Santa Rosa Subregional Long-Term Wastewater Project

GEOTECHNICAL ASSESSMENT OF ALTERNATIVE RESERVOIR SITES AND PIPELINE ROUTES VOLUME 1 - REPORT

SANTA ROSA SUBREGIONAL LONG-TERM WASTEWATER PROJECT

Prepared for

City of Santa Rosa
and
U.S. Army Corps of Engineers

January 1996

Prepared by

RUST ENVIRONMENT & INFRASTRUCTURE
695 RIVER OAKS PARKWAY, SAN JOSE, CA 95134 • 408/232-2800

for

HARLAND BARTHOLOMEW & ASSOCIATES, INC.

January 26, 1996
Project No. 88230.355

Harland Bartholomew & Associates, Inc.
2233 Watt Avenue, Suite 330
Sacramento, California 95825

Attention: Mr. Anders J. Hauge
Vice President

Subject: Final Report
Geotechnical Assessment of Alternative Reservoir Sites and Pipeline Routes
Santa Rosa Subregional Long-Term Wastewater Project

Gentlemen:

We are pleased to submit the results of our geologic/geotechnical assessment of alternative reservoir sites and pipeline routes for the City of Santa Rosa Subregional Long-Term Wastewater Project. The findings presented herein constitute our final report covering the alternative storage sites for which field investigation and conceptual engineering have been performed. These alternative project storage components include the Valley Ford East, Carroll Road North, Bloomfield, Huntley, Two Rock, Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point reservoir sites. In addition, findings from our geotechnical assessment of various proposed pipeline routes to reservoir storage sites and reuse or discharge areas for the alternative projects being considered are presented herein.

The geotechnical studies documented herein, including the performance of geologic/seismic hazards evaluation and geotechnical engineering pertaining to the established alternative reservoir storage sites and pipeline routes, have been performed to provide the necessary data to support the environmental analysis for the project and to support the engineering design to a facilities planning level of detail.

We appreciate the opportunity to be of service to Harland Bartholomew & Associates, Inc. and the City of Santa Rosa on this important project and trust that this report meets your present needs. Please contact us if there are any questions.

Very truly yours,

RUST Environment & Infrastructure

Antonio S. Buangan
Senior Geologist
CEG No. 824, California

Stanley H. Kline
Senior Geotechnical Engineer/Project Manager
GE No. 477, California

n:\wp\geo\rep\88230\final\letter

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

SECTION 1
INTRODUCTION

1 INTRODUCTION

1.1 GENERAL

This report presents the results of Rust Environment & Infrastructure's (Rust's) geologic/ geotechnical assessment of alternative reservoir sites and pipeline routes for the City of Santa Rosa Subregional Long-Term Wastewater Project. The alternative reservoir storage sites considered for study in the environmental evaluation of this project were selected by the City of Santa Rosa Board of Public Utilities (BPU) based on screening of numerous potential sites and recommendations of sites for further study by the project's engineering staff. This report presents the findings and evaluations of nine reservoir sites selected for study, for which field investigation work and geotechnical engineering work were performed. In addition, findings from the geotechnical assessment of various proposed pipeline routes to reservoir storage sites and reuse or discharge areas for the alternative projects being considered are presented herein.

The major project alternatives currently under consideration by the City of Santa Rosa for the wastewater project are listed below:

- Alternative No. 1 - No Project
- Alternative No. 2 - South County Reclamation
- Alternative No. 3 - West County Reclamation
- Alternative No. 4 - Geysers Discharge
- Alternative No. 5 - Direct Discharge

For the above project alternatives, the south and west county reclamation options are the alternatives that require a major storage component, and thus, construction of a dam and reservoir. The scope of Rust's involvement on this project is primarily the geotechnical assessment and conceptual design of the various alternative dam and reservoir storage components associated with the reclamation project alternatives. This does not include the conceptual design of appurtenant works such as spillways, inlet/outlet works, and diversion facilities, which are provided by others. The geotechnical assessment of pipeline routes involved in all alternatives but the no project alternative is also included.

Harland Bartholomew & Associates, Inc. (HBA) has the overall responsibility to the City of Santa Rosa for the environmental analysis and documentation, and supporting technical studies of the various project components and alternatives. Rust has performed the geotechnical investigation of the dam and reservoir storage alternatives, and the geotechnical assessment of pipeline routes as a subconsultant to HBA.

1.2 SCOPE OF WORK

The geotechnical studies documented herein have been performed to provide the necessary data to support the environmental analysis for the project and to support the engineering design to a facilities planning level of detail. More specifically, the geotechnical scope of work consisted of the following:

1.2.1 Refinement of Alternative Storage Component Sites

Based on the project alternatives selected for evaluation in the environmental analysis, a potential list of reservoir sites from previous studies was screened to arrive at a short list of sites that could adequately serve each of the project alternatives which require storage. Sites were evaluated jointly with Parsons Engineering Science, Inc. based on their environmental constraints, relative storage volume, proximity to other elements of alternatives, cost effectiveness, and hydraulic suitability. This task resulted in a recommended list of alternative storage sites to be carried forward for additional study.

In addition, a study of potential new reservoirs in the South County and Russian River watershed areas was conducted to provide an identification of potential reservoir sites within the project area that may have been overlooked by previous studies by others or rejected based on criteria different from that being used for this study. The search for potential new sites was based on study of topographic maps. A map identifying each new candidate reservoir site and a memorandum with a table listing the proposed characteristics of the potential reservoirs was provided at the conclusion of the study.

1.2.2 Geotechnical Engineering

The scope of work for geotechnical investigation and conceptual engineering at each alternative reservoir storage site included review of available geologic/seismic data, a limited exploration program consisting of drilling and backhoe test pitting (except Bloomfield and Two Rock due to available data from previous studies) to assess foundation conditions and availability of construction materials, limited laboratory testing (except Bloomfield and Two Rock), and geologic and engineering analysis, including conceptual dam and reservoir layouts and an opinion of probable construction cost. Evaluation of the reservoir sites to an expanded configuration was made, as applicable, relative to configurations and capacities from previous studies. In addition, estimated conceptual level cost curves were developed for reservoir earthwork construction, based on a range of dam sizes and reservoir capacities, to allow flexibility in evaluating alternatives. Only one conceptual dam design and reservoir layout for each site is illustrated in the study results, representing the maximum practical storage capacity of the site, or the maximum required storage capacity considered for the project alternative (4,500 million gallons or 13,810 acre feet).

The scope of work for geotechnical study of alternative pipeline routes included review of available data and site reconnaissance, which formed the basis for evaluation of site conditions, geotechnical feasibility, identification of potential geologic/seismic hazards or other geotechnical problems, and recommendations for possible mitigation measures, as appropriate. The assessment included the major pipeline routes from the treatment plant to each alternative storage reservoir and from each reservoir to major distribution locations for reuse. Evaluation of pipeline routes for the Geysers discharge alternative and the Russian River direct discharge alternative are also included.

1.2.3 Geotechnical Assessment Report

This written report was prepared to document the basis and results of the geotechnical evaluation of alternative reservoir sites and pipeline routes. The report contains geologic and exploration maps and cross sections of the alternative reservoir sites, conceptual dam and reservoir layouts, conceptual dam design cross sections, evaluation of construction materials availability and characteristics, conceptual earthwork construction cost estimates and cost curves, and construction considerations. In addition, mapping of potential geologic/seismic hazards and significant adverse geotechnical conditions along alternative pipeline routes, along with possible mitigation measures, are provided in the report. The report provides overall conclusions with comparisons of geotechnical-related aspects of the alternative reservoir storage sites studied and assessment of the geotechnical feasibility of dam, reservoir, and pipeline construction. The report also documents the field and laboratory investigations, including field logs and lab test results, and seismic refraction work, as applicable.

1.3 AUTHORIZATION

The work performed for this study by Rust, as documented in this report, was authorized by HBA, pursuant to HBA's subcontract agreement dated July 14, 1993 and modifications to the subcontract agreement according to the following amendments:

- Amendment No. 1 dated May 3, 1994
- Amendment No. 2 dated August 9, 1994
- Amendment No. 3 dated October 6, 1994
- Amendment No. 4 dated March 14, 1995
- Amendment No. 5 dated June 2, 1995

Rust is a subconsultant on this work for the City of Santa Rosa. HBA, as prime consultant, is providing services to the City of Santa Rosa. The work has been coordinated through Mr. Anders J. Hauge with HBA.

1.4 LIMITATIONS

The data, information, interpretations, and recommendations in this report are presented solely as bases and guides for the conceptual level designs of the proposed alternative dams, reservoirs, and pipelines for the Santa Rosa Subregional Long-Term Wastewater Project. The conclusions and professional opinions presented herein were developed by Rust in accordance with generally accepted geotechnical engineering principles and practices. This warranty is in lieu of all other warranties, either express or implied. These data, conclusions, and recommendations should be considered to relate only to the specific project and locations discussed herein. Rust is not responsible for any conclusions and recommendations that may be made by others.

This report has not been prepared for use by parties other than HBA and their various subconsultants, the City of Santa Rosa, and the reviewers of the Santa Rosa Subregional Long-Term Wastewater Project. It may not be used by other parties for other uses. If any changes are made in the project described in this report, the conclusions and recommendations contained herein shall not be considered valid unless the changes are reviewed by Rust and the conclusions and recommendations of this report are modified or approved in writing. The conceptual designs presented herein are not intended for use as construction documents.

SECTION 2
ALTERNATIVE RESERVOIR SITES

2 ALTERNATIVE RESERVOIR SITES

In evaluating the storage component of the current Santa Rosa Subregional Long-Term Wasterwater Project for the present environmental study, previously identified alternative storage sites were revisited and considered relative to the criteria and requirements of the present study. In addition, an independent assessment of potential storage sites was made to confirm that no significant sites were missed or screened out under past criteria by previous studies. The list of previously identified potential storage sites within the west county, south county, and Sebastopol areas numbers over 50. These various sites, previously evaluated to varying degrees of study, have been presented and discussed relative to previous project studies by Woodward-Clyde Consultants (WCC) in two primary documents (WCC, 1988 and 1990).

Considering that storage is only one component of the wastewater project and that numerous alternative projects, each with its own set of interrelated project components, are being evaluated in the environmental study, it was necessary to pare down the list of potential alternative reservoir sites to a manageable level for study to a facilities planning level of detail. Recommendations for further study of potential storage sites to the facilities planning level were based primarily on engineering considerations, but if obvious environmental flaws were identified, these were also considered. In reducing the list of potential storage sites for further study, alternative sites were evaluated jointly with Parsons Engineering Science, Inc., based on their environmental constraints, relative storage volume, proximity to other elements of alternatives, cost effectiveness, and hydraulic suitability. More specifically, the following general engineering criteria and considerations were used in eliminating previously identified potential storage sites from further consideration and establishing the sites comprising the alternative storage components for the project:

- Use fewest sites necessary. The cost of constructing multiple reservoir sites is excessive. In addition to the greater cost of constructing several reservoirs instead of one, there is also additional cost of constructing piping to convey water between the various reservoirs and reuse areas. Permitting multiple sites would also present difficulties. Multiple reservoirs also present considerable management and maintenance difficulties. Without additional storage by other means, such as aquifer storage, it was established that any reservoir having a capacity less than 1,000 million gallons (3,069 acre-feet) would require more than three reservoirs to serve the 1 percent, or even the 5 percent, maximum Russian River discharge alternative. Given the objective to avoid developing an unecessarily complex system by constructing no more than one or two additional storage reservoirs, the 1,000 million gallon capacity was established as the cutoff for minimum required storage at any potential reservoir site.

- Maximize cost effectiveness of storage sites. Some storage reservoirs provide very little storage for relatively high cost. This typically is the case when it is necessary to contruct a large embankment to create a small reservoir. It is preferable to use sites where topography lends itself to minimizing embankment volume while maximizing storage. A general criterion to avoid sites with greater than $5,000 construction cost per acre-foot of storage was established, because there are numerous reservoir sites (more than 30) with better cost effectiveness, based on preliminary cost estimates of dam and reservoir construction from previous studies (WCC, 1988 and 1990).

- Proximity of storage site to the treatment plant, existing reclaimed water distribution system, and proposed reuse areas. It was established that storage sites should be located where they can conveniently serve the proposed reuse areas with a minimum of piping and pumping costs.

- Hydraulic suitability. It was established that storage sites should be located so as to minimize required pumping capacity and operating pumping costs.

As a result of the evaluation of alternative reservoir storage sites based on the above criteria, and recommendations to and decisions made by the BPU regarding which sites would be carried forward for further study, the final list of alternative storage sites to be considered in the environmental study was established. These sites are listed in Table 2-1 and are shown on the location map on Figure 2-1. Considering the varying degrees of study of alternative reservoir sites by past investigations, one of the primary objectives of this evaluation and assessment is to study the selected alternative reservoir storage sites to the same degree of detail and base the conceptual design of the dam and reservoir at each alternative site on field and laboratory investigations and geotechnical engineering that are similar in magnitude and scope for each site.

TABLE 2-1

ALTERNATIVE RESERVOIR STORAGE SITES

General Location[1]	Site Name	Current Site Designation	Previous Site Designation[2]
West County	Valley Ford East	S53B	V-4
West County	Carroll Road North	S56	V-7
West County	Bloomfield	S40B	B1-A
West County	Huntley	S44	T-1
West County	Two Rock	S20C	T-6A
South County	Adobe Road	S27B	AD-1B
South County	Lakeville Hillside	S31A	L-2A
South County	Tolay Creek[3]	S39	---
South County	Sears Point	S35	SP-1

[1] See Figure 2-1.
[2] (WCC, 1988 and 1990)
[3] Two different reservoir configurations are evaluated for the Tolay Creek alternative storage site. One configuration (referred to by some as configuration "A") would inundate the entire Tolay Creek valley and is referred to as the alternative "without backdam" throughout this report. The second configuration (referred to by some as configuration "C") would only inundate a portion of the valley as limited by a retention dike, or "backdam", across the central portion of the valley. This configuration is referred to as the alternative "with backdam" throughout this report.

SECTION 3
REGIONAL GEOLOGIC AND SEISMIC SETTING

3 REGIONAL GEOLOGIC AND SEISMIC SETTING

3.1 GENERAL

This section includes a discussion of the geologic and seismic setting of the project region. The discussion of the regional geology is further subdivided into the west county and south county areas. The west county area refers to alternative sites on the hills west of Cotati Valley, while the south county area refers to sites east of the Petaluma River valley (Figure 2-1). The alternative reservoir sites in the west county area presented in this report include the Valley Ford East, Carroll Road North, Bloomfield, Huntley, and Two Rock sites. The south county reservoir sites include the Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point sites. Site specific geologic conditions at each of the alternative reservoir storage sites are presented in Section 4. Geologic conditions along the various alternative pipeline routes are discussed in Section 9.

3.2 REGIONAL GEOLOGIC AND TECTONIC SETTING

The project region encompassing the reservoir storage sites, which comprises most of Sonoma County and adjacent northern Marin County, is immediately east of the San Andreas fault zone. The northwest-trending San Andreas fault zone is the junction between two crustal plates, the North American plate which forms the land mass to the east, and the Pacific plate which is mostly under water in the vicinity of the project area. The land masses west of Tomales Bay and along the Sonoma coast north of Fort Ross are part of the Pacific plate. The Pacific plate on the west side of the San Andreas fault is moving northerly relative to the North American plate. The movement between these two plates, over many millions of years, has produced the northwest-trending ridges and valleys present in Sonoma County. The plate boundary is defined by many subparallel faults, which, together with the San Andreas fault, dominate the seismic activity in the project region.

The geologic units that underlie the project region are depicted in the Santa Rosa Quadrangle geologic map of the California Division of Mines and Geology Regional Geologic Map Series

(Wagner and Bortugno, 1982) and described in the geology of the Santa Rosa Quadrangle (Wagner and Bortugno, 1983). The oldest geologic formation in the project region east of the San Andreas fault is comprised of rocks of the Franciscan Complex which are Jurassic to Early Cretaceous in age. These rocks were deposited as sediments in a deep ocean trench at the junction of two crustal plates. The Franciscan Complex forms the core of the mountain ranges in the eastern and western parts of Sonoma County and consists of folded and faulted sandstones, shale, conglomerate, chert and greenstone, and associated serpentinized ultramafic rocks. Much younger (Miocene to Pliocene) sediments, including the Wilson Grove Formation (marine sandstone, conglomerate, and tuff) and the Petaluma Formation (mostly non-marine claystone, siltstone, and mudstone), were deposited on top of Franciscan Complex rocks. During Pliocene time, volcanic activity occurred and resulted in the widespread deposition of the Sonoma Volcanics in the eastern part of the county. The Sonoma Volcanics are comprised of basalt, andesite, rhyolite, tuff, and other pyroclastic rocks and are the main rock constituents of the Sonoma, Sonoma-Napa, and Mayacamas Mountains. Following a period of structural deformation and erosion, valleys and plains were formed in the Sonoma Volcanics and in the Glen Ellen Formation of Pleistocene age which consists of fluvial gravel, silt, sand, and clays eroded from the adjacent highlands and deposited on top of the Sonoma Volcanics. Recent alluvium that underlies the northwest-trending valleys constitutes the youngest geologic unit in the area. Landslide deposits are a common occurrence in the Franciscan Complex and Petaluma Formation, and are locally abundant in the soil-like units of the Sonoma Volcanics.

West of the San Andreas fault are formations that have been repeatedly displaced by the horizontal movement of the Pacific plate during the past 25 million years. Some of the land has moved as much as 200 miles northwest from its original place of deposition. This crustal shift has produced the granite block known as Bodega Head, the only occurrence of granite in Sonoma County. It resembles the granite of the Tehachapi Mountains in Southern California. Other rocks west of the San Andreas fault are mostly Late Cretaceous and Early Tertiary (98 million to 24 million years old) marine sandstone, shale, and conglomerate. Among the various formations are quartzite and recrystallized limestone that are older than the Franciscan Complex.

3.2.1 West County Regional Geology

The west county region includes the hilly areas bounded by Cotati Valley to the east and Bodega Bay to the west. The predominant geologic formation is the Pliocene-age Wilson Grove Formation (formerly Merced Formation) which consists mostly of marine sedimentary rocks. The Wilson Grove Formation underlies a relatively extensive area of this portion of the Coast Ranges which is predominantly underlain by the older bedrock units of the Franciscan Complex and the Great Valley Sequence. The Wilson Grove Formation appears to have been deposited on an erosional surface of the Franciscan Complex bedrock over a wide area that extends from Cotati Valley westward to the Pacific Ocean. The Wilson Grove Formation is described as comprised of sandstone, conglomerate, limestone concretions, and tuff, although mapping during this investigation indicates the presence of massive sandy siltstone and siltstone units. The Valley Ford East, Carroll Road North, and Bloomfield sites are for the most part underlain by the Wilson Grove Formation. Later geologic deformation resulted in fault-contact relationships between the Wilson Grove and Franciscan Complex geologic formations. Erosion of the Wilson Grove Formation during its geologic history exposed windows of Franciscan Complex rocks amongst Wilson Grove rocks. Examples of these areas are the Huntley and Two Rock sites where Franciscan Complex bedrock is exposed in the lower portions of the valley with Wilson Grove rocks capping the adjoining ridge tops.

3.2.2 South County Regional Geology

The Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point alternative reservoir sites are located in the western foothills of the Sonoma Mountains where they border Petaluma Valley. The main geologic formations in this part of the project region are the Petaluma Formation and the Sonoma Volcanics, both of Pliocene age. Relatively small areas of the much older (Jurassic to Early Cretaceous age) Franciscan Complex rocks are in fault contact with Pliocene-age rocks in the southern portion of the region.

The Petaluma Formation is described as consisting of massive claystone, siltstone, mudstone with lenses of friable sandstone, and thin interbeds of fossiliferous limestone. It is mostly non-marine. The Sonoma Volcanics consist of a variety of volcanic rocks that include basalt, andesite, rhyolite, tuff, and pyroclastic rocks. They occur as interlayers and/or capping on the Petaluma Formation. The distribution of these geologic formations follows the northwest-trending regional geologic structure and is best exemplified by the northwest-trending active Rodgers Creek fault that passes through the central portion of the region and the potentially active Tolay fault. The Adobe Road and Lakeville Hillside sites are located entirely in bedrock units of the Petaluma Formation on the western flanks of the southern Sonoma Mountains. The Petaluma Formation is the predominant bedrock unit at the Tolay Creek and Sears Point sites.

3.3 SEISMICITY AND FAULTING

3.3.1 Historical Seismicity

The alternative reservoir sites, pipelines, and other alternative project features are located in one of the most seismically active regions in the United States, and earthquakes are a common occurrence. Since the mid-nineteenth century, hundreds of earthquakes have been felt in Sonoma County. A few of these earthquakes were strong enough to cause damage in the project region. The great San Francisco earthquake (18 April 1906) on the San Andreas fault had an estimated magnitude (M) of 8.3 on the Richter scale. During this earthquake, about 50 people were killed in the Santa Rosa area and extensive damage occurred in the business district of Santa Rosa. The October 1969 earthquakes on the Healdsburg fault registered M5.6 and M5.7. Although no deaths occurred, several million dollars of damage occurred. Numerous breaks in the water pipeline system occurred in the eastern part of Santa Rosa. More recently, the M4.9 earthquake along the Hayward fault (26 January 1986) and the M7.1 Loma Prieta earthquake on the San Andreas fault (17 October 1989) were felt in the county, but no damage was reported to major pipeline facilities. Current estimates of the 30-year probability of a magnitude 7 or greater earthquake on the Rodgers Creek fault indicate a 22 percent probability of occurrence (Working Group of California Earthquake Probabilities, 1990). There is a 67 percent probability of one or more large earthquakes occurring in the greater Bay Area within the next 30 years.

3.3.2 Faulting

There are several active and potentially active fault zones within Sonoma County that could affect project facilities (Figure 3-1). These include faults that have been historically active (during the last 200 years), those that have been active in the geologically recent past (about the last 11,000 years, usually referred to as Holocene in the geologic time scale), and those that have been active at some time during the Quaternary geologic period (the last two million years), often termed "potentially active". The California Division of Mines and Geology (Hart, 1992) defines "potentially active" faults as those showing evidence of displacement during Quaternary time. The Quaternary or potentially active classification does not preclude the possibility that Holocene (last 11,000 years) movement may have occurred. Exceptions were made for certain Quaternary faults that were presumed to be inactive based on direct geologic evidence of inactivity during all of Holocene time or longer. The San Andreas, Healdsburg-Rodgers Creek, Maacama, and West Napa fault zones are all historically active and are Holocene in age. Portions of each of these major fault zones have been classified as Quaternary because they do not display evidence of Holocene movement, but displace geologic units of Quaternary age (last two million years). Other faults in the project area that are classified as Quaternary age are the Tolay, Americano Creek, Bloomfield, Dunham, and Joy Woods fault zones (Wagner and Bortugno, 1982). Figure 3-1 shows the relationship of significant faults to the alternative reservoir sites. The relationship of significant faults to alternative pipeline routes is provided in Section 9.

The active San Andreas fault is a source of future large earthquakes that could affect the project area. The Shelter Cove to San Juan Bautista segment is capable of generating a magnitude 7.8 earthquake (Wesnousky, 1986). The Healdsburg-Rodgers Creek fault, a northward extension of the Hayward fault, was the source of the October 1969 (M5.6 and M5.7) Santa Rosa earthquakes and is capable of producing an estimated magnitude 6.9 earthquake (Wesnousky, 1986).

The Tolay fault extends northwesterly from Sears Point for about 22 miles to a location about 6 miles southwest of Santa Rosa (Figure 3-1). The southeastern segment of the Tolay fault was zoned as an Alquist-Priolo Special Studies Zone in 1976, but was removed from the zone in 1982 on the basis of Fault Evaluation Report 140 (Hart, 1982). The fault was removed from the special studies zone because it did not meet the criteria for zoning under the California Division of Mines and Geology (CDMG) fault evaluation program, that is, "only those faults considered active (Holocene) and well-defined as surface features are zoned". The Santa Rosa fault map classifies the Tolay fault as a Quaternary-age fault, since it shows evidence of displacement within the last two million years. Trenching across the postulated trace of the Tolay fault for this investigation at two locations in the vicinity of the Tolay Creek site indicated that old landslide deposits underlie the area and did not show any evidence of faulting. If the Tolay fault exists in the area investigated, it would be older than the old landslide deposits encountered. Discussion of the Tolay fault relative to site specific geologic conditions is presented in Section 4.9.2. According to Hart (1982), if the Tolay fault is Holocene active, then such activity is minor, distributive, and restricted to the southeastern segment of the fault where it is in close proximity to the well-defined and active Rodgers Creek fault. The Tolay fault is postulated to be capable of producing a magnitude 6.5 earthquake (Wesnousky, 1986).

The Bloomfield, Dunham, and Americano Creek faults confined to the west county area are mapped as Quaternary faults and therefore are considered potentially active, according to the CDMG definition discussed previously. The Dunham fault is about 4 miles long, sub-parallel to the northwest segment of the Tolay fault, and about 1 to 2 miles southwest of the Tolay fault. It is a sinuous fault separating Franciscan Complex rocks to the northeast from the Wilson Grove Formation to the southwest. Bortugno (1982) classifies the Dunham fault as a Quaternary fault. No evidence of Holocene displacement was identified during studies by Woodward-Clyde Consultants (1989).

The Bloomfield fault is about 9 miles long, sub-parallel to the Dunham fault, and about 1 to 1.5 miles southwest of the Dunham fault. The Bloomfield fault is a slightly sinuous fault that separates Franciscan Complex rocks to the northeast from the Wilson Grove Formation to the southwest. The fault is classified as Quaternary, with the age of most recent movement being unknown (Bortugno, 1982). The Bloomfield fault was previously studied by Woodward-Clyde Consultants (1990) relative to a proposed damsite (T-5) in the Two Rock area. Their investigation consisted of aerial photo interpretation, geologic reconnaissance mapping, and two shallow sidehill excavations (Figure 4-7). The fault zone is up to 11 feet wide and consists of fractures, shears, and gouge. Alluvial deposits of possibly late Quaternary-age have not been displaced by the fault. The excavation across the fault revealed that the associated shear zones do not extend into the Quaternary-age colluvium. Based on this data, Woodard-Clyde concluded that the Bloomfield fault does not show evidence of Holocene or late Quaternary activity.

The Americano Creek fault is located 1 to 2 miles southwest of the Bloomfield fault. It is about 5.5 miles long, downthrown to the northeast, and displaces Franciscan Complex rocks to the southwest in contact with the Wilson Grove sedimentary rocks to the northeast.

The Dunham, Bloomfield, and Americano Creek faults are within 1 or 2 miles of proposed alternative dam sites; however, because of their short lengths and activity classification, they are not considered as significant as the major active San Andreas or Rodgers Creek faults which are located at somewhat greater distances from the alternative reservoir sites, or the potentially active Tolay fault. Table 3-1 provides a listing of distances and directions to the more significant faults discussed above from the alternative dam sites. The significant faults that affect alternative pipeline routes are discussed in greater detail in Section 9.

Numerous other faults exist throughout the study area (Figure 3-1). These faults are pre-Quaternary in origin, generally related to the coastal thrust belt or the Coast Ranges thrust fault. They were active tens of millions of years ago, but have not shown evidence of activity during the last two million years.

TABLE 3-1

DISTANCES TO SIGNIFICANT FAULTS
ALTERNATIVE RESERVOIR SITES

Reservoir Site	Distance (miles) and Direction to		
	San Andreas Fault[1]	Rodgers Creek Fault[2]	Tolay Fault[3]
Valley Ford East	6.5 southwest	14 northeast	7 east
Carroll Road North	7.5 southwest	13 northeast	6 east
Bloomfield	7.5 southwest	13 northeast	6 east
Huntley	7 southwest	13 northeast	6 northeast
Two Rock	11 southwest	9 northeast	2 northeast
Adobe Road	18 southwest	1.8 northeast	1 southwest
Lakeville Hillside	18 southwest	2 northeast	1 northeast
Tolay Creek	19 southwest	1 northeast	0
Sears Point	20 southwest	0.6 northeast	0.6 southwest

[1] Holocene / active fault. Maximum Credible Earthquake (MCE) magnitude 7.8 for the Shelter Cove to San Juan Bautista segment (Wesnousky, 1986).
[2] Holocene / active fault. MCE magnitude 6.9 (Wesnousky, 1986).
[3] Quaternary / potentially active fault. MCE magnitude 6.5 (Wesnousky, 1986).

SECTION 4
DAM AND RESERVOIR
SITE CONDITIONS

4 DAM AND RESERVOIR SITE CONDITIONS

4.1 GENERAL

This section presents the geologic and geotechnical conditions at the nine alternative reservoir storage sites that have been investigated. From the west county to the south county areas, these sites include Valley Ford East, Carroll Road North, Bloomfield, Huntley, Two Rock, Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point (Figure 2-1). The discussions for each site include a description of field investigation work; site geology; foundation conditions for the proposed dam and appurtenant structures (spillway and inlet/outlet works), including potential seepage and possible mitigation measures; and reservoir slope stability and leakage potential.

The assessment of the geologic and geotechnical site conditions is based on the results of our data review; the results of various field investigation programs, including site reconnaissance and subsurface exploration; and our experience working in similar type geologic environments. During these investigations, we conducted subsurface field exploration at the Valley Ford East, Carroll Road North, Huntley, Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point sites. The Bloomfield and Two Rock sites were previously explored to a similar degree; therefore, our assessment for these sites is based primarily on previous data and our own observations from site reconnaissance.

A site geologic and exploration map was compiled for each alternative reservoir site and is presented at the end of this section. The footprint of the proposed dam and reservoir outline for maximum storage is shown on each map for reference in discussing site conditions. In addition, a geologic cross section of the proposed dam foundation is presented for selected sites with somewhat more complex geologic or site conditions. An assessment of construction materials, based on the reservoir site conditions, is presented in the next section of the report.

4.2 VALLEY FORD EAST

4.2.1 Field Investigation

The field investigation program at the Valley Ford East alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, and test pitting. The site reconnaissance geologic mapping was conducted on September 27 - 28, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling and test pitting were performed on November 8-9, 1994.

A total of five exploration borings were drilled and sampled. Water packer tests were conducted in selected borings to assess permeability properties of potential foundation materials. Fourteen backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite area and to assess potential borrow materials in the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. The geologic mapping and locations of exploration borings and test pits are shown on Figure 4-1. A detailed description of the field investigation program, logs of exploration borings and test pits, results of the water packer tests, and results of the laboratory testing are provided in the appendices to the report.

4.2.2 Site Geology

The entire proposed reservoir site is underlain by the Wilson Grove Formation (formerly Merced Formation) bedrock which consists of massive sandy siltstone and siltstone (Figure 4-1). Bedding is not discernible, and where noted, is generally subhorizontal. Some exposures near the ridge top to the west show slight to moderate dips to the northeast. The siltstone bedrock is soft in hardness and weakly cemented. It appears tight and compact. Bedrock is overlain by alluvium in the channel and up to 6.5 feet of colluvium in the lower and flatter slopes of the proposed reservoir. Alluvium is confined to the flat valley floor which at the proposed damsite is about 250 to 300 feet wide. It attains thicknesses of up to 16 feet and consists of soft clayey sand, sandy clay, sandy silt, and silty sand.

Very few slope instability features were noted and consisted primarily of erosion scars in the Wilson Grove siltstone. Groundwater occurs in the alluvium and occasional seeps and springs were noted in the proposed reservoir slopes.

4.2.3 Foundation Conditions

- **Dam Foundation Conditions** - The proposed damsite is located across a broad valley with flat to gently sloping sides. Localized maximum slopes in the damsite area are about 3.5:1 (horizontal to vertical) and are found on the uppermost abutment slopes; overall average slopes are flatter. The bedrock foundation material consists entirely of the Wilson Grove Formation which is comprised predominantly of massive sandy siltstone. Although the siltstone is soft in hardness and weakly cemented, it is strong and should provide an adequate foundation for an earth embankment.

  In order to attain adequate foundation conditions, excavation depths beneath the entire dam footprint of up to 20 feet will be required in the channel area to strip and remove the alluvium. In the abutment areas, average excavation depths of 5 feet are anticipated to remove the weaker colluvial and topsoil material overlying the bedrock units. An additional excavation of 10 feet into tighter siltstone is estimated for the impervious core zone of the dam. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

  Seepage potential in the massive siltstone is anticipated to be low. Water packer tests in Boring VF-B1 show estimated permeabilities of 7.5×10^{-6} cm/sec (average of three tests) and 6.2×10^{-6} cm/sec (average of three tests) at depth intervals of 29 to 44 feet and 44 to 59 feet, respectively (Table 4-2). These permeability values are considered low and are lower than the permeability value of 5.5×10^{-5} cm/sec when grouting becomes feasible. Based on the bedrock type, its physical character, and estimated permeabilities, it appears that the siltstone foundation is tight and that grouting is not required; however, this needs to be verified by further testing during design studies.

Material from the required foundation excavation can be incorporated in the embankment. The excavation plan should consider optimum extraction of a relatively thin layer of sandy clay as a potential source of impervious material within the colluvium, discussed in more detail in Section 5. Although the massive siltstone was difficult to excavate with a small backhoe in the exploration test pits, mass excavation should be possible with heavy excavation equipment. Groundwater in the alluvium appears to be of limited extent and should be readily handled during construction.

- **Spillway and Inlet/Outlet Works Foundation Conditions** - Based on the existing topographic conditions, a spillway alignment could be sited on either abutment. Both will require relatively extensive cuts in the approach channel (spillway entrance) area. A left (east) abutment spillway could be routed through an existing drainage swale and would be about 1,700 feet long, while a right (west) abutment spillway alignment would be approximately 1,000 feet long. The foundation material is anticipated to be massive, soft in hardness, but strong Wilson Grove siltstone. Excavation depths of up to 20 feet will be required to attain an adequate foundation. Full concrete lining along the entire length of the spillway will be required because of the soft, erodible nature of the bedrock. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

  The proposed inlet/outlet conduit could be sited on either side of the channel. Foundation material is anticipated to be dense and strong Wilson Grove Formation siltstone. Required excavation depths of up to 20 feet to attain a competent foundation are estimated in the channel area for the inlet/outlet works.

4.2.4 Reservoir Slope Stability and Leakage Potential

Few minor landslides were mapped in the slopes of the proposed reservoir area. Most are associated with incised erosion scars that follow steep drainage courses (Figure 4-1). Erosion gullies generally expose the Wilson Grove Formation siltstone and attest to the potential erodibility of this bedrock unit, particularly in areas of concentrated surface flow. Borrow excavation in the reservoir will result in extensive exposures of the Wilson Grove Formation;

therefore, the borrow area grading plan should consider appropriate cut slopes and provisions for drainage measures to avoid concentrated flow on cut slopes. Based on only minor, localized existing slope instability, strong formation materials with limited, localized instability potential, and variable topography with a lesser effect on stability, the risk potential of major landsliding at the Valley Ford East site under reservoir operating conditions is considered relatively low.

Reservoir leakage potential is considered to be low due to the generally massive structure and low permeability of the Wilson Grove bedrock underlying the site. However, although no apparently permeable layers were encountered in the exploration borings, the presence of springs mapped in the proposed reservoir slopes may be related to discrete permeable lenses within the Wilson Grove Formation. The extent and distribution of these potential permeable lenses are not known; however, judging from the minor occurrence of springs in the reservoir area, these permeable lenses appear to be of limited extent. This needs to be verified during further design studies. Potential mitigation measures, if such permeable zones exist, include localized grouting and/or blanketing with impervious clay.

4.3 CARROLL ROAD NORTH

4.3.1 Field Investigation

The field investigation program at the Carroll Road North alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, and test pitting. The site reconnaissance geologic mapping was conducted on September 29 - 30, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling and test pitting were performed on July 31 through August 2, 1995.

A total of three exploration borings were drilled and sampled. Water packer tests were conducted in selected borings to assess permeability properties of potential foundation materials. Nine backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite area and to assess potential borrow materials in the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. The geologic mapping and locations of the exploration borings and test pits are shown on Figure 4-2. A geologic cross section of the dam foundation is also provided on Figure 4-3. A detailed description of the field investigation program, logs of exploration borings and test pits, results of the water packer tests, and results of the laboratory testing are provided in the appendices to the report.

4.3.2 Site Geology

Bedrock underlying the proposed reservoir area is the Wilson Grove Formation (formerly Merced Formation), comprised of massive sandy siltstone, silty sandstone, and sandy claystone with possible interbeds of coarser sandstone (Figure 4-2). These rock units are generally weakly cemented, soft in hardness, and friable. Most of the few bedding exposures noted were measured ranging from nearly flat-lying to dipping, in various directions, up to about 20 degrees. Variation in the observed bedding attitudes (strike and dip of bedding) is probably due to cross-bedding structures of the sedimentary beds. An isolated outcrop of granular material (gravelly sand) was observed within finer-grained sandy siltstone, indicating that localized, more permeable units occur within the Wilson Grove Formation. Numerous springs mapped throughout the site suggest that such lenses may comprise discrete groundwater conduits. Incised creek banks below the flat valley floor typically expose Wilson Grove Formation bedrock, particularly on the west bank. Recent alluvium is confined along a narrow strip coinciding with the active creek channel. The remainder of the valley floor is underlain by thick clayey colluvium.

Very few landslides were noted within the proposed reservoir area. Most of these are small and apparently related to erosion and/or spring activity. A very large scarp located above and east of the proposed reservoir may be the result of prolonged erosion.

The trace of the Bloomfield fault, as shown on the geologic map compiled by Blake and others (1971) and plotted on Figure 4-2, passes through the extreme north and east arms of the proposed reservoir. The Bloomfield fault is classified as Quaternary, with the age of the most recent movement being unknown (Bortugno, 1982). Woodward-Clyde Consultants (WCC, 1990) in their previous study of the Two Rock site concluded that the Bloomfield fault does not show evidence of Holocene or late Quaternary activity and is therefore not considered active in accordance with the California Division of Mines and Geology fault evaluation program (Hart, 1992).

4.3.3 Foundation Conditions

- **Dam Foundation Conditions -** The proposed damsite is located across a narrow stream valley paralleled by Carroll Road. Localized maximum slopes in the damsite area are about 3:1 (horizontal to vertical) and are found on the right (west) abutment; overall average slopes are flatter. The subsurface geology along the dam axis is depicted in the geologic section shown on Figure 4-3. The bedrock foundation material consists entirely of the Wilson Grove Formation which is comprised predominantly of massive sandy siltstone and silty sandstone. Although soft in hardness and friable, these bedrock units are strong and should provide an adequate foundation for an earth embankment.

  In the abutment slopes, the Wilson Grove bedrock is covered by a few feet of colluvial soils. In the valley floor, boring CR-B3 indicated 24 feet of sandy clay to clayey sand alluvium. Required foundation excavation depths are estimated to average 5 feet in the abutment areas to remove shallow colluvial soils and severely weathered bedrock, and 25 feet in the channel area to remove the weak alluvial soil materials. An additional 10 feet of excavation is estimated for the foundation beneath the impervious core zone of the dam to reach fresher and tighter bedrock materials. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

  The Wilson Grove Formation, as noted in test pit exposures, natural outcrops, and drill core samples, appears massive, compact, and tight; therefore, the seepage potential through the dam foundation is considered low. Water packer tests were performed in two borings in the dam foundation. In Boring CR-B3 in the channel area, a permeability value of less than 6.9×10^{-6} cm/sec (average of three tests) was estimated in siltstone/sandy siltstone at a depth interval of 35 to 50 feet, which generally confirms the low permeability of these rock units (Table 4-2 and Figure 4-3). In Boring CR-B2 on the left (east) abutment, several attempts were made to water packer test an interval of slight drilling fluid loss in the siltstone unit at a depth of 42 to 53 feet; however, these were unsuccessful because of the inability of obtaining a seal around the packer. This drilling water loss and a similar observation at a depth interval of 13 to 16 feet in sandstone is attributed to bedding plane fractures in the siltstone/sandstone units. It is therefore possible that seepage through discrete bedding plane fractures may occur; however, this will probably be confined to the upper weathered zones of the Wilson Grove Formation. If these weathered fracture zones are relatively shallow, the foundation excavation for the impervious core zone of the embankment could be extended to a depth below these zones to mitigate against seepage. Another mitigation measure is localized grouting of the fractures. Based on the bedrock type, its physical character, and estimated permeabilities, it appears that the siltstone/sandstone foundation is relatively tight and overall foundation grouting is not required. Some localized grouting of bedding plane fractures is possible. The presence and extent of these fractures should be investigated during design studies.

Material from the required foundation excavation can be incorporated in the embankment. Similar to Valley Ford East, mass excavation should be possible with heavy excavation equipment, and groundwater is anticipated to be of limited extent and readily handled during construction.

- **Spillway and Inlet/Outlet Works Foundation Conditions -** Based on site topography and the conceptual dam layout configuration, a preferred spillway alignment is situated through the left (east) abutment ridge just east of the dam. Although shorter in length, a spillway alignment on the right (west) side would require extensive excavation for the spillway channel because of the steeper slopes. The spillway approach channel would be located across a broad ridge at the top of the left abutment and would extend to a small side drainage just downstream of the dam. The approximate length of the spillway channel from the top of the dam to where it reenters the creek is about 1,700 feet. Construction of the spillway would require excavations of up to 30 feet deep through soft, friable siltstone and sandstone to attain an adequate foundation. Full concrete lining will be required along the entire length of the spillway. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

The proposed inlet/outlet conduit could be located on either side of the channel. Foundation material is anticipated to be Wilson Grove siltstone and sandstone. Required excavation depths of up to 25 feet to attain a competent foundation are estimated in the channel area for the inlet/outlet works.

