults thus predicted by this model is about 0.1 inches to 8 inches (0.2 to 20 cm). The high end of this range is based on the assumption that all of the differential east-directed displacement of the tectonic wedge is accommodated by dextral slip on a single northeast-striking fault. WLA favors distribution of the total wedge displacement across the GG-1, GG-2, GG-3 and S-2 faults, and thus their preferred range of coseismic displacement on an individual fault for this model is about 0.25 inches to 3.4 inches (0.5 to 9 cm).

c. Elastic Dislocation Modeling

In this approach, WLA uses numerical modeling to evaluate potential coseismic slip on the northeast-striking dextral faults. The model assumes that dextral slip on the faults releases elastic strain of the hanging wall block produced by coseismic slip on the blind Funks and Bear Valley segments of the Great Valley thrust fault. All numerical models distances were scaled to duplicate the geometry and depth of faults and their relative distances as inferred from analysis of geologic maps (Brown and Rich, 1961) and seismic reflection data (Appendix A). WLA tested a variety of models to assess a range of potential surface displacements on the northeast-striking GG and S faults. The model results consistently indicate that, for a variety of rupture scenarios on the Funks and Bear Valley segments, maximum triggered or sympathetic surface displacement on the GG and S faults is about 2.5 inches (6 cm).

d. Discussion and Conclusions

The two kinematic models that explicitly relate the magnitude of slip on the blind thrust fault to slip on the northeast-striking faults in the hanging wall block both predict up to about 3 inches (about 8 cm) of surface displacement on the GG and S faults. The tectonic wedge model predicts maximum displacements up to about 8 inches (20 cm) if all of the deformation is accommodated by slip on a single fault rather than distributed across several faults. Alternatively, the numerical models based on elastic dislocation theory predict about 2.5 inches (6 cm) of displacement. Based on these models, therefore, WLA concludes that maximum surface displacements on the GG and S faults probably will not exceed about 8 inches (20 cm), and are likely to be lower (on the order of about 2.4 to 4 inches (i.e., 6 to 10 cm).

WLA emphasizes that their assumption that the northeast-striking dextral faults may accommodate triggered slip during large earthquakes on proximal segments of the Great Valley fault is conservative, because paleoseismic studies provide positive evidence for no surface-faulting activity on these structures during the Holocene.

10.5 Seismicity and Ground Motion

Seismicity

As mentioned in Section 10.1, DWR, ND completed the Phase I report and WLA completed the Phase II report for this subject. Details are available in both documents and the following is a summarization of data from these two.

The seismicity of the western Sacramento Valley and Coast Ranges has been recorded by a number of different agencies over the past 100 years. These agencies include the University of California at Berkeley, the California Department of Conservation, the U.S. Geological Survey, and the Department of Water Resources. Earthquakes with magnitudes as small as M1 and M2 have been recorded in the Project area since the installation of the Northern California Seismic Network began in 1975. DWR in 1991, as part of the Red Bank Project study, worked with the USGS to install four additional seismic stations in the area. The USGS provided DWR with an analysis of the data by the network. According to the USGS, the number of earthquakes recorded by the network is typically 3 or less and often none per month.

WLA evaluated earthquake activity in northwestern California to identify potential seismic sources capable of generating significant ground motion at the proposed DWR dam sites, and to further characterize the seismotectonic setting of the study region. The boundaries of the seismicity study region were selected to include potential seismic sources within 62 miles (100 km) of the dam sites, and to provide sufficient data to evaluate the seismic activity of geologic structures identified as potentially significant in earlier phases of this study. The study region extends from latitude 38 to 41 degrees north and from longitude 124.5 to 120.5 degrees west. A catalog of earthquake locations and magnitudes was compiled for the Sacramento Valley region covering the area shown on Figure 4-1.

For the purpose of this study, the earthquake record can be divided into two time periods, herein referred to as the historical period (1850 through 1969), and the instrumental period (1970 through 2000). The historical period covers the time prior to the installation of short-period seismic networks, which generally occurred in the 1970's for much of the western United States (Engdahl and Rinehart, 1991). In California, modern networks have been operating since 1967 (Oppenheimer et al., 1992). By 1970, network coverage in northern California was sufficient for earthquakes to be recorded on three or more stations, a necessary requirement for computationally rigorous hypocentral determinations (Klein et al., 1988). Earthquake activity in the study region currently is monitored by the Northern California Seismic Network (NCSN) and by seismograph stations operated by the University of California, Berkeley (UCB).

Sources for the instrumental catalog are NCSN and UCB. The instrumental seismicity catalog includes data on earthquake origin time, location, magnitude, number of observations, location error statistics, and an overall hypocentral location quality assessment. Merging the NCSN and UCB catalogs produced an integrated seismicity catalog. Events should be treated cautiously because accurate magnitude calculations depend on an average of well-distributed station estimates and the validity of applying Richter's southern California attenuation relationship to events in other regions. These and other problems related to consistent estimates of earthquake magnitude between the various reporting agencies were not resolved in the Sites study.

Significant Regional Historical Earthquakes

This section reviews significant historical earthquakes in the regional seismicity study area, exclusive of the Sacramento Valley. These earthquakes illustrate and help characterize the seismic potential of source zones in areas adjacent to the Sacramento Valley that may affect the project area. Potential regional seismic sources include: the Bartlett Springs fault zone in the northern Coast Ranges to the west of the Sacramento Valley; the Cascadia subduction zone to the northwest; and the Sierran Nevada range to the east.

Moderate to strong earthquakes have been reported in northern California since the mid 1800's. Historical seismicity in the study region is summarized on Figure 4-2. The red pentagon symbols on the map represent the location of 19th century earthquakes taken from Toppozada et al. (1981). The location and magnitude of these earthquakes are based on reports of intensities of ground shaking. The green squares (magnitudes reported) and triangles (no magnitude reported) represent earthquake epicenters from the UCB catalog for the period 1910 to 1950. These event locations were determined using data from the seismographs in the region. The blue squares (magnitudes reported) and triangles (no magnitudes reported) represent earthquake epicenters from 1950 through 1969. The installation of a higher-gain seismograph at Mineral in 1949 considerably improved the location of earthquakes in this period (Uhrhammer, 1991). Significant historical earthquakes that occurred in relatively close proximity to the DWR dam sites are discussed in WLA's Sections 4.2.3.1 (North Coast Ranges), 4.2.3.2 (Western Sierra Nevada), and 4.2.3.3 (Coast Ranges – Sierran Block Boundary Zone).

Some of the more prominent events are: the M 6.2 1898 Sonoma County, the M 6.5 Mendocino County, the M 6.6 1954 Arcata, the M 5.7 1940 Chico, the M 6 1889 Antioch, and the three M 5.5 – 6.4 1892 Winters-Vacaville events. For details of these events and others see Sections 4.2.3.1 through 4.2.3.3. The Winters-Vacaville sequence of events is of most importance because they appear to be associated with the Great Valley fault. O'Connell et al. (2001) conclude that the likely sources of the 1892 Winters-Vacaville earthquake sequence were blind, west-dipping segments of the Great Valley fault.

Seismic Source and Maximum Earthquake

The Great Valley fault, as discussed in WLA's report, is the potentially seismogenic fault that accommodates most of the shortening within the CRSBZ. The Funks and Bear Valley segments are the structural segments of the Great Valley fault closest to the Sites and Golden Gate Dam sites. Other segments of the Great Valley fault are known or inferred to have generated the 1983 Coalinga and 1892 Winters-Vacaville earthquakes (e.g., O'Connell et al., 2001). Neotectonic investigations have documented evidence for Quaternary growth of folds overlying segments of the Great Valley fault beneath the Rumsey Hills and Dunnigan Hills 27 miles (44 km) south of the Sites and Golden Gate Dam sites. Thus, there is a general consensus among the seismotectonic community that the Great Valley fault is an active or potentially active seismic source in the modern transpressional tectonic setting.

Data acquired and analyzed for this study provide indirect evidence for late Quaternary activity of the Funks segment of the Great Valley thrust fault system. These data include:

1) Evidence for late Quaternary surface rupture on the Salt Lake fault from paleoseismic trenching investigations. Specifically, WLA interprets data from trenches excavated across the fault to indicate that at least one and probably three or more surface ruptures have occurred on the Salt Lake fault in the past 30,000 to 70,000 years. If it is assumed that surface-rupturing events associated with earthquakes on the Funks segment have a regular recurrence, then this evidence strongly suggests that at least one surface-rupturing event probably has occurred in the past 35,000 years. As discussed previously, WLA interprets that the Salt Lake fault terminates down dip against the Funks segment of the Great Valley fault (Figure E-2). If this interpretation is correct, then surface displacement on the Salt Lake fault is derived from slip at depth on the Funks segment. WLA thus concludes that stratigraphic and structural relations exposed in trenches across the Salt Lake fault provide indirect evidence of at least one earthquake on the blind Funks segment of the Great Valley fault during the past 35,000 years.

2) Morphometric analysis of regional topography, incorporating GIS analysis of available digital elevation models, shows patterns of topographic residuals coincident with the Sites anticline and Salt Lake thrust fault, and which are consistent with localized late Quaternary uplift above the Funks segment.

3) Morphometric analyses of streams draining eastward across the Coast Ranges foothills, in general, and the Sites anticline, in particular, reveal patterns of localized fluvial incision and channel morphology consistent with active surface uplift above the Funks segment of the Great Valley fault.

WLA therefore concludes that the Funks segment of the Great Valley thrust system is an active seismic source, according to criteria for fault activity adopted by the Division of Safety of Dams (DSOD, 1995; Fraser, 1997).

Although WLA did not perform similar investigations of the Bear Valley segment south of the dam sites, they conservatively conclude that this segment also is an active fault because it lies within a recognized zone of late Cenozoic tectonic activity (i.e., the "Coast Ranges-Sierra Block Boundary Zone"). It also lies between the active Funks segment to the north, and the tectonically active Rumsey Hills-Dunnigan Hills region to the south (Unruh and Moores, 1992; Unruh et al., 1995).

The controlling seismic source for both dam sites is the Bear Valley segment of the Great Valley fault system (Figure E-3). The selection of the Bear Valley segment as the controlling seismic source is based on comparison of the response spectrum for a maximum earthquake on this fault with response spectra for earthquakes on other active seismic sources within a 31-mile (50-km) radius of the dam sites (Chapter 6). The Bear Valley segment of the Great Valley fault is imaged by seismic reflection data as a west-dipping feature in the 3 to 6 mile (5 to 9 km) depth range that juxtaposes east and west-dipping strata against a package of underlying bright, high amplitude, subhorizontal to west-dipping reflectors. Based on analysis of map-scale geologic structures and reflection seismic data, WLA interprets that the Bear Valley segment is about 14 miles (23 km) long, strikes north-south, and dips about 21° to the west. If the Bear Valley segment maintains a constant dip to the brittle-ductile transition depth at a depth of about 9 miles (15 km), then the total potential rupture width is about 14 miles (23 km). Given a 14 mile (23 km) rupture length and 14 mile (23 km) rupture width, WLA calculates a rupture area of 207 square miles (529 km^2) for the Bear Valley segment of the Great Valley fault. Empirical regression relations in Wells and Coppersmith (1994) give an associated Maximum Credible or Design Earthquake magnitude of M_w 6.8 located 4.8 and 4.4 miles respectively from the Golden Gate and Sites Dam sites. See Chapter 6 for details on the Maximum Earthquake Magnitudes.