4.3.4 Reservoir Slope Stability and Leakage Potential

The few landslides that were mapped in the proposed reservoir area are small and apparently related to erosion and/or localized springs (Figure 4-2). Within the reservoir area slopes, exposures of the Wilson Grove Formation siltstone and fine sandstone are limited to these erosion scars and gullies. Given the generally noncohesive quality of the bedrock, the reservoir area slopes are considered to have a high potential for erosion. Borrow excavation in the reservoir will result in extensive exposures of the Wilson Grove Formation; therefore, the borrow area grading plan should consider appropriate cut slopes and provisions for drainage measures to avoid concentrated flow on cut slopes. Based on only minor, localized existing slope instability, strong formation materials with limited, localized instability potential, and variable topography with a lesser effect on stability, the risk potential of major landsliding at the Carroll Road North site under reservoir operating conditions is considered relatively low.

Reservoir leakage potential is considered to be low due to the generally massive structure and low permeability of the Wilson Grove Formation bedrock underlying the site. However, as mentioned previously, the numerous springs mapped during the site reconnaissance could represent localized groundwater occurring along permeable units or bedding plane fractures within the bedrock. The presence and extent of such units or fractures will need to be identified during further design studies. If present, the areas where permeable lenses or fractures daylight into the reservoir floor could be treated by localized grouting and/or blanketing with impervious clay to mitigate against reservoir leakage.

Since the Bloomfield fault crosses the proposed reservoir and will be in contact with reservoir water, the possibility of the fault acting as a potential seepage path should be investigated during design studies. A possible mitigation measure to control seepage is to blanket the segment of the fault trace that crosses the reservoir with impervious clay.

4.4 BLOOMFIELD

4.4.1 Field Investigation

The Bloomfield alternative reservoir storage site was previously explored by Woodward-Clyde Consultants (WCC, 1990), including eight borrow area (four alluvial and four bedrock) and four damsite area borings, and a seismic refraction survey along the proposed dam axis. Three of the borings were drilled along the proposed dam axis in the channel and lower abutment area.

No additional subsurface exploration work was conducted as part of the present investigation. However, a site reconnaissance, including geologic mapping, was conducted on October 6 - 7, 1994 to observe existing field conditions, to evaluate and confirm site condition data developed from previous investigations, and to independently assess the geologic and geotechnical conditions at the reservoir site. A compilation of the previous exploration performed at the Bloomfield site and the geologic mapping for this investigation are shown on Figure 4-4.

4.4.2 Site Geology

Bedrock underlying the proposed dam and reservoir area is the Wilson Grove Formation (formerly Merced Formation), consisting predominantly of siltstone to very fine sandstone (Figure 4-4). Occasional outcrops of low to moderately plastic claystone were observed in the reservoir area, and some thick intervals of claystone were noted on WCC borrow exploration boring logs. An outcrop of gravelly silty sand that appears to be within the Wilson Grove Formation was observed in the creek channel. The bedrock is soft, friable, apparently massive (i.e., bedding was not observed), and generally appears tight.

Franciscan Complex bedrock consisting of sheared shale and sandstone occurs to the north of the Bloomfield fault, at the north end of the proposed reservoir. In previous studies (Blake and others, 1971), Franciscan bedrock is in contact with the Wilson Grove Formation along this fault. However, Wilson Grove Formation was mapped to the north of the Blake fault trace during this investigation. This suggests that either the Bloomfield fault occurs north of the Blake location along the Franciscan Complex/Wilson Grove Formation contact, as shown on

Figure 4-4, or that the Franciscan/Wilson Grove contact does not occur along the Bloomfield fault.

Alluvium underlies the flat, narrow valley floor through the lower portion of the reservoir and damsite, as well as the broader valley floor (fan area) at the north end of the reservoir. The width of the alluvial area along the proposed dam axis is about 300 feet. The alluvium may locally be over 40 feet thick upstream of the damsite. Both plastic and non-plastic alluvial soils (sandy clays, and silty sands/sandy silts, respectively) were observed in vertical creek bank exposures, although WCC boring logs suggest the alluvium is predominantly silty to sandy clay with lesser silty and clayey sands. Colluvium overlies bedrock on slopes above the flat valley floor. The colluvium occurs as a layer of silty clay less than one foot thick on the upper slopes and presumably thickens toward the valley floor.

4.4.3 Foundation Conditions

- **Dam Foundation Conditions** - The proposed damsite is located across a relatively broad valley with gently sloping sides. Localized maximum slopes in the damsite area are about 2:1 (horizontal to vertical) and are found on the upper left (east) abutment; overall average slopes are much flatter. The bedrock foundation material consists entirely of the Wilson Grove Formation which is comprised predominantly of sandy siltstone and fine sandstone. Although soft in hardness, these bedrock units are strong and should provide an adequate foundation for an earth embankment.

  In the channel area, WCC's seismic refraction profile along the proposed dam axis suggests a relatively uniform depth to bedrock beneath the alluvial-filled portion of the valley. The profile shows an interface between 1,500 feet/sec (compression or P-wave velocity) and 6,000 feet/sec materials at a depth of about 10 feet. This contact presumably represents the contact between alluvium and bedrock. Several outcrops of Wilson Grove Formation in the lower creek channel suggest similarly shallow bedrock. WCC damsite boring logs indicate alluvium ranges from 7 to 11 feet deep; however, these depths are questionable, as no sampling through the alluvium was performed in the two borings drilled along the dam axis. The log of boring B1A-3, drilled in the valley floor about 700 feet north of the current proposed dam axis, shows material with a low penetration resistance (6 blows/ft with a Modified California sampler) occurring to a depth of at least 20 feet, and possibly as deep as 28 feet. This low penetration resistance is not representative of material with a P-wave velocity of 6,000 feet/sec. Similarly low penetration resistance was encountered to the total depth of alluvial borrow boring C1, at 21.5 feet, and marginally higher penetration resistance (12 to 15 blows/ft) was encountered in boring C2 to a depth of 39 feet. The depth of these materials in borings C1 and C2 suggests that unrecognized, similarly-deep alluvium could pass through the proposed dam foundation area. Based on the preceding assessment, a more reliable definition of top of bedrock (in particular, foundation-quality bedrock) will need to be made along the channel foundation area during design. For the purpose of conceptual design and preliminary cost estimating, assumption of an average excavation depth of 25 feet beneath the dam footprint, with an additional 10 feet for the impervious core zone of the dam, is recommended within the flat alluvial channel area (approximately 300 feet wide).

On the left (east) abutment, the WCC seismic refraction profile shows an unusually thick (about 40 feet) upper layer of low velocity material (1,500 feet/sec) on the middle abutment area. However, foundation-quality bedrock was encountered at very shallow depths in three of the four bedrock borrow borings drilled in the upper reservoir area slopes. These borings encountered drive sampler (2-inch inside diameter California sampler) penetration resistance of greater than 100 blows/ft at depths of generally less than 3 feet. This shallow occurrence of competent bedrock is consistent with observations of the similar Wilson Grove Formation materials encountered in exploration test pits on the abutment slopes at the Valley Ford East and Carroll Road North reservoir sites. Lower penetration resistance (27 to 43 blows/ft) was encountered to a depth of about 15 feet in the fourth bedrock borrow boring, drilled about 800 feet upstream (north) of the left abutment. The apparently common occurrence of shallow, competent bedrock in the reservoir area suggests that at least some shallow, foundation-quality bedrock will be encountered within the dam footprint. The area of deep, low seismic velocity material would nevertheless require close examination during design studies. For the purpose of conceptual design, assumption of an average excavation depth of 20 feet in the left abutment foundation area, with an additional 10 feet beneath the impervious core zone of the dam, is recommended.

On the right (west) abutment, the WCC seismic refraction profile shows up to about 20 feet of low velocity material (1,500 feet/sec) on the middle abutment area. However, given the preceding discussion on excavation depths for the left abutment, it appears likely that portions of the right abutment would similarly require only shallow excavation. For the purpose of conceptual design, assumption of an average excavation depth of 10 feet in the right abutment foundation area, with an additional 10 feet beneath the impervious core zone of the dam, is recommended. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

Hydraulic conductivity testing of the Wilson Grove Formation bedrock has not been performed at the Bloomfield site. However, limited water packer testing was performed in Wilson Grove siltstone underlying the Valley Ford East and Carroll Road North sites to the west. These tests produced estimated permeabilities of 6.2 to 7.5 x 10^{-6} cm/sec (Table 4-2). Based on the apparent, very close similarity of bedrock conditions at the Valley Ford East, Carroll Road North, and Bloomfield sites, it appears that grouting will not be required at the Bloomfield site. This should be verified, however, by thorough evaluation of hydraulic conductivity of the foundation during design studies.

Material from the required foundation excavation can be incorporated in the embankment. Similar to Valley Ford East and Carroll Road North, mass excavation should be possible with heavy excavation equipment, and groundwater is anticipated to be of limited extent and readily handled during construction.

- **Spillway and Outlet Works Foundation Conditions** - Similar anticipated foundation conditions on both abutments indicate that a spillway could be sited on either side of the dam. However, the site topography produces a shorter alignment on the right (west) abutment (about 1,300 feet long) versus a left abutment route (about 1,900 feet). The right abutment could also prove to be more preferable due to a possibly greater depth to competent bedrock along the left abutment, as suggested by WCC's seismic refraction survey results. The anticipated spillway foundation would consist of soft, massive Wilson Grove siltstone to very fine sandstone. An average excavation depth of 20 feet to attain an adequate foundation on the right abutment should be assumed for conceptual design purposes. Full concrete lining along the entire length of the spillway will be required due to the erodibility of bedrock underlying the site. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

The proposed outlet conduit could be sited on either side of the channel. An average excavation depth of 25 feet to attain a competent foundation in Wilson Grove material should be assumed for conceptual design purposes for the outlet works.

4.4.4 Reservoir Slope Stability and Leakage Potential

Very few landslides were observed in the reservoir area during reconnaissance mapping. In addition, fewer erosion scars and springs were noted at this site than at the Valley Ford East or Carroll Road North sites (Figure 4-4). However, some erosion of reservoir slopes should be expected at fluctuating reservoir levels, due to the relatively high erosion potential of the soft and fine-grained Wilson Grove Formation bedrock. Borrow excavation in the reservoir will result in extensive exposures of the Wilson Grove Formation; therefore, the borrow area grading plan should consider appropriate cut slopes and provisions for drainage measures to avoid concentrated flow on cut slopes. Based on only minor, localized existing slope instability, strong formation materials with limited, localized instability potential, and variable topography with a lesser effect on stability, the risk potential of major landsliding at the Bloomfield site under reservoir operating conditions is considered relatively low.

Reservoir leakage potential is considered to be low due to the generally massive structure and low permeability of the Wilson Grove bedrock underlying the site. However, the presence of springs in the reservoir area suggests that some permeable interbeds may occur within the Wilson Grove Formation. As mentioned previously, an outcrop of gravelly silty sand was noted along the creek bank in the channel area, within finer-grained material that appears to be bedrock. Based on the predominance of fine grained bedrock that is exposed in outcrop, and the limited number of springs within the reservoir area, it appears that any permeable lenses would be of limited extent. However, this would need to be verified during further design studies. Source areas for potential seepage, if identifiable, could be mitigated by localized grouting and/or blanketing with impervious clay to prevent reservoir losses.

4.5 HUNTLEY

4.5.1 Field Investigation

The Huntley alternative reservoir storage site was previously investigated as a Class III landfill site by the County of Sonoma in 1989. Woodward-Clyde Consultants (WCC, 1989) performed a preliminary geological study for this investigation, which included the installation of two borings with piezometers in the valley floor and one boring on top of the west ridge.

The field investigation program for this study at the Huntley alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, test pitting, and geophysical surveys. The site reconnaissance geologic mapping was conducted on February 27 - 28, 1995 utilizing aerial photo maps and USGS topographic base maps. The drilling, test pitting, and geophysical surveys were performed on July 28 and August 2 - 4, 1995.

A total of three exploration borings were drilled and sampled. Water packer tests were conducted in selected borings to assess permeability properties of potential foundation materials. Eleven backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite area and to assess potential borrow materials in the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. Two seismic refraction survey lines were performed, one on each dam abutment. The geologic mapping and locations of the exploration borings, test pits, and seismic lines are shown on Figure 4-5. A geologic cross section of the dam foundation is also provided in Figure 4-6. A detailed description of the field investigation program, logs of exploration borings and test pits, results of the water packer tests, results of the laboratory testing, and results of the geophysical surveys are provided in the appendices to the report.

4.5.2 Site Geology

The proposed dam and reservoir site is underlain by bedrock units of the Wilson Grove Formation (formerly Merced Formation) and the Franciscan Complex (Figure 4-5). The older Franciscan Complex rocks are found in the valley floor and lower slopes, while the younger Wilson Grove sedimentary rocks occur in depositional contact with the Franciscan rocks (overlying the Franciscan Complex) and are thus found at the upper portions of slopes and on ridge tops. The contact between the Wilson Grove and Franciscan dips down gently toward the north and east portions of the reservoir area. Due to erosion of the overlying Wilson Grove Formation, the Franciscan bedrock is exposed in the lower portion of the reservoir. The Franciscan Complex in the reservoir area is comprised of melange-type material which consists of a chaotic mixture of sheared, crushed shale and siltstone with intervening areas of relatively unsheared, fractured to massive sandstone and greenstone. The Wilson Grove Formation consists of massive, fine grained, weakly cemented, friable siltstone and fine to coarse grained sandstone.

Shallow alluvium occurs along the channel and consists of sandy clay to clayey sand with pockets of gravelly clay and silty sand. Relatively thick colluvium (sandy clay and clayey sand) is found overlying the Franciscan Complex rocks on the lower portions of the lower and flatter slopes adjoining the channel. Another area of colluvium that overlies the Wilson Grove Formation is found on a broad, elevated drainage swale immediately upstream of the east side of the proposed dam.

4.5.3 Foundation Conditions

- **Dam Foundation Conditions -** The proposed damsite is located across a broad valley with gentle to moderate slopes. Localized maximum slopes in the damsite area are about 2:1 (horizontal to vertical) and are found on the uppermost abutment slopes; overall average slopes are much flatter. The subsurface geology along the dam axis is depicted in the geologic section shown on Figure 4-6. The bedrock foundation material consists of the Franciscan Complex in the channel and lower abutment slopes, and the Wilson Grove Formation in the upper abutment slopes. The subhorizontal contact relationship between these two geologic formations is interpreted from the results of exploration borings and seismic refraction surveys (Figure 4-6). The Franciscan Complex rocks, including the melange-type materials described previously, are strong and should provide an adequate foundation for an earth embankment. Although the Wilson Grove siltstone and sandstone are soft in hardness and weakly cemented, they are strong and should likewise provide adequate foundation support.

Estimates of average required excavation depths to attain adequate foundation conditions, based on the results of subsurface exploration, are about 10 feet in the channel area through the alluvium/colluvium and into the Franciscan Complex bedrock, and about 5 feet in the abutment areas to remove the weaker colluvial and topsoil material overlying the bedrock units. An additional 10 feet of excavation is estimated for the foundation beneath the impervious core zone of the dam to reach tighter, less weathered bedrock materials. Soft, sheared or clay gouge zones may occur locally in the Franciscan Complex foundation and may require some overexcavation. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

The contact between the Franciscan Complex and Wilson Grove Formation appears to be a potential zone of seepage as indicated by springs and seepage areas observed in the vicinity of the contact within the proposed reservoir area. This contact could also provide a potential seepage path through the dam foundation. Water packer testing conducted in boring HT-B3 in the right (west) abutment at a depth interval of 35 to 76 feet straddled the Wilson Grove/Franciscan contact and showed an estimated permeability value of 5.3×10^{-5} cm/sec (Table 4-2 and Figure 4-6). This permeability value is considered fairly low; however, it probably represents a variation in the permeability of the contact. Other portions of the contact may have permeabilities that are relatively higher than that measured by the packer test at one location. During design studies, the permeability of the contact should be investigated further so that specific mitigation measures can be developed to properly minimize seepage potential. For the purpose of conceptual design, an assumption of required blanketing of the contact with an impervious material in the dam foundation and into the reservoir area to mitigate dam foundation seepage potential through the contact is recommended. Water packer tests in Boring HT-B2 at a depth interval of 20 to 58 feet in the Franciscan melange showed an estimated permeability value of less than 2.9 x 10^{-6} cm/sec (average of three tests), which is considered tight (Table 4-2 and Figure 4-6). However, within the Franciscan melange, local masses of fractured sandstone or greenstone bedrock could occur and extend continuously across the dam foundation, thus providing localized potential seepage paths. If these conditions occur in the dam foundation, they could be mitigated by localized grouting of the fractured rock. This is another potential condition that will require further investigation during design studies.

Material from the required foundation excavation can be incorporated in the dam embankment. Mass excavation of both the Wilson Grove Formation and Franciscan Complex materials should be possible with heavy excavation equipment. Groundwater and seepage conditions are anticipated to require some special handling during construction.

- **Spillway and Outlet Works Foundation Conditions** - A preferred alignment for the spillway is located on the left (east) abutment to take advantage of the flat ridge on top of the abutment and a natural drainage swale downstream of the dam alignment. This alignment is about 2,000 feet long. The spillway approach channel and the upper part of the spillway channel is anticipated to be founded in the Wilson Grove Formation, and the lower portion of the spillway channel is anticipated to be founded in the Franciscan Complex rock. Excavation depths of up to 20 feet are estimated to reach adequate foundation material. The weakly cemented and friable sandstone and siltstone of the Wilson Grove Formation and the Franciscan melange foundation materials will require full concrete lining along the entire length of the spillway. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

  The proposed outlet conduit could be located on either side of the channel. The bedrock foundation material is anticipated to be Franciscan melange material. Required excavation depths of about 20 feet are anticipated to reach adequate bedrock foundation material. Local, weaker sheared or clay gouge zones may require local overexcavation.

4.5.4 Reservoir Slope Stability and Leakage Potential

Other than creek bank slumping and minor shallow earth flows, no evidence of mass instability was observed at the reservoir site. The existing slopes within the reservoir area are generally rounded and uniform. As discussed for the Valley Ford East, Carroll Road North, and Bloomfield sites, the Wilson Grove Formation, which occupies the upper portion of the Huntley reservoir area, has a significant erosion potential, particularly in areas of concentrated surface flows. Borrow excavation in the reservoir will result in extensive exposures of the Wilson Grove Formation; therefore, the borrow area grading plan should consider appropriate cut slopes and provisions for drainage measures to avoid concentrated flow on cut slopes. Based on only minor, localized existing slope instability, strong formation materials with limited, localized instability potential, and variable topography with a lesser effect on stability, the risk potential of major landsliding at the Huntley site under reservoir operating conditions is considered relatively low.

The occurrence of springs and seepage zones along the Wilson Grove Formation/Franciscan Complex contact in the proposed reservoir area suggests that water bearing zones exist within the reservoir foundation which could provide pathways for water to leak from the reservoir. As discussed in the previous section, the water packer testing that straddled the Wilson Grove/Franciscan contact in Boring HT-B3 at the damsite showed a relatively low permeability that may represent a variation in the permeability of the contact. A thorough investigation of the seepage potential along the geologic contact will be required during subsequent design studies. For the purpose of conceptual design and preliminary cost estimating, a mitigation measure considered to control seepage through the contact would consist of clay blanketing along the contact in the reservoir area . Lining of about 5 percent of the reservoir area is assumed for controlling reservoir leakage along the geologic contact.

A minor discontinuous fault has been mapped on the upstream and east side of the proposed reservoir (Figure 4-5). The fault places the Wilson Grove Formation in contact with Franciscan Complex rock and has been mapped as Quaternary in the Santa Rosa Quadrangle Map Showing

Recency of Faulting (Bortugno, 1982). The fault is poorly defined with no obvious geomorphic features to define its extent. During design studies, this possible fault should be investigated relative to a potential seepage path for reservoir water.

4.6 Two Rock

4.6.1 Field Investigation

Three potential dam locations at the Two Rock alternative reservoir storage site, including the current location under consideration for this study, were previously investigated by Woodward-Clyde Consultants (WCC, 1988 and WCC, 1990). Previous studies included exploration borings, test pits, and seismic refraction survey (four lines) within the current proposed dam foundation area.

No additional subsurface exploration was conducted as part of the present investigation. However, a site reconnaissance, including geologic mapping, was conducted on October 21, 1994 to observe existing field conditions, to evaluate and confirm site condition data developed from previous investigations, and to independently assess the geologic and geotechnical conditions at the reservoir site. A compilation of the previous exploration performed in the vicinity of the damsite currently being considered and the geologic mapping for this investigation are shown on Figure 4-7.

4.6.2 Site Geology

The bedrock geologic unit at the proposed damsite consists entirely of Franciscan Complex, which is comprised of graywacke sandstone with interbedded shale and siltstone, chert, silica carbonate, and possibly greenstone (Figure 4-7). Chert and silica carbonate occur as prominent outcrops scattered in the damsite and reservoir area. This type of bedrock association suggests that the formation is of the melange type, a chaotic mixture of intact rock masses (greenstone, graywacke, chert, and silica carbonate) in a matrix of sheared and crushed shale and siltstone and clay gouge. The disturbed nature of this geologic unit is attributed to the deformation that the Franciscan Complex rock units have been subjected to during the geologic past.

The Wilson Grove Formation (formerly Merced Formation), which consists of massive sandy siltstone, occurs as a capping on the Franciscan Complex bedrock and is thus found atop ridges surrounding the proposed reservoir at higher elevations. Surficial deposits overlying the bedrock include the alluvium along the creek channel and the colluvium on the lower slopes. These surficial deposits consist of silty sand, clayey sand, and silty gravel. Other surficial deposits include fill associated with small earthen dikes that impound stock ponds.

4.6.3 Foundation Conditions

- **Dam Foundation Conditions** - The proposed damsite is located across a steep-sided canyon with a broad U-shaped valley that is about 400 feet wide. Maximum slopes in the damsite area are about 2:1 (horizontal to vertical). The bedrock foundation material consists entirely of the Franciscan Complex which is strong and should provide an adequate foundation for an earth embankment.

  WCC's previous investigation at the damsite included two borings (T6A-1 and T6A-2) and four seismic refraction lines along the proposed dam alignment. The two borings along the alignment at the base of the abutments indicate adequate bedrock foundation at a depth of about 30 feet. Bedrock consists of "metasiltstone". Shear zones and slickensides described in boring T6A-1 indicate that Franciscan melange-type materials exist in the foundation area. Suitable bedrock foundation is shallower in the abutment slopes. WCC's seismic refraction lines indicate high velocity material (competent bedrock) at a depth of about 10 feet in the abutment slopes.

  Average required foundation excavation depths are estimated to be on the order of 30 feet in the valley floor (channel area) and about 10 feet in the abutments. An additional 10 feet of excavation is estimated for the impervious core zone of the dam and may be locally deeper in shear zone materials. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

  Fractured graywacke, silica carbonate, and chert units may be present in the dam foundation and right abutment ridge, and could provide potential seepage paths.

Therefore, seepage mitigation measures, such as grouting, should be considered during design. For the purpose of conceptual design and preliminary cost estimating, assumption of a double row grout curtain extending to maximum depths on the order of 200 feet into the dam foundation, along the full length of the dam is recommended. The chert/silica carbonate zone in the right side of the proposed reservoir appears to project to the right abutment ridge (Figure 4-7). In this situation, these bedrock units could provide potential seepage paths through fractures. Therefore, grouting should also be considered on the right abutment ridge. For cost estimating purposes, a double row grout curtain to maximum depths of about 200 feet and a length of about 1,000 feet is estimated. Future design studies should specifically address seepage potential through the dam foundation and right abutment ridge in greater detail.

Material from the required foundation excavation can be incorporated in the embankment. Mass excavation should generally be possible with heavy excavation equipment; however, more resistant bedrock types encountered within the Franciscan Complex may require some localized blasting. Groundwater that will require handling during construction is anticipated to be generally limited to the valley floor area.

- **Spillway and Outlet Works Foundation Conditions** - A spillway alignment could be located in either abutment. Both will require extensive excavation in the spillway approach channel area. Since extensive excavation is required, a preferred location would be the right abutment. The required excavation for the spillway approach channel could be laid out in conjunction with a potential rock borrow development on the right (north) side of the reservoir (discussed in Section 5). Material anticipated in the spillway foundation is similar to the dam. Excavation depths of up to 20 feet are estimated to reach adequate foundation material. If massive graywacke, chert, or silica carbonate is encountered, concrete lining may be limited to providing a smooth, hydraulically efficient channel surface as opposed to an otherwise rough rock surface. However, if soft melange and fractured siltstone occur in the foundation, full concrete lining will be required. For the purpose of conceptual design and preliminary cost estimating, the assumption of full concrete lining along the entire length of the spillway is recommended.

The proposed outlet conduit could be located on either side of the channel. Foundation material is anticipated to be Franciscan Complex graywacke and melange, similar to the spillway. Excavation depths on the order of 30 feet are estimated. Materials generated from the the required excavation for the spillway and outlet works can be incorporated in the dam embankment. Some blasting may be required in the harder, massive graywacke, greenstone, chert, and silica carbonate.

4.6.4 Reservoir Slope Stability and Leakage Potential

Few landslides occur in the reservoir area and recurrence of landslides or new landslides are not expected to significantly impact operation of the reservoir at the Two Rock site. The borrow area grading plan should consider appropriate cut slopes so as to mitigate potential instability conditions. Based on only minor, localized existing slope instability, strong formation materials with limited, localized instability potential, and variable topography with a lesser effect on stability, the risk potential of major landsliding at the Two Rock site under reservoir operating conditions is considered relatively low.

If developed, a potential quarry rock source on the right (north) side of the reservoir would create rock exposures that would be in contact with reservoir water; some of this material, such as the fractured chert and silica carbonate may be permeable enough to provide seepage paths for reservoir leakage. If such a potential exists, mitigation measures, such as blanket grouting or slush grouting, would be appropriate. In conjunction with further design-level exploration work to define the extent of potential rock sources, the investigation should also address potential seepage through these areas by in-place field permeability tests. For other fractured rock of the Franciscan Complex that may be exposed during construction, treatment by localized grouting and/or blanketing with impervious clay is assumed for mitigation of potential reservoir leakage.

4.7 ADOBE ROAD

4.7.1 Field Investigation

The field investigation program at the Adobe Road alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, and test pitting. The site reconnaissance geologic mapping was conducted on September 12 - 13, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling and test pitting were performed on September 12 - 13, 1994.

A total of three exploration borings were drilled and sampled. Water packer tests were conducted in one boring to assess permeability properties of potential foundation materials. Ten backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite area and to assess potential borrow materials in the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. The geologic mapping and locations of exploration borings and test pits are shown on Figure 4-8. A detailed description of the field investigation program, logs of exploration borings and test pits, results of the water packer tests, and results of the laboratory testing are provided in the appendices to the report.

4.7.2 Site Geology

The bedrock geologic unit underlying the entire proposed reservoir area consists of sedimentary rocks of the Petaluma Formation (Figure 4-8). At the reservoir site, the Petaluma Formation is comprised predominantly of claystone and siltstone with interbeds of sandstone and pebbly conglomerate. Outcrops are rare and when noted, are usually found on landslide scarps, creek banks, and man-made excavations. Claystones are rarely exposed because of their soft nature. The most prevalent outcrops consist of sandy siltstone, sandstone, and conglomerate. A prominent exposure of sandstone and conglomerate is found in an existing quarry upstream of the left (east) abutment of the proposed dam. The quarry exists above the conceptual maximum reservoir elevation of 340 feet.

Bedding orientation is variable and may be attributed to disturbance by folding and landsliding; however, the general orientation of the strike of bedding is northwest-southeast with moderate to very steep dips to both the northeast and southwest. Variable bedding in the sandstone and conglomerate is probably attributable to cross bedding.

Numerous recent landslides exist within and above the proposed reservoir area (Figure 4-8). The landslides range from small (about 10 feet across) to as much as 300 feet wide. The mapped individual landslides are readily apparent from the geomorphic expressions of topographic scarps and hummocky topography. The results of exploration suggest deeper and much more extensive older landslide deposits within the reservoir area (Qls_1 on Figure 4-8).

Colluvium occurs on the flatter portions of hillside slopes and attains thicknesses on the order of 15 to 20 feet. These are clayey type materials that have accumulated as a result of the mass-wasting process and may include landslide deposits. Recent alluvium refers to the mixed clay, silt, sand, and gravel in the stream channel.

Springs were noted at several locations in the area. This indicates water-bearing units within the Petaluma Formation. At the reservoir site, the seepage may be related to the relatively permeable sandstone/conglomerate units of the Petaluma Formation.

4.7.3 Foundation Conditions

- **Dam Foundation Conditions** - The proposed damsite is located across a broad valley of Adobe Creek. Localized maximum slopes in the damsite area are about 2:1 (horizontal to vertical); overall average slopes are flatter. In the proposed dam foundation area, Adobe Creek is relatively incised, about 10 to 30 feet along the center of the valley, and adjoins broad relatively flat benches that gradually steepen toward the top of the abutments.

  Based on the results of the field investigation, the geologic materials underlying the proposed dam footprint consist of alluvium, colluvium, landslide deposits, and Petaluma Formation bedrock. The recent alluvium is confined to the active stream channel, consists of mixed clay, silt, sand, and gravel, and is probably on the order of 5 to 10 feet thick. The relatively broad and flat benches adjoining the stream channel are underlain by colluvium or colluvium/landslide deposits which in turn overlie the Petaluma

Formation bedrock. The colluvium consists of highly plastic, expansive clays with interlayers of sandy clay and clayey sand as noted in Boring AD-B1 and Test Pits AD-P1, AD-P3, and AD-P4 (Figure 4-8). The colluvium/landslide deposit on the right (west) side bench is interpreted from Test Pit AD-P10, where at least 15 feet of chaotically mixed old mudflow type deposits were encountered.

The alluvium, colluvium, and colluvium/landslide deposits are underlain by Petaluma Formation bedrock. In the channel and adjacent flat benches, and the right abutment, the Petaluma Formation is comprised predominantly of claystone/siltstone with interbeds of sandstone and pebbly conglomerate. In the upper left abutment, sandy siltstone, sandstone and pebbly conglomerate are the predominant materials.

In the active stream, required excavation depths on the order of 10 feet are estimated. In the adjoining flat benches (channel area), required excavations averaging about 20 feet deep are anticipated to remove the weak, soft alluvium and colluvium/landslide deposits overlying the claystone/siltstone of the Petaluma Formation. The claystone/siltstone is soft in hardness, friable, and compact. Blow count data indicates that as a soil, the claystone/siltstone is very stiff to hard in consistency. It should provide an adequate foundation for an earth embankment. Because of the relatively weak nature of these bedrock materials, engineering stability analyses will be important during design-level studies. The sandstone/pebbly conglomerate on the upper left abutment should be suitable as foundation material below an average excavation depth of about 10 feet. On the upper right abutment, recent landslide deposits have been mapped and will require excavation and removal. An average excavation depth of 20 feet is estimated for the upper right abutment. In all dam foundation areas across the abutments and channel, an additional excavation of 10 feet is estimated for the impervious core zone of the dam. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

Seepage potential in the tight claystone/siltstone is anticipated to be very low. A constant head test at a depth interval of 49 to 71.5 feet in Boring AD-B1 in claystone produced an estimated permeability of 3.7×10^{-7} cm/sec which is considered tight (Table 4-2). The occurrence of springs in the dam and reservoir area may be related to the relatively permeable sandstone and conglomerate of the Petaluma Formation. Water packer tests of similar sandstone materials at the Lakeville Hillside site to the south showed permeabilities of 2.0 x 10^{-4} cm/sec to 2.9 x 10^{-5} cm/sec. This permeability is probably related to the porosity of the material rather than fractures. Grouting of materials exhibiting these magnitudes of permeability to mitigate seepage would be very difficult and ineffective. Therefore, other seepage mitigation measures such as clay blanketing of exposed sandstone and conglomerate upstream of the dam footprint and a key trench beneath the impervious core zone of the dam should be considered to lengthen seepage paths for reduction of potential dam foundation seepage. For the impervious core zone, an additional excavation of about 10 feet below the general excavation depth to suitable foundation is recommended as discussed above.

Most material from the required foundation excavation can be incorporated in the embankment. Mass excavation should be relatively easy with conventional earthwork construction equipment. Groundwater and seepage conditions are anticipated to require some special handling during construction.

- **Spillway and Inlet/Outlet Works Foundation Conditions** - Based on topographic and geologic conditions, a preferred alignment for a spillway is on the left (east) abutment. The spillway alignment would be routed through the broad ridge at the top of the left abutment and then through a small natural swale downstream. The spillway alignment is anticipated to be in soft sandstone/conglomerate on the upper abutment and in soft, soil-like claystone /siltstone on the lower abutment. Excavation depths of up to 40 feet are estimated to reach adequate foundation material. Full concrete lining will be required along the entire length of the spillway. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

  The proposed inlet/outlet conduit could be located on either side of the channel. Foundation material is anticipated to be soil-like, weak claystone/siltstone with possibly minor amounts of sandstone. Requried excavation depths to attain a competent foundation are anticipated to be on the order of 30 feet. Because of the potential for accelerated reservoir siltation, as discussed in the next section, appropriate design provisions should be considered to protect the inlet/outlet structure in the reservoir bottom.

4.7.4 Reservoir Slope Stability and Leakage Potential

Several recent landslides were mapped in the reservoir area and attest to the potential instability of the Petaluma Formation claystone/siltstone (Figure 4-8). Landslide sizes range from small (10 feet across) to 300 feet across. The results of the exploration, specifically on the east side of the reservoir, indicate extensive and deep old landslide deposits (mostly sheared highly plastic clay-type materials). These materials are included in the potential impervious borrow source shown on Figure 4-8. The proposed reservoir will have an adverse impact on the stability conditions of the reservoir slopes since the potentially unstable materials will be subject to alternate saturation and drying resulting from annual fluctuation of the reservoir level. Reactivation of existing slides and creation of new landslides are anticipated. A massive rapid slide movement that could impact dam integrity is unlikely given the type of existing landslides, the fine grained nature of the on-site materials, and the topographic conditions. Based on the prevalence of existing slope instability, steeper topography than at some of the other sites, and formation materials more susceptible to sliding, the risk potential of landsliding at the Adobe Road site under reservoir operating conditions is considered relatively high.

The key impacts of reservoir instability include highly accelerated siltation of the reservoir which could affect the location of the inlet/outlet and therefore the size of the storage dead pool, slope instability effects on adjacent land use above reservoir elevations, and visual impact. Quantification of the rate of siltation is difficult; however, based on the distribution of existing landslide deposits, it is postulated that instability and resulting siltation could generate about 100,000 to 200,000 cubic yards annually and say 1 to 2 million cubic yards over a period of 10 years.

Landslides can occur anywhere in the reservoir. Because of the random distribution of landslide occurrence, it would be impractical and costly to completely mitigate slope instability by massive site grading work. The excavation plan for borrow materials within the reservoir should incorporate mitigation of slope instability, to the degree possible, in the area of the excavation.

The evaluation of reservoir leakage is similar to the assessment of seepage through the dam foundation. Potential reservoir leakage would be through the relatively permeable sandstone/ conglomerate of the Petaluma Formation. During borrow material excavation, these granular materials may be exposed in the reservoir, and would therefore be in contact with reservoir water. A possible mitigation method would be to blanket areas of exposed granular material with the plentiful clay that occurs in the reservoir. For the purposes of estimating the amount of required blanketing, 30 percent of the proposed reservoir area is assumed to require blanketing. This is the assumed portion of the reservoir over which the more permeable Petaluma sandstone/ conglomerate would be exposed.

4.8 LAKEVILLE HILLSIDE

4.8.1 Field Investigation

The field investigation program at the Lakeville Hillside alternative reservoir storage site consisted of site reconnaissance geologic mapping and drilling. The site reconnaissance geologic mapping was conducted on September 21 - 22, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling was performed on October 31 through November 2, 1994.

A total of five exploration borings were drilled and sampled. Water packer tests were conducted in two borings to assess permeability properties of potential foundation materials. Two creek bank exposures were logged and sampled as part of the borrow materials assessment in the proposed reservoir area. Representative samples were obtained for laboratory testing. The geologic mapping and locations of the exploration borings and other sample locations are shown on Figure 4-9. A geologic cross section of the dam foundation is also provided on Figure 4-10. A detailed description of the field investigation program, logs of exploration borings and creek bank exposures, results of the water packer tests, and results of the laboratory testing are provided in the appendices to the report.

4.8.2 Site Geology

The entire proposed damsite area is underlain by bedrock units of the Petaluma Formation which consist of claystone, sandy claystone, and siltstone with interbedded sandstone and pebbly conglomerate (Figure 4-9). The claystones and siltstone are very soft, friable, and moderately to highly plastic. The sandstone and pebbly conglomerate are weakly cemented and friable. The coarser components of the sandstone and conglomerate are derived from Franciscan Complex rocks such as sandstone, shale, and greenstone. The relative amounts of claystone/siltstone and sandstone/conglomerate in the foundation area are unknown because of the lack of bedrock exposures. However, based on the type of subsurface materials encountered in the exploration borings, an average of 40 percent for the sandstone/conglomerate is roughly estimated. The strike of bedding is northeast to northwest with moderate dips to the west and east. Variations in bedding attitudes are probably related to folding and landsliding.

Landslide deposits exist on both dam abutments. Hummocky topography is readily apparent on the right abutment slopes from the proposed dam alignment to about 1,000 feet upstream. Subdued hummocky topography also occurs on the left (east) abutment. Boring LH-B5 in the upper left abutment indicates old landslide material to a depth of about 40 feet (Figure 4-10). The interpretation of the existence of this slide material is based on mixed, black topsoil-type material (clayey gravel) encountered at this depth. A recent landslide exists about 500 feet downstream of the dam alignment on the right (west) side (Figure 4-9). This slide was reportedly a reactivation of a smaller old slide during the 1992-93 rainy season (personal communication, Mr. Al Marcucci, September 22, 1994). The slide has a vertical scarp of up to 15 feet and is about 200 feet wide. The log of Boring LH-B2 indicates a landslide depth of about 37 feet. Since part of this landslide lies within the footprint of the dam embankment, it will require excavation and removal from the foundation area.

The creek channel is about 75 to 100 feet wide. Recent alluvium in the channel consists of sandy clay interbedded with clayey sand and gravelly clay. It is 9 feet deep in Boring LH-B1 and probably on the order of up to 15 feet thick.

4.8.3 Foundation Conditions

- **Dam Foundation Conditions** - The proposed damsite is located across a relatively narrow, steep-sided drainage. Maximum slopes in the damsite area are about 2:1 (horizontal to vertical). The subsurface geology along the dam axis is depicted in the geologic section shown on Figure 4-10.

  The bedrock foundation material consists entirely of the Petaluma Formation which is comprised of interbedded claystone, sandy claystone, siltstone, sandstone, and pebbly conglomerate. These sedimentary bedrock units are soft, friable, and soil-like. As a soil, the materials have a stiff to very stiff consistency for the claystone and siltstone, and a dense to very dense consistency for the sandstone and conglomerate. They appear to possess strengths similar to or stronger than compacted earthfill and should provide an adequate foundation for an earth embankment. Because of the relatively weak nature of these bedrock materials, engineering stability analyses will be important during design-level studies.

  Excavation and removal of weaker surficial deposits will be required to attain adequate foundation conditions. In the channel area, average excavation depths of 30 feet for the entire dam embankment are anticipated plus an additional 10 feet beneath the impervious core zone of the dam. In the abutment areas, average excavation depths of about 25 feet are estimated to remove possible landslide deposits plus an additional 10 feet beneath the impervious core zone. In the left (east) abutment, local excavation depths of up to 40 feet below ground surface may be required. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

  The anticipated foundation material consists of both the tight claystone/siltstone layers and the interbedded, relatively permeable sandstone/conglomerate. The strike of bedding is roughly perpendicular to the proposed dam alignment; therefore, the occurrence of relatively permeable layers would likewise extend across the dam footprint. This condition is considered adverse relative to seepage potential. The tightness of the claystone unit is confirmed by an estimated permeability from water packer testing of 5.9

x 10^{-6} cm/sec in Boring LH-B1 at a depth interval of 56.5 to 63.5 feet (Table 4-2 and Figure 4-10). Water packer tests in Boring LH-B1 and a constant head test in Boring LH-B5 in the sandstone/conglomerate indicate permeability values ranging from 1.8 x 10^{-4} cm/sec to 2.9 x 10^{-5} cm/sec which are considered low to moderate permeability. The water bearing properties of the sandstone /conglomerate are manifested by the existence of associated springs within the proposed dam and reservoir area and groundwater encountered in conglomerate in Boring LH-B5. This type of permeability is probably related to the porosity of the sandstone/conglomerate, although it may also be related locally to fractures as observed in outcrops. Pore permeability is very difficult and impractical to grout, particularly in sandstone and conglomerate with a fine silty matrix as exists at this site. Fracture permeability can be more effectively grouted; however, further information would be required during design studies to assess the practicality and extent of possible grouting. An alternative of mitigating seepage through the sandstone/conglomerate is by clay blanketing of exposures of these materials upstream of the dam to lengthen seepage paths. Further studies would be required during design-level work to define the extent and refine permeability properties of the sandstone/conglomerate so that more definitive mitigation measures can be considered and outlined.

Most material from the required foundation excavation can be incorporated in the embankment. Mass excavation should be relatively easy with conventional earthwork construction equipment. Groundwater and seepage conditions are anticipated to require some special handling during construction.

- **Spillway and Inlet/Outlet Works Foundation Conditions** - Spillway siting assumes that the spillway will discharge into the same drainage channel the dam is sited on. Spillway alignments on both abutments could be considered. Both will have similar constraints of routing through landslide deposits, of long (1,000 to 1,200-foot) alignments, and of requiring extensive, massive excavations. Excavation depths of 30 to 50 feet are estimated to attain an adequate foundation. Full concrete lining along the entire length of the spillway channel will be required because of the soft, soil-like nature of the bedrock foundation materials. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

The proposed inlet/outlet conduit could be located on either side of the channel. Foundation material is anticipated to be soil-like claystone/siltstone and sandstone/conglomerate, similar to the dam foundation. Required excavation depths to attain a competent foundation are anticipated to be on the order of up to 40 feet. The discharge end of the outlet conduit will require location outside landslide areas downstream of the dam footprint. Because of the potential for accelerated reservoir siltation, as discussed in the next section, appropriate design provisions should be considered to protect the inlet/outlet structure in the reservoir bottom.