The structural model adopted for this study relates slip on northeast-striking faults (GG-1, GG-2, GG-3, and S-2) that pass through or near the dam sites to differential shortening in the upper crust above the structural boundary between the Funks and Bear Valley segments of the Great Valley fault. WLA interprets that the northeast-striking faults terminate downward against the Funks segment of the Great Valley fault, and act as tear faults to accommodate greater northeast translation and shortening of the hanging wall block of the Funks segment relative to the Bear Valley segment (Figure E-4). WLA's preferred interpretation is that the GG-1, GG-2, GG-3, and S-2 faults move sympathetically during moderate to large magnitude earthquakes on the Funks thrust ramp, and probably do not behave as independent seismic sources. Elastic dislocation models support this interpretation, and suggest that minor triggered movement also may occur on these faults during earthquakes on the Bear Valley segment.

Although WLA concludes that the northeast-striking faults are not independent seismic sources, they may be a source of aftershocks following an earthquake on the Funks or Bear Valley segments. WLA calculates a response spectrum for the largest potential aftershock at zero distance for comparison with the response spectrum for the controlling event on the Bear Valley segment. Based on our analysis of seismic reflection data, WLA interprets that the northeast-striking faults are confined to the hanging wall block of the Funks segment and that their maximum rupture depth is about 5 km (Figure E-4). The exception is fault GG-1, which has such a short surface trace that WLA interprets it to have a maximum depth of 2-3 km. From regression relations in Wells and Coppersmith (1994), WLA calculates an associated range of aftershock magnitudes from M_w 5.3 to M_w 5.4. WLA conservatively adopts M_w 5.4 as the maximum magnitude for aftershocks on faults GG-2, GG-3, and S-2.

The two models utilized by WLA in Chapter 6 explicitly relate the magnitude of slip on the blind thrust fault to slip on the northeast-striking faults in the hanging wall block. Both predict up to about 3.4 inches (1 to 9 cm) of surface displacement on the GG and S faults. The first model predicts maximum displacements up to about 5.5 inches (14 cm) if all of the deformation is accommodated by slip on a single fault rather than distributed across several faults. Maximum surface displacements of about 8 inches (20 cm) are predicted by the tectonic wedge model (Section 5.2.2.2), using the most conservative assumptions about coseismic slip on the Salt Lake fault and distribution of deformation across the GG and S faults. WLA prefers lower values of about 0.25 inches to 3.4 inches (0.5 to 9 cm) predicted by this model with less conservative assumptions. These lower values are more consistent with the results of the first model and the elastic dislocation models. Based on results obtained from all three modeling approaches, WLA concludes that maximum surface displacements on the GG and S faults probably will not exceed about 8 inches (20 cm), and are likely to be lower (on the order of about 2.4 to 4 inches (i.e., 6 to 10 cm).

Ground Motions

Chapter 7 in WLA's report provides an evaluation of the estimated strong ground shaking at the Sites and Golden Gate dam sites during maximum earthquakes from active seismic sources in the study region. The vibratory ground motion produced by an earthquake can be quantitatively described in a variety of ways. Release of stored elastic strain during an earthquake causes the ground surface at a point to oscillate in a range of frequencies, each of which is persistent for a certain length of time as the earthquake waves pass by. The horizontal and vertical acceleration of a point on the ground due to shaking varies as a function of earthquake magnitude and type, regional and local geology, site-source distance, and frequency of vibration. Given a record of the ground acceleration versus time, the horizontal and vertical accelerations can be integrated to obtain horizontal and vertical velocities and displacements of the ground surface. It is common engineering practice to characterize earthquake ground motion by plotting the maximum magnitude of the response of a simple one-degree-of-freedom oscillator as a function of vibration period and damping ratio of the oscillator. This type of plot is known as a *response spectrum* (Chopra, 1981). Response quantities that are computed include absolute acceleration, relative velocity, relative displacement, and basal shear.

WLA's study calculated earthquake ground motions that are presented in a series of response spectra that plot spectral absolute acceleration (in units of g, the acceleration due to gravity) as a function of vibration period (in seconds) for a damping ratio of 5% of critical. Chapter 7, Section 7.2 describes published empirical attenuation relations used to derive spectral acceleration as a function of earthquake magnitude and site-source distance. Section 7.3 describes the selection of the controlling source, which is the seismic source that produces the maximum levels of strong ground shaking at the Sites and Golden Gate Dam sites. Section 7.4 presents the maximum earthquake response spectra calculated for the controlling seismic source.

The response spectra presented in WLA's report do not describe displacements or strains that may be experienced by engineered structures at the Sites and Golden Gate dam sites. These quantities cannot be computed without accounting for the duration of shaking at a given period, and without a priori knowledge or modeled estimate of the vibration response of the structure itself. Using published empirical attenuation relations, it is common to obtain relatively high spectral accelerations (i.e., > 1g) at periods in the range of about 0.1 sec to 1 sec for moderate magnitude earthquakes that occur within 10 to 20 km of a site. In terms of evaluating the stability of a structure, these high values at shorter periods may be less significant than lower accelerations at longer periods, depending on the actual size, geometry and design of the structure.

WLA adopted the following two-step approach for computing response spectra for earthquakes on the Bear Valley segment of the Great Valley fault:

1) Calculate the 84th-percentile, 5%-damped response spectra from the Abrahamson and Silva (1997) and Sadigh et al. (1997) attenuation equations, and average the results: and

2) Modify the resulting response spectrum for fault-rupture directivity effects using the procedure in Somerville et al. (1997), as appropriate.

These spectra are to be used in the design of major dams. The directivity effect evaluated in step 2 of the ground motion analysis impacts the duration of shaking and the amplitude of long period motion. For rupture that is directed toward the site, the ground motion is compressed in time (shorter duration) with larger long period amplitudes. An additional effect of the directivity is that there is a systematic difference in the long period ground motion on the two horizontal components when they are oriented normal and parallel to the fault strike (Somerville et al., 1997). The directivity effect produces an increase in the long period motion on the component that is orthogonal to the fault strike. There also is a corresponding decrease in the component parallel to the fault strike. This increase in the long-period motion on the fault-normal component leads to large long-period pulses in the ground motion in the forward rupture direction.

Average response spectra for the maximum earthquake on the Bear Valley segment were prepared by computing the 50^{th} and 84^{th} percentile level of 5% damped spectral acceleration from the Abrahamson and Silva (1997) and Sadigh et al. (1997) attenuation equations, as described in step 1 above. The pairs of spectra from the Abrahamson and Silva and the Sadigh et al. equations were averaged to produce the 50^{th} and 84^{th} percentile spectra in Figure E-5 (Golden Gate) and Figure E-6 (Sites). Modified 84^{th} percentile spectra showing directivity effects also are prepared (Figures E-7 and E-8); these figures also show unmodified 84^{th} percentile spectra for comparison.

Comparison of response spectra indicates that the zero period ordinate (i.e., peak ground acceleration – PGA) for the maximum aftershock is greater than the PGA for the controlling event on the Bear Valley segment by about 20%. At periods greater that 0.1 second, which is the band of interest for large engineered structures, damped spectral acceleration is significantly higher for the controlling event. The difference in PGA between the two events is not important; dams designed to a maximum earthquake (and higher ground motions at periods greater than 0.1 second) on the Bear Valley segment should not be adversely affected by an aftershock at zero distance (Chapter 6).

WLA's ground motion analysis has determined that a peak ground acceleration (PGA) of 0.8g would be generated from an MCE of M_W 6.8 on the Bear Valley segment of the Great Valley fault.

10.5.1 Reservoir Triggered Seismicity

Reservoir-triggered seismicity (RTS), which is the triggering of earthquakes by the physical processes that accompany the impoundment of reservoirs, is recognized as a potential hazard to many large dams. Worldwide, at least five earthquakes of magnitude 6 and greater have been associated with reservoir impoundment (Gupta, 1992; Seeber et al., 1995). The largest known reservoir-triggered earthquake was a M_w 6.3 at the Koyna dam in western India (Gupta and Rastogi, 1976). This earthquake (December 10, 1967) resulted in 200 deaths, over 1500 injuries, and caused considerable damage to the engineered structures in the vicinity of the dam (Gupta and Rastogi, 1976).

Because of the potential to seriously damage impoundment structures and cause catastrophic flooding, RTS has been intensively studied (Gupta and Rastogi, 1976; Simpson, 1986; O'Reilly and Rastogi, 1986). It is not clear, however, what physical mechanism predominates in the triggering of earthquakes by impoundment and under what circumstances the hazard is increased. A correlation is observed between dam height and increased seismicity, which suggests that the potential for triggering earthquakes should be considered in dam design (Packer et al., 1979). Two mechanisms are thought to be acting in the triggering of faults, acting either independently or in concert (Simpson et al., 1988; Scholz, 1990):

(1) A change in elastic stress in the underlying crust as the reservoir is filled or goes through fill and release cycles; and
(2) An increase in fluid pore pressure at depths at which earthquakes nucleate thereby reducing the effective normal stress acting on the fault plane.

The combined effects of change in elastic stress and pore fluid diffusion may explain the occurrence of earthquakes at reservoirs a number of years after initial impoundment during periods when the lake level fluctuates. For example, the Koyna earthquake occurred five and a half years after impoundment, and the M 5.3 Aswan Dam earthquake (Egypt; November 14, 1981) occurred seventeen years after impoundment (Simpson et al., 1988).

Several possible cases of reservoir–triggered seismicity in northern California have been evaluated (Allen, 1982). The best known is the M_L 5.7 earthquake at Oroville, approximate 31 miles (50 km) east of the DWR dam sites in the Sierran foothills, on August 1, 1975 (Toppozada and Morrison, 1982). Anderson et al. (1982) has suggested that an increase in seismicity in the CRSB boundary zone during a period of rapid filling of the San Luis Reservoir may be a possible case of RTS. Based on an apparent increase in seismicity during a rapid filling in the late 1950's, DWR (1978) suggested that Lake Berryessa may represent a case of RTS. In the San Francisco Bay area, Wong and Strandberg

(1996) investigated possible cases of RTS at Briones and Del Valle reservoirs. In the northern Sacramento Valley, some investigators also proposed that an increase in microseismicity at Lake Shasta during filling was an induced event (Packer et al., 1979; Baecher and Keeney, 1982). These examples are discussed in greater detail in the following two sections.