4.8.4 Reservoir Slope Stability and Leakage Potential

Several recent landslides were mapped in the reservoir area and attest to the potential instability of the Petaluma Formation claystone/siltstone (Figure 4-9). Landslide sizes range from small (10 feet across) to large (500 feet across). The proposed reservoir will have an adverse impact on the stability conditions of the reservoir slopes since the potentially unstable materials will be subject to alternate saturation and drying resulting from annual fluctuation of the reservoir level. Reactivation of existing slides and creation of new landslides are anticipated. A massive rapid slide movement that could impact dam integrity is unlikely given the type of existing landslides, the fine grained nature of the on-site materials, and the topographic conditions. Based on the prevalence of existing slope instability, steeper topography than at some of the other sites, and formation materials more susceptible to sliding, the risk potential of landsliding at the Lakeville Hillside site under reservoir operating conditions is considered relatively high.

The key impacts of reservoir instability include highly accelerated siltation of the reservoir which could affect the location of the inlet/outlet and therefore the size of the storage dead pool, slope instability effects on adjacent land use above reservoir elevations, and visual impact. Quantification of the rate of siltation is difficult; however, based on the distribution of existing landslide deposits, it is postulated that instability and resulting siltation could generate about 50,000 to 100,000 cubic yards annually and say 0.5 to 1 million cubic yards over a period of 10 years.

Landslides can occur anywhere in the reservoir. Because of the random distribution of landslide occurrence, it would be impractical and costly to completely mitigate slope instability by massive site grading work. The excavation plan for borrow materials within the reservoir should incorporate mitigation of slope instability, to the degree possible, in the area of the excavation.

Groundwater occurs at the reservoir site as attested to by the presence of springs and existing wells (Figure 4-9). An active well is located near the Marcucci residence about 800 feet southwest of the damsite on the right abutment ridge. The well was reportedly constructed in 1970 to a depth of about 200 feet (personal communication, Mr. Al Marcucci, September 21, 1994). The water level measured by Department of Water Resources personnel on September 21, 1994 was at 59 feet below the ground surface. There is also a recently installed well at the Domaine Chandon vineyard in the central ridge of the proposed reservoir. The presence of springs and wells in the area indicates the existence of water bearing units at the reservoir site and therefore, the potential for reservoir leakage.

The evaluation of reservoir leakage is similar to the assessment of seepage through the dam foundation. Potential reservoir leakage would be through the relatively permeable sandstone/ conglomerate of the Petaluma Formation. During borrow material excavation, these granular materials may be exposed in the reservoir, and would therefore be in contact with reservoir water. A possible mitigation method would be to blanket areas of exposed granular material with the plentiful clay that occurs in the reservoir. For the purposes of estimating the amount of required blanketing, 40 percent of the proposed reservoir area is assumed to require blanketing. This is the assumed portion of the reservoir over which the more permeable Petaluma sandstone/ conglomerate would be exposed.

4.9 TOLAY CREEK

4.9.1 Field Investigation

The field investigation program at the Tolay Creek alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, test pitting, fault trenching, and geophysical surveys. The site reconnaissance geologic mapping was conducted on October 12 - 13 and October 28 - 31, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling, test pitting, trenching, and geophysical surveys were performed on July 14 - 26, 1995. The investigation at the Tolay Creek site was designed to cover multiple dam sites involved in the two alternative reservoir configurations being evaluated, including the main dam site common to both configurations, the north and west saddle dams associated with the full valley inundation scheme (alternative without backdam), and the backdam associated with the partial inundation scheme (alternative with backdam).

A total of nine exploration borings were drilled and sampled. Twenty two backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite areas and to assess potential borrow materials within and outside the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. Two exploratory trenches, 150 and 360 feet long, were excavated with a backhoe across the postulated trace of the Tolay fault. Seven seismic refraction survey lines were performed within proposed dam foundation and potential borrow areas. The geologic mapping and locations of the exploration borings, test pits, trenches, and seismic lines are shown on Figure 4-11 and Figure 4-12. A geologic cross section of the main dam foundation is also provided on Figure 4-13. A detailed description of the field investigation program, logs of exploration borings and test pits, logs of fault exploration trenches, results of the laboratory testing, and results of the geophysical surveys are provided in the appendices to the report.

4.9.2 Site Geology

The proposed reservoir area is underlain by the Petaluma Formation (claystone and sandstone), Sonoma Volcanics (andesite, basalt, rhyolite, and ash flow tuff), and Franciscan Complex

(Figure 4-11). The Petaluma Formation and Sonoma Volcanics are younger geologic units that overlie the Franciscan Complex. At the project area, the Franciscan Complex rocks are found at higher elevations, near the upper parts of the reservoir slopes and atop the adjacent broad ridges. The Franciscan Complex consists of melange, a chaotic mixture of intact masses of sandstone, greenstone, chert, and blue schist in a sheared shaley and clayey matrix.

The main dam site is underlain by the Petaluma Formation claystone and Sonoma Volcanics comprised of andesites and rhyolitic ash flow tuffs (Figure 4-12). Old landslide deposits involving these two geologic formations have been interpreted from the geomorphologic conditions and the results of subsurface exploration at the main dam site. The north saddle dam site is underlain entirely by the Petaluma Formation claystone and sandstone with alluvium in the channel section (Figure 4-11). The west saddle dam site is underlain by Petaluma Formation claystone in the north abutment area and old landslide deposits, derived from Franciscan Complex and Sonoma Volcanics materials, in the south abutment area and valley floor (Figure 4-11). The alternative backdam site across the broad valley floor is underlain by silty clay to clayey sand alluvium with thicknesses of 27.5 and 30.5 feet encountered in two exploration borings (Figure 4-11). The alluvium overlies Petaluma Formation claystone and sandstone.

Few landslides were mapped in the reservoir area during the site reconnaissance. Although the Petaluma Formation and soil-like units of the Sonoma Volcanics (ash flow tuffs) are prone to landsliding, the gentle slopes surrounding the valley floor and forming the sides of the proposed reservoir do not presently exhibit a lot of active instability. However, the old landslide deposits interpreted at the main dam site encompass a major portion of the proposed dam abutment foundation areas and will impact the geotechnical considerations at this site. Proposed reservoir operations could have an adverse impact on the old landslides, if left unmitigated.

Several springs were mapped during the site reconnaissance. The springs encountered probably represent localized groundwater in old landslide deposits and local sandstone beds within the Petaluma Formation.

The mapped trace of the Tolay fault as shown on published geologic maps and plotted on Figures 4-11 and 4-12 trends northwesterly through the sites for the proposed main dam, backdam, and west saddle dam. Although not considered active, the apparent presence of the fault within the foundation areas of several of the proposed dams prompted a limited fault trenching program with the objective of locating the fault and assessing its age, relative to existing geologic units that it may or may not displace and that can be associated with a geologic age, if found. During our reconnaissance mapping and exploration at the Tolay Creek alternative reservoir site, we did not encounter the fault. This fault does not show evidence of Holocene activity, and is therefore not considered active according to California Division of Mines and Geology fault evaluation criteria. Exploration trenches TC-T1 and TC-T2, excavated across the postulated trace of the Tolay fault near the Tolay Creek reservoir area and at locations selected to most likely encounter the fault if present within the depth limitation of exploration, did not show any evidence of faulting in old landslide deposits exposed in the trenches. If the fault is present at depths greater than could be explored, it would be older than the old landslide deposits encountered in the exploration trenches within the depths explored. The age of the landslide deposits is not known and would be difficult to estimate. Thus, the limited fault trenching was not conclusive in confirming, with site specific data, that the fault is older than active Holocene classification. However, based on a comprehensive review by others of the Tolay fault, and in conjunction with this investigation, no specific evidence of activity, such as observation of fault displacement in geologically young (i.e., less than 11,000 years old) materials, has been encountered (Hart, 1982). A more detailed discussion of the Tolay fault is presented in Section 3.

The Tolay fault at the Tolay Creek alternative reservoir site is located about 1 mile southwest of the active Rogers Creek fault. Because of the proximity of the active Rodgers Creek fault to the Tolay fault and their subparallel relationship, it would be prudent and conservative to assume that some sympathetic movement could occur on the Tolay fault as a result of activity and fault movement along the active Rodgers Creek fault. A maximum surface displacement of 6 feet is estimated for the Rodgers Creek fault during a magnitude 7 earthquake, although the more prevalent average displacement is usually half the maximum value, or 3 feet (Toppozada and others, 1994). The magnitude of potential sympathetic movement on the adjacent Tolay fault, if any at all, would be a fraction of the maximum surface displacement along the Rodgers Creek fault.

4.9.3 Foundation Conditions

- **Main Dam Foundation Conditions** - The proposed main dam site is located at the relatively narrow constriction of Tolay Creek, immediately downstream of the broad flat-floored Tolay valley (Figure 4-11 and Figure 4-12). Relatively steep slopes, about 1.5:1 (horizontal to vertical), exist in the damsite area and extend about 100 feet vertically above the creek channel to a relatively extensive bench on both sides of the canyon. The anomalous topography is typical of slump block landslide geomorphology. This geomorphology is prevalent on both slopes above Tolay Creek downstream of the main dam site and is believed related to extensive and massive old landslide deposits. The subsurface geology along the main dam axis is depicted on the geologic section shown on Figure 4-13.

  The narrow constriction at the main dam site below the flat bench areas is attributed to the presence of hard andesite masses which act as a resistant capping on softer Petaluma Formation claystone and Sonoma Volcanics ash flow tuff, thereby restricting mass wasting of the canyon slopes. Boring TC-B1, located at the edge of the flat bench in the upper left (east) abutment, was drilled to assess the depth and extent of the andesite outcrop located at the top of the left canyon slope. The boring encountered hard, fractured andesite to a depth of 52 feet. Rock cores show that the andesite is closely to moderately fractured; fractures are randomly oriented with iron stained surfaces. Some fractures are infilled with clay. Total drilling water loss was noted in this boring. Drilling below the andesite indicated it to be underlain by Petaluma Formation claystone. The claystone is soft, friable, crushed, and sheared. Above the claystone contact, the andesite is closely to intensely fractured and consists of mixed clay and andesite rock fragments. Based on the condition of the andesite and claystone and the landslide geomorphology of the area, the andesite and claystone encountered in Boring TC-B1 to a depth of 68 feet is interpreted as part of an old landslide deposit. In Boring TC-B2, located at the upslope portion of the right (west) abutment bench, the subsurface material consists entirely of Petaluma Formation claystone to the total depth drilled of 70 feet. A depth of interpreted landslide material at 46 feet is based on a core sample of very soft, gray clay gouge and the intensely crushed, sheared, brecciated claystone and siltstone above this depth. Our interpretation of the old landslide geometry is shown on Figure 4-13.

Based on the results of the field investigation drilling and sampling, the old landslide material appears to be a strong, compact soil material and could be as strong as the proposed earth embankment. The results of the seismic refraction survey also indicate seismic velocities ranging from 6,550 to 8,450 feet per second which is more than is expected for consolidated earthfill material. However, in order to confirm this condition and assess the effects of reservoir operation on the old landslide abutments, extensive exploration, laboratory testing, and engineering analyses will be required and are beyond the scope of the present study. Therefore, for the purpose of conceptual design and preliminary cost estimating, we have conservatively assumed that the interpreted old landslide deposits will require excavation and removal from the dam foundation and that the dam embankment will be founded on in-place Petaluma Formation or Sonoma Volcanics. Estimated excavation contours reflecting this condition are superimposed on the main dam site geologic map and illustrate the significant impact of this requirement (Figure 4-12).

Seepage potential in the Petaluma Formation claystone and siltstone is anticipated to be low. Some relatively permeable layers of sandstone and conglomerate may be associated with the claystone. Seepage mitigation of these layers, if exposed in the dam foundation footprint, could be accomplished by localized clay blanketing. Fractured andesite, if found in the foundation, could also represent potential seepage paths. Mitigation measures against this seepage potential could either be impervious clay blanketing or localized grouting.

- **Alternative Upstream Main Dam Foundation Conditions -** The discovery of the significant old landslide deposits at the Tolay Creek main dam site prompted a field decision, approved by Harland Bartholomew & Associates, Inc., to explore a possible alternative alignment about 1,000 feet upstream of the originally proposed damsite (Figure 4-12) and to obtain additional subsurface data before completing the field investigation at the Tolay Creek site, should it turn out to be needed as determined later during office studies. This alternative alignment is upstream of the area of landslide geomorphology discussed above. This upstream alternative was explored with three additional exploration borings, in addition to three test pits and one seismic refraction line that were already a part of reservoir area borrow exploration. The alternative alignment is located across the broad valley immediately upstream of the Tolay Creek constriction at the original main dam site (Figure 4-12).

An andesite rock knob occurs at the west side of the channel on the lower right (west) abutment. Both abutments are gently sloping except for the moderate slope on the upper left (east) abutment. Bedrock units at the alternative alignment consist of the Petaluma Formation and Sonoma Volcanics. In Boring TC-B7 near the channel, alluvium is 11.5 feet thick and underlain by Petaluma claystone. Boring TC-B9 near the saddle area of the upper right abutment, west of the rock knob, also encountered claystone to a depth of 32 feet. Hard andesite was encountered below the claystone and may be correlated with the andesite exposed on the rock knob to the east. Boring TC-B8, located in the upper right abutment area, was drilled into landslide material to an interpreted depth of 40 feet. Sheared serpentine was encountered from 36 to 40 feet and could represent the base of the disturbed (slide) zone. For an earth embankment at this alternative upstream location, required foundation excavation would consist of removal of the localized landslide deposit on the right abutment, estimated up to 40 feet thick, and removal of alluvium and soft, weathered claystone in the channel area, averaging about 20 feet thick. The andesite rock knob would provide a strong foundation; however, it is most likely permeable because of fractures and would therefore require grouting to seal the fractures and mitigate potential seepage. Test Pit TC-P19 in the upper left abutment encountered weathered, closely and loosely fractured andesite to a depth of 12 feet. Foundation excavation would require removal of these materials to depths of about 20 feet to attain less weathered rock, and localized grouting of the fractured andesite would be required to mitigate seepage in this foundation area also.

- **Backdam Foundation Conditions** - The proposed backdam site for the partial inundation alternative is about a one mile long alignment that crosses the midsection of Tolay valley (Figure 4-11). The dam alignment was explored by two borings, one seismic refraction line, and three test pits. The entire damsite is underlain by alluvium which in turn overlies the Petaluma Formation. The exploration drilling at this site encountered Petaluma Formation claystone at 30.5 feet in Boring TC-B6, and claystone and sandstone at depths of 27.5 feet and 37.5 feet, respectively, in Boring TC-B4. The overlying alluvium consists of silty clay to sandy clay with interlayers of clayey sand. Blow count data indicates that the alluvium is firm to stiff in consistency and appears to be reasonably strong. Depending on the embankment design, and considering the large foundation area of the long embankment, a bedrock foundation may not be required. Thus, it may not be necessary to excavate and remove all of the alluvium from the foundation. A minimum average stripping depth of 5 feet is estimated to remove the upper loose and organic topsoil. Toward the abutment ends of the long dam, Petaluma Formation is anticipated to occur within about 10 feet of the surface and would comprise the foundation material in these localized areas. For a zoned embankment design, a minimum additional excavation of 3 feet is estimated for the impervious core zone foundation. Estimated average dam foundation excavation requirements are summarized in Table 4-1. Seepage potential in the Petaluma Formation and overlying clayey alluvium beneath the proposed backdam is anticipated to be low.

- **North Saddle Dam Foundation Conditions** - The north saddle dam (Figure 4-11) is underlain entirely by bedrock units of the Petaluma Formation. Claystone and sandstone were encountered in the subsurface exploration at this site. Boring TC-B5 in the channel area encountered 11.5 feet of alluvium overlying Petaluma claystone and sandstone. Average excavation depths of 5 feet and 10 feet are anticipated in the abutment slopes and channel section, respectively (Table 4-1). An additional excavation of 5 feet is estimated beneath the impervious core zone of the dam. Seepage potential through the north saddle dam foundation is anticipated to be very low because of tight Petaluma Formation and the thick clayey alluvium in the reservoir area, which acts as a natural impervious liner.

- **West Saddle Dam Foundation Conditions** - The west saddle dam (Figure 4-11) is underlain by Petaluma Formation claystone on the right (north) abutment, and old landslide deposits derived from Franciscan Complex melange and Sonoma Volcanics materials on the left (south) abutment and valley floor (channel area). Exploration at this site consisted of one seismic refraction survey line, one test pit, and a 360-foot long exploration trench. The exploration trench was part of the fault investigation for the Tolay Creek site and was located across the postulated trace of the Tolay fault. Material interpreted as old landslide deposits was encountered along the entire length of the trench. The old landslide material is essentially a chaotically mixed, sheared silty to sandy clay with traces of rock fragments derived from the Franciscan Complex. The soil materials appear to be strong and tight and should provide an adequate foundation for the small earth embankment required at this location to close the reservoir (alternative without backdam). An average excavation depth for the entire dam footprint is estimated to be 5 feet, with an additional excavation of 5 feet beneath the impervious core zone of the dam (Table 4-1). Seepage potential in the west saddle dam foundation is anticipated to be very low because of the clayey nature of the site subsurface materials.

Most material from the required foundation excavation at the various dam sites can be incorporated in the embankments. Excess excavated landslide deposits from the main dam site can be deposited within the reservoir area. Mass excavation should be relatively easy with conventional earthwork construction equipment. Groundwater and seepage conditions are anticipated to require some special handling during construction, particularly at the main dam site.

- **Spillway and Outlet Works Foundation Conditions -** The spillway alignment at the main dam could be sited on either abutment. The spillway excavation will require coordination with the dam foundation excavation plan to remove the old landslide deposits. The proposed outlet conduit at the main dam could also be located on either side of the channel. Foundation material for both the spillway and outlet conduit is anticipated to be soft Petaluma Formation or Sonoma Volcanics. The Sonoma Volcanics could range from soft soil-like tuff to hard andesite rock. Full concrete lining will be required along the entire length of the spillway. Spillway and outlet works excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

4.9.4 Reservoir Slope Stability and Leakage Potential

Few landslides were mapped in the proposed reservoir area during the site reconnaissance. Most of these were located above the maximum reservoir level on the east side of the reservoir. The reservoir could have an adverse impact on the stability of slopes underlain by Petaluma claystone or Franciscan Complex melange, since these potentially unstable materials will be subject to alternate saturation and drying resulting from annual fluctuation of the reservoir level. However, due to the general lack of existing slides within the proposed reservoir area and the relatively low slope gradient of natural slopes in the area, mass movement that could significantly impact reservoir operation is unlikely. However, shallow, localized to extensive mudflows are possible and would contribute locally to reservoir siltation. Based on this lesser extent of active existing slope instability and more gentle topography than exist at the Adobe Road and Lakeville Hillside sites, but the presence of the same formation materials more susceptible to sliding, the risk potential of landsliding at the Tolay Creek site under reservoir operating conditions is considered moderate.

Reservoir leakage potential is considered to be relatively low due to the generally low permeability of the Franciscan Complex and Petaluma claystone underlying the proposed reservoir. The andesite in the vicinity of the main dam site may constitute locally high seepage potential, but can be treated by localized grouting and/or clay blanketing, as appropriate. Several springs that were mapped during the site reconnaissance likely represent localized groundwater that is concentrated along isolated fracture systems within the Franciscan Complex or associated with landslide deposits. The entire reservoir is underlain by thick clayey alluvium which acts as a natural impervious blanket across the reservoir bottom. In utilizing the alluvium as a borrow source for embankment construction, considering the abundance of this material, the borrow area grading plan should maintain a thick layer of the clay material across the reservoir bottom after construction.

4.10 SEARS POINT

4.10.1 Field Investigation

The field investigation program at the Sears Point alternative reservoir storage site consisted of site reconnaissance geologic mapping, drilling, test pitting, and geophysical surveys. The site reconnaissance geologic mapping was conducted on September 14 - 15, 1994 utilizing aerial photo maps and USGS topographic base maps. The drilling, test pitting, and geophysical surveys were performed on July 12 - 13, 1995.

A total of three exploration borings were drilled and sampled. Water packer tests were conducted in one boring to assess permeability properties of potential foundation materials. Twelve backhoe test pits were excavated to assess shallow foundation conditions in the potential damsite area and to assess potential borrow materials in the proposed reservoir area. Representative samples were obtained from selected test pits for laboratory testing. Two seismic refraction survey lines were performed within proposed dam foundation and potential borrow areas. The geologic mapping and locations of the exploration borings, test pits, and seismic lines are shown on Figure 4-14. A geologic cross section of the dam foundation is also provided on Figure 4-15. A detailed description of the field investigation program, logs of exploration borings and test pits, results of the water packer tests, results of the laboratory testing, and results of the geophysical surveys are provided in the appendices to the report.

4.10.2 Site Geology

The bedrock underlying the proposed dam and reservoir area predominantly consists of Petaluma Formation claystone (Figure 4-14). This material is generally soft and friable, and appears to be mostly massive. Rare bedding exposures were measured, striking north to northwest and dipping about 15 to 30 degrees east. The claystone includes interbedded siltstone and cemented, fine-grained sandstone with rare interbeds of hard limestone. Scattered outcrops of hard, strong andesite and soil-like rhyolitic ash flow tuff occur locally along the south side of the proposed reservoir.

Alluvium and colluvium underlies the flat valley floor. The three exploration borings in the valley floor indicate alluvium/colluvium thicknesses of 28.5, 34.5, and greater than 40 feet. The alluvium/colluvium consists of moderately to highly plastic silty clay to sandy clay with interbedded clayey sand and thin lenses of silty sand and gravelly sand. The colluvial soils overlying the bedrock slopes are commonly dark gray to black clay with pervasive shrinkage cracks, indicating the expansive quality of the soils and underlying claystone bedrock.

Numerous recent and old landslides have occurred within and above the proposed reservoir area (Figure 4-14). Some of the slides within the immediate reservoir area are as wide as 400 feet, and extend in length as much as 1,000 feet downslope. Much more extensive old landslide deposits are found on the upstream west portion of the proposed reservoir (Figure 4-14). Most of these slides are readily apparent from their geomorphic expression, including hummocky topography and scarps.

4.10.3 Foundation Conditions

- **Dam Foundation Conditions -** The proposed damsite is located across the broad, flat-floored valley of Tolay Creek with generally gently sloping sides. Localized maximum slopes in the damsite area are about 2.5:1 (horizontal to vertical) and are found on the left (east) abutment slopes; overall average slopes are much flatter, particularly in the right (west) abutment area. The subsurface geology along the dam axis is depicted in the geologic section shown on Figure 4-15. The bedrock foundation material consists entirely of the Petaluma Formation which is comprised of claystone with interbedded sandstone and siltstone. The claystone is a massive, compact, tight, soil-like bedrock unit that should provide an adequate foundation for an earth embankment.

  Boring SP-B1 on the east side of the Tolay Creek channel and at the base of the left abutment slope indicated 28.5 feet of clayey alluvium overlying the Petaluma Formation claystone. In Boring SP-B2 and Boring SP-B3, located in the reservoir area, the thickness of the alluvium is in excess of 40 feet and is 34.5 feet, respectively. Based on this data, the thickness of the alluvium at the damsite could attain depths similar to the reservoir borings. Therefore, average excavation depths to remove the weak alluvium/colluvium in the channel area are estimated to be 30 feet with maximum excavation depths in the channel alluvium on the order of 40 feet. Excavation depths in the abutment areas are dictated by the interpreted depths of old landslide deposits shown on the geologic section (Figure 4-15). Estimated average excavation depths are 25 feet in the left abutment and 30 feet in the right abutment. For the impervious core zone of the dam, an additional 10 feet of excavation is estimated to attain relatively fresher and tighter bedrock. Estimated average dam foundation excavation requirements are summarized in Table 4-1.

The Petaluma claystone, as noted in boring core samples and outcrops, appears massive and tight; therefore the seepage potential is anticipated to be low. Water packer tests in the claystone in Boring SP-B1 indicate low permeability values ranging from 1.1×10^{-5} cm/sec (average of three tests) to 3.4×10^{-6} cm/sec (average of three tests) at depth intervals of 38 to 70 feet and 50 to 70 feet, respectively (Table 4-2 and Figure 4-15). It is possible that relatively permeable sandstone beds occur within the claystone; however, their distribution appears to be limited at this site, based on the outcrop mapping. If they do exist in the exposed foundation, mitigation to control seepage could be by clay blanketing.

Material from the required foundation excavation can be incorporated in the embankment. Mass excavation should be relatively easy with conventional earthwork construction equipment. Groundwater and seepage conditions are anticipated to require special handling during construction.

- **Spillway and Outlet Works Foundation Conditions -** Based on topographic conditions and the presence of more significant alluvial/colluvial deposits on the west side of Tolay Creek, a preferred spillway alignment is situated through the upper, flat northeast ridge forming the left (east) abutment for the dam. The alignment would pass through the top of the left abutment ridge and extend back to Tolay Creek downstream of the dam. This alignment is about 1,200 feet long, as opposed to a 1,600-foot alignment through the right abutment and across the flat valley floor. Construction of the spillway will require deep excavations through old landslide deposits and soft, friable Petaluma Formation claystone. Excavation depths of 30 to 40 feet are estimated to attain an adequate foundation. Full concrete lining will be required along the entire length of the spillway. Spillway excavation should be possible with heavy excavation equipment, and materials generated from the required excavation can be incorporated in the dam embankment.

The proposed outlet conduit would appear best located on the left (east) side of the Tolay Creek channel due to the significant alluvial/colluvial deposits on the west side of the channel. Soft, friable claystone is anticipated to comprise the majority of the conduit foundation. Required excavation depths to attain a competent foundation are anticipated to be on the order of up to 40 feet.

- **Diversion Channel Foundation Conditions** - Based on evaluation of diversion requirements for the various alternative storage reservoirs by others, the Sears Point site has the most significant requirement for diversion due to its large drainage basin. The conceptual design calls for construction of a diversion channel along the right (west) side of the reservoir. Because of the geologic conditions of weak soil-like, erodible materials, full concrete lining of any diversion channels will be required. Construction of a cut bench along the right side reservoir rim for installation of a diversion channel may have localized effects on the stability of uphill slopes and would need to be taken into account during design. As planned, the diversion channel would be unavoidably routed through and impacted by old landslide deposits which would require mitigation to the degree feasible, as any tendency for movement would tend to be incompatible with the rigid-type structure of a concrete lined diversion channel. The diversion channel route will require detailed investigation (geotechnical work) to assess specific slope instability condiitons. In addition, a significant amount of maintenance associated with keeping the integrity of the diversion channel intact and the clean-up of slide debris that could interfere with the diversion channel operations, related to reservoir slope instability, should be expected.

4.10.4 Reservoir Slope Stability and Leakage Potential

Numerous landslides mapped in the proposed reservoir area attest to the potential instability of the Petaluma Formation claystone (Figure 4-14). The proposed reservoir will have an adverse impact on the stability conditions of the reservoir slopes since the potentially unstable materials will be subject to alternate saturation and drying resulting from annual fluctuation of the reservoir level. Reactivation of existing slides and creation of new landslides are possible. However, mass movement that could significantly impact reservoir operation is unlikely because of the gentle topography and the plastic nature of the on-site materials. Shallow, localized to extensive mudflows are possible and would contribute locally to reservoir siltation. Based on the lesser extent of active existing slope instability and more gentle topography than exist at the Adobe Road and Lakeville Hillside sites, but the presence of the same formation materials more susceptible to sliding, the risk potential of landsliding at the Sears Point site under reservoir operating conditions is considered moderate.

Reservoir leakage potential is considered to be low due to the generally massive structure and low permeability of the Petaluma claystone underlying the site and the extensive overlying clayey alluvial and colluvial soils in the wide channel area. Several springs that were mapped during the site reconnaissance likely represent localized groundwater that is concentrated along minor sandstone interbeds or fracture systems. The springs were concentrated along the south side of the reservoir and were often found within landslide areas or near volcanic (tuff or rhyolite) outcrops. In utilizing the alluvium/colluvium as a borrow source for construction, considering the abundance of this material, the borrow area grading plan should maintain a thick layer of the clay material across the reservoir bottom after construction.

TABLE 4-1

ESTIMATED AVERAGE DAM FOUNDATION EXCAVATION

ALTERNATIVE RESERVOIR SITES

	Estimated Average Excavation Depth (feet)					
	Impervious Core Zone			Other Embankment Zones		
Reservoir Site	Left Abutment	Channel	Right Abutment	Left Abutment	Channel	Right Abutment
Valley Ford East	15	30	15	5	20	5
Carroll Road North	15	35	15	5	25	5
Bloomfield	30	35	20	20	25	10
Huntley	15	20	15	5	10	5
Two Rock	20	40	20	10	30	10
Adobe Road	20	30	30	10	20	20
Lakeville Hillside	40	40	35	25	30	25
Tolay Creek[1]						
north saddle dam	10	15	10	5	10	5
west saddle dam	10	10	10	5	5	5
backdam	8	8	8	5	5	5
Sears Point	35	40	40	25	30	30

[1] This table not applicable to Tolay Creek main dam. Different approach used to account for required foundation excavation. Actual estimated foundation excavation contours developed, as shown on Figure 4-12.

TABLE 4-2

SUMMARY OF FIELD PERMEABILITY TESTING

Reservoir Site	Drill Hole No.	Test Interval (feet)	Estimated Permeability (cm/sec)	Formation Material
Valley Ford East	VF-B1	29.0-44.0	7.5×10^{-6}	Wilson Grove sandy siltstone
	VF-B1	44.0-59.0	6.2×10^{-6}	Wilson Grove sandy siltstone
Carroll Road North	CR-B3	35.0-50.0	$<6.9 \times 10^{-6}$	Wilson Grove siltstone
Huntley	HT-B2	20.0-58.0	$<2.9 \times 10^{-6}$	Franciscan Complex melange
	HT-B3	35.0-76.0	5.3×10^{-5}	Wilson Grove siltstone/sandstone and Franciscan Complex graywacke
Adobe Road	AD-B1	49.0-71.5	3.7×10^{-7}	Petaluma claystone
Lakeville Hillside	LH-B1	29.5-31.0	2.0×10^{-4}	Petaluma sandstone
	LH-B1	29.5-31.0	2.9×10^{-5}	Petaluma sandstone
	LH-B1	56.5-63.5	5.9×10^{-6}	Petaluma claystone
	LH-B5	35.0-45.0	1.8×10^{-4}	Petaluma conglomerate
Sears Point	SP-B1	50.0-70.0	$<3.4 \times 10^{-6}$	Petaluma claystone
	SP-B1	38.0-70.0	$<1.1 \times 10^{-5}$	Petaluma claystone

SECTION 5
EMBANKMENT DAM
CONSTRUCTION MATERIALS

5 EMBANKMENT DAM CONSTRUCTION MATERIALS

5.1 GENERAL

This section describes the sources, quantity, and quality of available on-site construction materials and imported materials required for construction of embankment dams at each of the alternative reservoir storage sites. Estimated available quantities of critical on-site borrow materials, primarily impervious-type construction materials, from various sources are provided. Detailed discussions of the field investigations performed to sample and assess the availability and characteristics of potential on-site borrow materials are presented in Section 4 and Appendix A. Exploration locations from both previous and present studies, as applicable, as well as estimated primary borrow areas for the critical required materials (primarily imperious borrow), are shown on the geologic and exploration maps for each site in Section 4. Logs of the exploratory drill holes and test pits are provided in Appendix A. Discussion of the laboratory testing performed on samples of potential on-site construction materials to evaluate their characteristics and suitability is presented in Appendix B, along with the complete test results.

As explained in Section 6, which addresses the conceptual dam and reservoir design, the geotechnical and seismic conditions at the various reservoir sites require the consideration of an earth embankment dam to form the required alternative reservoirs. A zoned earthfill dam would generally require four basic types of construction materials, namely impervious core, random shell, filter and drain materials, and rock for slope protection and riprap. The objective in assessing construction materials at the various sites is to maximize the use of on-site materials within the reservoir footprint, utilizing various types of materials in a zoned embankment arrangement that will result in the least overall embankment volume and will minimize the requirement for imported materials. The evaluation of each of these types of construction materials for the various alternative reservoir sites is provided in the following sections.

5.2 VALLEY FORD EAST

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Valley Ford East alternative reservoir storage site is as follows:

- **Impervious Core** - Suitable clay core materials are not readily available in sufficient quantity at the site, particularly within the limits of the reservoir area. The majority of the surficial materials (colluvium and alluvium) is a clayey sand to silty sand with lenses of sandy clay. On the broad rolling terrain on the east side of the proposed reservoir (lower reservoir slopes), the Wilson Grove Formation is overlain by up to 6.5 feet of colluvial material. Within the colluvium is a discrete layer of plastic sandy clay averaging about 2 feet in thickness, which constitutes the transition material between the surficial clayey sand and the sandy siltstone bedrock, and the primary source of suitable on-site impervious core material. For the primary impervious borrow area limited within the dam and reservoir footprint, as outlined on Figure 4-1, with an average thickness of 2 feet, only about 80,000 cubic yards of available suitable clay core material is estimated. Assuming a similar thickness for an area downstream and east of the proposed damsite (Figure 4-1), an additional quantity of 490,000 cubic yards is estimated. Since the clay layer is within the colluvium, it would be necessary to strip 1 to 3 feet of clayey sand surficial soil to reach the clay layer. This stripped material would be suitable for incorporation in the random shell zones of the embankment. The insufficient supply of impervious core material is addressed further in the following Sections 6 and 7.

  Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the surficial colluvial soils generally classifies as a low plastic sandy clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 50 percent, and the plasticity index ranges between 9 and 17 percent. One permeability test on a representative sample of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 5.5×10^{-7} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell** - On-site materials for the random zones of the embankment can be obtained partly from the alluvial deposits, and for the most part, from the massive sandy siltstone of the Wilson Grove Formation. . The alluvium consists typically of clayey sand, silty sand, sandy clay, and sandy silt. Substantial quantities of the Wilson Grove siltstone are available within the reservoir area. However, considering the relatively small surface area of the reservoir, a carefully designed grading plan will be required to limit borrow excavation within the reservoir footprint. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability, the possibility of required localized clay blanketing of permeable zones exposed by the excavation, and drainage measures to avoid concentrated flow and control erosion on the excavated slopes. Excavation should be possible with conventional heavy excavation equipment. Ripping will likely be required because of the massive nature of the bedrock. The rolling topographic terrian in the reservoir area allows for greater ease of borrow excavation.

  Based on laboratory index properties testing of gradation and plasticity characteristics on a number of samples obtained from the subsurface field investigation, the available on-site random shell material derived from the Wilson Grove siltstone generally classifies as a non to low plastic silty sand to sandy silt. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 20 percent, and the plasticity index ranges between 0 and 16 percent. One permeability test on a representative sample of potential random shell material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 1.3×10^{-5} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap, and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.3 CARROLL ROAD NORTH

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Carroll Road North alternative reservoir storage site is as follows:

- **Impervious Core** - Suitable clay core materials are available from the alluvium and colluvium in the valley floor of the proposed reservoir area. The primary potential impervious borrow area encompassing these materials is shown on Figure 4-2. The alluvium/colluvium was explored by mapping, test pitting to depths ranging from 12 to 16 feet, and one boring to a depth of 41 feet. The maximum explored thickness of the alluvium/colluvium is 26 feet in Boring CR-B1. The alluvium/colluvium consists predominantly of sandy clay with clayey sand interbeds. Near the active stream channel, lenses of silty sand and gravelly sand (as noted in Boring CR-B3) occur within the finer grained soils and would not be desirable for impervious core. The estimated volume of available suitable clay core material from the primary impervious borrow area outlined on Figure 4-2, based on an average thickness of 15 feet, is 1,980,000 cubic yards. Groundwater was encountered at depths below 10 feet at the time of field investigation. Part of the impervious borrow excavation will encounter some groundwater, and the required degree of controlling water in the excavation will depend on the time of year when excavation is performed.

  Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the alluvium/colluvium generally classifies as a low to moderately plastic sandy clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 50 percent, and the plasticity index ranges between 9 and 29 percent. One permeability test on a representative sample of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 6.3 x 10^{-7} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell** - On-site materials for the random zones of the embankment can be obtained from the Wilson Grove Formation, which is the predominant bedrock unit at the site. This formation consists of massive sandy siltstone and silty sandstone with interbeds of sandy claystone. Substantial quantities of the Wilson Grove siltstone/sandstone are available within the reservoir area. However, considering the relatively small surface area of the reservoir, a carefully designed grading plan will be required to limit borrow excavation within the reservoir footprint. More specifically, the required grading plan will involve excavating the ridges that extend into the reservoir, including the broad ridge between the left (east) side of the dam and the east arm of the reservoir, the central broad ridge between the east and north arms of the reservoir, and the relatively narrow ridge on the west side of the reservoir. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability, the possibility of required localized clay blanketing of permeable zones or fractures exposed by the excavation, and drainage measures to avoid concentrated flow and control erosion on the excavated slopes. Excavation should be possible with conventional heavy excavation equipment. Ripping will likely be required because of the massive nature of the bedrock. The siltstone/sandstone is weakly cemented, friable, and soft in hardness and is therefore anticipated to break down to a sandy silt or silty sand soil material.

  Based on laboratory index properties testing of gradation and plasticity characteristics on a number of samples obtained from the subsurface field investigation, the available on-site random shell material derived from the Wilson Grove siltstone/sandstone generally classifies as a low plastic sandy silt. For the range of tests performed, the plasticity index ranges between 2 and 5 percent. One permeability test on a representative sample of potential random shell material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 4.8 x 10^{-5} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.4 BLOOMFIELD

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Bloomfield alternative reservoir storage site is as follows:

- **Impervious Core** - Suitable clay core materials are not readily available in sufficient quantity at the site, particularly within the limits of the reservoir area. Previous construction materials investigations at the Bloomfield site (WCC, 1990) concluded that plastic alluvium occurs upstream of the dam axis in sufficient quantity for construction of an impervious core. Based on geologic mapping and the results of four alluvial borrow borings with limited laboratory testing (a total of four Atterberg limits tests and no sieve analyses), WCC estimated 1,100,000 cubic yards of core material would be available from an alluvial borrow area with an average excavation depth of 11 feet. The WCC boring logs suggest that the upper 15 feet of alluvium is almost exclusively clay, with little or no interbedding of non-plastic soils. However, based on site reconnaissance performed for this study, outcrops of both sandy clays and silty sands/sandy silts are exposed along the creek bank, indicating that some interbedding of plastic and non-plastic materials probably occurs within the alluvium. Assuming that the alluvium is more interbedded than implied on the WCC logs, a lesser volume of available suitable clay core material of about 480,000 cubic yards is proposed for the primary impervious borrow area limited within the dam and reservoir footprint as outlined on Figure 4-4. This estimate is based on the alluvial area upstream of the dam as mapped during this investigation, and an assumed 5-foot thickness of clayey soil. These estimates of the thickness and overall availability of clay borrow within the alluvium are conservative and considered appropriate for this conceptual-level design study. The insufficient supply of impervious core material is addressed further in the following Sections 6 and 7.

Two of the four WCC bedrock borrow holes apparently encountered shallow claystone, extending from near the surface to depths of 10 to 15 feet (substantiated by very limited laboratory testing, consisting of one sieve analysis and no Atterberg limits testing). Approximately 30 percent of the cumulative footage (244.5 feet) from the four bedrock borings is logged as claystone. Several outcrops of low to moderately plastic claystone were observed during our site reconnaissance. If claystone actually comprises a significant portion of reservoir area bedrock, it could be used to supplement an alluvial borrow source of core material. It is conceivable that over 1,000,000 cubic yards of plastic bedrock material are available, based on WCC's estimate that over 4,000,000 yards of random fill material (as discussed below) are available from their three bedrock borrow areas. However, accurately defining the limits of claystone bedrock could be difficult and would require extensive field exploration with detailed laboratory testing. Additionally, interbedding within the bedrock might require segregating the claystone from non-plastic material, and the actual distribution of claystone could require deep excavations to provide sufficient quantities. Both of these factors could prove cost-prohibitive or impractical to development of a clay borrow source in bedrock. For the purpose of conceptual-level design, it is assumed that claystone bedrock would not provide a significant source for core material.

Groundwater within the alluvium was encountered as shallow as 10 feet below the ground surface during WCC investigations; therefore (for the purpose of conceptual design) an assumed average excavation depth for an alluvial borrow source should be limited to 10 feet. Deeper groundwater was encountered in several of the bedrock borrow borings, at depths of about 45 feet.

- **Random Shell** - WCC's construction materials investigation estimated approximately 4,350,000 cubic yards of suitable shell material are available by excavating Wilson Grove Formation siltstone/sandstone, and lesser claystone, from reservoir area slopes in three discrete borrow areas. Two of these areas are situated below elevation 240 feet.

WCC concluded that these materials are suitable for embankment shell construction. Additional laboratory testing would be performed during design-level studies to adequately characterize the various bedrock units (sandstone, siltstone, and claystone).

Although the WCC estimated volume of shell material from specific defined borrow areas is somewhat less than the volume required for the maximum-sized dam considered by this study (see Section 8), substantial and sufficient quantities of the Wilson Grove siltstone/sandstone material are considered available within the reservoir area since the Wilson Grove Formation comprises the bedrock throughout the reservoir area. However, considering the relatively small surface area of the reservoir, a carefully designed grading plan will be required to limit borrow excavation within the reservoir footprint. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability, the possibility of required localized clay blanketing of permeable zones exposed by the excavation, and drainage measures to avoid concentrated flow and control erosion on the excavated slopes. Excavation should be possible with conventional heavy excavation equipment. Ripping will likely be required because of the massive nature of the bedrock.