Lake Oroville, Butte County

Lake Oroville is a 3.5 million acre-foot capacity reservoir with a maximum depth of 722 feet (220 m), located in Butte County approximately 31 miles (50 km) east of the DWR dam sites (Figure 4-1). The 771-foot-high (235-m) earth-fill dam was constructed in 1967. No change in seismicity was observed during the initial filling or during the following seven years of normal operation (Toppozada and Morrison, 1986). The 1975 Oroville earthquake sequence began in late June during the summer drawdown. Following a reduction in reservoir level during the previous winter to repair the intakes to the power plant, the lake was filled rapidly by the spring runoff. The M_L 5.7 mainshock, which occurred on August 1, was preceded by two M 4+ foreshocks and followed by two M 4+ aftershocks on August 2. The aftershock sequence decayed over several months. The events occurred on the Cleveland Hills fault about 7 miles (11 km) southwest of the dam (Section 4.3.3.2.1; Lahr et al., 1976; Savage et al., 1976). The focal depth for the mainshock was probably around 5 km and most of the aftershocks were between 3 and 6 miles (5 and 10 km) deep (Langston and Butler, 1976). Fracturing at the surface was consistent with the projected plane of the aftershocks and with the sense of motion from focal mechanisms. Trenching indicated that there had been prior rupturing of this fault (Clarke, 1976). The aftershock sequence was monitored by seismographs deployed after the mainshock; consequently, the rupture plane was well identified. Focal mechanisms determined from the aftershock monitoring study exhibit predominantly normal slip on west-dipping planes (Bufe et al., 1976).

Numerous investigations have been conducted with the intention of demonstrating the link between the reservoir and the Oroville sequence. Gupta (1992) presented a summary of these studies. One mechanism proposed by Toppozada and Morrison (1982) suggested that the increase in vertical load from the impoundment acted to increase the normal stress acting on the west-dipping fault plane. During the nearly eight years of normal operation fluid from the reservoir was forced down towards the fault plane, gradually increasing the pore fluid pressure. As the pressure increased the effective normal stress restraining the fault was reduced. Rupture occurred during the summer drawdown when the load from the reservoir was reduced, releasing the strain energy stored on the fault. Toppozada and Morrison (1982) have observed that the seismicity continued during each subsequent seasonal fluctuation, at least between 1975 and 1982, but at a decreasing rate. This suggests that the strain has been relieved in the 1975 rupture zone, although not necessarily in the surrounding region.

The distance of the hypocenter from the reservoir and the length of time elapsed between impoundment and seismic strain release suggest that, if this is a case of induced seismicity, then the mechanism may have been related to a change in pore fluid pressure as well as a change in elastic stress due to loading.

Lake Berryessa

Lake Berryessa, impounded by Monticello Dam in 1957, is located in the CRSB boundary zone approximately 56 miles (90 km) south of Sites. The 234 million-cubic-meter reservoir has a maximum water depth of 279 feet (85 m) and began to fill at a rapid rate in 1958 (DWR, 1978). In 1958, 11 earthquakes occurred in the vicinity of the lake compared to an average of 1.2 events per year from 1944 to 1956 (DWR, 1978). In the following year, 1959, 4 earthquakes occurred. Subsequently, an average of 1 event per year occurred from 1960 to 1971 (DWR, 1978). Based on this pattern, DWR (1978) suggested that the increase in seismicity beginning in 1958 was a case of RTS, and that it might recur if the reservoir were significantly expanded in size. Wong and Strandberg (1996) reviewed the DWR report and, while noting the uncertainty of the earthquakes recorded before the 1970's, concluded that it is a possible case of RTS.

San Luis Reservoir

San Luis Reservoir is located in the southern CRSB boundary zone on the west side of the San Joaquin Valley near Los Banos. The 2.1 million acre-foot impoundment has a maximum water depth of 341 feet (104 m; Anderson et al., 1982). Based on records from a seismograph station installed prior to filling in 1967, the average rate of earthquake occurrence from 1966 to 1979 within 12 miles (20 km) of the reservoir was approximately 10 event per year (Anderson et al., 1982). During a period of rapid inflow in January and February 1969, 41 earthquakes were recorded in the vicinity, followed by an additional 38 events during the remainder of the year. Subsequent to this, seismicity returned to the background level (Anderson et al., 1982). Anderson et al. (1982) consider the 1969 activity to be an instance of RTS. Wong and Stranberg (1996) reviewed this work and classified the San Luis activity as a questionable case of RTS, noting that in 1974 a swarm of 11 earthquakes occurred at the southern end of the reservoir during a period when there were no significant changes in water level.

Lake Shasta

Shasta Dam was completed in 1945 to impound the 4.5 million acre-foot capacity Shasta Reservoir. The depth of the water column at the dam is approximately 525 feet (160 m). The lake began filling in December 1943. A short period seismograph (station SHS) was installed near Shasta Dam to monitor the reservoir. During 1944 a number of small earthquakes were recorded at SHS, leading some observers to add Shasta Lake to the list of possible RTS cases (Packer et al., 1979). Station SHS was operated for ten years by the U.S. Coast and Geodetic Survey and in 1952 was turned over to UCB to be included in their network. The original records for this period, which covered the intial filling of the reservoir, are apparently lost (LaForge and Hawkins, 1986). Urhammer and Wright (1985) examined the relation between the seismicity recorded at SHS in 1944 compared to the rate of seismicity during the period 1952 – 1963. They concluded that there was no statistical difference between the 1944 seismicity and the background rate. They did not observe a correlation between the rate of seismicity and intial impoundment or subsequent lake level fluctuations during this period. In 1983 additional stations were added to the region around Shasta Lake to provide increased the coverage of microseismic activity. LaForge and Hawkins (1986) reviewed these results and concluded that there was no indication of reservoir-induced seismicity at Lake Shasta.