- **Other Materials** - Hard, strong outcrops of Franciscan Complex sandstone occur on the steep, south-facing ridge slope above the north end of the reservoir. Inspection of several of these outcrops revealed that much of this rock is actually closely fractured; although difficult to initially break from the outcrop (with a rock pick), the sandstone would eventually break (with repeated blows) into small fragments along internal, old fractures in the rock mass. These harder outcrops are probably surrounded by more intensely fractured and weathered Franciscan material (e.g., sheared shale). Based on these observations, very limited amounts of durable, riprap-quality rock may be present in the Franciscan bedrock, north of the Bloomfield fault and above the north end of the reservoir. Exploration drilling via rock coring, and possibly some seismic refraction work, would be necessary during design studies to evaluate the potential for using these materials. For the purpose of conceptual design, it is prudent to assume that hard, durable rock for slope protection and riprap will require importing from commercial sources. Suitable aggregates for filter, drain, and concrete materials will also require importing. Import material requirements are addressed in greater detail in Section 7.

5.5 HUNTLEY

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Huntley alternative reservoir storage site is as follows:

- **Impervious Core** - Suitable clay core materials are available from the alluvium and colluvium in the valley floor of the proposed reservoir area. A supplemental source of clay materials is the thick colluvium on a broad drainage swale immediately upstream of the left (east) abutment of the dam. The primary potential impervious borrow areas encompassing these materials are shown on Figure 4-5. The alluvium and colluvium were explored by mapping and test pitting to depths of up to 14.5 feet. The maximum explored thickness of the alluvium/colluvium in the valley floor is 12 feet; the clayey colluvium in the east drainage is up to 14.5 feet thick. The alluvium and colluvium consists predominantly of sandy clay and clayey sand. The alluvium contains minor interbeds of silty, gravelly sand. The estimated volumes of available suitable clay core materials from the primary impervious borrow areas outlined on Figure 4-5, based on an average thickness of 10 feet, are 970,000 cubic yards in the valley floor and 330,000 cubic yards in the east drainage swale. In addition to the alluvium and colluvium, the more weathered and sheared bedrock materials of the Franciscan Complex exposed in the lower portion of the reservoir can be used to supplement the impervious core borrow as needed. Groundwater was encountered in the alluvium at depths of 7.5 to 9 feet at the time of field investigation. Part of the impervious borrow excavation will encounter some groundwater, and the required degree of controlling water in the excavation will depend on the time of year when excavation is performed.

  Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the alluvium/colluvium and sheared Franciscan melange generally classifies as a low plastic sandy clay to clayey sand. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 40 percent (alluvium/colluvium), and the plasticity index ranges between 10 and 15 percent. One permeability test on a representative sample of potential impervious core material derived from the alluvium/colluvium, fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 2.8 x 10^{-7} cm/sec. An additional permeability test on potential impervious core material derived from the sheared Franciscan melange yielded a coefficent of permeability of 2.6 x 10^{-7} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell** - On-site materials for the random zones of the embankment can be obtained from two sources, comprised of the Franciscan Complex at the bottom and lower slopes of the reservoir and the Wilson Grove Formation at the higher reservoir elevations, primarily from the flatter east side of the reservoir (Figure 4-5). The Franciscan Complex is comprised of the melange, which is a chaotic mixture of sheared, crushed shale and clay gouge with included masses of hard graywacke sandstone, greenstone, and chert. The Wilson Grove Formation consists of massive silty sandstone, siltstone, and fine to coarse grained sandstone. Substantial quantities of the combined Franciscan melange and Wilson Grove siltstone/sandstone are available within the reservoir area. However, considering the relatively small surface area of the reservoir, a carefully design grading plan, altering the shape of the reservoir, will be required to limit borrow excavation within the reservoir footprint. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability (particularly in the clayey portions of the Franciscan melange), the possibility of required localized clay blanketing of permeable zones or fractures exposed by the excavation (particularly the geologic contact area between the Franciscan Complex and the Wilson Grove Formation), and drainage measures to avoid concentrated flow and control erosion on the excavated slopes (particularly in the more erodible Wilson Grove Formation). Excavation should be possible with convential heavy excavation equipment. Heavy ripping is anticipated, particularly in the harder included rock masses of the Franciscan melange and the massive sandstone of the Wilson Grove Formation. The melange is expected to excavate to a mixture of angular gravels with sand and clay. Cobble and boulder-size blocks are also anticipated from the breakdown of the included rock masses. The siltstone/sandstone is weakly cemented and friable, and is therefore anticipated to break down to a sandy silt or silty sand soil material. Groundwater is anticipated in the valley floor excavation and will require control during borrow excavation.

- **Other Materials -** No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.6 Two Rock

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Two Rock alternative reservoir storage site is as follows:

- **Impervious Core** - Suitable clay core materials are available from the alluvium in the dam and reservoir channel area. The primary potential impervious borrow area encompassing this material is shown on Figure 4-7. The alluvium was explored during previous construction materials investigations at this site (WCC, 1990). Based on these previous studies, which included subsurface exploration borings and test pits and limited laboratory testing, and based on site reconnassiance performed for this study, the alluvium consists predominantly of sandy clay and silty clay with low to moderate plasticity. The estimated volume of available suitable clay core material from the primary impervious borrow area limited within the dam and reservoir footprint, as outlined on Figure 4-7, based on an average thickness of 6 feet, is 280,000 cubic yards. This estimate of thickness and overall availability of clay borrow within the alluvium, which also contains some more granular materials (sand and gravel) not desirable for impervious core, is somewhat less than previous available volume estimates made by WCC, but is conservative and considered appropriate for this conceptual-level design study. The above estimated available impervious core volume generated from the alluvium within the reservoir is, in itself, an insufficient supply for the volume required for the maximum-sized dam considered by this study (see Section 7). Additional alluvium which can produce additional suitable clay core materials exists downstream of the proposed damsite. Additionally, considering the objective to limit borrow excavation within the reservoir footprint, suitable impervious-type core material can also be generated from the more weathered and sheared Franciscan Complex bedrock materials within the reservoir area to supplement the alluvial source. It is anticipated that the Franciscan materials can be relied on as a substantial source of impervious core material. Based on the results of the previous investigations, some required groundwater control is expected for borrow excavation in the alluvium.

- **Random Shell** - On-site materials for the random zones of the embankment can be obtained from two sources, comprised of the Franciscan Complex occupying a majority of the reservoir area and the Wilson Grove Formation in the broad, flat basin at the upstream end of the reservoir. The Franciscan Complex is comprised of melange, which is a chaotic mixture of sheared, crushed shale and fractured sandstone with included masses of hard graywacke sandstone, greenstone, chert, and silca carbonate. The Wilson Grove Formation consists of massive sandy siltstone. Substantial quantities of the combined Franciscan melange and Wilson Grove siltstone are available within the reservoir area. Excavation should be possible with heavy excavation equipment with rippers. It is possible that occurrences of hard masses of graywacke, greenstone, chert, and silica carbonate may require local blasting. The melange is expected to excavate to a mixture of angular gravels in a sandy and clay matrix. The siltstone is anticipated to break down to a sandy silt or silty sand soil material.

- **Rock Riprap and Slope Protection Material** - Chert and silica carbonate bedrock units occurring in wide discrete zones could be a possible source of rock for riprap and slope protection. The silica carbonate is a very hard, massive, fine grained rock. Although the chert is thinly bedded, folded, and intensely fractured, the fractures are generally healed and fused together. The fractured chert acts as a massive rock that breaks down into large, cobble to boulder-size coherent blocks. A potential rock source is a prominent zone of very hard chert and silica carbonate that appears to form the backbone of a ridge that cuts across a small side drainage immediately upstream of the right (north) dam abutment. It is possible that this rock zone, about 200 feet wide in the drainage, extends easterly into the reservoir (as indicated by scattered rock outcrops). Assuming an average width of 100 feet, a length of 1,500 feet, an average thickness of 50 feet, and a 60 percent availability of suitable rock-like material, about 150,000 cubic yards is estimated (Figure 4-7). The excess material could be incorporated in the random shell zones of the embankment. Quarry development would most likely require blasting. The limits of a quarry developed to obtain this potential rock material would extend outside the reservoir footprint into the right (north) abutment ridge and the adjacent ridge immediately upstream. Considering the objective of limiting on-site borrow within the reservoir area, the development of this borrow source is conservatively not assumed for conceptual design. Should this on-site rock source be pursued at a later project stage, further design-level subsurface investigation would be required to define the extent of this potential rock source and confirm its material quality.

- **Other Materials** - Based on the preceding discussion, it is assumed for conceptual design that hard rock-type materials for slope protection and riprap will be imported. Suitable aggregates for filter, drain, and concrete materials will also require importing from commercial sources. Import material requirements are addressed in greater detail in Section 7.

5.7 ADOBE ROAD

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Adobe Road alternative reservoir storage site is as follows:

- **Impervious Core** - The colluvium and landslide deposits within the proposed reservoir area, existing mostly on the broad benches near the valley floor along the east side of the reservoir, will provide the primary source for impervious core materials. The primary potential impervious borrow area encompassing these materials is shown on Figure 4-8. The colluvium/landslide deposits consist predominantly of plastic silty clays. The estimated volume of available clay core material from the primary impervious borrow area outlined on Figure 4-8, based on an average thickness of 25 feet, is 2,650,000 cubic yards. The Petaluma Formation claystone can also provide an impervious core material source.

Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the colluvium/landslide deposits and Petaluma claystone soils generally classifies as a moderate to highly plastic clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 50 percent, and the plasticity index ranges between 23 and 34 percent. One permeability test on a representative sample of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 3.6×10^{-8} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell** - On-site materials for the random zones of the embankment can be obtained from the Petaluma Formation, which is the bedrock unit existing at the site. This formation consists predominantly of massive claystone and siltstone with interbedded sandstone and conglomerate. Substantial quantities of the Petaluma claystone/siltstone are available at the reservoir site. However, considering the large required embankment volumes (see Section 8) and the narrow reservoir configuration with relatively small surface area, localized borrow excavation outside the reservoir footprint appears necessary. A carefully designed grading plan will be required to minimize borrow excavation outside the reservoir footprint while attempting to mitigate against reservoir slope instability inherent to the on-site materials. More specifically, the required grading plan will involve excavating the broad ridges that extend into the reservoir on the west side immediately upstream of the damsite. The estimated maximum extent of these excavations is shown on Figure 4-8. Based on an excavation area of about 1,600 feet by 1,600 feet for each of the two ridges, and based on an average depth of 40 feet, about 7,500,000 cubic yards is estimated for these source areas. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability and the possibilty of required localized clay blanketing of permeable zones exposed by the excavation. Excavation should be relatively easy with conventional earthwork construction equipment. Some ripping may be required because of the massive nature of the bedrock. The excavated Petaluma Formation material is expected to be a mixture of silty clay, sandy clay, and clayey sand.

In general, considering the workability and strength characteristics of most of the available on-site construction materials at Adobe Road (predominance of highly plastic clays), the quality of available construction materials at west county reservoir sites is significantly better.

An alternative source of a relatively more granular random shell zone material is hill 452 at the top of the left (east) dam abutment, which is presently being quarried. A possible area of sandy siltstone/sandstone/pebbly conglomerate is interpreted to underlie the ridge top as shown on the geologic map (Figure 4-8). If this area were to be considered, it would require excavation of the top of hill 452 above the maximum reservoir level. A quantity of about 1,000,000 cubic yards is estimated from this area. Visual impact of this cut would be significant. This potential additional source is not assumed for design in keeping with the desire to maximize borrow sources within the reservoir footprint.

Based on laboratory index properties testing of gradation and plasticity characteristics on a number of samples obtained from the subsurface field investigation, the available on-site random shell material derived from the Petaluma sandstone/conglomerate generally classifies as a low plastic silty sand. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 30 percent, and the plasticity index measured by one test is 4 percent. One permeability test on a representative sample of potential random shell material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 1.7×10^{-5} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Moisture Barrier (Select Fill)** - Since the bulk of the available materials for the random zone have potentially highly plastic properties, it will be necessary to protect the dam embankment slopes from the formation of desiccation cracks resulting from the alternate wetting and drying conditions related to reservoir operations. Therefore, granular, non-plastic earth materials will be required as liner protection for the embankment slopes.

  Select, granular, non-plastic material for mitigating the formation of shrinkage cracks on the slopes of the dam can be obtained from the sandstone and conglomerate layers of the Petaluma Formation. The results of the field mapping and subsurface exploration indicate the presence of these units which are anticipated to be exposed during the random shell borrow excavation.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.8 LAKEVILLE HILLSIDE

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Lakeville Hillside alternative reservoir storage site is as follows:

- **Impervious Core** - The colluvial deposits, landslide deposits, and Petaluma Formation claystone in the flatter, central portion of the proposed reservoir area will provide the primary source for impervious core materials. The primary potential impervious borrow area encompassing these materials is shown on Figure 4-9. The colluvium/landslide deposits and claystone, after excavation and breakdown, consist predominantly of plastic silty clays. The estimated volume of available clay core material from the primary impervious borrow area outlined on Figure 4-9, based on an average thickness of 30 feet, is 850,000 cubic yards.

Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the colluvium/landslide deposits and Petaluma claystone generally classifies as a highly plastic clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 75 percent, and the plasticity index ranges between 29 and 44 percent. One permeability test on a representative sample of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 6.4×10^{-9} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell -** On-site materials for the random zones of the embankment can be obtained from the Petaluma Formation, mainly from the flatter central and east portions of the reservoir area, which is the bedrock unit existing at the site. This formation consists predominantly of massive claystone and siltstone with interbedded sandstone and conglomerate. Substantial quantities of the Petaluma claystone/siltstone are available at the reservoir site. However, a carefully designed grading plan will be required to limit borrow excavation within the reservoir footprint while attempting to mitigate against reservoir slope instability inherent to the on-site materials. The design of the borrow excavation plan should consider maximum cut slopes to maintain adequate slope stability and the possibility of required localized clay blanketing of permeable zones exposed by the excavation. Excavation should be relatively easy with conventional earthwork construction equipment. Some ripping may be required because of the massive nature of the bedrock. The excavated Petaluma Formation material is expected to be a mixture of silty clays, clayey sands, and gravelly clays.

In general, considering the workability and strength characteristics of most of the available on-site construction materials at Lakeville Hillside, (predominance of highly plastic clays), the quality of available construction materials at west county reservoir sites is significantly better.

- **Moisture Barrier (Select Fill) -** Since the bulk of the available materials for the random zone have potentially highly plastic properties, it will be necessary to protect the dam embankment slopes from the formation of desiccation cracks resulting from the alternate wetting and drying conditions related to reservoir operations. Therefore, granular, non-plastic earth materials will be required as liner protection for the embankment slopes.

  Select, granular, non-plastic material for mitigating the formation of shrinkage cracks on the slopes of the dam can be obtained from the sandstone and conglomerate layers of the Petaluma Formation. The results of the field mapping and subsurface exploration indicate the presence of these units which are anticipated to be exposed during the random shell borrow excavation.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.9 TOLAY CREEK

Assessment of the basic types of required earth and rock materials for construction of the various alternative embankment dams (main dam, north saddle dam, and west saddle dam for the alternative without a backdam, and main dam and backdam for the partial inundation alternative) at the Tolay Creek alternative reservoir storage site is as follows:

- **Impervious Core -** The clayey alluvium across the extensive Tolay Creek valley will provide the primary source for impervious core materials. The primary potential impervious borrow areas encompassing these materials are shown on Figures 4-11 and 4-12. The alluvium consists of silty clay to sandy clay to clayey sand with local interbeds of silty sand and gravelly sand. Exploration boring data in the backdam foundation area across the alluvium indicate alluvial thickness on the order of up to 30 feet. This thickness and the extensive lateral distribution of the alluvium indicates the presence of an abundant supply of clay materials adequate to meet the volume requirements for all the various embankments proposed at the reservoir site. The estimated volume of available suitable clay core material from the primary impervious borrow areas outlined on Figures 4-11 and 4-12, based on an average thickness of 20 feet between the main dam and backdam and 10 feet near the saddle dams, is 7,760,000 cubic yards. Impervious core needs for each embankment can be obtained from the valley alluvium proximate to the particular damsite.

Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the clayey alluvium generally classifies as a moderate to highly plastic clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 50 percent, and the plasticity index ranges between 17 and 56 percent. Two permeability tests on representative samples of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded coefficients of permeability of 2.1×10^{-8} cm/sec and 4.5×10^{-8} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell -** On-site materials for the random zones of the various embankments can be obtained from the Petaluma Formation which is the predominant bedrock unit existing at the site, as well as excess alluvial and/or landslide deposits. The formation materials consist predominantly of claystone and sandstone. Substantial quantities of the Petaluma claystone/sandstone, as well as the other surficial deposits noted, are available at the reservoir site. Excavation should be relatively easy with conventional earthwork construction equipment. Some ripping may be required.

The use of the above-described predominant on-site materials in the random shell embankment zones, having similar characteristics as impervious core materials, makes the dam become a more homogeneous embankment structure. In general, considering the workability and strength characteristics of most of the available on-site contruction materials at Tolay Creek (predominance of highly plastic clays), the quality of available construciton materials at west county reservoir sites is significantly better.

As part of the field exploration program for construciton borrow materials, the availability of better quality (more granular, less plastic, and stronger) random shell material was investigated. Based on the site geology and reconnaissance, three potential sources of better quality random shell and/or rock materials were studied, as discussed below.

An area of Sonoma Volcanics located on a hilly site about 3,000 feet downstream of the main dam site was investigated as a potential random/rock source (Figure 4-12). This site was explored by two test pits and two seismic refraction lines The results of the exploration indicate that the area is underlain by mixed volcanic rocks including agglomerate and rhyolitic ash flow tuff. This area is estimated to produce mixed soil and rock with about 20 to 30 percent gravel to boulder-size rock in a sandy clay matrix. About 600,000 cubic yards of material is roughly estimated to be available at this site. Development of this source would require a relatively extensive quarry outside the reservoir area. As a result, considering the objective to limit borrow activities within the reservoir area, the use of this source is not assumed for conceptual design.

A second potential random/rock source investigated is the "rock knob" area located about 500 to 1,500 feet upstream of the main dam site (Figure 4-12). Hard andesite is exposed on top and along the broad ridge that forms the knob. Two test pits and a 600-foot seismic refraction line were performed at this site. The test pits encountered severely to moderately weathered, closely to moderately fractured andesite; about 50 percent of the excavated material from the test pits is gravel to boulder-size andesite. The seismic refraction survey indicates high velocity (rock-like) material underlying the knob at a depth of about 30 feet. The distribution of the andesite is highly variable, as noted elsewhere in the reservoir; therefore, the quantity of available hard rock is difficult to estimate without extensive exploration. However, for the purpose of this conceptual-level study, the rock knob is roughly estimated to produce about 300,000 cubic yards of mixed rock (about 30 percent) and soil material, based on an average excavation depth of 20 feet over the potential earth/rock borrow area outlined on Figure 4-12. This is a fairly small source of potentially better quality construction material relative to some of the required volumes of random material required for the alternatives involving the larger embankment structures (see Section 8).

A third potential better quality random/rock source investigated is an existing quarry located near the Cardoza Ranch on the central west side of the reservoir. The quarry is located on a small hill mostly outside the proposed reservoir area (Figure 4-11). The geologic material at this source consists of Franciscan Complex rocks, including graywacke sandstone and greenstone with interbedded siltstone and shale. The quarry material excavates to a silty sandy gravel. Other hills in the immediate area appear to be underlain by similar geologic materials and could provide additional potential sources for random shell material. Based on an average excavation depth of 20 feet over the potential earth/rock borrow area outlined on Figure 4-11, about 1,500,000 cubic yards of material is estimated from this source. However, considering the objective to limit borrow activities within the reservoir area, only limited use of this source is assumed for conceptual design.

Due to the apparent limited availability of more granular, less plastic earth/rock materials within the reservoir area, the design will need to reflect use of the more prevalent alluvial and Petaluma claystone/sandstone materials for the bulk of the random shell material, reserving the limited more granular and less plastic materials from the "rock knob" and existing quarry sources for the select fill moisture barrier material discussed below. It is recommended that during future design-level studies, further consideration be given to the availability of additional, better quality random/rock materials existing outside of the reservoir footprint, particularly the existing quarry source shown on Figure 4-11. Utilization of greater amounts of these materials within the dam embankment section will improve the design and could potentially have some associated cost savings.

- **Moisture Barrier (Select Fill)** - Since the bulk of the assumed available materials for the random zone have potentially highly plastic properties, it will be necessary to protect the dam embankment slopes from the formation of desiccation cracks resulting from the alternate wetting and drying conditions related to reservoir operations. Therefore, granular, non-plastic earth materials will be required as liner protection for the embankment slopes.

  Select, granular, non-plastic material for mitigating the formation of shrinkage cracks on the slopes of the dams is assumed to be obtained from the "rock knob" and existing quarry sources discussed above.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

5.10 SEARS POINT

Assessment of the basic types of required earth and rock materials for construction of an embankment dam at the Sears Point alternative reservoir storage site is as follows:

- **Impervious Core** - The clayey alluvium and colluvium across the extensive valley floor within the proposed reservoir area will provide the primary source for impervious core materials. The primary potential impervious borrow area encompassing these materials is shown on Figure 4-14. The alluvium attains depths of up to 40 feet. Exploration of the alluvium/colluvium in the reservoir area included several test pits and two auger borings to depths of 40 feet. The alluvium/colluvium consists of silty clay to sandy clay interbedded with clayey sand. The estimated volume of available clay core material from the primary impervious borrow area outlined on Figure 4-14, based on an average thickness of 20 feet, is 2,470,000 cubic yards.

Based on laboratory index properties testing of gradation and plasticity characterstics on a number of samples obtained from the subsurface field exploration, the available on-site impervious core material derived from the clayey alluvium and colluvium generally classifies as a highly plastic clay. For the range of tests performed, the percentage of fines (percent by weight passing the No. 200 sieve) generally exceeds 55 percent, and the plasticity index ranges between 27 and 48 percent. One permeability test on a representative sample of potential impervious core material fabricated to density and moisture conditions that would be specified for earthfill dam construction yielded a coefficient of permeability of 6.3×10^{-9} cm/sec. Complete laboratory test results are provided in Appendix B.

- **Random Shell -** On-site materials for the random zones of the embankment can be obtained from the Petaluma Formation, which is the predominant bedrock unit existing at the site, as well as excess alluvial, colluvial, and/or landslide deposits. The formation materials consist predominantly of massive claystone with interbedded siltstone and sandstone. Substantial quantities of the Petaluma claystone, as well as the other surficial deposits noted, are available at the reservoir site. Excavation should be relatively easy with conventional earthwork construction equipment. Some ripping may be required because of the massive nature of the bedrock.

The use of the above-described predominant on-site materials in the random shell embankment zones, having similar characteristics as impervious core materials, makes the dam become a more homogeneous embankment structure. In general, considering the workability and strength characteristics of most of the available on-site construction materials at Sears Point (predominance of highly plastic clays), the quality of available construction materials at west county reservoir sites is significantly better.

An area of volcanic rock (andesite outcrops) upstream of the dam on the west reservoir slope was identified during the reconnaissance mapping as a potential source of rock and/or random material. The area was explored by four test pits and two seismic refraction lines. The results of the exploration indicate that the andesite has a spotty occurrence, is highly variable, and is associated with low density rhyolitic ash flow tuffs. Therefore, this potential source investigated for rock or random material is not considered viable and was not considered further.

- **Moisture Barrier (Select Fill)** - Since the bulk of the available materials for the random zone have potentially highly plastic properties, it will be necessary to protect the dam embankment slopes from the formation of desiccation cracks resulting from the alternate wetting and drying conditions related to reservoir operations. Therefore, granular, non-plastic earth materials will be required as liner protection for the embankment slopes.

  No select, granular, non-plastic material for mitigating the formation of shrinkage cracks on the slopes of the dam was identified at the Sears Point reservoir site. Thus, it is assumed, for conceptual design, that this material will require importing from a commercial source.

- **Other Materials** - No hard rock-type materials suitable for slope protection or riprap and no suitable aggregates for filter, drain, or concrete materials exist at the reservoir site. These materials will require importing from commercial sources and are addressed in greater detail in Section 7.

SECTION 6
DAM AND RESERVOIR CONCEPTUAL DESIGN

6 DAM AND RESERVOIR CONCEPTUAL DESIGN

6.1 GENERAL

This section presents the conceptual dam and reservoir design at a facilities planning level of detail for the alternative storage sites, including Valley Ford East, Carroll Road North, Bloomfield, Huntley, and Two Rock in the west county area and Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point in the south county area (Figure 2-1). At all of the sites, embankment-type dams are considered to make best use of the locally available construction materials, and foundation strength and stiffness are not sufficient to support concrete or roller-compacted concrete dams. Thus, the conceptual design of the project storage components is based on the ability to construct earthfill embankment dams at the various alternative reservoir sites.

The embankment dam design for the various alternative storage sites is based on the existing dam foundation conditions as described in Section 4, maximizing the utilization of on-site construction materials, minimizing and controlling dam foundation seepage, and providing a stable and safe structure for all operating conditions. The following factors were considered in the development of the conceptual embankment designs presented herein:

- Satisfaction of established design criteria.
- Optimization of location and alignment of the embankment structure.
- Foundation conditions and excavation requirements.
- Characteristics and availability of on-site construction materials.
- Need for imported construction materials.
- Reservoir capacity.
- Control of potential embankment and foundation seepage.
- Provision for adequate stability under most critical loading conditions.
- Location and function of appurtenant structures.

6.2 STORAGE CAPACITY

To size the embankment dam required at the various alternative storage sites, necessary for design and cost estimating, area-capacity curves were developed for each reservoir site. These relationships are provided on Figures 6-1 through 6-10 for the Valley Ford East, Carroll Road North, Bloomfield, Huntley, Two Rock, Adobe Road, Tolay Creek, Lakeville Hillside, and Sears Point sites, respectively. As indicated in Section 2, Table 2-1, two different reservoir configurations are evaluated for the Tolay Creek alternative storage site, one without a backdam (configuration "A" by others and referenced herein as "without backdam") and one with a backdam (configuration "C" by others and referenced herein as "with backdam"). The area-capacity curves for the Tolay Creek site without and with a backdam are provided on Figures 6-8 and 6-9, respectively. The curves are based on reservoir areas and estimated storage volumes above existing ground contours and upstream of the proposed dam axis. The area and capacity curves for this conceptual level of detail do not take into account the presence of the embankment fill upstream of the dam axis, which would tend to be compensated by increased area and capacity from borrow of construction materials from the reservoir area.

The reservoir sizes investigated at each of the alternative sites, except Lakeville Hillside, have been varied from a lower limit of 1,500 million gallons (4,603 acre-feet), to an upper limit of 4,500 million gallons (13,810 acre-feet), or the practical topographic limit of the site, whichever is less. An intermediate storage capacity has been chosen to correspond to a reservoir water surface elevation midway between the upper and lower limits. At Lakeville Hillside, the topography of the site limits the maximum sized reservoir to about 1,500 million gallons, and thus, only one size of reservoir has been considered at this site. Reservoir storage capacity and associated dam crest elevation and size data for the various sizes investigated are summarized in Tables 6-1 and 6-2 for the west county and south county sites, respectively.

6.3 DESIGN CRITERIA

Based on the results of evaluations of geologic, seismic, and other site conditions, construction materials availability, and known California Division of Safety of Dams (DSOD) requirements, preliminary design criteria and considerations related to the storage site embankment dam design have been established. The following general criteria have been adopted to guide the layout and design of all embankment dams presented in this report:

- Internal zones of embankments selected and dimensioned to maximize utilization of locally available construction materials, particularly within the reservoir footprint, and to provide for control of internal seepage and resistance to earthquake-induced cracking or other deformations.

- Outer slopes of embankments dimensioned to provide stability under normal reservoir conditions as well as during strong earthquake shaking.

- Special attention given to internal embankment zoning and outer slopes of embankment where the possibility exists for surface displacement of a fault within the dam footprint.

- Dam crest width of 30 feet.

- Embankment freeboard of 15 feet provided above normal maximum reservoir level to provide surcharge storage during a Probable Maximum Flood (PMF) and to compensate for both long-term and seismically-induced settlements.

- Embankment filter and drain materials consisting of clean, graded gravel to sand/gravel material to be obtained from commercial sources off-site, to assure adequate quality.

- Upstream faces of embankments protected full-height by 2 foot-thick (normal to slope) layer of graded riprap material, imported for all sites.

- Downstream faces of embankments protected full-height by one foot-thick (normal to slope) layer of graded rock slope protection material, imported for all sites.

- Embankment shell zones to be founded on top of weathered bedrock surface by removing overlying alluvial and colluvial soils, except for the Tolay Creek backdam.

- Embankment impervious core zones to be founded in bedrock below the highly weathered zone, except for the Tolay Creek backdam, with curtain grouting carried out beneath the core, where practical, to reduce seepage beneath the dam.

- Impervious blanketing of exposed pervious areas of the reservoir and borrow areas provided to reduce potential reservoir seepage.

- Spillways to consist of an ungated control section, a lined chute or channel, and an energy dissipator which discharges into the same drainage occupied by the reservoir.

- Spillways sized to prevent overtopping of dam during a PMF.

- Outlet works to serve as diversion conduits during construction.

- Outlet works sized to enable emergency evacuation of the upper 10 percent of the reservoir depth within 7 to 10 days, as well as to satisfy normal operating requirements.

6.4 Dam Layout and Design Section

The layout and design of embankment dams for the alternative storage sites at this preliminary level of study has been based upon a review of the results of previous studies by others, very limited field and laboratory investigations carried out for the alternative sites as part of this study, with the exception of Bloomfield and Two Rock for which similar investigations have been performed by others previously, and substantial engineering judgment, based on past experience and knowledge of other dam projects with similarities or comparability in seismic environment, construction materials, dam height, and hazard potential. The conceptual designs developed for all sites are based on investigations and engineering that are similar in magnitude and scope for each site. No detailed field or laboratory investigations or design studies have been carried out for any of the alternative reservoir sites. That level of investigation will follow the selection of a specific project for implementation.

The following sections discuss the design features and considerations specific to the proposed conceptual embankment dam designs at the various alternative reservoir sites. Conceptual layouts and cross sections of the maximum-sized dam design considered are provided which illustrate the proposed internal embankment zoning as discussed for each site. Comparisons of estimated total embankment volume and storage efficiency, in terms of a storage volume to embankment volume ratio, for the range of reservoir sizes investigated are provided by the summary data in Tables 6-1 and 6-2.

6.4.1 Valley Ford East

The principal project features at the Valley Ford East alternative reservoir storage site would include an embankment-type dam, spillway, inlet/outlet works, and conveyance facilities. A conceptual layout and cross section of the dam, with recommended general alignments of the spillway and inlet/outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-11 and 6-12.

The dam would be a zoned earthfill structure with a maximum height of up to 135 feet (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam would be somewhat flatter than the design for the Two Rock site (Section 6.4.5), because the Wilson Grove Formation materials available for construction of the shells of the dam at Valley Ford East are somewhat less competent than the Franciscan Complex materials at Two Rock.

There are insufficient quantities of naturally-occurring plastic clay materials (alluvium and colluvium) available within the reservoir area at the Valley Ford East site for construction of an impervious core zone of sufficient dimension to minimize seepage through the dam and resist earthquake-induced cracking or other deformations. An additional source of alluvium and colluvium exists just downstream of the dam (Figure 4-1), but it is unknown whether it would be acceptable to develop borrow sources outside of the reservoir area. This approach is not assumed for design at this level. The only other materials available from within the reservoir would be the weathered bedrock of the Wilson Grove Formation. However, these materials, after excavation, are at best marginally plastic, and would have little resistance by themselves to earthquake-induced cracking or other deformations. Even if a limited amount of the weathered bedrock were to be mixed with the more plastic alluvium/colluvium from within the reservoir area and even if additional clay materials were obtained from the additional potential source downstream of the dam, there would still be an insufficient quantity of suitable combined material to construct an effective impervious core zone for the maximum-sized dam. As a result of these limitations, the impervious core zone for the dam at Valley Ford East has been conservatively assumed to be constructed of materials from within the reservoir, mixed in place with powdered bentonite to provide the required plasticity. The general technique of admixing for the improvement of soil properties is widely used in lime stabilization of road bases and construction of soil-cement facings on dams. The specific technique of creating a plastic core material with a soil-bentonite mixture was applied to Sugar Pine Dam, above Auburn, by the USBR about 15 years ago, using a pugmill for mixing. The most suitable locally available materials for this mixture will probably be the non-plastic materials derived from excavation of the Wilson Grove Formation, although the alluvium/colluvium could also be used depending on the mixing method (for instance, using a pugmill).

Although it may be possible to separate some rock from the random borrow materials, it is conservatively assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

6.4.2 Carroll Road North

The principal project features at the Carroll Road North alternative reservoir storage site would include an embankment-type dam, spillway, inlet/outlet works, and conveyance facilities. A conceptual layout and cross section of the dam, with recommended general alignments of the spillway and inlet/outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-13 and 6-14.

The dam would be a zoned earthfill structure with a maximum height of up to 190 feet (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are the same as the design for the Valley Ford East site, somewhat flatter than the design for the Two Rock site (Section 6.4.5), because the Wilson Grove Formation materials available for construction of the shells of the dam at Carroll Road North are somewhat less competent than the Franciscan Complex materials at Two Rock.

Unlike the Valley Ford East site, there appears to be sufficient quantities of naturally-occurring plastic clay materials (alluvium and colluvium) available within the reservoir area at the Carroll Road North site for construction of an impervious core zone of sufficient dimension to minimize seepage through the dam and resist earthquake-induced cracking or other deformations. Thus, the need for admixing of bentonite to create a suitable impervious core material of sufficient quantity is avoided. In fact, the estimated available quantities of clay materials indicate that a somewhat wider impervious core zone than the minimum section shown on Figure 6-14 would be possible, as may be determined desirable during detailed design (see Sections 5 and 7).

Although it may be possible to separate some rock from the random borrow materials, it is conservatively assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

6.4.3 Bloomfield

The principal project features at the Bloomfield alternative reservoir storage site would include an embankment-type dam, spillway, outlet works, and conveyance facilities. A separate reservoir inlet facility is planned apart from the dam. A conceptual layout and cross section of the dam, with general recommended alignments of the spillway and outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-15 and 6-16.

The dam would be a zoned earthfill structure with a maximum height of up to 190 feet (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are the same as the design for the Valley Ford East site, somewhat flatter than the design for the Two Rock site (Section 6.4.5), because the Wilson Grove Formation materials available for construction of the shells of the dam at Bloomfield are somewhat less competent than the Franciscan Complex materials at Two Rock.

As at the Valley Ford East site, there are insufficient quantities of naturally-occurring plastic clay materials (alluvium and colluvium) available within the reservoir area at the Bloomfield site for construction of an impervious core zone of sufficient dimension to minimize seepage through the dam and resist earthquake-induced cracking or other deformations. Like Valley Ford East, an additional source of alluvium and colluvium exists just downstream of the dam, but it is unknown whether it would be acceptable to develop borrow sources outside of the reservoir area. This approach is not assumed for design at this level. Also like Valley Ford East, the only other materials available from within the reservoir would be the weathered bedrock of the Wilson Grove Formation. However, these materials, after excavation, are at best marginally plastic, and would have little resistance by themselves to earthquake-induced cracking or other deformations. Even if a limited amount of the weathered bedrock were to be mixed with the more plastic alluvium/colluvium from within the reservoir area, there would still be an insufficient quantity of suitable combined material to construct an effective impervious core zone for the maximum-sized dam. As a result of these limitations, the impervious core zone of the dam at Bloomfield has, like Valley Ford East, been conservatively assumed to be constructed of materials from within the reservoir, mixed in place with powdered bentonite to provide the required plasticity. The most suitable locally available materials for this mixture will probably be the non-plastic materials derived from excavation of the Wilson Grove Formation, although the alluvium/colluvium could also be used depending on the mixing method (for instance, using a pugmill).

Although it may be possible to separate some rock from the random borrow materials, it is conservatively assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

6.4.4 Huntley

The principal project features at the Huntley alternative reservoir site would include an embankment-type dam, spillway, outlet works, and conveyance facilities. A separate reservoir inlet facility is planned apart from the dam. A conceptual layout and cross section of the dam, with the general alignments of the spillway and outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-17 and 6-18.

The dam would be a zoned earthfill structure with a maximum height of up to 210 feet (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are somewhat steeper than at some of the other west county sites (Valley Ford East, Carroll Road North, and Bloomfield), because the Franciscan Complex materials available for construction of the shells of the dam at Huntley are more competent than the Wilson Grove Formation materials available at the other sites.

Although the available quantity of clayey alluvium and colluvium from the valley floor and the drainage swale upstream of the left (east) dam abutment is limited, sufficient additional quantities of suitably plastic Franciscan Complex materials should be available for construction of the impervious core zone of the dam.

Although it may be possible to separate some rock from the random borrow materials, it is conservatively assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

6.4.5 Two Rock

The principal project features at the Two Rock alternative reservoir site would include an embankment-type dam, spillway, outlet works, and conveyance facilities. A separate reservoir inlet facility, involving a tunnel through the ridge at the back of the reservoir, is planned apart from the dam. A conceptual layout and cross section of the dam, with the general alignments of the spillway and outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-19 and 6-20.

The dam would be a zoned earthfill structure with a maximum height of up to 225 feet (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell. Foundation bedrock conditions at the Two Rock site are anticipated to warrant construction of a grout curtain beneath the impervious core zone for foundation seepage control.

The outer slopes of the dam are the same as the design for Huntley, somewhat steeper than at some of the other west county sites (Valley Ford East, Carroll Road North, and Bloomfield), because the Franciscan Complex materials available for construction of the shells of the dam at Two Rock are more competent than the Wilson Grove Formation materials available at the other sites.

Similar to Huntley, although the available quantity of clayey alluvium from the valley floor is limited, sufficient additional quantities of suitably plastic Franciscan Complex materials should be available for construction of the impervious core zone of the dam.

Although it appears that riprap and downstream slope protection materials can be produced on-site by quarrying and processing chert and silica-carbonate rocks that occur in a prominent band along the right (north) side of the reservoir (Figure 4-7), the limits of a quarry developed to obtain these materials would extend significantly beyond the reservoir footprint. Thus, in satisfying the objective of limiting borrow of on-site construction materials to the reservoir area, it is conservatively assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

6.4.6 Adobe Road

The principal project features at the Adobe Road alternative reservoir site would include an embankment-type dam, spillway, inlet/outlet works, and conveyance facilities. In addition, a storm water diversion facility is planned along the right (west) side of the reservoir. A conceptual layout and cross section of the dam, with general recommended alignments of the spillway and inlet/outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-21 and 6-22.

The dam would be a zoned earthfill structure with a maximum height of up to 205 feet (3,700 million gallon or 11,355 acre-foot maximum storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are somewhat flatter than at the west county sites, because the Petaluma Formation moderate to highly plastic materials available for construction of the shells of the dam at Adobe Road are somewhat less competent than the Wilson Grove Formation materials at the west county sites, and even less competent than the Franciscan Complex materials at Huntley and Two Rock.

Because the site is located at a distance of about 2 miles from the Rodgers Creek fault, the impervious core of the dam is wider than at the west county sites to better resist earthquake-induced cracking.

Because of the moderate to highly plastic nature of the predominant available construction materials, they will be highly susceptible to desiccation cracking when exposed to air. To prevent moisture loss and resulting cracking on both the upstream and downstream faces of the dam, a 20- foot-wide zone of non-plastic material referred to as a "moisture barrier" zone would be placed at both faces, protected in turn by riprap (upstream) and slope protection (downstream). This zone of material would also be extended across the crest of the dam, to prevent moisture loss from the top of the impervious core zone. A sufficient quantity of material suitable for construction of this "moisture barrier" appears to occur within the reservoir.

It is assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

Borrow excavation in the reservoir area will have to be carefully laid out and controlled in order to avoid undercutting the natural slopes, thus triggering landslides in the weak materials that underlie the site, and to avoid significantly narrowing the relatively thin ridges on the east and west sides of the reservoir, thus increasing reservoir seepage. To avoid these problems, the volumes of embankment material required for the intermediate and upper limits of reservoir storage will probably necessitate excavations that extend somewhat above the reservoir footprint (Figure 4-8).

6.4.7 Lakeville Hillside

The principal project features at the Lakeville Hillside alternative reservoir site would include an embankment-type dam, spillway, inlet/outlet works, and conveyance facilities. A conceptual layout and cross section of the dam, with general recommended alignments of the spillway and inlet/outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-23 and 6-24.

The dam would be a zoned earthfill structure with a maximum height of up to 135 feet (1,500 million gallon or 4,603 acre-foot maximum storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are the same as the design for the Adobe Road site, somewhat flatter than at the west county sites, because the Petaluma Formation moderate to highly plastic materials available for construction of the shells of the dam at Lakeville Hillside are somewhat less competent than the Wilson Grove Formation materials at the west county sites, and even less competent than the Franciscan Complex materials at Huntley and Two Rock.

Similar to Adobe Road, the Lakeville Hillside site is located at a distance of about 2 miles from the Rodgers Creek fault. Therefore, the impervious core of the dam is wider than at the west county sites, as at Adobe Road, to better resist earthquake-induced cracking.

Also like Adobe Road, because of the moderate to highly plastic nature of the predominant available construction materials, they will be highly susceptible to desiccation cracking when exposed to air. To prevent moisture loss and resulting cracking on both the upstream and downstream faces of the dam, a 20-foot-wide zone of non-plastic material referred to as a "moisture barrier" zone would be placed at both faces, protected in turn by riprap (upstream) and slope protection (downstream). This zone of material would also be extended across the crest of the dam, to prevent moisture loss from the top of the impervious core zone. A sufficient quantity of material suitable for construction of this "moisture barrier" appears to occur within the reservoir.

It is assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

Borrow excavation in the reservoir area will have to be carefully laid out and controlled in order to avoid undercutting the natural slopes, thus triggering landslides in the weak materials that underlie the site, and to avoid significantly narrowing the relatively thin ridge on the west side of the reservoir, thus increasing reservoir seepage.

6.4.8 Tolay Creek

The principal project features at the Tolay Creek alternative reservoir site would include multiple embankment-type dams, a spillway and outlet works at the main dam, and conveyance facilities. A separate reservoir inlet facility, involving a tunnel through the ridge along the right (southwest) side of the reservoir for the alternative with a backdam, is planned apart from the dams. In addition, a storm water diversion facility is planned along the left (northeast) side of the reservoir for the alternative without a backdam and along the right (southwest) side of the reservoir for the alternative with a backdam.

A conceptual layout of the main dam, with general recommended alignments of the spillway and outlet works is shown on Figure 6-25. Refer to Figure 4-11 for a plan showing the layout of the north and west saddle dams for the alternative without a backdam and the layout of the backdam for the alternative with only partial inundation of the Tolay Creek site. A conceptual cross section of the main dam, which also applies to the west saddle dam for the alternative without a backdam, with descriptions of the proposed embankment construction materials, is shown on Figure 6-26. A conceptual cross section of the backdam for the partial inundation alternative, with descriptions of the proposed embankment construction materials, is shown on Figure 6-27. The conceptual cross section of the north saddle dam for the alternative without a backdam is the same as that presented earlier for the Adobe Road site (Figure 6-22).

The various dams would be zoned earthfill structures with maximum heights of up to 85, 35, and 23 feet for the main dam, north saddle dam, and west saddle dam, respectively, for the alternative without a backdam; and 115 and 65 feet for the main dam and backdam, respectively, for the alternative with a backdam (4,500 million gallon or 13,810 acre-foot storage capacity), depending upon required storage capacity. The various dams would each consist of an impervious core (widened for the embankments founded across the Tolay fault trace), flanked by shells of random material, with a vertical to steeply sloping chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

With the exception of the backdam, the outer slopes of the dams are the same as the design for the Adobe Road site, somewhat flatter than at the west county sites, because the moderate to highly plastic Petaluma Formation materials available for construction of the shells of the dams at Tolay Creek are somewhat less competent than the Wilson Grove Formation materials at the west county sites, and even less competent than the Franciscan Complex materials at Huntley and Two Rock.

As discussed in Section 4.9.3, poor foundation conditions encountered in both abutments at the main dam site and the associated conservative approach to remove the interpreted large landslide deposits comprising both abutments to reach suitable foundation will result in very large required foundation excavation volumes relative to embankment fill volumes. Since the dam construction itself would tend to provide a stabilizing effect between the abutments across the drainage, it is conceivable some of the abutment slide materials could be left in place, perhaps in conjunction with a required buttress or other section modification for added stability in the downstream and possibly upstream direction, as required. These refinements, which would need to be based on detailed engineering slope stability analyses, could result in some cost reductions and would be pursued during detailed design. Similarly, the magnitude of required foundation excavation and preparation at the main dam site might make what would initially appear to be a less appropriate alternate dam alignment location a more attractive and more cost-effective location. Based on some additional consideration of this during field investigation and office engineering studies, one such potential alternative alignment for the main dam is indicated on Figure 4-12. Again, these are refinements in the project which could lower costs somewhat that are design-level considerations.

Because the foundation area of the backdam for the partial inundation alternative is so large (Figure 4-11), and since the alluvial materials across the wide valley overlying the Petaluma Formation bedrock (up to on the order of 30 feet thick) are generally impervious clay materials, it was judged more cost effective to develop a design for the backdam to be founded on the alluvium, as opposed to a bedrock foundation which is assumed for all other dam designs, with appropriate adjustments to the embankment design section. This approach results in somewhat large embankment fill volumes, that avoids very large volumes of foundation excavation. In recognition of weaker foundation materials with this approach, the outer slopes of the backdam are flatter than the other south county dams comprised primarily of the same Petaluma Formation moderate to highly plastic materials available for construction of the shells of the dams, but that are founded on a bedrock surface (Figure 6-27). It is noted that a more refined, more cost effective design for the backdam might include somewhat steeper local outer slopes, similar to the outer slopes of the other south county dams, with a berm arrangement against the lower portion of the outer slopes. These refinements would be most appropriately made during detailed design, based on engineering slope stability analyses.

The Tolay Creek site is located at a distance of about 1 mile from the Rodgers Creek fault. Therefore, the impervious core of the various dams is wider than at the west county sites, as at Adobe Road, to better resist earthquake-induced cracking. In addition, the impervious core is widened significantly for those embankments that would be founded across the trace of the Tolay fault. This includes the main dam, west saddle dam (alternative without backdam), and the backdam (partial inundation alternative) (Figure 4-11). Although the Tolay fault is not classified as an active fault, considering the proximity of the Tolay Creek site to the active Rodgers Creek fault and at this conceptual design level, it is considered prudent for the designs of embankments founded across the Tolay fault trace to reflect the potential for displacement due to sympathetic movement along the Tolay fault as a result of a significant event on the nearby Rodgers Creek fault. As a result, a decision was made to incorporate design features into the embankments across the fault trace to accommodate fault displacement. These features include a thick, plastic internal core zone of sufficient width to prevent rupture and resist cracking in the event of fault displacement of the magnitude discussed in Section 4.9.2 (up to on the order of 2 to 4 feet maximum displacement assumed), and generous, high capacity chimney and blanket drain zones downstream of the core zone with appropriate filter protection designed to stop piping of core material, yet safely handle large seepage flow rates, in the event of cracking through the impervious core zone. As reflected on Figures 6-26 and 6-27, the conceptual design sections developed for the main dam, west saddle dam, and backdam incorporate an impervious core zone with a width that is greater than 2.5 times the maximum reservoir head. The chimney drain width has been increased from the nominal 10 feet for all other dams to 15 feet for dams across the Tolay fault trace and the blanket drain thickness has been increased from 5 to 8 feet, both increases to accommodate anticipated additional filter zoning requirements within the drains.

Like Adobe Road, because of the moderate to highly plastic nature of the predominant available construction materials, they will be highly susceptible to desiccation cracking when exposed to air. To prevent moisture loss and resulting cracking on both the upstream and downstream faces of the various dams, a 20-foot-wide zone of non-plastic material referred to as a "moisture barrier" zone would be placed at both faces, protected in turn by riprap (upstream) and slope protection (downstream). This zone of material would also be extended across the crest of the dams, to prevent moisture loss from the top of the impervious core zone. A sufficient quantity of material suitable for construction of this "moisture barrier" appears to occur within the reservoir. It is expected that this material would be derived primarily from the Sonoma Volcanics andesite in the outcrop area just upstream of the main dam site (Figure 4-12) and from Franciscan Complex graywacke sandstone and greenstone in the existing quarry area at the base of the ridge forming the right (southwest) side of the reservoir at the northern end of the reservoir (Figure 4-11).

The "moisture barrier" construction material generated from these sources is anticipated to be an earth-rock material comprised of a non to low plastic silty sand-gravel mixture by the time the material is excavated from the source, reworked, and placed in the embankment fill. It is noted that this material would have superior strength characteristics over the more prevalent available construction materials generated from the moderate to highly plastic Petaluma Formation materials. If sufficient quantities of these less plastic, stronger materials were available, improvements in the dam designs, with perhaps some cost reduction if somewhat steeper outer embankments slopes were allowed, could result with greater incorporation of these materials in the outer random shell zones. For purposes of this conceptual design and in keeping with the objective of maximizing the utilization of on-site construction materials within the reservoir area, the Tolay Creek dam designs are based on minimal use of these stronger materials, limited to use as a "moisture barrier" layer over the entire embankment section for its non to low plasticity properties, since a significant portion of the identified sources for these materials falls outside the reservoir area (Figure 4-11). The assumed borrow source availability for these materials for the conceptual designs presented is limited to within the reservoir area and environmental survey area as shown on Figure 4-11. Refinement of the availability and use of these higher quality construction materials would be considered during detailed design.

It is assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials for the various dams will be obtained from commercial sources off-site.

6.4.9 Sears Point

The principal project features at the Sears Point alternative reservoir site would include an embankment-type dam, spillway, outlet works, and conveyance facilities. A separate reservoir inlet facility is planned apart from the dam. In addition, a storm water diversion facility is planned along the right (west) side of the reservoir. A conceptual layout and cross section of the dam, with general recommended alignments of the spillway and outlet works, and descriptions of the proposed embankment construction materials, are shown on Figures 6-28 and 6-29.

The dam would be a zoned earthfill structure with a maximum height of up to 118 feet (3,800 million gallon or 11,662 acre-foot maximum storage capacity), depending upon required storage capacity. The dam would consist of an impervious core, flanked by shells of random material, with a vertical chimney drain at the downstream edge of the core to intercept seepage, connecting to a blanket drain located principally on the valley floor beneath the downstream shell.

The outer slopes of the dam are the same as the design for the Adobe Road site, somewhat flatter than at the west county sites, because the Petaluma Formation moderate to highly plastic materials available for construction of the shells of the dam at Sears Point are somewhat less competent than the Wilson Grove Formation materials at the west county sites, and even less competent than the Franciscan Complex materials at Huntley and Two Rock.

The Sears Point site is located at a distance of less than 1 mile from the Rodgers Creek fault. Therefore, the impervious core of the dam is wider than at the west county sites, as at Adobe Road, to better resist earthquake-induced cracking.

Like Adobe Road, because of the moderate to highly plastic nature of the predominant available construction materials, they will be highly susceptible to desiccation cracking when exposed to air. To prevent moisture loss and resulting cracking on both the upstream and downstream faces of the dam, a 20-foot-wide zone of non-plastic material referred to as a "moisture barrier" zone would be placed at both faces, protected in turn by riprap (upstream) and slope protection (downstream). This zone of material would also be extended across the crest of the dam, to prevent moisture loss from the top of the impervious core zone. A sufficient quantity of material suitable for construction of this "moisture barrier" does not appear to occur within the reservoir area. Thus, it is conservatively assumed for purposes of estimating construction costs, that all "moisture barrier" materials will be obtained from commercial sources off-site.

It is assumed for purposes of estimating construction costs, that all riprap and downstream slope protection materials will be obtained from commercial sources off-site.

TABLE 6-1

DAM AND RESERVOIR DATA
ALTERNATIVE RESERVOIR SITES - WEST COUNTY

Reservoir Site	Dam Crest Elevation (feet MSL)	Dam Height[1] (feet)	Reservoir Storage Capacity[2] (million gallons)	Reservoir Storage Capacity[2] (acre-feet)	Estimated Total Embankment Volume[3] (cubic yards)	Storage Efficiency (acre-feet/ 1,000 c.y.)
Valley Ford East	170	135	4,500	13,810	3,712,000	3.7
	145	110	2,900	8,900	2,295,000	3.9
	120	85	1,500	4,603	1,343,000	3.4
Carroll Road North	265	190	4,500	13,810	3,726,000	3.7
	240	165	2,800	8,593	2,527,000	3.4
	215	140	1,500	4,603	1,620,000	2.8
Bloomfield	270	190	4,500	13,810	6,230,000	2.2
	245	165	2,800	8,593	4,410,000	1.9
	215	135	1,500	4,603	2,571,000	1.8
Huntley	300	210	4,500	13,810	5,041,000	2.7
	270	180	2,900	8,900	3,219,000	2.8
	235	145	1,500	4,603	1,872,000	2.5
Two Rock	375	225	4,500	13,810	3,484,000	4.0
	345	195	2,800	8,593	2,311,000	3.7
	315	165	1,500	4,603	1,465,000	3.1

[1] Measured above downstream toe of embankment.
[2] Based on maximum operating pool 15 feet below dam crest (15-foot normal freeboard) and including dead storage below outlet works. Not reduced by volume of embankment fill upstream of dam axis or increased by volume of borrow from reservoir area for embankment construction.
[3] Includes embankment fill volume replacing required foundation excavation and all backdam and saddle dam volumes, as applicable.

TABLE 6-2

DAM AND RESERVOIR DATA
ALTERNATIVE RESERVOIR SITES - SOUTH COUNTY

Reservoir Site	Dam Crest Elevation (feet MSL)	Dam Height[1] (feet)	Reservoir Storage Capacity[2] (million gallons)	Reservoir Storage Capacity[2] (acre-feet)	Estimated Total Embankment Volume[3] (cubic yards)	Storage Efficiency (acre-feet/ 1,000 c.y.)
Adobe Road	355	205	3,700	11,355	6,242,000	1.8
	335	185	2,600	7,979	4,778,000	1.7
	310	160	1,500	4,603	3,277,000	1.4
Lakeville Hillside	215	135	1,500	4,603	1,181,000	3.9
Tolay Creek (without backdam)	255	85[4] / 35[5] / 23[6]	4,500	13,810	956,000	14.4
	250	80[4] / 30[5] / 17[6]	3,400	10,434	807,000	12.9
	240	70[4] / 20[5] / 6[6]	1,500	4,603	512,000	9.0
Tolay Creek (with backdam)	285	115[4] / 65[7]	4,500	13,810	5,304,000	2.6
	270	100[4] / 50[7]	3,000	9,207	3,266,000	2.8
	255	85[4] / 35[7]	1,500	4,603	1,819,000	2.5
Sears Point	155	118	3,800	11,662	2,430,000	4.8
	140	103	2,600	7,979	1,803,000	4.4

[1] Measured above downstream toe of embankment.
[2] Based on maximum operating pool 15 feet below dam crest (15-foot normal freeboard) and including dead storage below outlet works. Not reduced by volume of embankment fill upstream of dam axis or increased by volume of borrow from reservoir area for embankment construction.
[3] Includes embankment fill volume replacing required foundation excavation and all backdam and saddle dam volumes, as applicable.
[4] Main dam.
[5] North saddle dam.
[6] West saddle dam
[7] Backdam.

120	83	1,500	4,603	1,074,000	4.3

SECTION 7
DAM AND RESERVOIR CONSTRUCTION CONSIDERATIONS

7 DAM AND RESERVOIR CONSTRUCTION CONSIDERATIONS

7.1 GENERAL

This section discusses typical construction operations and procedures, including anticipated types of equipment and work scheduling, associated with dam and reservoir construction. The information provided is based on previous experience with projects similar in type and magnitude. In addition, the availability and use of on-site construction materials are summarized in terms of earthwork construction requirements and comparison of available versus required quantities of the critical material types. The requirements for import construction materials are provided, including sources, required quantities, and import material transport considerations.

7.2 CONSTRUCTION ACTIVITIES

Although various contractors will take different approaches to construction, the following basic activities will be required for dam and reservoir construction:

- Mobilization of construction equipment.
- Clearing of dam and reservoir area.
- Stripping of dam foundation and on-site borrow areas.
- Dam foundation excavation and on-site borrow area excavation.
- Control of water.
- Dam foundation drilling and grouting (only anticipated at the Two Rock site and only selective grouting at the Huntley and Tolay Creek sites).
- Dam foundation clean-up and preparation.
- Earthwork fill placement for dam construction.
- Earthwork fill placement for reservoir lining (varies with site and not required at all sites).

- Tunnel construction for inlet pipeline (only planned at the Two Rock and Tolay Creek sites).
- Construction of appurtenant structures and ancillary facilities such as spillway, inlet/outlet conduit, diversion channels (only planned at the Adobe Road, Tolay Creek, and Sears Point sites), pipelines, access roads, fencing, etc.
- Installation of dam instrumentation such as piezometers, survey/settlement monuments, etc.
- Site clean-up and demobilization.

7.3 AVAILABILITY AND USE OF ON-SITE CONSTRUCTION MATERIALS

Detailed discussions of the sources, quantity, and characteristics of available on-site borrow materials for dam construction at the various alternative reservoir storage sites were provided in Section 5. Based on the assessment of site conditions (Section 4) and construction materials (Section 5), the conceptual embankment dam designs for the alternative reservoir storage sites, presented in Section 6, were developed. The available on-site construction materials can be categorized into three primary types, according to their function in the various zoned embankment designs, and associated with their basic sources, as summarized in Table 7-1.

In developing the zoned embankment designs presented in Section 6, one of the primary construction considerations is confirmation of adequate quantities of various material types associated with their proposed use in the various embankment zones. The availability of adequate volumes of suitable impervious materials for the internal dam core seepage barrier is typically one of the more critical situations relative to the availability of on-site construction materials in general. For this situation, it is prudent to prove out the availability of a minimum of 1.5 times the material quantity required by the design. Table 7-2 summarizes the comparison of estimated available versus required quantities of impervious-type construction materials for the maximum-sized dams considered at the alternative reservoir storage sites.

Comparison of available versus required quantities of the other types of construction materials was not made to the same degree of detail as for the impervious-type materials. The various embankment dam designs and their associated selected outer slopes are based on the recognition that the widespread prevalent on-site formation materials, which may have somewhat variable material properties, would be allowed for use in the outer random shell zones typically comprising a majority of the embankment section. However, since the estimated volumes of the random embankment zones are quite large in a lot of cases and the surface area of many of the reservoirs is relatively small, and considering the objective to limit on-site borrow materials to within the reservoir footprint, the comparison of available quantities within the reservoir limits versus required quantities was evaluated. In looking at an idealized overall average excavation depth over the reservoir area that would be required to generate the required material volumes, and also evaluating more realistic localized borrow areas within the reservoir excavated to greater depths under the concept of a designed grading plan with maximum cut slopes, it was concluded that required random materials could be obtained within the reservoir limits for all sites except the Adobe Road site, as discussed in Section 5.7. It is noted, however, that the sites that will require a carefully designed grading plan, in addition to Adobe Road, to accomplish limitation of borrow within the reservoir footprint appear to be the Valley Ford East, Carroll Road North, Bloomfield, and Huntley sites.

7.4 REQUIREMENTS FOR IMPORT CONSTRUCTION MATERIALS

As discussed in Section 5, no suitable aggregates for filter, drain, or concrete materials exist at any of the alternative reservoir storage sites. In addition, with the exception of the Two Rock site, no hard rock type materials suitable for slope protection or riprap exist at the various sites. Thus, these types of construction materials required by the designs shown in Section 6 will require importing from commercial sources. In the case of the Two Rock site, it is also conservatively assumed that required slope protection and riprap materials would be imported, since development of a quarry to obtain these materials on site would conflict with the objective of limiting borrow of on-site construction materials to within the reservoir footprint (Section 6.4.5). The various aggregates and rock products for the embankment dam drainage and slope protection zones will need to be clean, durable materials conforming to design gradations and sizes, and thus, will be processed materials meeting strict material specifications. In addition, investigation of the Sears Point reservoir site did not identify a suitably non to low plastic on-site construction material appropriate for use as a select fill for the required moisture barrier zone of the dam at this site. Thus, the moisture barrier material required for the Sears Point dam design is assumed to also be an imported material.

Since the costs of imported, processed rock products for dam construction are usually quite significant, an in-depth evaluation of available commercial sources, associated haul distances, and resulting in-place material costs was made. Initially, significant commercial quarries and pits within about 100 miles of the project area were identified as potential sources. Based on direct contacting of a majority of the identified quarries, a reduced list of commercial sources that would be able to produce the volumes of required materials and meet the level of quality expected to be specified resulted. The identified potential sources for the various required import construction materials are listed in Table 7-3.

Tables 7-4, 7-5, 7-6, and 7-7 provide listings of the required import construction material quantities for filter/drain, riprap/bedding, downstream slope protection, and moisture barrier materials, respectively, based on the conceptual designs shown in Section 6 for the maximum-sized dams considered at the alternative reservoir storage sites. Required import volumes for the range of smaller dams investigated to develop cost curves can be found in Section 8, which provides complete tabulations of all quantity and cost estimates made for the alternative reservoir sites.

The significant import construction material volumes and haul distances from commercial sources can be a significant environmental factor associated with typical dam and reservoir construction. To assist in this evaluation, Tables 7-4 through 7-7 also tabulate estimated truck trips required to import the various required materials based on assumed truck haul capacity. The estimated haul distance from the assumed quarry source to the alternative reservoir storage site used in the import materials cost estimating (Section 8) is also provided.

7.5 CONSTRUCTION EQUIPMENT

The most equipment-intensive activity associated with dam and reservoir construction is probably the earthwork fill placement. Typical types of primary earthwork equipment associated with the major earthwork and a possible range of the equipment spread for a typical reservoir being evaluated (this would include Valley Ford East, Carroll Road North, Bloomfield, Huntley, Two Rock, Adobe Road, and Sears Point, similar in magnitude, depending on the alternative; Tolay Creek is larger in magnitude and more spread out with multiple structures and Lakeville Hillside is significantly smaller) may include the following:

- Dozers (Cat D8 or larger) 3 to 5
- Scrapers (loader/trucks is an alternative) 5 to 8
- Graders 2
- Water wagons 2 to 3
- Self-propelled compactors (Cat 825) 2 to 3
- Backhoe excavator 2 to 3
- Loader and Trucks

Other operations requiring specialty equipment at some sites include drilling and grouting (Two Rock, Huntley, and Tolay Creek), localized blasting, and tunneling (Two Rock and Tolay Creek). The above typical equipment listing does not include equipment associated with hauling of imported construction materials, and does not reflect other special equipment for construction of appurtenant facilities or concrete and pipeline construction. Equipment spreads will vary for different sites and reservoir sizes depending on the earthwork quantities, will vary throughout the job depending on the stage of construction and working area, and will vary depending on the contractor's approach and construction schedule.

7.6 CONSTRUCTION SCHEDULE

As with types of equipment, the schedule for dam and reservoir construction projects can vary significantly depending on the parameters established and the specific site conditions. However, based on some assumed production rates for the major earthwork, work schedules, and construction season, one can make a judgment regarding the overall length of construction:

• Range of total earthwork fill volumes for maximum-sized reservoirs (4,500 million gallon = 13,810 acre-foot or maximum site capacity, excluding Lakeville Hillside and Tolay Creek without backdam).	2.4 to 6.2 million cubic yards
• Assumed earthwork production rate (based on spread of 6 scrapers with 30 cubic yard capacity, 6 trips per hour cycle time at 10 hours per day)	10,000 cubic yards/day
• Work shift	10 hours/day - 6 days/week
• Construction schedule (March through October)	8 months

Based on the above assumptions, the number of days required to place the range of fill volume indicated would be 240 to 620 days. Considering the assumed work shift and schedule shown, construction at this rate would span 1.2 to 3.1 construction seasons. Higher production rates, up to a point, could be achieved with more equipment or longer construction shifts. Considering this and the other associated construction activities in addition to fill placement, some of which has to be staged with the major earthwork, it appears reasonable to assume that complete construction of one of the typical maximum capacity dam and reservoir projects, including all the ancillary facilities, would span 2 to 3 construction seasons.

TABLE 7-1

SUMMARY OF AVAILABLE ON-SITE CONSTRUCTION MATERIALS

On-Site Construction Material Type	General Location	Basic On-Site Source
Impervious Core	West County	clayey alluvium/colluvium, supplemented by clayey Franciscan Complex materials at Huntley and Two Rock sites
	South County	clayey alluvium/colluvium, supplemented by clayey landslide deposits and Petaluma Formation materials at Adobe Road and Lakeville Hillside sites
Random Shell	West County	primarily Wilson Grove Formation materials, plus Franciscan Complex materials at Huntley and Two Rock sites
	South County	primarily Petaluma Formation materials, plus alluvium/colluvium/landslide deposits at Tolay Creek and Sears Point sites
Select Fill (Moisture Barrier)	West County	not applicable
	South County	coarser, low plasticity Petaluma Formation materials at Adobe Road and Lakeville Hillside sites; coarser, low plasticity Sonoma Volcanics and Franciscan Complex materials at Tolay Creek site; not available at Sears Point site

TABLE 7-2

ESTIMATED AVAILABLE VERSUS REQUIRED IMPERVIOUS ON-SITE CONSTRUCTION MATERIALS ALTERNATIVE RESERVOIR SITES

Reservoir Site	Estimated Available Impervious Material[1] (cubic yards)	Estimated Required Impervious Material[2] (cubic yards)	Available/ Required Volume
Valley Ford East	80,000	608,000	0.1[3]
Carroll Road North	1,980,000	547,000	3.6
Bloomfield	480,000	878,000	0.5[3]
Huntley	1,300,000	799,000	1.6[4]
Two Rock	280,000	475,000	0.6[5]
Adobe Road	2,650,000	1,250,000	2.1
Lakeville Hillside	850,000	282,000	3.0
Tolay Creek (without backdam)	7,760,000	378,000[6]	20.5
Tolay Creek (with backdam)	6,610,000	1,971,000[7]	3.4
Sears Point	2,470,000	522,000	4.7

---

[1] Based on assumed areas and average depths of primary impervious borrow areas outlined on Section 4 geologic and exploration maps and as discussed in Section 5.
[2] Based on conceptual design shown in Section 6 for maximum-sized dams considered (4,500 million gallon =13,810 acre-foot capacity for all sites, except 3,700 million gallon = 11,355 acre-foot capacity at Adobe Road, 1,500 million gallon = 4,603 acre-foot capacity at Lakeville Hillside, and 3,800 million gallon = 11,662 acre-foot capacity at Sears Point).
[3] Insufficient impervious on-site construction materials. Design calls for soil-bentonite mixture for creation of adequate core material.
[4] Franciscan Complex materials suitable for impervious core also available to supplement primary alluvium/colluvium source.
[5] Insufficient impervious on-site construction materials from only primary alluvium source. Franciscan Complex materials suitable for impervious core also available to adequately supplement primary source.
[6] Includes main dam and north saddle dam.
[7] Includes main dam and backdam.

TABLE 7-3

POTENTIAL SOURCES OF IMPORT CONSTRUCTION MATERIALS

Source	Location	Import Construction Material Type
SYAR Industries	Healdsburg	filter and drain
SYAR Industries[1]	Lake Herman	riprap and slope protection
~~Northern Aggregates~~	~~Hopland~~	~~filter and drain~~ riprap and slope protection
San Rafael Rock Quarry[1]	San Rafael	filter and drain riprap and slope protection
Kaiser Sand and Gravel	Windsor	filter and drain
Parnum Paving	Ukiah	filter and drain riprap and slope protection

[1] Assumed quarry sources for cost estimating (Section 8) based on overall lowest combined material and haul cost for each of the alternative reservoir storage sites.

TABLE 7-4

ESTIMATED FILTER/DRAIN
IMPORT CONSTRUCTION MATERIAL REQUIREMENTS
ALTERNATIVE RESERVOIR SITES

Reservoir Site	Estimated Required Quantity[1] (cubic yards)	Estimated Truck Trips[2]	Estimated Haul Distance[3] (miles)
Valley Ford East	144,000	9,600	36
Carroll Road North	123,000	8,200	35
Bloomfield	169,000	11,267	34
Huntley	160,000	10,667	32
Two Rock	98,000	6,533	29
Adobe Road	180,000	12,000	23
Lakeville Hillside	47,000	3,133	18
Tolay Creek (without backdam)	98,000[4]	6,533	21
Tolay Creek (with backdam)	450,000[5]	30,000	21

---

[1] Based on conceptual design shown in Section 6 for maximum-size dams considered (4,500 million gallon =13,810 acre-foot capacity for all sites, except 3,700 million gallon = 11,355 acre-foot capacity at Adobe Road, 1,500 million gallon = 4,603 acre-foot capacity at Lakeville Hillside, and 3,800 million gallon = 11,662 acre-foot capacity at Sears Point).

[2] Based on 15 cubic yard truckload capacity.

[3] One-way distance between assumed quarry source at San Rafael Rock Quarry, San Rafael and reservoir site.

[4] Includes main dam and north saddle dam.

[5] Includes main dam and backdam.

Sears Point	100,000	6,667	18

TABLE 7-5

ESTIMATED RIPRAP/BEDDING IMPORT CONSTRUCTION MATERIAL REQUIREMENTS ALTERNATIVE RESERVOIR SITES

Reservoir Site	Estimated Required Quantity[1] (cubic yards)	Estimated Truck Trips[2]	Estimated Haul Distance[3] (miles)
Valley Ford East	65,000	5,417	51
Carroll Road North	54,000	4,500	50
Bloomfield	79,000	6,583	49
Huntley	70,000	5,833	48
Two Rock	39,000	3,250	45
Adobe Road	68,000	5,677	36
Lakeville Hillside	18,000	1,500	26
Tolay Creek (without backdam)	32,000[4]	2,667	29
Tolay Creek (with backdam)	139,000[5]	11,583	29
Sears Point	37,000	3,083	23

---

[1] Based on conceptual design shown in Section 6 for maximum-size dams considered (4,500 million gallon =13,810 acre-foot capacity for all sites, except 3,700 million gallon = 11,355 acre-foot capacity at Adobe Road, 1,500 million gallon = 4,603 acre-foot capacity at Lakeville Hillside, and 3,800 million gallon = 11,662 acre-foot capacity at Sears Point).

[2] Based on 12 cubic yard truckload capacity.

[3] One-way distance between assumed quarry source at SYAR Industries, Lake Herman and reservoir site.

[4] Includes main dam and north saddle dam.

[5] Includes main dam and backdam.

TABLE 7-6

ESTIMATED DOWNSTREAM SLOPE PROTECTION
IMPORT CONSTRUCTION MATERIAL REQUIREMENTS
ALTERNATIVE RESERVOIR SITES

Reservoir Site	Estimated Required Quantity[1] (cubic yards)	Estimated Truck Trips[2]	Estimated Haul Distance[3] (miles)
Valley Ford East	27,000	2,250	51
Carroll Road North	24,000	2,000	50
Bloomfield	33,000	2,750	49
Huntley	32,000	2,667	48
Two Rock	18,000	1,500	45
Adobe Road	33,000	2,750	36
Lakeville Hillside	7,000	583	26
Tolay Creek (without backdam)	12,000[4]	1,000	29
Tolay Creek (with backdam)	55,000[5]	4,583	29
Sears Point	14,000	1,167	23

[1] Based on conceptual design shown in Section 6 for maximum-sized dams considered (4,500 million gallon =13,810 acre-foot capacity for all sites, except 3,700 million gallon = 11,355 acre-foot capacity at Adobe Road, 1,500 million gallon = 4,603 acre-foot capacity at Lakeville Hillside, and 3,800 million gallon = 11,662 acre-foot capacity at Sears Point).

[2] Based on 12 cubic yard truckload capacity.

[3] One-way distance between assumed quarry source at SYAR Industries, Lake Herman and reservoir site.

[4] Includes main dam and north saddle dam.

[5] Includes main dam and backdam.

\TABLE 7-7

ESTIMATED MOISTURE BARRIER
IMPORT CONSTRUCTION MATERIAL REQUIREMENTS
ALTERNATIVE RESERVOIR SITES

Reservoir Site	Estimated Required Quantity[1] (cubic yards)	Estimated Truck Trips[2]	Estimated Haul Distance[3] (miles)
Valley Ford East	---	---	---
Carroll Road North	---	---	---
Bloomfield	---	---	---
Huntley	---	---	---
Two Rock	---	---	---
Adobe Road	---	---	---
Lakeville Hillside	---	---	---
Tolay Creek (without backdam)	---	---	---
Tolay Creek (with backdam)	---	---	---
Sears Point	190,000	12,667	18

[1] Based on conceptual design shown in Section 6 for maximum-sized dams considered (4,500 million gallon =13,810 acre-foot capacity for all sites, except 3,700 million gallon = 11,355 acre-foot capacity at Adobe Road, 1,500 million gallon = 4,603 acre-foot capacity at Lakeville Hillside, and 3,800 million gallon = 11,662 acre-foot capacity at Sears Point).
[2] Based on 15 cubic yard truckload capacity.
[3] One-way distance between assumed quarry source at San Rafael Rock Quarry, San Rafael and reservoir site.

SECTION 8
DAM AND RESERVOIR CONSTRUCTION COST

8 DAM AND RESERVOIR CONSTRUCTION COST

This section summarizes the results of quantity and cost estimates made for the earthwork-related aspects of dam and reservoir construction for the various alternative reservoir sites, over a range of storage capacities. For all but the Lakeville Hillside site, several sizes of reservoir have been laid out and the construction costs of the dams have been estimated in 1995 dollars. With this data, curves relating dam construction cost to dam height or reservoir storage have been developed for each alternative reservoir storage site. These curves provide a comparison of the cost effectiveness of the various sized reservoirs investigated and can be interpolated to provide cost information for other-sized reservoirs.

Detailed estimates of construction cost have been developed for the earthwork-related aspects of dam and reservoir construction at each of the alternative storage sites. For purposes of estimating construction costs, it is assumed that all dams will be constructed over a two year period, that dewatering of dam foundations will be required, and that materials from required excavations other than the dam foundation (spillways, inlet/outlet works, etc.) and borrow sources for impervious and random shell zones of the embankments will be placed directly into the embankment fill. However, it is assumed that dam foundation excavation material, imported filter and drain materials, riprap, and downstream slope protection will have to be stockpiled and rehandled during placement.

The earthwork construction cost estimates are based on quantity take-offs and unit prices for the major dam and reservoir construction cost elements, including reservoir clearing, foundation excavation, grouting (only at Two Rock site), embankment fill for the various internal zones, and reservoir lining (only at Adobe Road and Lakeville Hillside sites). Also included is a lump sum allowance for unlisted items such as mobilization, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation. Unit pricing for all cost items except commercial rock products (filter and drain materials, riprap, and slope protection) is based on data and experience from other projects, considering similarities in material types, volumes, placement constraints, and construction conditions, indexed to 1995 levels based on Bureau of Reclamation cost data for "Earth Dams" published in Engineering News Record magazine. Unit prices for commercial rock products have been based on actual quoted quarry prices, calculated hauling costs for the sources indicated in Section 7, and estimated placement costs.

Tables 8-1 and 8-2 present a summary of total estimated earthwork-related costs for dam and reservoir construction at the west county and south county alternative reservoir sites, respectively, for the range of reservoir sizes investigated. The tables also provide the estimated costs in terms of unit storage cost efficiency. Tables 8-3 through 8-30 provide the detailed earthwork construction quantity estimates with established unit prices and estimated costs for each reservoir size considered at each alternative storage site. The cost estimates are presented graphically on Figure 8-1 in the form of estimated earthwork construction cost versus dam height, on Figure 8-2 in the form of estimated earthwork construction cost versus reservoir storage capacity, and on Figure 8-3 in the form of unit storage cost versus reservoir storage capacity. The cost curves for all of the alternative sites are presented on the same figure for ease of comparison. The general basis and limitations of the cost estimates are listed on the various cost estimate tables and figures.

TABLE 8-1

EARTHWORK CONSTRUCTION COST ESTIMATE SUMMARY
ALTERNATIVE RESERVOIR SITES - WEST COUNTY

Reservoir Site	Dam Crest Elevation (feet MSL)	Dam Height[1] (feet)	Reservoir Storage Capacity[2] (million gallons)	Reservoir Storage Capacity[2] (acre-feet)	Estimated Construction Cost[3] ($)	Unit Storage Cost ($/acre-foot)
Valley Ford East	170	135	4,500	13,810	36,004,000	2,607
	145	110	2,900	8,900	23,917,000	2,687
	120	85	1,500	4,603	15,099,500	3,280
Carroll Road North	265	190	4,500	13,810	31,270,000	2,264
	240	165	2,800	8,593	21,912,000	2,550
	215	140	1,500	4,603	14,737,000	3,202
Bloomfield	270	190	4,500	13,810	56,527,500	4,093
	245	165	2,800	8,593	41,870,500	4,873
	215	135	1,500	4,603	25,807,000	5,607
Huntley	300	210	4,500	13,810	40,784,000	2,953
	270	180	2,900	8,900	26,812,000	3,013
	235	145	1,500	4,603	16,401,500	3,563
Two Rock	375	225	4,500	13,810	32,188,000	2,331
	345	195	2,800	8,593	22,329,000	2,599
	315	165	1,500	4,603	15,218,500	3,306

[1] Measured above downstream toe of embankment.
[2] Based on maximum operating pool 15 feet below dam crest (15-foot normal freeboard) and including dead storage below outlet works. Not reduced by volume of embankment fill upstream of dam axis or increased by volume of borrow from reservoir area for embankment construction.
[3] 1995 dollars. Limited to dam embankment earthwork construction costs. Does not include spillway, inlet/outlet works, and other ancillary facilities or engineering, administration, land acquisition, and contingency costs. (See Section 8 and following tables for detailed basis).

TABLE 8-2

EARTHWORK CONSTRUCTION COST ESTIMATE SUMMARY
ALTERNATIVE RESERVOIR SITES - SOUTH COUNTY

Reservoir Site	Dam Crest Elevation (feet MSL)	Dam Height[1] (feet)	Reservoir Storage Capacity[2] (million gallons)	(acre-feet)	Estimated Construction Cost[3] ($)	Unit Storage Cost ($/acre-foot)
Adobe Road	355	205	3,700	11,355	58,005,000	5,108
	335	185	2,600	7,979	45,195,000	5,664
	310	160	1,500	4,603	32,117,000	6,977
Lakeville Hillside	215	135	1,500	4,603	16,106,000	3,499
Tolay Creek (without backdam)	255	85[4] / 35[5] / 23[6]	4,500	13,810	18,608,000	1,347
	250	80[4] / 30[5] 17[6]	3,400	10,434	16,781,500	1,608
	240	70[4] / 20[5] / 6[6]	1,500	4,603	13,239,000	2,876
Tolay Creek (with backdam)	285	115[4] / 65[7]	4,500	13,810	62,544,500	4,529
	270	100[4] / 50[7]	3,000	9,207	43,375,000	4,711
	255	85[4] / 35[7]	1,500	4,603	28,797,000	6,256
Sears Point	155	118	3,800	11,662	25,566,500	2,192
	140	103	2,600	7,979	19,652,500	2,463
	120	83	1,500	4,603	12,413,500	2,697

[1] Measured above downstream toe of embankment.
[2] Based on maximum operating pool 15 feet below dam crest (15-foot normal freeboard) and including dead storage below outlet works. Not reduced by volume of embankment fill upstream of dam axis or increased by volume of borrow from reservoir area for embankment construction.
[3] 1995 dollars. Limited to dam embankment earthwork construction costs. Does not include spillway, inlet/outlet works, and other ancillary facilities or engineering, administration, land acquisition, and contingency costs. (See Section 8 and following tables for detailed basis).
[4] Main dam.
[5] North saddle dam.
[6] West saddle dam.
[7] Backdam.