Potential for Triggered Seismicity in the Vicinity of the Dam Sites

The probability of the occurrence of earthquakes in and around a reservoir may be increased by impoundment through the two mechanisms cited above. The effect of increase in elastic stress due to the load depends on the tectonic environment. An increase in elastic stress will increase the chances of failure on normal faults and decrease the probability of failure on thrust faults (Scholz, 1990). For vertical strike-slip faults an increase in vertical load would have no addition effect outside of increasing the pore fluid pressure. The zone of influence around a reservoir in which elastic stress changes occur may be between 6 and 9 miles (10 and 15 km; Scholz, 1990). The effect of increased pore fluid pressure may be due to diffusion through fractures driven by the load applied by the water column or a decrease in pore volume by an increase in volumetric strain from the change in elastic stress (Simpson et al., 1988). An investigation of these effects at a number of RTS sites has led Simpson et al. (1988) to suggest that they are manifested as two general types of reservoir-triggered seismicity patterns: rapid response, in which activity increases almost immediately on the first filling of the reservoir, and delayed response, in which increased activity does not occur until several seasonal filling cycles have occurred.

There are many cases of reservoir-induced seismicity in which the response to impoundment is rapid and the increase in activity is almost immediate. The response of the crust to the filling of Lake Mead is a good example. The 466-foot-high (142-m) Hoover Dam impounds Lake Mead, which began filling in 1935. Earthquake activity started in 1936. In 1937, as the 28.5 million-acre-foot capacity reservoir neared its normal operating level, over 100 earthquakes were felt locally (Gupta, 1992). Seismicity continued sporadically culminating in a M 5 earthquake in May 1939. In other cases, such as Koyna and Oroville, the onset of seismic activity is delayed for a number of years after the reservoir has been filled and is operating normally. In general, it has been observed that cases of rapid response tends to produce swarms of small shallow earthquakes located in the immediate vicinity of the reservoir and cases of delayed response tend to produce larger deeper earthquakes located at some distance (approximately 6 miles [10 km] in the cases of Koyna and Oroville) from the reservoir (Scholz, 1990).

Triggered earthquakes appear to be generated by very small stress changes, sometimes a fraction of a bar (Scholz, 1990). This suggests that the faults are in a state of pre-critical stress, requiring only minor reductions in effective normal stress to relieve strain. In regions where the principal tectonic stress is extensional these conditions for failure may be easier to meet. Most examples of triggered seismicity occur in regions of low tectonic loading dominated by normal faulting or strike-slip faulting (Scholz, 1990). The Golden Gate and Sites Dam sites are located in the actively folding and thrusting section of the CRSB boundary zone where the maximum principal stress is expected to be horizontal. Despite its proximity to Lake Oroville, the tectonic environment at Sites is distinctly different. The Sites anticline is inferred to overlie an east-dipping reverse fault that represents a backthrust to the underlying west-dipping blind detachment fault at approximately five km below the surface (Figure 4-7). Fracture permeability might reasonably be expected to be less in this compressional environment relative to the extensional environment across the valley. Fluid from the proposed reservoir could still diffuse down to seismogenic depths (3 miles [5 km]) if the pressure is high enough (i.e., a deep water column behind the dam). But the increase in elastic stress from the reservoir would tend to reinforce the normal stress across the detachment fault, moving it away from failure conditions. Although much remains to be learned about the causitive mechanisms for reservoir-induced seismicity, based on previous cases it would seem that conditions at Sites and Golden Gate do not favor the triggering of earthquakes by construction or operation of a reservoir.

11.0 CONSTRUCTION MATERIALS

The Department of Water Resources has investigated the availability of construction materials for the Sites Reservoir Project and their investigation is documented in the following reports. Northern District, Geology Section produced two separate reports on the subject matter. One report was produced as Appendix P of the July 2000 OSI Progress Report. The other is the September 2001 Construction Materials Update. In addition, the Division of Engineering produced a June 2002 Materials Investigation, Testing, and Evaluation Program Report. The ND reports are draft and the DOE report represents the final summary of feasibility level material investigations, testing and evaluation program.

This report addresses the availability of impervious materials in both the proposed reservoir area and local terrace deposits, suitability of the Venado sandstone as riprap, rockfill, or aggregate, and the occurrence of appropriate aggregate sources within an economically reasonable haul distance. Investigations performed to date have focused on the dam structures since material requirements for the dams are a major component of the Sites Project

Previous Work

Golden Gate and Sites Dam sites were previously investigated by the U.S. Bureau of Reclamation in feasibility studies conducted in 1969 and 1980. Several studies have investigated the availability and suitability of construction materials for the Sites Reservoir Project. A report entitled *Engineering Geology Appendix-Part II* (USBR, Project Development Division, Geology Branch, 1969) provided geologic data for the USBR's use in preparing cost estimates for the proposed project and appurtenant structures. The 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 backhoe test pits 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 the mapping of proposed impervious materials from terrace deposits in Antelope Valley upstream from each site and identifying potential Venado sandstone rock quarrying sites including the existing Sites quarry downstream of the proposed Sites Dam site and the southeast ridge at Golden Gate Dam site. Summary results of the USBR testing and analysis and volume estimates are presented in Table 1 of the Appendix P report. Site sample locales and associated areas investigated are shown on Figure 2 in the Appendix P report.

The USBR conducted additional studies on saddle dams and rock testing published in *Construction Materials Report for Sites Dam, Golden Gate Dam, and Dike Sites* (USBR, Mid-Pacific Region Geology Branch) 1980. The results of this testing are presented in Table 2 of the Appendix P report. 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.

The construction materials investigation program identified the following material types within or near the proposed Sites Reservoir project area:

- Alluvial Deposits (recent and older alluvium)
- Venado Sandstone of the Cortina Formation (fresh and weathered)
- Mudstone of the Boxer Formation

These material types were further investigated, tested, and evaluated to explore their suitability for use as the following types of construction materials:

- Impervious Materials
- Rockfill and Riprap Materials
- Random Materials
- Filter, Drain, and Transition Materials
- Concrete Aggregate

Impervious Materials

A surplus of impervious material exists within or near the Sites Reservoir project (DOE 6/02). Previous studies by USBR identified four main areas of deposits encompassing roughly 36 million cubic yards of material. Additional impervious materials are located within required excavation areas for the appurtenant structures and Funks Reservoir enlargement.

The proposed impervious materials are classified as low to medium plasticity clays (CL), with lesser amounts of high plasticity clays (CH) and clayey sands (SC). Dry, moist, and saturated densities were found to be 109 pcf, 127 pcf, and 131 pcf, respectively. Permeability tests indicate the material is very impervious with results on the order of 10^{-8} to 10^{-9} cm/s. From CUE triaxial testing, total friction angle (ϕ) was found to be 14º with a total cohesion (C) of 650 psf. Effective friction angle (ϕ') was found to be 21.5º with an effective cohesion (C') of 600 psf.

Although only limited testing was performed as part of the feasibility level investigation, testing and evaluation indicate the impervious materials are suitable for use in the proposed embankment dams.

Rockfill and Riprap Material

The best available source of clean rockfill material within the project area is the fresh Venado sandstone, distinguishable from the weathered Venado sandstone. Four prospective sandstone quarry areas have been identified near the dam sites. Sufficient quantities of Venado sandstone are available in the proposed quarry areas, foundation excavations, and tunnel excavations for construction of the embankment sections currently under consideration.

Petrographic examination characterizes the Venado sandstone as an arkosic graywacke with fine to medium grained structure, and comprised mostly of quartz and feldspar. Test results indicate the specific gravity to be approximately 2.5, while absorption results ranged from roughly 3% to 5%. Unconfined compressive strength testing on the fresh Venado sandstone indicates strengths of about 9,600 psi for the dry material and about 7,000 psi for the saturated material. Shear strength estimations indicate a friction angle (ϕ') of 42º. Dry, moist, and saturated densities were found to be 116 pcf, 122 pcf, and 136 pcf, respectively.

Material testing and evaluation indicate the fresh Venado sandstone to be of sufficient quality for use as clean rockfill and riprap materials. In addition to the testing and evaluation performed as part of this investigation, the suitability of the Venado sandstone is evidenced by its performance at Funks Reservoir's dam. The upstream slope protection on this embankment dam is comprised of the Venado sandstone and has been performing satisfactorily since the mid-1970s. Another indicator of the suitability of the Venado sandstone is a review and comparison of particle breakage of the Venado sandstone and Pyramid Dam argillite during large-scale triaxial testing performed by UC Berkeley in the 1970s. The particle breakage of the sandstone was comparable to the argillite, which has performed satisfactorily as rockfill material in Pyramid Dam, both as riprap and shell material.

Random Material

Random embankment material will be comprised of materials unsuitable for use as clean rockfill. It will consist of weathered sandstone, mudstone, slopewash, etc. from excavations for the dam foundations, appurtenant structures, and the rockfill quarries. Abundant quantities of random material are available for construction of Golden Gate, Sites, and the saddle dams (DOE 6/02).

It is anticipated that two general types of random materials will be generated during construction depending upon the source of the material. One type of random material will be comprised of predominantly weathered sandstone (Kcvs), and interbedded sandstone and mudstone (Kcvsm) from the Cortina Formation, while the other type will be predominantly mudstone (Kbm) from the Boxer Formation. It should be pointed out that the mudstone from near-surface excavations in the Boxer Formation will tend to be "soil like", because of its propensity to break down when exposed to air and water (slaking), and excavation and compaction operations. The weathered Cortina formation will tend to be a dirty rockfill.

Compressive strength testing indicates the mudstone and weathered sandstone have compressive strengths of approximately 3,500 psi and 5,000 psi, respectively. Warranting special note, the average compressive strength of the mudstone only included one near surface sample, while the majority of the samples were obtained at depth. That near surface sample demonstrated a compressive strength of 1,200 psi, which indicates that the material comprised of mudstone from excavations will be of low strength.

Shear strength estimations indicate an effective friction angle (ϕ') of 40º for the material comprised of predominantly weathered sandstone. The material comprised predominantly of mudstone was estimated to have an effective friction angle (ϕ') of 35º, a total friction angle (ϕ) of 15º, and a total cohesion of 600 psf (DOE 6/02). In-place densities for the random material as a whole were assumed to be equivalent to the rockfill densities. Dry, moist, and saturated densities were estimated to be 116 pcf, 122 pcf, and 136 pcf, respectively.