TABLE 8-3

EARTHWORK CONSTRUCTION COST ESTIMATE[1]
VALLEY FORD EAST RESERVOIR SITE
DAM CREST ELEVATION 170 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	285	acre	$1000.00	$285,000
Foundation Excavation	590,000	c.y.	$3.00	$1,770,000
Impervious Fill	608,000	c.y.	$12.00	$7,296,000
Random Fill	2,868,000	c.y.	$5.00	$14,340,000
Filter/Drain[2]	144,000	c.y.	$25.00	$3,600,000
Riprap/Bedding[2]	65,000	c.y.	$44.50	$2,892,500
Downstream Slope Protection[2]	27,000	c.y.	$41.50	$1,120,500
Allowance for Unlisted Items[3]	1	job	lump sum	$4,700,000
		Estimated Construction Cost[4] (1995 Dollars)		$36,004,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-4

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

VALLEY FORD EAST RESERVOIR SITE

DAM CREST ELEVATION 145 (2,900 million gallons = 8,900 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	222	acre	$1000.00	$222,000
Foundation Excavation	457,000	c.y.	$3.00	$1,371,000
Impervious Fill	429,000	c.y.	$12.00	$5,148,000
Random Fill	1,692,000	c.y.	$5.00	$8,460,000
Filter/Drain[2]	106,000	c.y.	$25.00	$2,650,000
Riprap/Bedding[2]	48,000	c.y.	$44.50	$2,136,000
Downstream Slope Protection[2]	20,000	c.y.	$41.50	$830,000
Allowance for Unlisted Items[3]	1	job	lump sum	$3,100,000
		Estimated Construction Cost[4] (1995 Dollars)		$23,917,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-5

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
VALLEY FORD EAST RESERVOIR SITE
DAM CREST ELEVATION 120 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	173	acre	$1000.00	$173,000
Foundation Excavation	350,000	c.y.	$3.00	$1,050,000
Impervious Fill	289,000	c.y.	$12.00	$3,468,000
Random Fill	939,000	c.y.	$5.00	$4,695,000
Filter/Drain [2]	70,000	c.y.	$25.00	$1,750,000
Riprap/Bedding [2]	32,000	c.y.	$44.50	$1,424,000
Downstream Slope Protection [2]	13,000	c.y.	$41.50	$539,500
Allowance for Unlisted Items [3]	1	job	lump sum	$2,000,000
		Estimated Construction Cost [4]		$15,099,500
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-6

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
CARROLL ROAD NORTH RESERVOIR SITE
DAM CREST ELEVATION 265 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	284	acre	$2000.00	$568,000
Foundation Excavation	656,000	c.y.	$3.00	$1,968,000
Impervious Fill	547,000	c.y.	$6.00	$3,282,000
Random Fill	2,978,000	c.y.	$5.00	$14,890,000
Filter/Drain[2]	123,000	c.y.	$25.00	$3,075,000
Riprap/Bedding[2]	54,000	c.y.	$44.50	$2,403,000
Downstream Slope Protection[2]	24,000	c.y.	$41.00	$984,000
Allowance for Unlisted Items[3]	1	job	lump sum	$4,100,000
		Estimated Construction Cost[4] (1995 Dollars)		$31,270,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-7

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

CARROLL ROAD NORTH RESERVOIR SITE

DAM CREST ELEVATION 240 (2,800 million gallons = 8,593 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	223	acre	$2000.00	$446,000
Foundation Excavation	528,000	c.y.	$3.00	$1,584,000
Impervious Fill	398,000	c.y.	$6.00	$2,388,000
Random Fill	1,983,000	c.y.	$5.00	$9,915,000
Filter/Drain [2]	90,000	c.y.	$25.00	$2,250,000
Riprap/Bedding [2]	38,000	c.y.	$44.50	$1,691,000
Downstream Slope Protection [2]	18,000	c.y.	$41.00	$738,000
Allowance for Unlisted Items [3]	1	job	lump sum	$2,900,000
		Estimated Construction Cost [4]		$21,912,000
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-8

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
CARROLL ROAD NORTH RESERVOIR SITE
DAM CREST ELEVATION 215 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	164	acre	$2,000	$328,000
Foundation Excavation	400,000	c.y.	$3.00	$1,200,000
Impervious Fill	254,000	c.y.	$6.00	$1,524,000
Random Fill	1,254,000	c.y.	$5.00	$6,270,000
Filter/Drain[2]	73,000	c.y.	$25.00	$1,825,000
Riprap/Bedding[2]	26,000	c.y.	$44.50	$1,157,000
Downstream Slope Protection[2]	13,000	c.y.	$41.00	$533,000
Allowance for Unlisted Items[3]	1	job	lump sum	$1,900,000
		Estimated Construction Cost[4]		$14,737,000
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-9

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
BLOOMFIELD RESERVOIR SITE
DAM CREST ELEVATION 270 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	259	acre	$1000.00	$259,000
Foundation Excavation	1,336,000	c.y.	$3.00	$4,008,000
Impervious Fill	878,000	c.y.	$12.00	$10,536,000
Random Fill	5,071,000	c.y.	$5.00	$25,355,000
Filter/Drain[2]	169,000	c.y.	$24.50	$4,140,500
Riprap/Bedding[2]	79,000	c.y.	$44.00	$3,476,000
Downstream Slope Protection[2]	33,000	c.y.	$41.00	$1,353,000
Allowance for Unlisted Items[3]	1	job	lump sum	$7,400,000
		Estimated Construction Cost[4]		$56,527,500
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-10

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
BLOOMFIELD RESERVOIR SITE
DAM CREST ELEVATION 245 (2,800 million gallons = 8,593 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	209	acre	$1000.00	$209,000
Foundation Excavation	1,081,000	c.y.	$3.00	$3,243,000
Impervious Fill	697,000	c.y.	$12.00	$8,364,000
Random Fill	3,491,000	c.y.	$5.00	$17,455,000
Filter/Drain[2]	133,000	c.y.	$24.50	$3,258,500
Riprap/Bedding[2]	64,000	c.y.	$44.00	$2,816,000
Downstream Slope Protection[2]	25,000	c.y.	$41.00	$1,025,000
Allowance for Unlisted Items[3]	1	job	lump sum	$5,500,000
		Estimated Construction Cost[4] (1995 Dollars)		$41,870,500

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-11

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
BLOOMFIELD RESERVOIR SITE
DAM CREST ELEVATION 215 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	148	acre	$1000.00	$148,000
Foundation Excavation	786,000	c.y.	$3.00	$2,358,000
Impervious Fill	401,000	c.y.	$12.00	$4,812,000
Random Fill	2,014,000	c.y.	$5.00	$10,070,000
Filter/Drain [2]	92,000	c.y.	$24.50	$2,254,000
Riprap/Bedding [2]	47,000	c.y.	$44.00	$2,068,000
Downstream Slope Protection [2]	17,000	c.y.	$41.00	$697,000
Allowance for Unlisted Items [3]	1	job	lump sum	$3,400,000
		Estimated Construction Cost [4]		$25,807,000
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-12

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

HUNTLEY RESERVOIR SITE

DAM CREST ELEVATION 300 (4,500 million gallons = 13,800 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	222	acre	$2000.00	$444,000
Foundation Excavation	528,000	c.y.	$3.50	$1,848,000
Impervious Fill	799,000	c.y.	$6.00	$4,794,000
Random Fill	3,933,000	c.y.	$5.00	$19,665,000
Filter/Drain[2]	160,000	c.y.	$24.00	$3,840,000
Riprap/Bedding[2]	70,000	c.y.	$44.00	$3,080,000
Downstream Slope Protection[2]	32,000	c.y.	$40.50	$1,296,000
Saddle Dams	47,000	c.y.	$11.00	$517,000
Allowance for Unlisted Items[3]	1	job	lump sum	$5,300,000
		Estimated Construction Cost[4]		$40,784,000
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-13

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
HUNTLEY RESERVOIR SITE
DAM CREST ELEVATION 270 (2,900 million gallons = 8,900 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	173	acre	$2,000	$346,000
Foundation Excavation	383,000	c.y.	$3.50	$1,340,500
Impervious Fill	566,000	c.y.	$6.00	$3,396,000
Random Fill	2,458,000	c.y.	$5.00	$12,290,000
Filter/Drain[2]	128,000	c.y.	$24.00	$3,072,000
Riprap/Bedding[2]	44,000	c.y.	$44.00	$1,936,000
Downstream Slope Protection[2]	23,000	c.y.	40.50	$931,500
Allowance for Unlisted Items[3]	1	job	lump sum	$3,500,000
		Estimated Construction Cost[4] (1995 Dollars)		$26,812,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-14

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

HUNTLEY RESERVOIR SITE

DAM CREST ELEVATION 235 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	124	acre	$2,000	$248,000
Foundation Excavation	271,000	c.y.	$3.50	$948,500
Impervious Fill	355,000	c.y.	$6.00	$2,130,000
Random Fill	1,383,000	c.y.	$5.00	$6,915,000
Filter/Drain[2]	89,000	c.y.	$24.00	$2,136,000
Riprap/Bedding[2]	29,000	c.y.	$44.00	$1,276,000
Downstream Slope Protection[2]	16,000	c.y.	40.50	$648,000
Allowance for Unlisted Items[3]	1	job	lump sum	$2,100,000
		Estimated Construction Cost[4]		$16,401,500
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-15

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

TWO ROCK RESERVOIR SITE

DAM CREST ELEVATION 375 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	285	acre	$3000.00	$855,000
Foundation Excavation	683,000	c.y.	$4.00	$2,732,000
Grout Curtain	74,000	l.f.	$35.00	$2,590,000
Impervious Fill	475,000	c.y.	$6.00	$2,850,000
Random Fill	2,854,000	c.y.	$5.00	$14,270,000
Filter/Drain [2]	98,000	c.y.	$23.50	$2,303,000
Riprap/Bedding [2]	39,000	c.y.	$43.00	$1,677,000
Downstream Slope Protection [2]	18,000	c.y.	$39.50	$711,000
Allowance for Unlisted Items [3]	1	job	lump sum	$4,200,000
		Estimated Construction Cost [4] **(1995 Dollars)**		$32,188,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-16

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

TWO ROCK RESERVOIR SITE

DAM CREST ELEVATION 345 (2,800 million gallons = 8,593 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	195	acre	$3000.00	$585,000
Foundation Excavation	535,000	c.y.	$4.00	$2,140,000
Grout Curtain	54,000	l.f.	$35.00	$1,890,000
Impervious Fill	359,000	c.y.	$6.00	$2,154,000
Random Fill	1,836,000	c.y.	$5.00	$9,180,000
Filter/Drain[2]	75,000	c.y.	$23.50	$1,762,500
Riprap/Bedding[2]	28,000	c.y.	$43.00	$1,204,000
Downstream Slope Protection[2]	13,000	c.y.	$39.50	$513,500
Allowance for Unlisted Items[3]	1	job	lump sum	$2,900,000
		Estimated Construction Cost[4]		$22,329,000
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-17

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

TWO ROCK RESERVOIR SITE

DAM CREST ELEVATION 315 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	128	acre	$3000.00	$384,000
Foundation Excavation	410,000	c.y.	$4.00	$1,640,000
Grout Curtain	40,000	l.f.	$35.00	$1,400,000
Impervious Fill	251,000	c.y.	$6.00	$1,506,000
Random Fill	1,124,000	c.y.	$5.00	$5,620,000
Filter/Drain[2]	60,000	c.y.	$23.50	$1,410,000
Riprap/Bedding[2]	21,000	c.y.	$43.00	$903,000
Downstream Slope Protection[2]	9,000	c.y.	$39.50	$355,500
Allowance for Unlisted Items[3]	1	job	lump sum	$2,000,000
		Estimated Construction Cost[4] (1995 Dollars)		$15,218,500

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-18

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
ADOBE ROAD RESERVOIR SITE
DAM CREST ELEVATION 355 (3,700 million gallons = 11,355 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	232	acre	$3000.00	$696,000
Foundation Excavation	1,373,000	c.y.	$3.00	$4,119,000
Impervious Fill	1,250,000	c.y.	$7.00	$8,750,000
Random Fill	4,273,000	c.y.	$6.00	$25,638,000
Moisture Barrier	392,000	c.y.	$5.00	$1,960,000
Filter/Drain[2]	180,000	c.y.	$22.00	$3,960,000
Riprap/Bedding[2]	68,000	c.y.	$40.50	$2,754,000
Downstream Slope Protection[2]	33,000	c.y.	$37.00	$1,221,000
Saddle Dams	46,000	c.y.	$11.00	$506,000
Reservoir Lining	443,000	c.y.	$7.00	$3,101,000
Allowance for Unlisted Items[3]	1	job	lump sum	$5,300,000
		Estimated Construction Cost[4] **(1995 Dollars)**		$58,005,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-19

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
ADOBE ROAD RESERVOIR SITE
DAM CREST ELEVATION 335 (2,600 million gallons = 7,979 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	192	acre	$3000.00	$576,000
Foundation Excavation	1,144,000	c.y.	$3.00	$3,432,000
Impervious Fill	956,000	c.y.	$7.00	$6,692,000
Random Fill	3,252,000	c.y.	$6.00	$19,512,000
Moisture Barrier	331,000	c.y.	$5.00	$1,655,000
Filter/Drain[2]	154,000	c.y.	$22.00	$3,388,000
Riprap/Bedding[2]	58,000	c.y.	$40.50	$2,349,000
Downstream Slope Protection[2]	27,000	c.y.	$37.00	$999,000
Reservoir Lining	356,000	c.y.	$7.00	$2,492,000
Allowance for Unlisted Items[3]	1	job	lump sum	$4,100,000
		Estimated Construction Cost[4]		$45,195,000
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-20

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

ADOBE ROAD RESERVOIR SITE

DAM CREST ELEVATION 310 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	143	acre	$3000.00	$429,000
Foundation Excavation	944,000	c.y.	$3.00	$2,832,000
Impervious Fill	675,000	c.y.	$7.00	$4,725,000
Random Fill	2,168,000	c.y.	$6.00	$13,008,000
Moisture Barrier	248,000	c.y.	$5.00	$1,240,000
Filter/Drain	123,000	c.y.	$22.00	$2,706,000
Riprap/Bedding[2]	42,000	c.y.	$40.50	$1,701,000
Downstream Slope Protection[2]	21,000	c.y.	$37.00	$777,000
Reservoir Lining	257,000	c.y.	$7.00	$1,799,000
Allowance for Unlisted Items[3]	1	job	lump sum	$2,900,000
		Estimated Construction Cost[4] (1995 Dollars)		$32,117,000

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-21

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
LAKEVILLE HILLSIDE RESERVOIR SITE
DAM CREST ELEVATION 215 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	146	acre	$1000.00	$146,000
Foundation Excavation	475,000	c.y.	$3.00	$1,425,000
Impervious Fill	282,000	c.y.	$7.00	$1,974,000
Random Fill	735,000	c.y.	$6.00	$4,410,000
Moisture Barrier	92,000	c.y.	$5.00	$460,000
Filter/Drain[2]	47,000	c.y.	$21.00	$987,000
Riprap/Bedding[2]	18,000	c.y.	$37.50	$675,000
Downstream Slope Protection[2]	7,000	c.y.	$34.00	$238,000
Reservoir Lining	613,000	c.y.	$7.00	$4,291,000
Allowance for Unlisted Items[3]	1	job	lump sum	$1,500,000
		Estimated Construction Cost[4] **(1995 Dollars)**		$16,106,000

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-22

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (without backdam)
DAM CREST ELEVATION 255 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	865	acre	$1,000.00	$865,000
Main Dam				
Foundation Excavation	2,044,000	c.y.	$3.00	$6,132,000
Impervious Fill	306,000	c.y.	$7.00	$2,142,000
Random Fill	164,000	c.y.	$6.00	$984,000
Moisture Barrier	122,000	c.y.	$5.00	$610,000
Filter/Drain [2]	77,000	c.y.	$21.50	$1,655,500
Riprap/Bedding [2]	24,000	c.y.	$38.50	$924,000
Downstream Slope Protection [2]	9,000	c.y.	$35.00	$315,000
North Saddle Dam				
Foundation Excavation	80,000	c.y.	$3.00	$240,000
Impervious Fill	72,000	c.y.	$7.00	$504,000
Random Fill	58,000	c.y.	$6.00	$348,000
Moisture Barrier	48,000	c.y.	$5.00	$240,000
Filter/Drain [2]	21,000	c.y.	$21.50	$451,500
Riprap/Bedding [2]	8,000	c.y.	$38.50	$308,000
Downstream Slope Protection [2]	3,000	c.y.	$35.00	$105,000
West Saddle Dam	44,000	c.y.	$11.00	$484,000
Allowance for Unlisted Items [3]	1	job	lump sum	$2,300,000
		Estimated Construction Cost [4] **(1995 Dollars)**		$18,608,000

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-23

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (without backdam)
DAM CREST ELEVATION 250 (3,400 million gallons = 10,434 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	813	acre	$1,000.00	$813,000
Main Dam				
Foundation Excavation	1,969,000	c.y.	$3.00	$5,907,000
Impervious Fill	265,000	c.y.	$7.00	$1,855,000
Random Fill	132,000	c.y.	$6.00	$792,000
Moisture Barrier	112,000	c.y.	$5.00	$560,000
Filter/Drain[2]	68,000	c.y.	$21.50	$1,462,000
Riprap/Bedding[2]	22,000	c.y.	$38.50	$847,000
Downstream Slope Protection[2]	8,000	c.y.	$35.00	$280,000
North Saddle Dam				
Foundation Excavation	69,000	c.y.	$3.00	$207,000
Impervious Fill	61,000	c.y.	$7.00	$427,000
Random Fill	41,000	c.y.	$6.00	$246,000
Moisture Barrier	41,000	c.y.	$5.00	$205,000
Filter/Drain[2]	18,000	c.y.	$21.50	$387,000
Riprap/Bedding[2]	7,000	c.y.	$38.50	$269,500
Downstream Slope Protection[2]	3,000	c.y.	$35.00	$105,000
West Saddle Dam	29,000	c.y.	$11.00	$319,000
Allowance for Unlisted Items[3]	1	job	lump sum	$2,100,000
		Estimated Construction Cost[4]		$16,781,500
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.

[2] Import material.

[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.

[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-24

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (without backdam)
DAM CREST ELEVATION 240 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	706	acre	$1,000.00	$706,000
Main Dam				
Foundation Excavation	1,818,000	c.y.	$3.00	$5,454,000
Impervious Fill	183,000	c.y.	$7.00	$1,281,000
Random Fill	58,000	c.y.	$6.00	$348,000
Moisture Barrier	93,000	c.y.	$5.00	$465,000
Filter/Drain[2]	58,000	c.y.	$21.50	$1,247,000
Riprap/Bedding[2]	18,000	c.y.	$38.50	$693,000
Downstream Slope Protection[2]	6,000	c.y.	$35.00	$210,000
North Saddle Dam				
Foundation Excavation	46,000	c.y.	$3.00	$138,000
Impervious Fill	38,000	c.y.	$7.00	$266,000
Random Fill	7,000	c.y.	$6.00	$42,000
Moisture Barrier	26,000	c.y.	$5.00	$130,000
Filter/Drain[2]	12,000	c.y.	$21.50	$258,000
Riprap/Bedding[2]	4,000	c.y.	$38.50	$154,000
Downstream Slope Protection[2]	2,000	c.y.	$35.00	$70,000
West Saddle Dam	7,000	c.y.	$11.00	$77,000
Allowance for Unlisted Items[3]	1	job	lump sum	$1,700,000
		Estimated Construction Cost[4] **(1995 Dollars)**		$13,239,000

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-25

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (with backdam)
DAM CREST ELEVATION 285 (4,500 million gallons = 13,810 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	487	acre	$1,000.00	$487,000
Main Dam				
Foundation Excavation	2,498,000	c.y.	$3.00	$7,494,000
Impervious Fill	623,000	c.y.	$7.00	$4,361,000
Random Fill	543,000	c.y.	$6.00	$3,258,000
Moisture Barrier	191,000	c.y.	$5.00	$955,000
Filter/Drain [2]	110,000	c.y.	$21.50	$2,365,000
Riprap/Bedding [2]	37,000	c.y.	$38.50	$1,424,500
Downstream Slope Protection [2]	14,000	c.y.	$35.00	$490,000
Backdam				
Foundation Excavation	565,000	c.y.	$3.00	$1,695,000
Impervious Fill	1,348,000	c.y.	$7.00	$9,436,000
Random Fill	1,532,000	c.y.	$6.00	$9,192,000
Moisture Barrier	423,000	c.y.	$5.00	$2,115,000
Filter/Drain [2]	340,000	c.y.	$21.50	$7,310,000
Riprap/Bedding [2]	102,000	c.y.	$38.50	$3,927,000
Downstream Slope Protection [2]	41,000	c.y.	$35.00	$1,435,000
Allowance for Unlisted Items [3]	1	job	lump sum	$6,600,000
		Estimated Construction Cost [4]		$62,544,500
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-26

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (with backdam)
DAM CREST ELEVATION 270 (3,000 million gallons = 9,207 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	425	acre	$1,000.00	$425,000
Main Dam				
Foundation Excavation	2,271,000	c.y.	$3.00	$6,813,000
Impervious Fill	435,000	c.y.	$7.00	$3,045,000
Ran dom Fill	326,000	c.y.	$6.00	$1,956,000
Moisture Barrier	153,000	c.y.	$5.00	$765,000
Filter/Drain [2]	89,000	c.y.	$21.50	$1,913,500
Riprap/Bedding [2]	31,000	c.y.	$38.50	$1,193,500
Downstream Slope Protection [2]	11,000	c.y.	$35.00	$385,000
Backdam				
Foundation Excavation	407,000	c.y.	$3.00	$1,221,000
Impervious Fill	834,000	c.y.	$7.00	$5,838,000
Random Fll	728,000	c.y.	$6.00	$4,368,000
Moisture Barrier	306,000	c.y.	$5.00	$1,530,000
Filter/Drain [2]	251,000	c.y.	$21.50	$5,396,500
Riprap/Bedding [2]	73,000	c.y.	$38.50	$2,810,500
Downstream Slope Protection [2]	29,000	c.y.	$35.00	$1,015,000
Allowance for Unlisted Items [3]	1	job	lump sum	$4,700,000
		Estimated Construction Cost [4]		$43,375,000
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet / outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and / or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-27

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
TOLAY CREEK RESERVOIR SITE (with backdam)
DAM CREST ELEVATION 255 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	355	acre	$1,000.00	$355,000
Main Dam				
Foundation Excavation	2,044,000	c.y.	$3.00	$6,132,000
Impervious Fill	306,000	c.y.	$7.00	$2,142,000
Ran dom Fill	164,000	c.y.	$6.00	$984,000
Moisture Barrier	122,000	c.y.	$5.00	$610,000
Filter/Drain[2]	77,000	c.y.	$21.50	$1,655,500
Riprap/Bedding[2]	24,000	c.y.	$38.50	$924,000
Downstream Slope Protection[2]	9,000	c.y.	$35.00	$315,000
Backdam				
Foundation Excavation	269,000	c.y.	$3.00	$807,000
Impervious Fill	598,000	c.y.	$7.00	$4,186,000
Random Fill	91,000	c.y.	$6.00	$546,000
Moisture Barrier	200,000	c.y.	$5.00	$1,000,000
Filter/Drain[2]	163,000	c.y.	$21.50	$3,504,500
Riprap/Bedding[2]	46,000	c.y.	$38.50	$1,771,000
Downstream Slope Protection[2]	19,000	c.y.	$35.00	$665,000
Allowance for Unlisted Items[3]	1	job	lump sum	$3,200,000
		Estimated Construction Cost[4]		$28,797,000
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, localized grouting and/or blanketing for seepage control, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-28

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

SEARS POINT RESERVOIR SITE

DAM CREST ELEVATION 155 (3,800 million gallons = 11,662 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	333	acre	$2,000	$666,000
Foundation Excavation	1,010,000	c.y.	$3.00	$3,030,000
Impervious Fill	522,000	c.y.	$7.00	$3,654,000
Random Fill	1,542,000	c.y.	$6.00	$9,252,000
Moisture Barrier[2]	190,000	c.y.	$13.00	$2,470,000
Filter/Drain[2]	100,000	c.y.	$21.00	$2,100,000
Riprap/Bedding[2]	37,000	c.y.	$36.50	$1,350,500
Downstream Slope Protection[2]	14,000	c.y.	$33.50	$469,000
Saddle Dams	25,000	c.y.	$11.00	$275,000
Allowance for Unlisted Items[3]	1	job	lump sum	$2,300,000
		Estimated Construction Cost[4]		$25,566,500
			(1995 Dollars)	

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-29

EARTHWORK CONSTRUCTION COST ESTIMATE [1]

SEARS POINT RESERVOIR SITE

DAM CREST ELEVATION 140 (2,600 million gallons = 7,979 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	274	acre	$2,000	$548,000
Foundation Excavation	829,000	c.y.	$3.00	$2,487,000
Impervious Fill	421,000	c.y.	$7.00	$2,947,000
Random Fill	1,102,000	c.y.	$6.00	$6,612,000
Moisture Barrier[2]	153,000	c.y.	$13.00	$1,989,000
Filter/Drain[2]	86,000	c.y.	$21.00	$1,806,000
Riprap/Bedding[2]	30,000	c.y.	$36.50	$1,095,000
Downstream Slope Protection[2]	11,000	c.y.	$33.50	$368,500
Allowance for Unlisted Items[3]	1	job	lump sum	$1,800,000
		Estimated Construction Cost[4] (1995 Dollars)		$19,652,500

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

TABLE 8-30

EARTHWORK CONSTRUCTION COST ESTIMATE [1]
SEARS POINT RESERVOIR SITE
DAM CREST ELEVATION 120 (1,500 million gallons = 4,603 acre-feet)

Item	Estimated Quantity	Unit	Unit Price	Estimated Cost
Reservoir Clearing	205	acre	$2,000	$410,000
Foundation Excavation	547,000	c.y.	$3.00	$1,641,000
Impervious Fill	276,000	c.y.	$7.00	$1,932,000
Random Fill	599,000	c.y.	$6.00	$3,594,000
Moisture Barrier[2]	105,000	c.y.	$13.00	$1,365,000
Filter/Drain[2]	67,000	c.y.	$21.00	$1,407,000
Riprap/Bedding[2]	20,000	c.y.	$36.50	$730,000
Downstream Slope Protection[2]	7,000	c.y.	$33.50	$234,500
Allowance for Unlisted Items[3]	1	job	lump sum	$1,100,000
		Estimated Construction Cost[4]		$12,413,500
			(1995 Dollars)	

---

[1] Limited to dam embankment earthwork construction. Does not include construction costs for spillway, inlet/outlet works, runoff diversion facilities, pipelines, pump stations, and other ancillary facilities.
[2] Import material.
[3] Includes such items as mobilization for earthwork, control of water, dam foundation preparation, and embankment instrumentation.
[4] Does not include costs for engineering, administration, land acquisition, rights-of-way, or permitting. No contingencies shown. Intended to be added to other component cost estimates by others before applying these general costs and contingencies as a percentage of the total estimate.

SECTION 9
GEOTECHNICAL ASSESSMENT OF ALTERNATIVE PIPELINE ROUTES

9 GEOTECHNICAL ASSESSMENT OF ALTERNATIVE PIPELINE ROUTES

9.1 GENERAL

This section presents a discussion of the general site geologic and geotechnical conditions, as well as potential geologic/seismic hazards and significant adverse geotechnical conditions along the proposed direct discharge, storage transmission, and irrigation distribution pipeline routes and at proposed pump station sites associated with the various project alternatives. General alternative mitigation measures to address potential geologic/seismic hazards are also included. The proposed alternative pipeline routes cover an extensive area; therefore, for discussion purposes in the following sections, the site conditions are addressed according to identified pipeline routes shown on Figures 9-1 and 9-2 and specific pipeline segments as defined in the following sections.

Figures 9-1 and 9-2 indicate the proposed alternative pipeline routes for the south project area and north project area, respectively, superimposed on available geologic base maps. The geologic units and associated geotechnical conditions along the pipeline routes, along with potential geologic/seismic hazards and other significant adverse geotechnical conditions, are summarized on these key figures. Reference to these figures should be made along with the following discussions.

9.2 SITE GEOLOGY AND POTENTIAL HAZARDS

The assessment of the geologic/geotechnical conditions along the alternative pipeline routes is based on our review of existing geologic information and a site reconnaissance along the routes performed on October 4 - 5, 1995. Specifically, sources of geologic data include the following geologic maps:

- Blake, M. C., Jr., Smith, J. T., Wentworth, C. M., and Wright, R. H., 1971, Preliminary geologic map of western Sonoma County and northernmost Marin County, California: U. S. Geological Survey Basic Data Contribution 12.

- Blake, M. C., Jr., Bartow, J. A., Frizzell, V. A., Jr., Schlocker, J., Sorg, D., Wentworth, C. M., and Wright, R. H., 1974, Preliminary geologic map of Marin and San Francisco Counties and parts of Alameda, Contra Costa, and Sonoma Counties, California: U. S. Geological Survey Miscellaneous Field Studies Map MF-574.

- Fox, K. F., Jr., Sims, J. D., Bartow, J. A., and Helley, E. J., 1973, Preliminary geologic map of eastern Sonoma County and western Napa County, California: U. S. Geological Survey Miscellaneous Field Studies Map MF-483.

- Sims, J. D., Fox, K. F., Bartow, J. A., and Helley, E. J., 1973, Preliminary geologic map of Solano County, and parts of Napa, Contra Costa, Marin and Yolo Counties, California: U. S. Geological Survey Miscellaneous Field Studies Map MF-484.

- McLaughlin, R. J., 1978, Preliminary geologic map and structural sections of the central Mayacmas Mountains and The Geysers steam field, Sonoma, Lake, and Mendocino Counties, California: U. S. Geological Survey Open File Report 78-389.

- California Division of Mines and Geology, 1983, Special Studies (Alquist-Priolo) Zones Maps of the Healdsburg, Jimtown and Santa Rosa quandrangles.

Portions of pertinent geologic maps listed above were compiled and used to create a base map for this assessment (Figures 9-1 and 9-2). The geologic units and associated geotechnical conditions are described along the various pipeline routes superimposed on the base geologic map (Figures 9-1 and 9-2). Areas or segments of potential geologic/seismic hazards such as surface fault rupture at active fault crossings, slope instability, and liquefaction are approximately shown. Other geotechnical conditions that could have a significant impact on pipeline design and construction, such as expansive soils, soft foundation materials, hard rock excavation, and erosion potential are also approximately shown. Because of the reconnaissance nature of the study, no attempt was made to define the degree or severity of the potential geologic/geotechnical impact. For example, slope instability areas include both areas of identified landsliding as well as areas underlain by potentially unstable geologic materials. The potential for liquefaction is also based on the possible occurrence of loose silt/sand layers under shallow groundwater conditions in areas mapped as alluvium. It is possible that site specific subsurface investigation may reveal that the site is underlain by clayey materials or that the groundwater level may be at greater depths so as to preclude liquefaction.

9.2.1 West County Storage Transmission Pipeline

The proposed west county storage transmission pipeline includes two primary alternative routes originating from the Laguna Wastewater Treatment Plant (WWTP) as shown on Figure 9-1. These routes are associated with separate reservoir inlet facilities at three of the five west county alternative reservoir storage sites, including Bloomfield, Huntley, and Two Rock. Combined inlet/outlet pipelines at the other two reservoir sites (Valley Ford East and Carroll Road North) are included with the distribution pipeline network for the associated agriculture irrigation area.

- **Laguna WWTP to Bloomfield storage reservoir:** This alternative route follows the Gravenstein Highway (State Route 116) northwesterly from the Laguna WWTP on Llano Road, turns west along Lone Pine Road, then southwest along Bloomfield Road to a location north of the town of Bloomfield. At this point, the route turns west to the upper end of the Bloomfield reservoir. The proposed pipeline route traverses areas underlain by Petaluma Formation near the start of the pipeline. Along most of the Lone Pine/Bloomfield Road segment, the pipeline route is in rolling hills underlain by the Wilson Grove Formation. Toward the west end of this segment, the route crosses an area of Franciscan Complex rocks. About 1.5 miles north of the town of Bloomfield, the pipeline route turns west from Bloomfield Road, crosses a drainage swale and continues cross country along a saddle that marks the Bloomfield fault. The pipeline route turns south and will cross the Bloomfield fault at the upper end of the proposed reservoir. The Bloomfield fault is mapped as a Quaternary fault and does not show any evidence of Holocene or late Quaternary acitivity; therefore the potential for surface rupture is considered unlikely. Localized hard excavation may be encountered in the pipeline route underlain by the Franciscan Complex. Surficial deposits include alluvial areas adjacent to the the Laguna de Santa Rosa Creek and Blucher Creek where potentially liquefiable materials could occur. Colluvium also occurs on the lower elevated slopes adjacent to alluvial valleys.

- **Laguna WWTP to Two Rock storage reservoir:** This alternative route starts at the Laguna WWTP on Llano Road, follows Llano Road south to Gravenstein Highway, then southeast along Gravenstein Highway to Blank Road. The proposed route then follows Blank Road south to Petersen Road and continues south to its intersection with Roblar Road. The route turns west along Roblar Road for about 0.5 miles where it turns south across open farm land to a proposed tunnel segment at the upper end of the proposed Two Rock reservoir. Alluvial materials are found in the low-lying areas in the vicinity of the Laguna de Santa Rosa Creek and other smaller creek channels. The northwest end of the mapped trace of the Tolay fault crosses the pipeline route just north of the intersection of Petersen Road and Roblar Road and separates two geologic units, the Petaluma Formation to the north and the Wilson Grove Formation to the south. According to the California Division of Mines and Geology (Hart, 1982), the Tolay fault shows no evidence to suggest that it is Holocene active and is therefore not included in the special studies zone. The Santa Rosa fault map classifies the Tolay fault as a Quaternary age fault.

  Along most of Gravenstein Highway, Blank Road, and Petersen Road, the proposed route will be underlain by the Petaluma Formation. South of the Tolay fault, the route is underlain by the Wilson Grove Formation. Franciscan Complex rocks are found at the southern end of this route, immediately north of and along the tunnel segment. The Franciscan rocks are highly variable and could include masses of hard rock that may be difficult to trench excavate.

  The proposed tunnel alignment will be in Franciscan Complex rock which is a highly variable rock ranging from soft sheared shales to hard masses of sandstone, chert, and greenstone. The tunneling conditions will therefore vary from soft to hard rock tunneling. Tunneling should be possible with conventional drill and blast techniques. Tunnel support will be required for the most part. Groundwater associated with shear zones in the Franciscan Complex will likely be encountered during tunneling. Materials generated from tunneling operations can be used in dam construction or for other required earthwork fills; the material volumes are very small relative to dam embankment volumes. A relatively detailed discussion of the geologic and geotechnical conditions along the the proposed tunnel alignment was developed during previous investigations by others (WCC, 1989).

- **Two Rock turn-off on Roblar Road to Huntley storage reservoir:** The continuation of the previous route to the Huntley reservoir follows Roblar Road west to Valley Ford Road. From the Valley Ford intersection, it turns south to a private road that extends over the hills to the upper end of the proposed Huntley reservoir. Along Roblar Road, the route is mostly in Wilson Grove Formation, except in the southern half where it crosses the alluvial valley of Americano Creek at several locations, and in the central part where a small area of Franciscan Complex rock is mapped in fault contact with the Wilson Grove Formation along the Bloomfield fault. As discussed previously, the Bloomfield fault is not considered active; therefore, surface rupture is considered unlikely. From the Valley Ford road crossing to the Huntley reservoir, the pipeline route follows a hilly terrain underlain by bedrock units of the Wilson Grove Formation and Franciscan Complex. The pipeline route crosses the northwest-trending Americano fault, which forms the northeast contact of the Wilson Grove Formation and Franciscan Complex. The Americano fault is not considered active. Shallow groundwater and silt/sand layers may occur in the alluvial areas and could be potentially liquefiable. Locally hard rock areas may also be encountered in the Franciscan Complex and may result in difficult trench excavation.

9.2.2 Americano Agriculture (West County)

The proposed Americano agriculture irrigation project facilities include the inlet and/or outlet pipelines to/from the alternative storage reservoirs in this area (Valley Ford East, Carroll Road North, and/or Bloomfield) and the irrigation distribution pipelines within the agriculture area (Figure 9-1). This proposed irrigation area comprises the drainage area of the Americano Creek between Roblar Road and the town of Valley Ford. The various alternative pipeline routes in the hilly or elevated areas are underlain by the Wilson Grove Formation. Along the valley floors, the pipeline routes cross alluvial areas of Americano Creek and tributary creeks. Some of this alluvium may contain potentially liquefiable saturated silt/sand layers within proposed foundation depths. Areas of thick colluvial soils are anticipated along segments of the pipeline routes, particularly at the elevated areas adjacent to the valley floors and at the base of hillsides.

9.2.3 Stemple Agriculture (West County)

The proposed Stemple agriculture irrigation project facilities include the outlet pipelines from the alternative storage reservoirs in this area (Huntley or Two Rock) and the irrigation distribution pipelines within the agriculture area (Figure 9-1). This proposed irrigation area is located in the upper drainage basin of Stemple Creek and includes pipeline routes along Valley Ford Road from its intersection with Roblar Road southeast to Bodega Avenue, Bodega Avenue to Petaluma/ Tomales Roads, Fallon/Two Rock Roads, Pepper/Meacham Roads, and Spring Hill/Purvine Roads. Two geologic bedrock formations are found in this area, namely the Wilson Grove Formation and the Franciscan Complex. The Franciscan Complex consists of melange materials, including soft sheared shaley soils which can be potentially unstable, expansive, and subject to creep movement, as well as included hard masses of sandstone, greenstone, and chert. Alluvium and colluvium are the primary surficial deposits. Potentially liquefiable material may be locally present in the alluvium.

9.2.4 South County Storage Transmission Pipeline

The proposed south county storage transmission pipeline as shown between designations SC-1 and SC-2 on Figure 9-1 and as discussed below consists of a route along Gravenstein Highway starting at its intersection with Blank Road (SC-1 on Figure 9-1), then south on Stony Point Road, northeast on West Railroad Avenue, southeast on Old Redwood Highway and Adobe Road, southwest on Frates Road, southeast on South Ely Road, southwest on Brown’s Lane and southeast along Lakeville Highway (State Route 116) to the Stage Gulch Road intersection (SC-2 on Figure 9-1).

The proposed pipeline route passes through areas underlain mostly by the Petaluma Formation along West Railroad Avenue, Old Redwood Highway, and Adobe Road. Local areas of Sonoma Volcanics are found along Stony Point Road south of the Gravenstein Highway. Local areas of Franciscan Complex rock are found near the south end of this segment along South Ely Road and Lakeville Highway, immediately north of Stage Gulch Road. Surficial deposits consist of alluvial fan deposits, colluvium, and local alluvium along creek courses. Existing roads, such as Adobe Road and Lakeville Highway, have been raised a few feet above the original natural ground with embankment fill. In general, a majority of the site soils along this route are expansive.

9.2.5 East Rohnert Park Agriculture (South County)

The proposed east Rohnert Park agriculture irrigation project facilities include the transmission pipeline along Petaluma Hill Road from Adobe Road north to Crane Canyon Road and the irrigation distribution pipelines within the agriculture area (Figure 9-1). The distribution lines branch off of Petaluma Hill Road to Crane Canyon Road, Sonoma State University, Roberts Road, and East Railroad Avenue. The agriculture area is generally flat with slightly elevated areas and a few rolling hills to the east. The proposed pipeline routes are underlain mostly by alluvium and alluvial fan deposits, and the Petaluma Formation in the southern part. Site soils are mostly expansive since most were apparently derived from the Petaluma Formation. Figure 9-1 shows a fault trace crossing the pipeline route near the Petaluma Hill Road/Crane Canyon Road intersection. This fault appears to branch off of the active Rodgers Creek fault to the southeast. The fault is not included in the special studies zone, and the Santa Rosa fault map classifies the fault as showing evidence of displacement during late Quaternary time.

9.2.6 North Petaluma Agriculture (South County)

The proposed North Petaluma agriculture irrigation project facilities include the transmission pipeline along Stony Point Road and the irrigation distribution pipelines within this relatively small agricultural area located west of Stony Point Road between West Railroad Avenue and Rainsville Road (Figure 9-1). The terrain varies from flat to rolling. For the most part, the route is underlain by the Petaluma Formation or expansive alluvial and colluvial soils derived from the Petaluma Formation. Toward the south end of this area along Rainsville Road, the route follows an elevated area of Wilson Grove Formation and adjoining low lying areas underlain by alluvial fan deposits.

9.2.7 Adobe Road Agriculture (South County)

The proposed Adobe Road agriculture irrigation project facilities include the inlet/outlet pipeline to/from the Adobe Road alternative storage reservoir in this area and the irrigation distribution pipelines branching off of the main south county storage transmission pipeline discussed in Section 9.2.4 (Figure 9-1). The geologic/geotechnical conditions discussed for the main transmission line along Adobe Road also apply to proposed branch pipelines for this agriculture area.

9.2.8 Lakeville / Bayflats Agriculture (South County)

The proposed Lakeville/Bayflats agriculture irrigation project facilities include the inlet/outlet pipelines to/from the alternative storage reservoirs in this area (Lakeville Hillside, Tolay Creek, and Sears Point) and the irrigation distribution pipelines within the agriculture area (Figure 9-1).

- **Stage Gulch Road to Tolay Creek storage reservoir north saddle dam (SC-2 to SC-3 on Figure 9-1):** From the Lakeville Highway intersection, this proposed pipeline route follows a steep winding section of Stage Gulch Road that is underlain locally by potentially unstable Franciscan Complex melange rocks. Instability along this reach is evident from distresss in the road pavement, embankments, and hillside slopes. The pipeline route crosses the Tolay fault which forms the contact between the Franciscan Complex to the west and the Petaluma Formation to the east. East of the Tolay fault, the pipeline route traverses areas underlain by the Petaluma Formation that are locally covered by colluvial soils. Alluvium is anticipated along the northeast portion of the route to the alternative Tolay Creek reservoir north saddle dam. Site soils along a majority of the route are anticipated to be expansive.

- **Lakeville Highway from Stage Gulch Road to Sears Point storage reservoir (SC-2 to SC-4 on Figure 9-1):** This proposed pipeline route essentially follows Lakeville Highway along the base of the rolling hills east of the highway. The route traverses areas underlain by alluvium, old alluvium and the Petaluma Formation. Near Cannon Road, the highway and pipeline route are at their closest proximity to the Petaluma River, and south of Cannon Road, the pipeline route follows Old Lakeville Road to avoid a low-lying marshy area. The pipeline route is generally at a higher elevation than the wetlands area along the Petaluma River; however, a low-lying area at the corner of Lakeville Highway and State Route 37 is underlain by Bay mud deposits which are anticipated to be soft and saturated (Figure 9-1). The roadway along these low-lying areas is apparently supported by embankment fill. Site soils along the route between Stage Gulch Road and State Route 37 are predominantly expansive. At the intersection of Lakeville Highway and State Route 37, the pipeline route turns northeast along State Route 37. This route rises to a hill that is underlain by older alluvium and the Petaluma Formation. The final leg of the route to the Sears Point alternative reservoir site along State Route 121 is underlain by the Petaluma Formation alluvial fan deposits and alluvium. After crossing Tolay Creek, the route continues north along a ridge of the Petaluma Formation, terminating at a proposed pump station downstrean of the Sears Point damsite. The Tolay fault crosses the pipeline route near the intersection of State Route 37 and State Route 121.

- **Lakeville Highway to Tolay Creek storage reservoir main dam (SC-5 to SC-6 on Figure 9-1):** This proposed pipeline route begins at the Lakeville Highway/Cannon Road intersection and follows Cannon Road northeast to a proposed tunnel section through a ridge to Tolay Valley. At the north end of the proposed tunnel, the pipeline turns southeast and follows the northeast side of the broad ridge to the proposed pump station downstream of Tolay Creek main dam site. Along Cannon Road, the pipeline route will be in the Petaluma Formation. The tunnel section appears to be in Franciscan Complex melange and would have variable tunneling conditions similar to the proposed Two Rock pipeline tunnel. Materials generated from tunneling operations can be used in dam construction or for other required earthwork fills; the material volumes are very small relative to dam embankment volumes. The route along the broad ridge is believed to be underlain by a mixture of Sonoma Volcanics, Franciscan Complex, and Petaluma Formation. These rock units may be associated with local slope instability, seepage areas, and local areas of massive hard rock. From the ridge top, the pipeline route extends downslope to the bottom of the canyon downstream of the damsite and will traverse an area underlain in part by old landslide deposits. Site soils along this entire route are predominantly expansive.

- **Lakeville Highway to Lakeville Hillside storage reservoir (SC-7 to SC-8 on Figure 9-1):** This short pipeline segment extends from Lakeville Highway to the proposed pump station downstream of the Lakeville Hillside damsite. It follows the natural drainage to the proposed alternative reservoir storage site. Geologic materials along the route include the Petaluma Formation, and alluvial and colluvial soils derived from the Petaluma Formation. These soils are anticipated to be expansive and potentially unstable on hillside slopes.

9.2.9 Geysers Transmission Pipeline

The proposed Geysers transmission pipeline route (Figure 9-2) begins at a proposed pump station at the existing Delta Pond facility and follows existing roads along a general northerly direction toward East Windsor. From the low-lying area, the pipeline route follows Chalk Hill Road, which runs a winding course in the hills east of Healdsburg, until it reaches the southern end of Alexander Valley. The pipeline route then follows State Route 128 to its intersection with Pine Flat Road on the northeast side of Alexander Valley. From this point, the proposed pipeline route essentially follows the winding and steep Pine Flat Road to the Geysers.

The Geysers pipeline route will require several stream and highway crossings and will traverse various geographic terrain ranging from the flat lands of the low-lying valleys to low-lying rolling hills to the rugged mountains at the Geysers.

- **Delta Pond near Santa Rosa Creek to the Pleasant Avenue/Chalk Hill Road intersection east of Windsor (G-1 to G-2 on Figure 9-2):** This segment is in the relatively flat valley between Windsor and Santa Rosa. The area is underlain by alluvium along the stream courses of Santa Rosa Creek, Mark West Creek, and Windsor Creek. The stream alluvium is surrounded by slightly elevated areas underlain by the Glen Ellen Formation which is comprised of older fluvial deposits of gravel, silt, sand, and clay with minor interbedded tuff. The pipeline route crosses local areas of alluvium but for the most part will be in the Glen Ellen Formation. The potential geologic/seismic hazard associated with the alluvium is liquefaction potential, particularly along and near stream courses and floodplain areas where groundwater may be shallow. Expansive soils may also be locally present in the surficial soils in this area.

- **Chalk Hill Road from Pleasant Avenue to State Route 128 on the south end of Alexander Valley (G-2 to G-3 on Figure 9-2):** This segment follows existing Chalk Hill Road which winds its way through hilly terrain with intervening local valley areas of Brooks Creek and Maacama Creek. The Glen Ellen Formation underlies the hilly areas along the southern most and north half of this segment. Shales, silltstone, and sandstone of the Great Valley Sequence are found on the central portion of this segment. The proposed pipeline route crosses local areas of serpentine and alluvium along Brooks Creek and Maacama Creek. These bedrock units are cut by several northwest-trending faults, most of which are mapped pre-Quaternary. Active strands of the Healdsburg fault zone cross the pipeline on the southern most portion of this segment (Figure 9-2). Potential geologic/seismic hazards include surface rupture where the active Healdsburg fault zone crosses the pipeline route, liquefaction potential in local alluvial areas near creek courses, and local slope instability and erosion potential in the weathered bedrock areas. Difficult excavation conditions may also be encountered in localized areas underlain by massive sandstones of the Great Valley Sequence.

- **State Route 128 from Chalk Hill Road to Alexander Valley Road (G-3 to G-4 on Figure 9-2):** This segment is located on the eastern edge of the southern tip of Alexander Valley and is underlain by alluvium, alluvial fan desposits, and Glen Ellen Formation. The principal potential geologic/seismic hazard along this segment of the proposed route is local areas of liquefaction potential near the Sausal Creek drainage. The Geysers Pump Station PS-G2 site located near the intersection of State Route 128 and Alexander Valley Road is underlain by alluvium and also has the liquefaction potential hazard.

- **Pine Flat Road from Alexander Valley to the Geysers Geothermal Steamfield (G-4 to G-5 on Figure 9-2):** This portion of the proposed pipeline route is located in the Mayacmas Mountains. The route follows the steep and winding Pine Flat Road that traverses bedrock units of the Franciscan Complex. The bedrock units include the melange, which is a chaotic mixture of fragmented rock masses in a sheared shaley matrix. Coherent blocks of greenstone, chert, serpentine, and sandstone have been mapped along the route. The melange materials are potentially unstable and often associated with unstable slopes. Several small to large landslide deposits have been mapped along the pipeline route and appear to be associated with the Franciscan Complex melange and serpentine. The landslide areas are clearly defined by hummocky landslide topography. Extensive areas of landslide deposits are found along Pine Flat Road from the steep massive bedrock area near Bear Creek to Geysers Pump Station PS-G3 and intermittently from PS-G3 to the distribution tank location (Figure 9-2). Distress in the road pavement, such as settlement, cracking, scarps, and washouts, was noted in several places and attests to the widespread slope instability in the area. Slope instability is a major geologic hazard along this portion of the proposed route. For the most part, the landslide deposits appear to extend beyond depths of the anticipated pipeline trench excavation. Because of the extensive distribution of landsliding, it would appear to be extremely difficult and prohibitively expensive to completely mitigate the slope instability problem.

  The active Maacama fault zone crosses the pipeline route at the foot of the mountain range at the south end of this segment and therefore poses potential surface rupture of the pipeline at this location (Figure 9-2). Other geologic hazards include the erosion potential of the weathered Franciscan rocks, particularly on hillside slopes and along creek crossings with steep gradients where concentrated surface run-off can occur. Geotechnical conditions that will have an impact on this segment include massive sandstone rocks near the mouth of Sausal Creek that will present excavation difficulty. Another important construction-related consideration is the narrow width of Pine Flat Road at several locations, combined with very steep uphill and downhill slopes, which restrict the location of trench excavation for the pipe. It would be preferable to site the pipeline trench as close to the inner side of the road as possible in order to found it deeper within in-place material, minimizing the impact of potential washouts or debris failures on the outer slopes.

Pump Station PS-G3 is located on a relatively resistant ridge of Franciscan Complex graywacke that is surrounded by landslide deposits. This mass of rock apparently represents a coherent block of hard rock within the Franciscan Complex melange. Pump Station PS-G4 is located on a broad ridge apparently underlain by granular terrace deposits over Franciscan rocks that should provide adequate foundation for the structure. The proposed location of two storage distribution tanks at the end of the pipeline route is located on a ridge top. The geologic map of the Geysers area by McLaughlin (1978) shows that the tank site is underlain by the Franciscan Complex melange. Since the tank site is on a ridge top, it is most likely underlain by the more resistant sandstone or greenstone within the Franciscan melange. Landslides have been mapped in the area but occur on lower slopes northwest of the tank site. Based on this information and a separate reconnaissance of the site on March 3, 1995, no apparent geologic/seismic hazards or other geotechnical factors exist that would preclude development of the proposed site for the storage tanks. Future design-level investigation studies will require mapping and subsurface exploration to evaluate and confirm geotechnical conditions.

9.2.10 Russian River Direct Discharge Transmission Pipeline

The proposed Russian River direct discharge transmission pipeline route (Figure 9-2) begins at the Delta Pond facility, follows the east side of Laguna de Santa Rosa Creek, west along River Road, north on Trenton Road, and continuing to Eastside Road for about a mile from its intersection with Trenton Road, then turns west to the proposed Russian River direct discharge outfall as shown on Figure 9-2.

The above route traverses through the alluvial areas of Laguna de Santa Rosa Creek along its southern segment, Mark West Creek and Windsor Creek along its central portion, and the Russian River at the north end. These alluvial materials may be potentially liquefiable, particularly if loose silt/sand layers and shallow groundwater are present. Other surficial deposits along the route include thick colluvial materials and road embankment fill. The elevated areas of the valley adjoining Laguna de Santa Rosa are underlain by the Glen Ellen Formation. Bedrock units include the Franciscan Complex which may contain localized masses of very hard rock that would be difficult to excavate. Wilson Grove Formation occurs along the northern portion of the route and may contain massive sandstone or conglomerate that may also be difficult to trench.

The proposed pump station at the beginning of the pipeline will be in alluvium which may be potentially liquefiable. The proposed pump station near Mark West Creek appears to be in the Glen Ellen Formation which should provide adequate foundation material.

9.2.11 Sebastopol Agriculture

The proposed Sebastopol agriculture irrigation project facilities include the transmission pipeline from the existing Delta Pond to the north end of the irrigation area near Graton and the irrigation distribution pipelines within the agriculture area (Figure 9-2). The area is comprised of rolling hills that are underlain entirely by the Wilson Grove Formation. The pipeline routes cross the alluvium of the Atascadero Creek valley at several locations. Thick colluvial soils may also be present near the base of the hillside slopes, and are anticipated to provide an adequate foundation. Other than the potential for liquefaction in local areas of the alluvium, no other potential geologic/seismic hazard has been identified that could impact the pipeline and pump station structures.

9.2.12 Fountaingrove Urban Irrigation

The proposed pipeline route for the Fountaingrove urban irrigation (Figure 9-2) is located in west and north Santa Rosa and extends from the existing West College Pond to the Fountaingrove area to the northeast. The route from the West College Pond to the Redwood Highway crossing is underlain mostly by older alluvial deposits, except on the south end where potentially liquefiable younger stream alluvium may be present. Along Redwood Highway, the pipeline route follows the base of a hill of potentially unstable Petaluma Formation materials; expansive soils and locally soft material may also be found along this reach. From Redwood Highway, the pipeline route turns east along Fountaingrove Parkway to the end of the pipeline at Fountaingrove Lake. Along Fountaingrove Parkway, the route crosses a hilly area underlain by faulted bedrock units of the Sonoma Volcanics and Petaluma Formation. The pipeline crosses the Rodgers Creek fault zone which is designated as a special studies zone by the California Division of Mines and Geology under the Alquist Priolo Special Studies Zone Act of 1972. The limits of the special studies zone where it crosses the pipeline route are indicated on Figure 9-2. Special considerations will be required to mitigate against potential rupture of the pipeline resulting from displacement along the active Rodgers Creek fault. The proposed pump station at the West College Pond facility is in alluvium and the pump station near the intersection of Old Redwood Highway and Fountaingrove Parkway is at the base of a hillside in Petaluma Formation material which is potentially unstable.

9.2.13 East Santa Rosa / Bennett Valley Urban Irrigation

The proposed pipeline route for the east Santa Rosa/Bennett Valley urban irrigation (Figure 9-2) begins at the West College Pond facility and trends generally east, following existing city streets. It closely parallels Santa Rosa Creek at the beginning of the route, crosses the creek at three locations in the Santa Rosa downtown area and continues east along the south side of State Route 12. East of the Sonoma County fairgrounds, the route branches off to Howart Memorial Park to the north, and to Bennett Valley Golf Course to the south. From the starting point at the West College Pond to the split, the route is in young and older alluvial materials. Where close to the creek, potentially liquefiable materials may be locally present. The active Rodgers Creek fault zone crosses the pipeline route west of the pipeline split (Figure 9-2), and measures to mitigate against potential pipeline rupture should be provided. The proposed pipeline branch to Howart Memorial Park follows a route underlain by alluvial fan deposits and Huichica Formation, both of which should provide adequate foundation material. The Bennett Valley branch crosses a hilly terrain underlain by Huichica Formation and Sonoma Volcanics. Seepage areas, local road distress, and potential slope instability were noted along the Bennett Valley

Road pipeline route between Mount Taylor Road and Bennett View Drive. The proposed pump station on Bennett Valley Road south of Santa Rosa is in older alluvial fan deposits which should provide an adequate foundation for the structure.

9.3 GEOTECHNICAL CONSIDERATIONS AND ALTERNATIVE MITIGATION MEASURES

Potential geologic/seismic hazards expected to have the most significant impact on the design and constructability of the various proposed alternative pipeline facilities are potential surface fault rupture at active fault crossings and slope instability. These potential hazards may require specialized pipeline design and construction techniques and may involve other geotechnical-related improvement projects for proper mitigation. In some cases, as discussed below, complete mitigation of the hazard may not be possible or practical. Other less significant geologic/seismic hazards and adverse geotechnical conditions affecting pipeline and/or pump station design and construction include liquefaction potential during seismic events, soft foundation conditions, hard rock conditions, and expansive soils. These conditions can generally be properly mitigated with standard design and construction techniques for pipelines and structures.

Surface fault rupture potential and the associated potential damage or rupture to a pipeline crossing the ruptured fault exists for future activity and movement along the active Rodgers Creek, Healdsburg, and Maacama fault zones (Figure 9-2). Relative to pipeline design and construction, the following types of general remedial measures can be considered to avoid or minimize undesirable effects of potential surface fault rupture:

- Use of special, more flexible or ductile pipeline materials and connections.
- Pipeline installation in a "snaked" configeration in a wider trench to accomodate more movement.
- Use of special backfill materials surrounding the pipe that are more forgiving in the event of movement.

Potential slope instability has been identified in several areas along the proposed pipeline routes (Figures 9-1 and 9-2); however, this potential hazard is most widespread and extensive in the Pine Flat Road segment of the Geysers transmission pipeline. Because of the extensive distribution of landsliding and potentially unstable materials in the Geysers area, in particular along the proposed Pine Flat Road route, it would be extremely difficult and would appear impractical and prohibitively expensive to be able to completely mitigate slope instability problems in these areas. Any engineering mitigation measures considered will probably be applicable only to localized areas where the landslide deposits are shallow and of limited extent. Siting the proposed pipeline through the extensive landslide areas must consider the likelihood of pipe breaks resulting from future nonseismic or seismically-induced landslide activity. If an alternative route, which would be desirable from a geotechnical standpoint, does not become a future consideration or possibility, a higher degree of risk will have to be accepted in design, construction, and operation of the pipeline sited through inherently unstable areas. For this situation, a higher level of safeguards should be incorporated into the design and operating plan for the pipeline.

Relative to pipeline construction through existing landslide areas of limited extent that would be mitigable, the following types of general remedial measures can be considered to avoid undesirable effects of potential instability:

- Avoidance of unstable area by proper investigation and siting.
- Stabilization by such methods as grading to an acceptably stable topographic condition, buttressing, pinning or retaining, and/or drainage to improve strength conditions.
- Removal and replacement of unstable materials.

Relative to pipeline and pump station construction in areas exhibiting liquefaction potential or having soft foundation conditions, typical remedial measures that can be considered to avoid undesirable effects of these conditions include overexcavation, removal, and replacement of unstable materials with engineered fill or, in the case of pump station construction, installation of a deep foundation system, such as piles, for proper foundation support beneath the unstable materials.

Highly plastic soils with a high shrink-swell potential exist along many segments of the proposed pipeline routes and at some of the proposed pump station sites, particularly in the south county area. With regard to providing an adequate foundation for structures in areas where these types of soils exist, the following types of general remedial measures can be considered to avoid the undesirable effects of high shrink-swell behavior:

- Removal and replacement with an engineered fill material having acceptable properties.
- Soil stabilization, such as lime treatment, to alter soil properties to an acceptable condition.
- Deepened footings in the plastic soils to such a level where moisture variation will not occur.
- Build-up of a construction pad with an engineered fill having acceptable properties (similar to first measure).

Most of these measures are particularly applicable to the proposed pump stations and other associated structure foundations; the existence of expansive soils is not a major hazard to pipelines.

In summary, a majority of the potential geologic/seismic hazards and other adverse geotechnical conditions along proposed pipeline routes and at proposed pump stations can be properly mitigated with standard, and in some cases specialized, design and construction techniques. Thus, pipeline and pump station design and construction along a majority of the proposed alternative routes appears to be favorable from a geotechnical standpoint. The exception to this general assessment is in the areas of extensive slope instability along portions of the Pine Flat Road segment of the Geysers transmission pipeline. The ability to mitigate slope instability in these areas to a degree that would eliminate the risk of pipe breaks resulting from future landslide activity appears to be extremely difficult and may be impractical and prohibitively expensive.

SECTION 10
CONCLUSIONS

10 CONCLUSIONS

10.1 DAM AND RESERVOIR ASSESSMENT

In order to consolidate the key conceptual design and construction considerations, assist in the evaluation of alternative storage components and alternative projects for the Santa Rosa Subregional Long-Term Wastewater Project, and summarize the details of this geotechnical assessment study of the nine selected alternative storage reservoirs, Table 10-1 and Table 10-2 were developed to highlight the key geologic and geotechnical conditions for a dam and reservoir at the Valley Ford East, Carroll Road North, Bloomfield, Huntley, and Two Rock alternative sites in the west county project area, and at the Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point alternative sites in the south county project area, respectively. In consolidating and summarizing the various geologic and geotechnical considerations, no attempt has been made to rank the alternative reservoir sites in any order of preference or desirability for this study. Many other considerations, including environmental factors, other project components that accompany storage, and the associated economics of the total project alternative need to be added to the results of this study before a project evaluation and selection process can be carried out. However, if desired, one can draw limited conclusions pertaining to the geotechnical-related desirability or drawbacks of the various alternative proposed dam and reservoir projects from the contents of Table 10-1 and Table 10-2.

As a result of our findings from the limited field and laboratory investigations, preliminary geotechnical assessment, and conceptual designs developed for the alternative reservoirs, we did not conclude the existence of fatal flaws that would preclude design and construction of a storage reservoir from a geotechnical standpoint at any of the nine alternative sites considered. However, the alternative reservoir storage sites with greater technical drawbacks or negative attributes, relative to other alternative sites, are as follows, with the associated less desirable condition noted:

- Adobe Road and Lakeville Hillside, and to a lesser extent Sears Point, relative to reservoir landslide potential.

- Adobe Road and Lakeville Hillside, relative to reservoir leakage potential.

- Valley Ford East and Bloomfield, relative to the limited supply of on-site impervious type construction materials.

- Adobe Road, Lakeville Hillside, Tolay Creek, and Sears Point (west county sites), relative to generally lower quality characteristics (workability and strength) of predominantly high plasticity on-site soils available for construction.

- Bloomfield, Adobe Road, Tolay Creek with backdam, and to a lesser extent Huntley, relative to dam and reservoir earthwork construction cost and associated storage efficiency (see Table 6-1 and Table 6-2).

10.2 PIPELINE ROUTES ASSESSMENT

Figure 9-1 and Figure 9-2 summarize in graphical form the principal potential geologic/seismic hazards and other potential significant adverse geotechnical conditions along the various proposed alternative pipeline routes which support the different project alternatives. As stated in Section 9, the key potential geologic/seismic hazards in the project area that can have a significant impact on pipeline design and construction are potential surface fault rupture at active fault crossings, liquefaction potential during seismic events, and slope instability. Other geotechnical conditions assessed for the project area that can impact pipelines are erosion potential, soft foundation conditions, hard rock conditions, and expansive soils. The identification of these potential hazards and adverse conditions for this assessment is based on existing available geologic information and site reconnaissance. As such, it is important to remember that noted hazards or adverse conditions may in fact be less severe or possibly not exist. This revised assessment would be based on more site specific investigation, including subsurface exploration, during subsequent project phases.

A majority of the assessed potential geologic/seismic hazards and other adverse geotechnical conditions can be properly mitigated with standard, and in some cases specialized (i.e., fault crossing construction), pipeline design and construction techniques, in conjunction with other geotechnical-related improvement projects, as discussed in Section 9. Thus, pipeline design and construction along a majority of the proposed alternative routes appear to be favorable from a geotechnical standpoint.

The one situation where this in not likely to be the case is associated with the extensive slope instability hazard areas along the Pine Flat Road segment of the Geysers transmission pipeline route. Because of the extensive distribution of landsliding and potentially unstable materials in the Geysers area, in particular along the proposed Pine Flat Road route, it would be extremely difficult and would appear impractical and prohibitively expensive to be able to completely mitigate slope instability problems in these areas. Any engineering mitigation measures considered will probably be applicable only to localized areas where the landslide deposits are shallow and of limited extent. Siting the proposed pipeline through the extensive landslide areas must consider the likelihood of pipe breaks resulting from future nonseismic or seismically-induced landslide activity. If an alternative route, which would be desirable from a geotechnical standpoint, does not become a future consideration or possibility, a higher degree of risk will have to be accepted in design, construction, and operation of the pipeline sited through inherently unstable areas. For this situation, a higher level of safeguards should be incorporated into the design and operating plan for the pipeline.

TABLE 10-1

SUMMARY OF DAM AND RESERVOIR GEOLOGIC AND GEOTECHNICAL CONDITIONS
ALTERNATIVE RESERVOIR SITES - WEST COUNTY

CONDITION	VALLEY FORD EAST	CARROLL ROAD NORTH	BLOOMFIELD	HUNTLEY	TWO ROCK
Maximum Storage (m.g./acre feet)	4,500 / 13,810	4,500 / 13,810	4,500 / 13,810	4,500 / 13,810	4,500 / 13,810
Dam Height (feet)	135	190	190	210	225
Seismicity and Faulting	• strong shaking potential • no mapped faults	• strong shaking potential • Quaternary Bloomfield fault through reservoir fringe	• strong shaking potential • Quaternary Bloomfield fault through reservoir fringe	• strong shaking potential • Quaternary unnamed fault near reservoir	• strong shaking potential • Quaternary Dunham fault at reservoir edge
Bedrock Geologic Formation	• Wilson Grove siltstone	• Wilson Grove siltstone/sandstone/ claystone	• Wilson Grove siltstone/sandstone	• Franciscan Complex melange • Wilson Grove siltstone/sandstone	• Franciscan Complex melange • Wilson Grove siltstone
Dam Foundation[1]	• moderate excavation to strong foundation	• moderate excavation to strong foundation	• moderate to deep excavation to strong foundation	• moderate excavation to strong foundation	• moderate to deep excavation to strong foundation
Reservoir Landslide Potential	low	low	low	low	low
Reservoir Leakage Potential	• low - minor, localized grouting and/or impervious blanketing assumed	• low - minor, localized grouting and/or impervious blanketing assumed	• low - minor, localized grouting and/or impervious blanketing assumed	• leakage potential in Wilson Grove/Franciscan contact - localized impervious blanketing of contact area assumed	• leakage potential in fractured, harder Franciscan Complex rock - dam foundation grout curtain and other minor, localized grouting and/or impervious blanketing assumed
Construction Materials	• insufficient supply of on-site impervious core - bentonite admixture proposed • careful grading plan required to limit random shell borrow within reservoir area • high erodibility potential of predominant on-site silty/sandy random shell materials • import requirement for riprap, slope protection, filter, and drain rock	• adequate supply of on-site impervious core • careful grading plan required to limit random shell borrow within reservoir area • high erodibility potential of predominant on-site silty/sandy random shell materials • import requirement for riprap, slope protection, filter, and drain rock	• insufficient supply of on-site impervious core - bentonite admixture proposed • careful grading plan required to limit random shell borrow within reservoir area • high erodibility potential of predominant on-site silty/sandy random shell materials • import requirement for riprap, slope protection, filter, and drain rock	• adequate supply of on-site impervious core • careful grading plan required to limit random shell borrow within reservoir area • high erodibility potential of some on-site silty/sandy random shell materials • good variety of available on-site construction materials • import requirement for riprap, slope protection, filter, and drain rock	• adequate supply of on-site impervious core • high erodibility potential of some on-site silty/sandy random shell materials • good variety of available on-site construction materials • import requirement for riprap, slope protection, filter, and drain rock • potential on-site source for hard rock type materials - not assumed for conceptual design
Dam Design	• bedrock foundation • 3.5:1 (H:V) upstream slope • 2.75:1 (H:V) downstream slope • central core with internal drainage	• bedrock foundation • 3.5:1 (H:V) upstream slope • 2.75:1 (H:V) downstream slope • central core with internal drainage	• bedrock foundation • 3.5:1 (H:V) dipstream slope • 2.75:1 (H:V) downstream slope • central core with internal drainage	• bedrock foundation • 3:1 (H:V) upstream slope • 2.5:1 (H:V) downstream slope • central core with internal drainage	• bedrock foundation • 3:1 (H:V) upstream slope • 2.5:1 (H:V) downstream slope • central core with internal drainage

[1] Excavation definition: range of required average depth in random shell zone abutment areas: minimal (up to 5'), moderate (5' to 10'), moderate to deep (10' to 20'), deep (20' to 40'), excessive (over 40'). Required excavation may be deeper in channel areas and beneath impervious core zone of dam.

TABLE 10-2

SUMMARY OF DAM AND RESERVOIR GEOLOGIC AND GEOTECHNICAL CONDITIONS
ALTERNATIVE RESERVOIR SITES - SOUTH COUNTY

CONDITION	ADOBE ROAD	LAKEVILLE HILLSIDE	TOLAY CREEK		SEARS POINT
			MAIN DAM	BACKDAM	
Maximum Storage (m.g./acre feet)	3,700 / 11,355	1,500 / 4,603	4,500 / 13,810		3,800 / 11,662
Dam Height (feet)	205	135	85 (w/out backdam)/115 (w/backdam)	65	118
Seismicity and Faulting	• strong shaking potential • no mapped faults	• strong shaking potential no mapped faults	strong shaking potential Quaternary Tolay fault trace through dam foundation		• strong shaking potential • Quaternary Tolay fault near reservoir
Bedrock Geologic Formation	• Petaluma claystone/siltstone with sandstone/conglomerate	• Petaluma claystone/siltstone with sandstone/conglomerate	Petaluma claystone/siltstone Sonoma Volcanics/Franciscan Complex		• Petaluma claystone • Sonoma Volcanics
Dam Foundation[1]	• moderate to deep excavation to adequate foundation	• deep excavation of landslide deposits to adequate foundation	• excessive excavation of old landslide deposits to adequate foundation	• minimal excavation to adequate foundation in alluvium - weaker alluvial foundation will affect embankment design	• deep excavation of alluvium/colluvium and landslide deposits to adequate foundation
Reservoir Landslide Potential	high	high	moderate		moderate
Reservoir Leakage Potential	• leakage potential in sandstone/conglomerate - partial reservoir lining in these areas assumed	• leakage potential in sandstone/conglomerate - partial reservoir lining in these areas assumed	low - minor, localized grouting and/or impervious blanketing of fractured Sonoma Volcanics assumed		• low
Construction Materials	• adequate supply of on-site impervious core • careful grading plan required to limit random shell borrow within reservoir area • less than desirable workability and strength characteristics, and desiccation and cracking potential of predominant high plasticity on-site materials • on-site availability of select fill moisture barrier material • import requirement for riprap, slope protection, filter, and drain rock	• adequate supply of on-site impervious core • less than desirable workability and strength characteristics, and desiccation and cracking potential of predominant high plasticity on-site materials • on-site availability of select fill moisture barrier material • import requirement for riprap, slope protection, filter, and drain rock	• abundant supply of on-site impervious core • less than desirable workability and strength characteristics, and desiccation and cracking potential of predominant high plasticity on-site materials • on-site availability of select fill moisture barrier material • import requirement for riprap, slope protection, filter, and drain rock	• adequate supply of on-site impervious core • less than desirable workability and strength characteristics, and desiccation and cracking potential of predominant high plasticity on-site materials • on-site availability of select fill moisture barrier material • import requirement for riprap, slope protection, filter, and drain rock	• abundant supply of on-site impervious core • less than desirable workability and strength characteristics, and desiccation and cracking potential of predominant high plasticity on-site materials • import requirement for riprap, slope protection, filter, and drain rock • import requirement for select fill moisture barrier material
Dam Design	• bedrock foundation • 4:1 (H:V) upstream slope • 3:1 (H:V) downstream slope	• bedrock foundation • 4:1 (H:V) upstream slope • 3:1 (H:V) downstream slope	• bedrock foundation • 4:1 (H:V) upstream slope • 3:1 (H:V) downstream slope	• alluvial foundation • 5:1 (H:V) upstream slope • 4:1 (H:V) downstream slope	• bedrock foundation • 4:1 (H:V) upstream slope • 3:1 (H:V) downstream slope

[1] Excavation definition: range of required average depth in random shell zone abutment areas: minimal (up to 5'), moderate (5' to 10'), moderate to deep (10' to 20'), deep (20' to 40'), excessive (over 40'). Required excavation may be deeper in channel areas and beneath impervious core zone of dam.

	• central core with internal drainage • moisture barrier cover	• central core with internal drainage • moisture barrier cover	• wide central core with high capacity internal drainage • moisture barrier cover	• wide central core with high capacity internal drainage • moisture barrier cover	• central core with internal drainage • moisture barrier cover

SECTION 11
REFERENCES

11 REFERENCES

Blake, M.C., Jr., Bartow, J.A., Frizzell, V.A., Schlocker, J., Sorg, D., Wentworth, C.M. and Wright, R.H., 1974, Preliminary geologic map of Marin and San Francisco Counties and parts of Alameda, Contra Costa, and Sonoma Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-574.

Blake, M.C. Jr., Smith, J.T., Wentworth, C.M., and Wright, R.H., 1971, Preliminary geologic map of western Sonoma County and northernmost Marin County, California: U.S. Geological Survey Basic Data Contribution 12, scale 1:62,500.

Bortugno, E. J. (Compiler), 1982, Map Showing Recency of Faulting, Santa Rosa Quadrangle, 1:250,000, California Division of Mines and Geology, Regional Geologic Map Series.

Budding, K. E., D. P. Schwartz, C. L. Ostergen, and D. F. Hoirup, Jr., 1989, Preliminary Slip Rate and Earthquake Recurrence on the Rodgers Creek Fault Zone, Northern California (ABS), Transactions, American Geophysical Union, v. 70, no. 43, p. 1211.

California Division of Mines and Geology, 1983, Special Studies (Alquist-Priolo) Zones Maps of the Healdsburg, Jimtown and Santa Rosa quandrangles.

Fox, K.F., Jr., Sims, J.D., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of eastern Sonoma County and western Napa County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-483.

Hart, E.W., 1992, Fault-Rupture Hazard Zones in California Alquist-Priolo Special Studies Zone Act of 1972 with Index to Special Studies Zones Maps, California Division of Mines and Geology, Special Publication 42, Revised 1992.

Hart, Earl W., 1982, Fault Evaluation Report FER 140 (Tolay Fault), unpublished report prepared by the California Division of Mines and Geology.

McLaughlin, R.J., 1978, Preliminary geologic map and structural sections of the central Mayacmas Mountains and The Geysers stream field, Sonoma, Lake, and Mendocino Counties, California: U.S. Geological Survey Open File Report 78-389.

Sims, J.D., Fox, K.F., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of Solano county, and parts of Napa, Contra Costa, Marin and Yolo Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-484.

Toppozada, T.R., Borchardt, G., Hailstrom, C.L., and Youngs, L.G., 1994, Planning Scenario for a Major Earthquake on the Rodgers Creek Fault in the Northern San Francisco Bay Area, California Division of Mines and Geology Special Publication 112.

U. S. Geological Survey, 1988, Probabilities of Large Earthquakes in California on the San Andreas Fault, Open File Report 88-398, p. 21.

Wagner, D. L. and E. J. Bortugno, (Compilers), 1982, Geologic Map of the Santa Rosa Quadrangle, California, 1:250,000, California Division of Mines and Geology, Regional Geologic Map Series, Map 2A, Sheet 1 of 5.

Wagner, D. L. and E. J. Bortugno, 1983, Geology of the Santa Rosa Quadrangle, California Geology, v. 36, no. 12, pp. 257-280.

Wesnousky, S. G., 1986, Earthquakes, Quaternary Faults and Seimic Hazards in California, Journal of Geophysical Research, vol. 91, no. 812, pp.12.587-12.631.

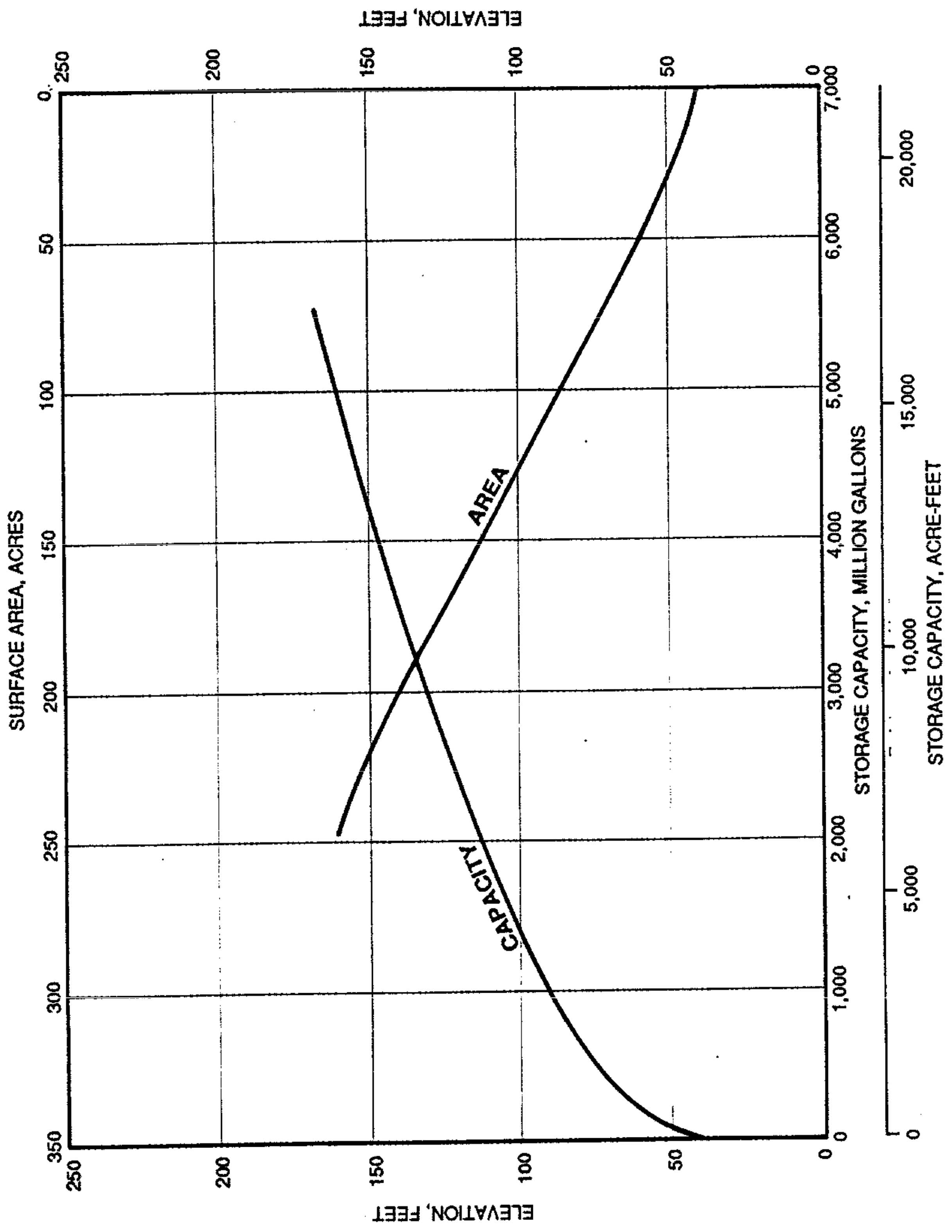
Woodward-Clyde Consultants, 1988, Santa Rosa Long Term Study, Technical Memorandum R2 Storage Feasibility and Siting, Nov. 1, 1988.

Woodward-Clyde Consultants, 1989, Preliminary Geologic Study, Five Alternative Class 3 Landfill Sites, Sonoma County, California.

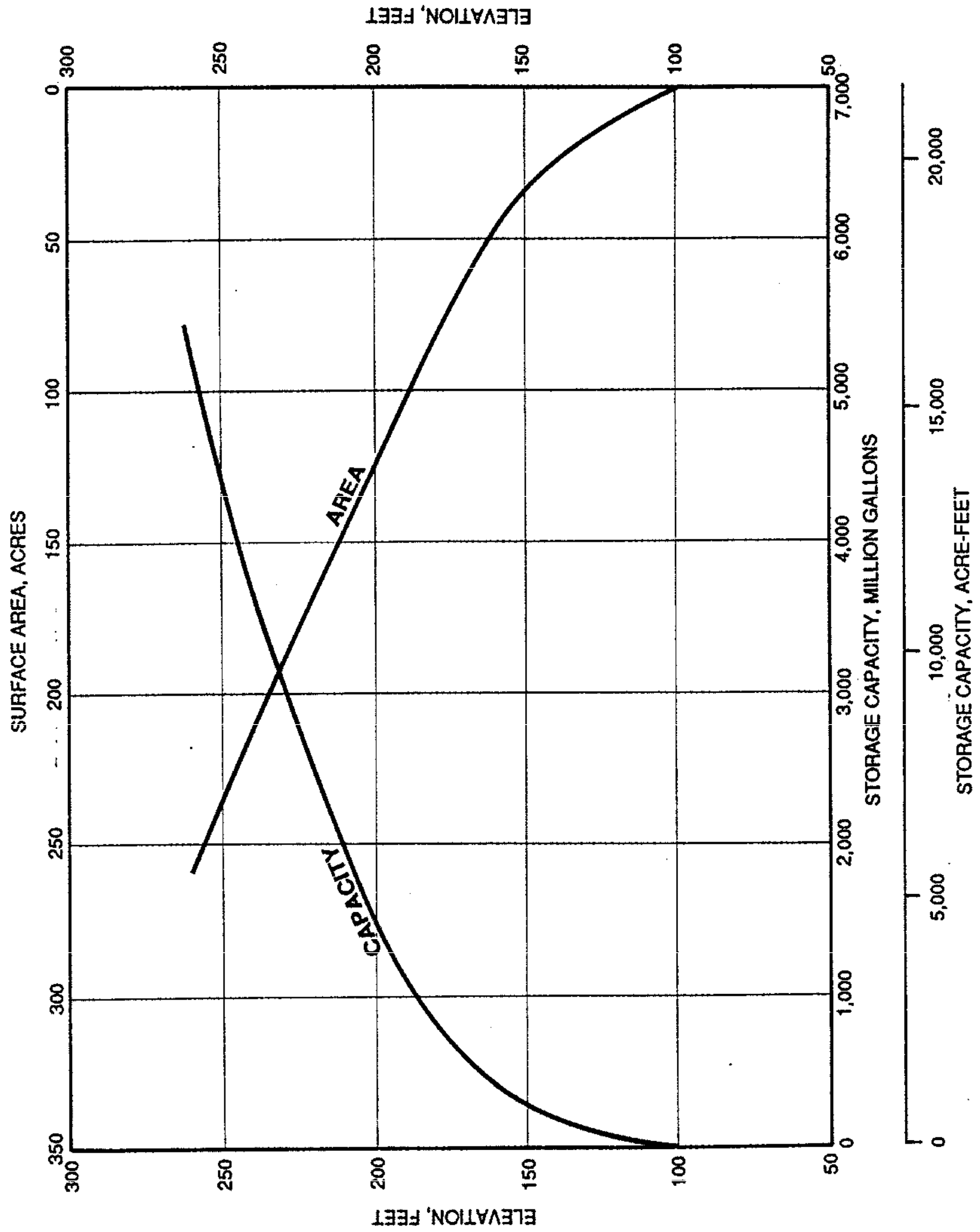
Woodward-Clyde Consultants, 1990, Long Term Detailed Reclamation Studies, Technical Memorandum No. R16, Storage Feasibility and Siting Phase 2, South County, West County and Sebastopol Sites, Nov. 11, 1990.

Working Group of California Earthquake Probabilities, 1990, Probabilities of Large Earthquakes in the San Francisco Bay Region, California; U.S. Geological Survey Circular 1053.