Since random materials are generally used in portions of the dam embankment where hydraulic conductivity and erosion resistant properties are not a consideration, a comprehensive evaluation of the random material's engineering properties is generally not required. As such, the limited testing and evaluation indicate the random materials are suitable for use in the proposed embankment dams (DOE 6/02).

Filter, Drain, and Transition Material

Since sufficient deposits of sand and gravel are not available in the project area, crushed Venado sandstone was evaluated for use as filter, drain, and transition materials. Although laboratory testing indicates crushed, fresh Venado sandstone may be suitable as filter, drain, and transition materials, it was not extensively tested as part of the feasibility level investigation since an extensive particle breakage and other evaluation would have been necessary. This particle breakage evaluation would have required test quarries and fills and was considered beyond the scope of this feasibility level investigation (DOE 6/02). Since the suitability of the Venado sandstone cannot be confirmed at this level of investigation, it is assumed that filter, drain, and transition materials for the embankment dams will be imported from the closest off-site sand and gravel deposits. One primary off-site deposit was identified as an old abandoned channel on Stony Creek, between Orland and Willows. It is approximately 35 road miles from the project, and has an estimated material availability of 160 million cubic yards that far exceeds the construction requirement.

Both shear strength and density were estimated from published data. The filter, drain, and transition materials are estimated to have a friction angle (ϕ') of 42º. Dry, moist, and saturated densities were also estimated at 115 pcf, 121 pcf, and 135 pcf, respectively.

Concrete Aggregate

As discussed in aforementioned section, sufficient deposits of sand and gravel are not available within the project area. Therefore, crushed Venado sandstone was also evaluated for use as concrete aggregate. Sources of sandstone are identical to those identified for use in the rockfill and riprap materials. Also, off-site sand and gravel deposits were identified as alternative material sources as part of the geologic exploration program.

Quality testing was the focus of the concrete aggregate evaluation. Specific gravity was found to be roughly 2.6, while absorption ranged from approximately 2% to 6%. Los Angeles Abrasion losses were about 11% at 100 revolutions and about 47% at 500 revolutions. Clay lumps and friable particles ranged from 1% to 5% (DOE 6/02). Organic impurities had standard colors of mostly “clear”. Bulk density was estimated at roughly 88 pcf.

Since the test results indicate that the crushed Venado sandstone only marginally meets the adopted concrete aggregate criteria, the suitability of the sandstone can not be confirmed without additional testing and evaluation considered beyond the scope of the feasibility level investigation. Therefore, it is assumed that concrete aggregate will be imported from the off-site sand and gravel deposit on Stony Creek presented as mentioned above. As discussed previously, an abundance of material is available from this borrow source.

In the June 2002 DOE report Table A presents a summary of the engineering properties recommended for use in the feasibility level embankment stability analysis. See this report for additional details on construction materials.

REFERENCES

DWR Reports

North of the Delta Offstream Storage Investigation, Technical Information Record, Geology of the Saddle Dam Alignment of the Sites Reservoir Project, Division of Planning and Local Assistance, San Joaquin Distirict, Resources Assessment Branch, June 1999

North of the Delta Offstream Storage Investigation, Technical Information Record SD-99-1, Geology of a Portion of the Salt Lake Fault Zone at the Proposed Sites-Colusa Reservoir, Glenn and Colusa Counties, Division of Planning and Local Assistance, Southern District, Resources Assessment Branch, June 1999

Geologic Study on the Feasibility of Sites and Golden Gate Dam Sites, Sites – Colusa Counties, Division of Engineering, Project Geology Report 94-30-01, Draft, June 1999

North of the Delta Offstream Storage Investigation, Progress Report, Appendix O: Phase 1 Fault and Seismic Hazards Investigation, Division of Planning and Local Assistance, Northern District, Geology Section, Draft, July 2000

North of the Delta Offstream Storage Investigation, Progress Report, Appendix P: Construction Materials Sampling and Testing, Division of Planning and Local Assistance, Northern District, Geology Section, Draft, August 2000

North of the Delta Offstream Storage Investigation, Progress Report, Appendix P: Construction Materials Sampling and Testing, 2001 Update, Division of Planning and Local Assistance, Northern District, Geology Section, Draft, March 2002

North of the Delta Offstream Storage Investigation, Progress Report, Appendix Q: Sites and Colusa Reservoir Foundation Studies, Division of Planning and Local Assistance, Northern District, Geology Section, Draft, February 2001 **(a complete list of references that were utilized in compiling Appendix Q are located at the end Appendix Q)**

North of the Delta Offstream Storage Investigation, Colusa and Glenn Counties, California, 2001 Update of Appendix Q – Foundation Studies, Division of Planning and Local Assistance, Northern District, Geology Section, December 2001

North of the Delta Offstream Storage Investigation, Sites Reservoir Feasibility Study, Materials Investigation, Testing, and Evaluation Program, Division of Engineering, June 2002

North of the Delta Offstream Storage Investigation, Sites Reservoir Engineering Feasibility Study, Golden Gate, Sites, and Saddle Dams, Division of Engineering, February 2003

Non-DWR Reports

Phase II Fault and Seismic Hazards Investigation, North of the Delta Offstream Storage, Integrated Storage Investigations, William Lettis and Associates, Inc., September 2002 (Appendixed to this report as a CD)