The Appendices to this document have been filed as
Exhibit F-1



RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	RESERVOIR AREA - CAPACITY CURVE VALLEY FORD EAST RESERVOIR SITE SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-1



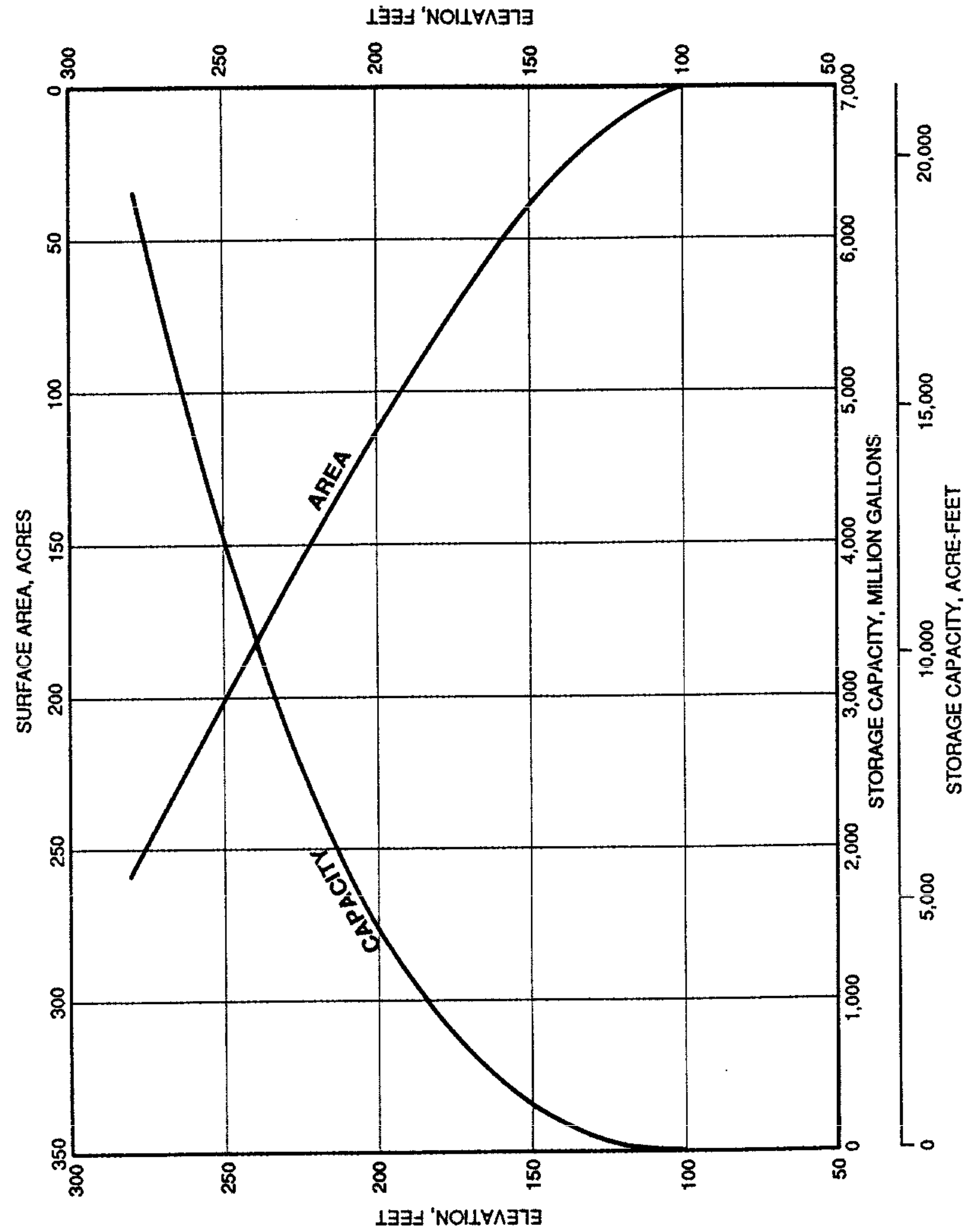
RUST ENVIRONMENT & INFRASTRUCTURE

San Jose, California

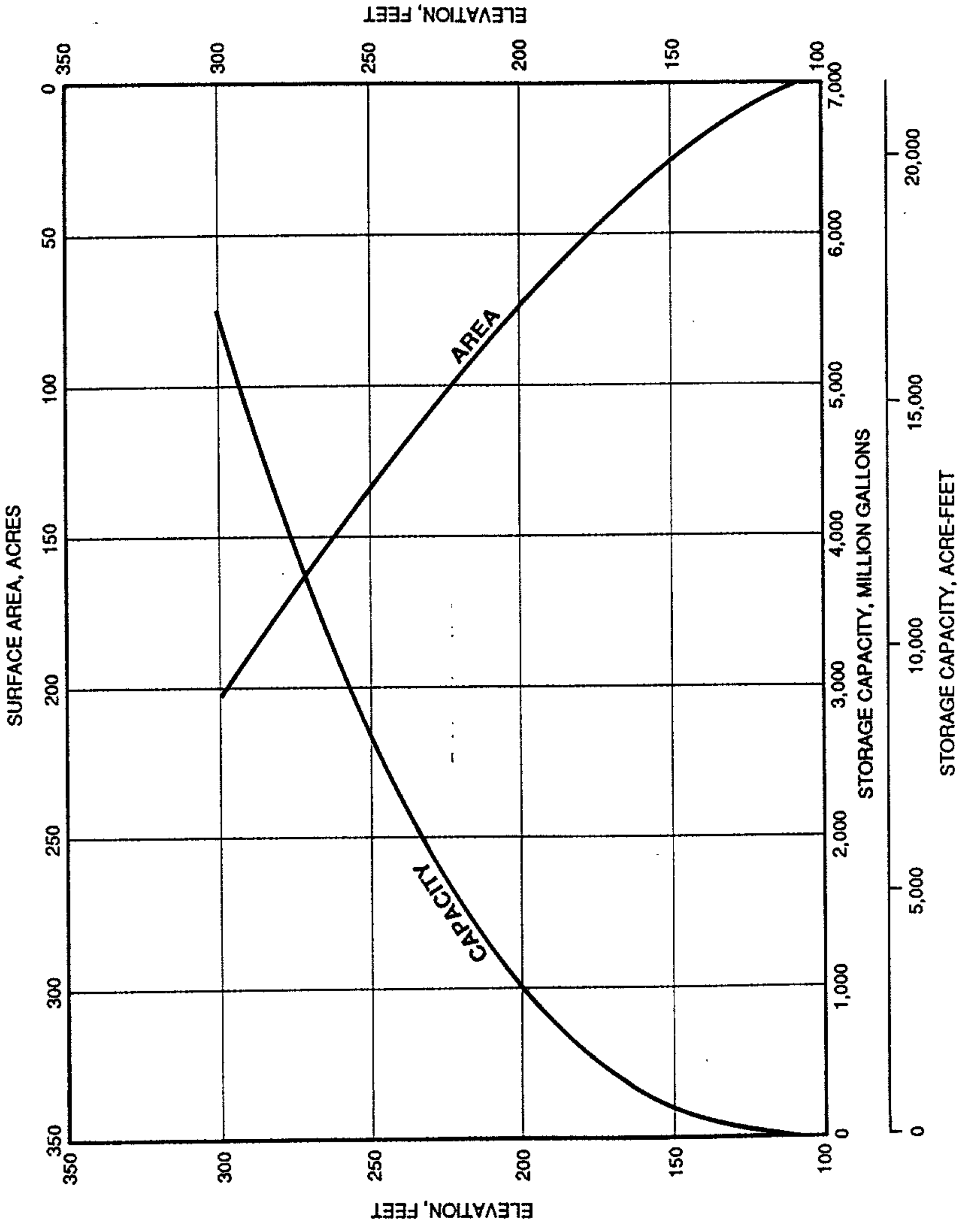
RESERVOIR AREA - CAPACITY CURVE
CARROLL ROAD NORTH RESERVOIR SITE

SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT

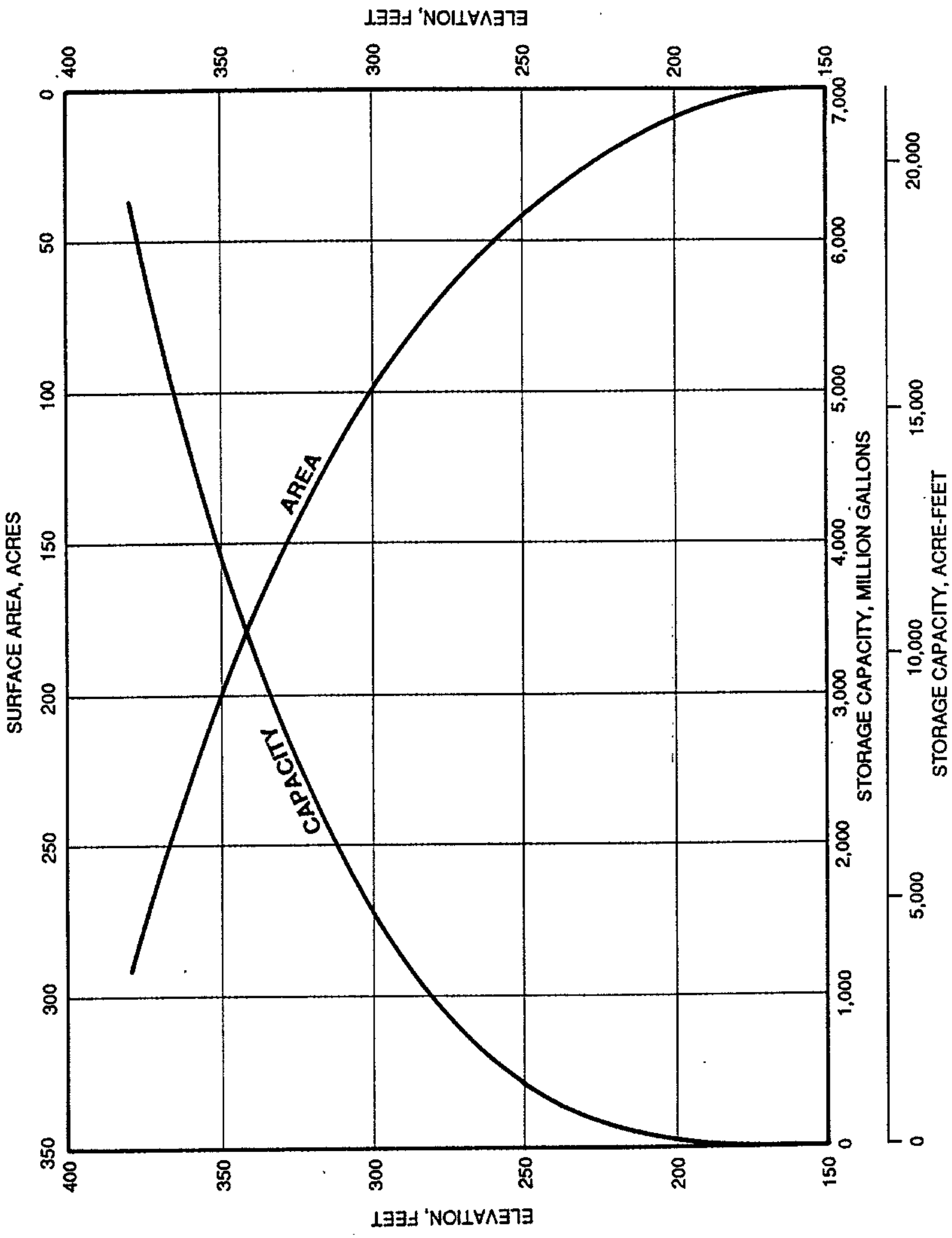
PROJECT NO.	88230
DATE	OCTOBER 1995
FIGURE NO.	6-2



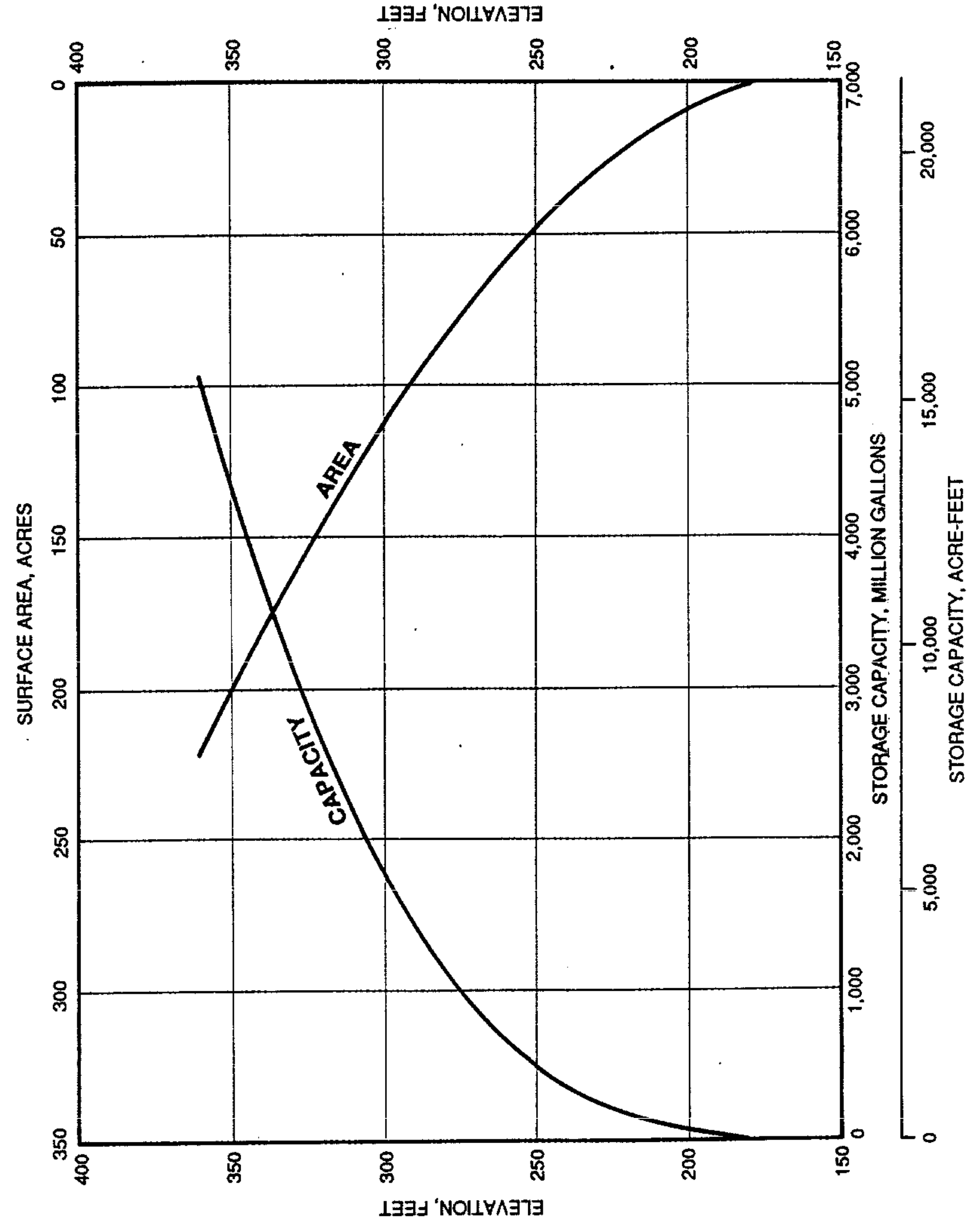
RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	RESERVOIR AREA - CAPACITY CURVE BLOOMFIELD RESERVOIR SITE SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-3



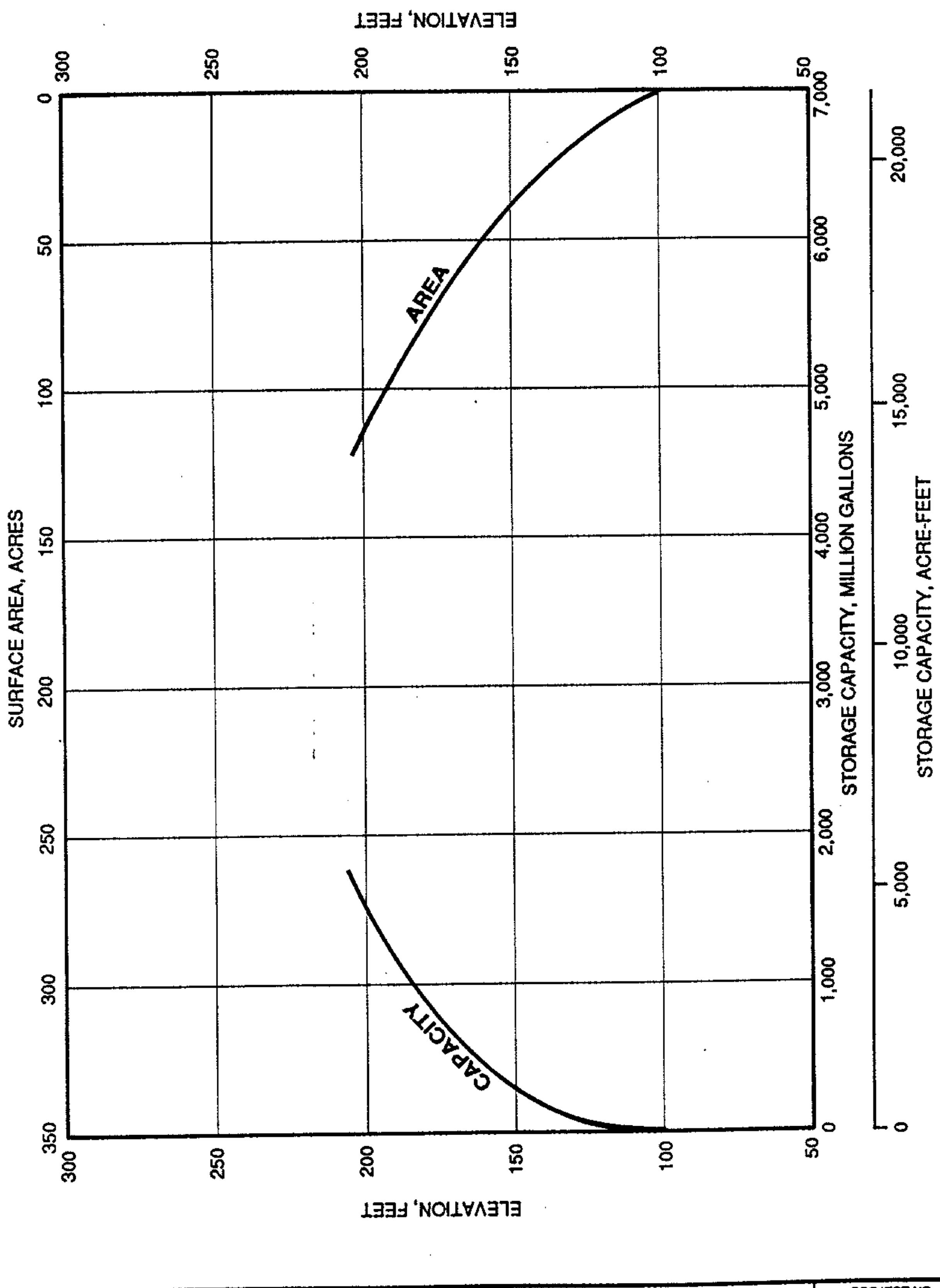
RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	RESERVOIR AREA - CAPACITY CURVE HUNTLEY RESERVOIR SITE SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-4



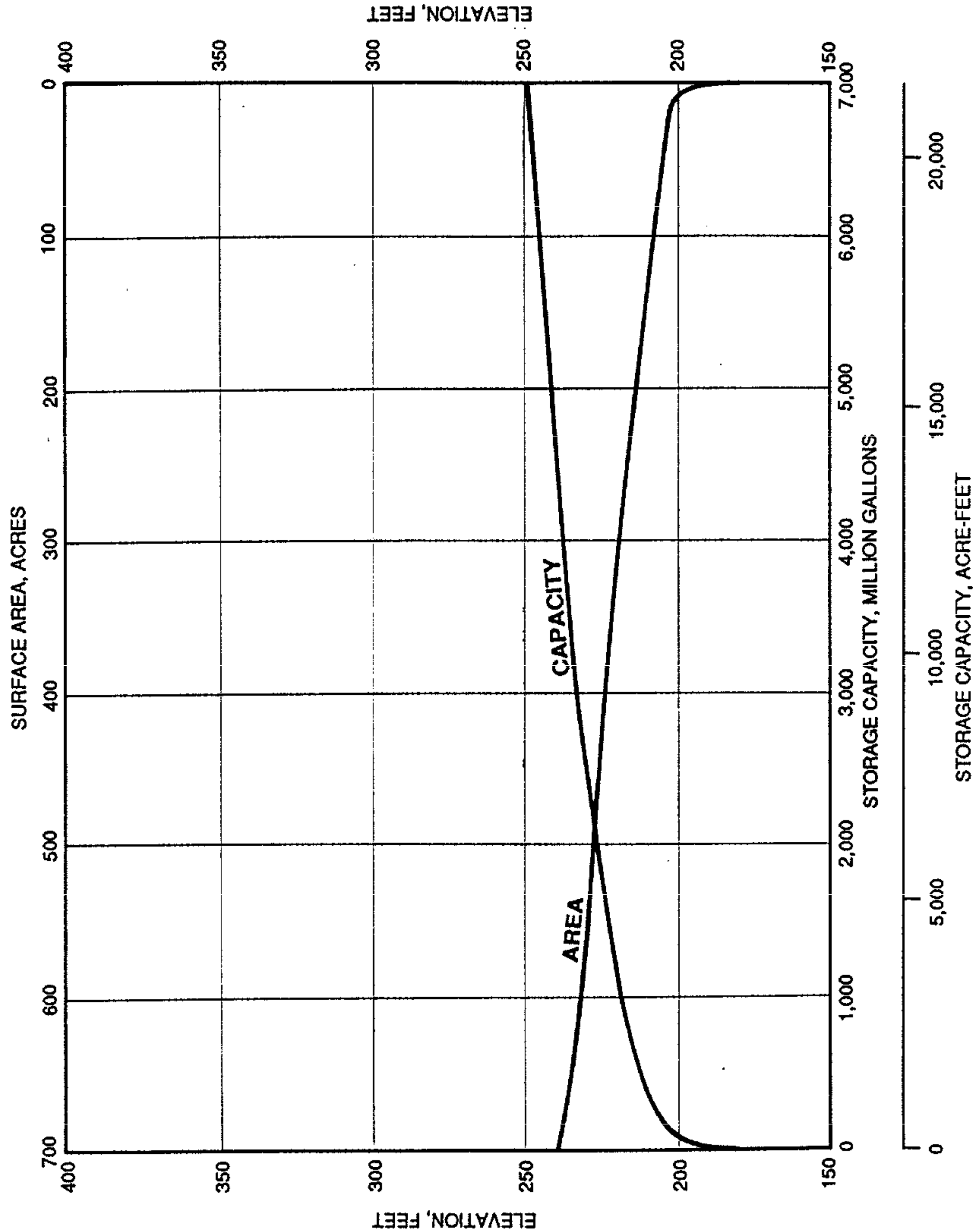
RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	RESERVOIR AREA - CAPACITY CURVE TWO ROCK RESERVOIR SITE SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-5



RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	RESERVOIR AREA - CAPACITY CURVE ADOBE ROAD RESERVOIR SITE SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-6



RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	**RESERVOIR AREA - CAPACITY CURVE** **LAKEVILLE HILLSIDE RESERVOIR SITE** **SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT**	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 6-7



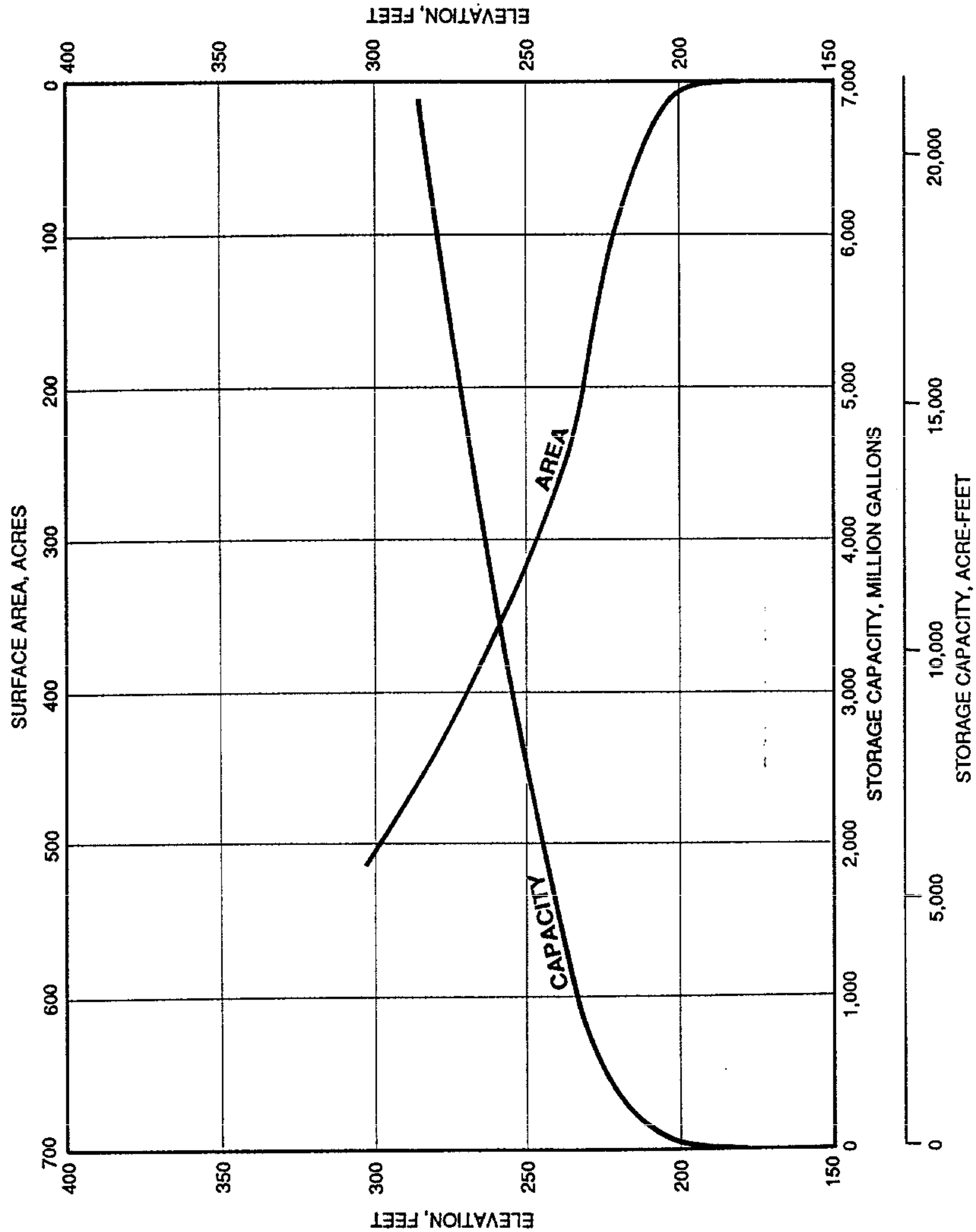
RUST ENVIRONMENT & INFRASTRUCTURE

San Jose, California

RESERVOIR AREA - CAPACITY CURVE
TOLAY CREEK RESERVOIR SITE
(without BACKDAM)

SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT

PROJECT NO.	88230
DATE	OCTOBER 1995
FIGURE NO.	6-8

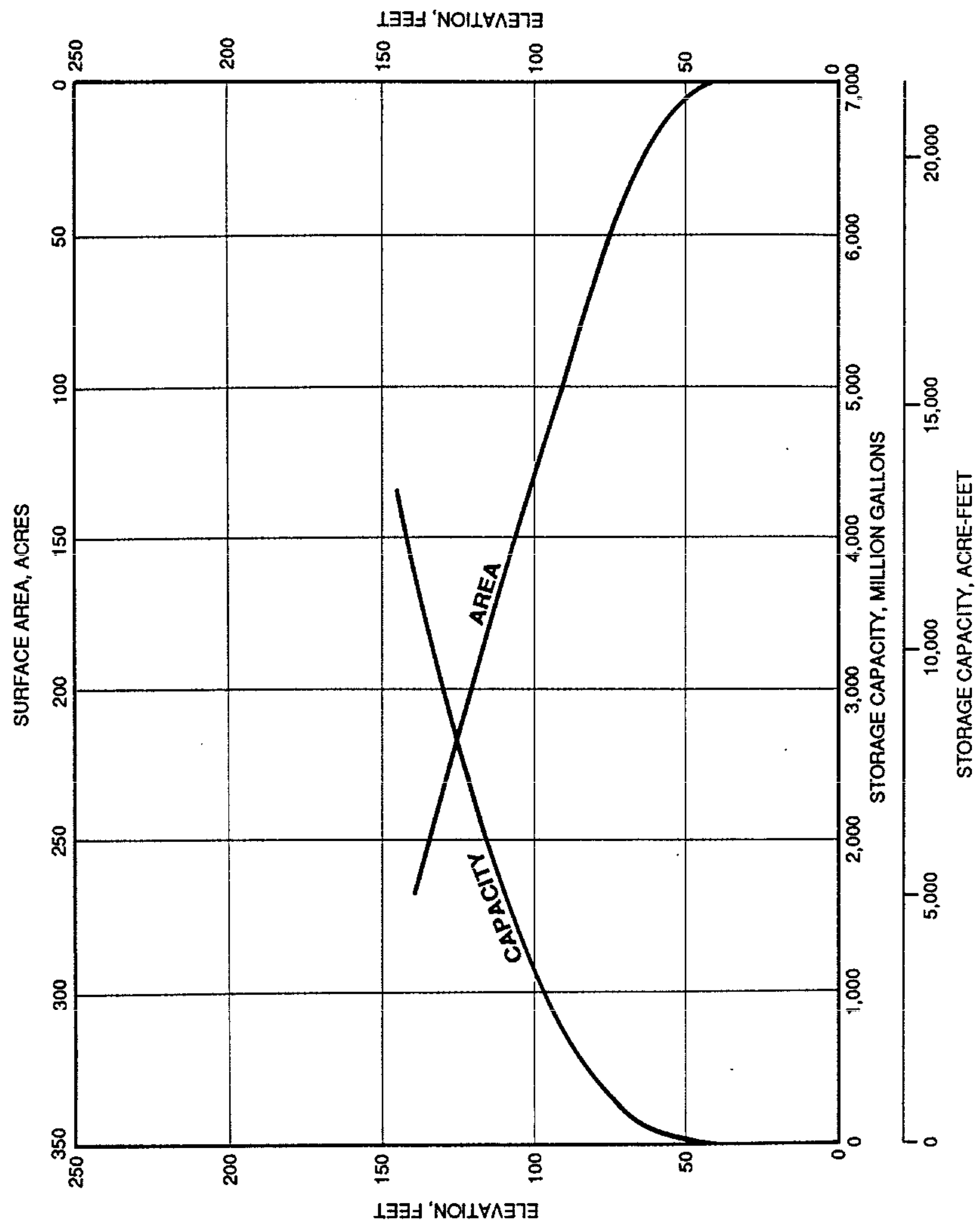


RUST ENVIRONMENT & INFRASTRUCTURE
San Jose, California

RESERVOIR AREA - CAPACITY CURVE
TOLAY CREEK RESERVOIR SITE
(with BACKDAM)

SANTA ROSA SUBREGIONAL LONG TERM
WASTEWATER PROJECT

PROJECT NO.	88230
DATE	OCTOBER 1995
FIGURE NO.	6-9

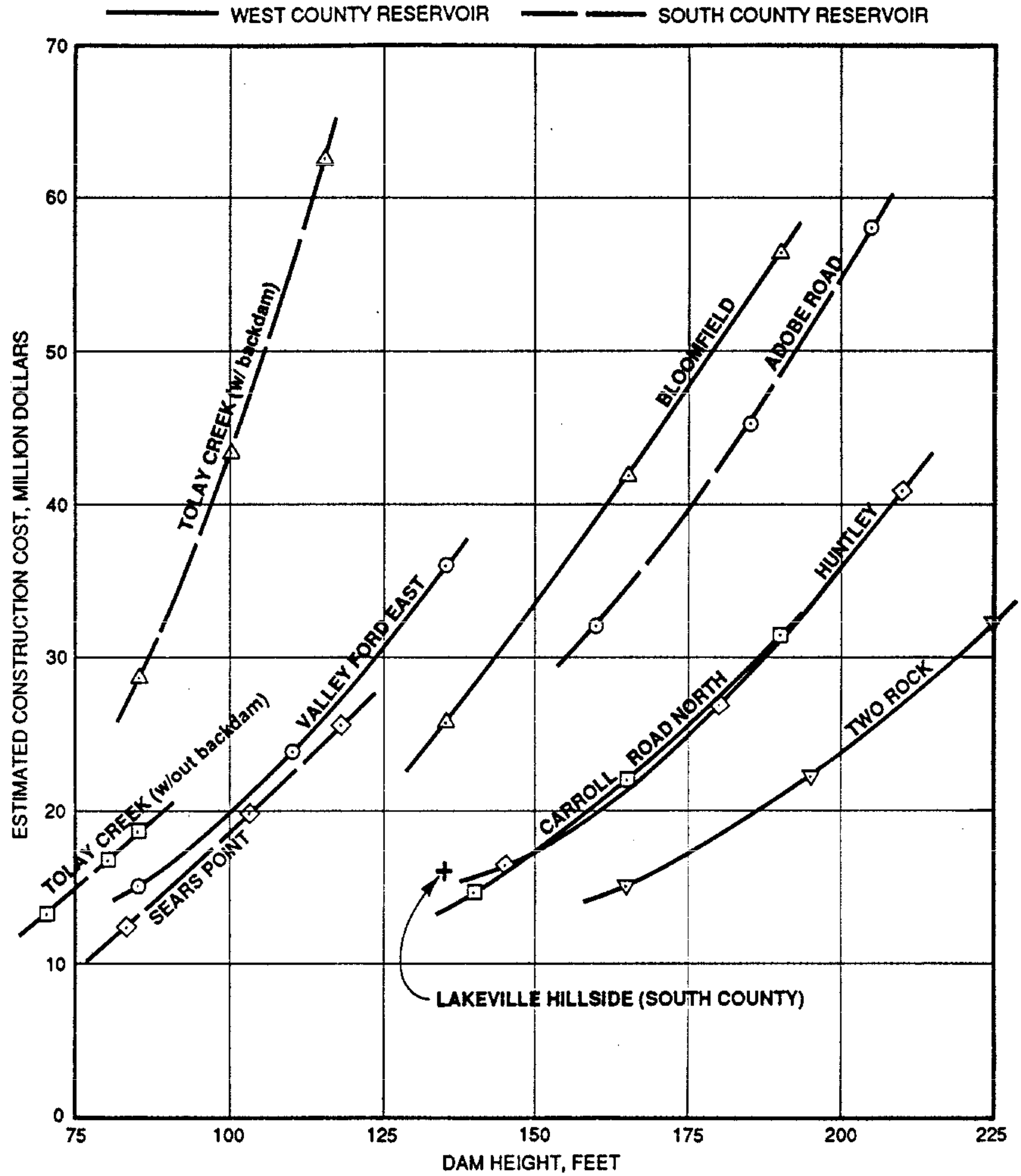


RUST ENVIRONMENT & INFRASTRUCTURE
San Jose, California

RESERVOIR AREA - CAPACITY CURVE
SEARS POINT RESERVOIR SITE

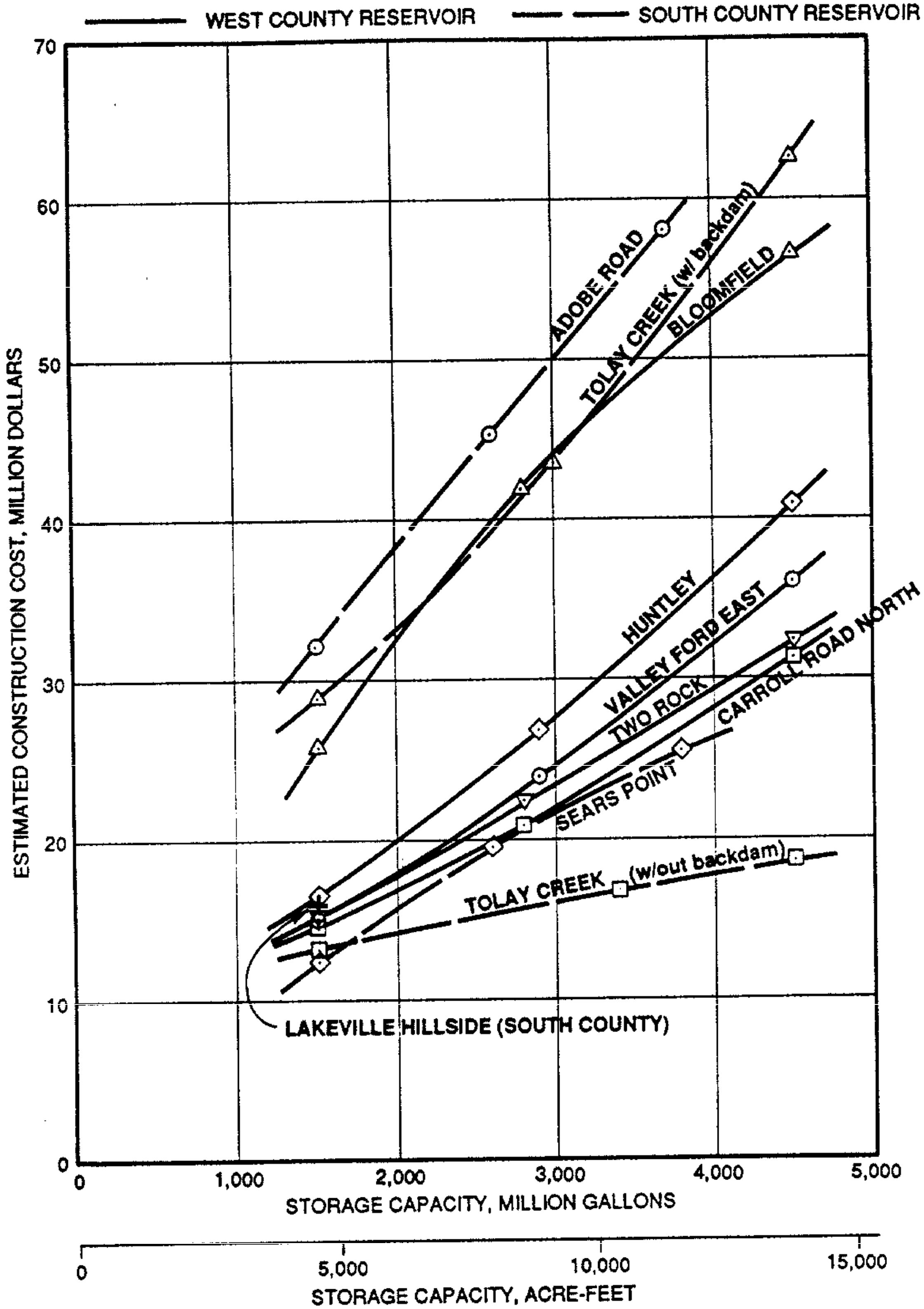
SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT

PROJECT NO.	88230
DATE	OCTOBER 1995
FIGURE NO.	6-10



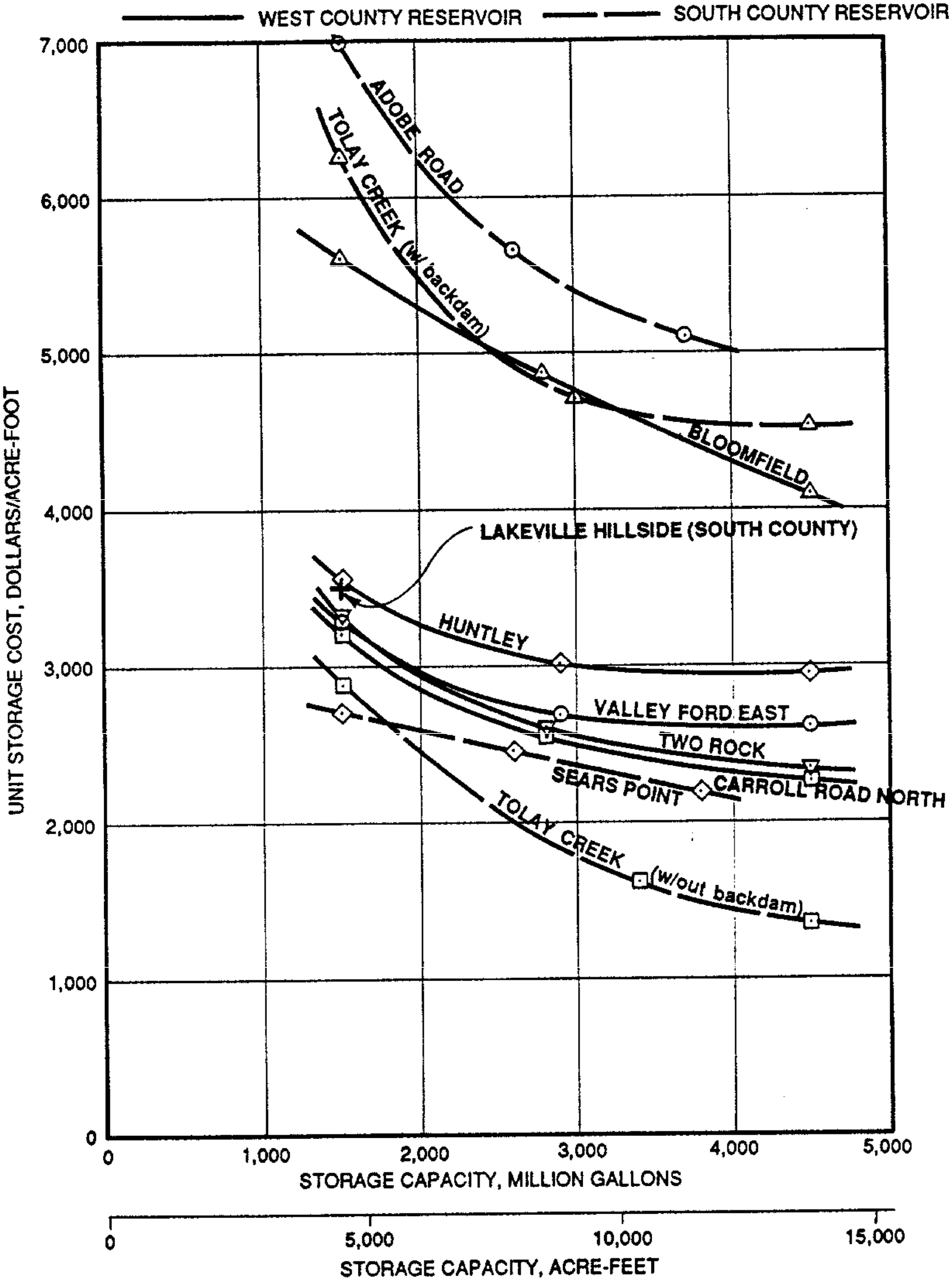
NOTE: ESTIMATED COSTS ARE 1995 DOLLARS, LIMITED TO EMBANKMENT EARTHWORK CONSTRUCTION COSTS. DOES NOT INCLUDE SPILLWAY, INLET/OUTLET WORKS, AND OTHER ANCILLARY FACILITIES OR ENGINEERING, ADMINISTRATION, LAND AQUISITION AND CONTINGENCY COSTS, TO BE ADDED BY OTHERS.

RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	DAM HEIGHT - CONSTRUCTION COST CURVES ALTERNATIVE RESERVOIR SITES SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 8-1



NOTE: ESTIMATED COSTS ARE 1995 DOLLARS, LIMITED TO EMBANKMENT EARTHWORK CONSTRUCTION COSTS. DOES NOT INCLUDE SPILLWAY, INLET/OUTLET WORKS, AND OTHER ANCILLARY FACILITIES OR ENGINEERING, ADMINISTRATION, LAND AQUISITION AND CONTINGENCY COSTS, TO BE ADDED BY OTHERS.

RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	STORAGE - CONSTRUCTION COST CURVES ALTERNATIVE RESERVOIR SITES SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 8-2



NOTE: ESTIMATED COSTS ARE 1995 DOLLARS, LIMITED TO EMBANKMENT EARTHWORK CONSTRUCTION COSTS. DOES NOT INCLUDE SPILLWAY, INLET/OUTLET WORKS, AND OTHER ANCILLARY FACILITIES OR ENGINEERING, ADMINISTRATION, LAND AQUISITION AND CONTINGENCY COSTS, TO BE ADDED BY OTHERS.

RUST ENVIRONMENT & INFRASTRUCTURE San Jose, California	STORAGE - UNIT STORAGE COST CURVES ALTERNATIVE RESERVOIR SITES SANTA ROSA SUBREGIONAL LONG TERM WASTEWATER PROJECT	PROJECT NO. 88230 DATE OCTOBER 1995 FIGURE NO. 8-3