GEOMATRIX

FINAL REPORT
WALNUT CREEK WATER TREATMENT PLANT EXPANSION
SEISMIC STUDY – PHASE II

Prepared for

East Bay Municipal Utility District
375 Eleventh Street
Oakland, California 94607-4240

October 1998
Project No. 3970

Geomatrix Consultants

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October 30, 1998
Project No. 3970

East Bay Municipal Utility District
375 Eleventh Street
P.O. Box 24055
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Attention: Mr. Xavier Irias, Project Manager

Subject: Final Report
Walnut Creek Water Treatment Plant Expansion
Seismic Study – Phase II

Geomatrix Consultants, Inc. is pleased to submit the enclosed final report on faulting conditions associated with the Franklin fault at the Walnut Creek Water Treatment Plant located in Walnut Creek, California. This report incorporates review comments provided by the District on October 19, 1998.

We have appreciated this opportunity to work with you on this very challenging project. Please contact the undersigned if you have any questions about this report, of if we can be of further service.

Sincerely,
GEOMATRIX CONSULTANTS, INC.

N. Timothy Hall, C.E.G.
Principal Geologist

John R. Wesling, C.E.G.
Senior Geologist

NTH/JRW
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EXECUTIVE SUMMARY

GENERAL

This report presents the results of the Phase II Seismic Study for the proposed expansion of the existing clearwell and other facilities at the East Bay Municipal Utility District (District) Walnut Creek Water Treatment Plant (WCWTP). The principal goal of this study was to evaluate the existence of active faults beneath the footprints of the two proposed clearwell expansion alternatives: (1) two 236-foot-diameter, 9,000,000 gallon capacity (each) steel water tanks west of the existing clearwell; and (2) an expansion of the existing lined, earthen clearwell (Plate 1). Additional facilities are also planned for the proposed expansion.

The Franklin fault, a northwest-trending, steeply dipping fault that lies on trend with and north of the active Calaveras fault, has been mapped across or close to the plant site by state, federal, and local geologists. Although the location of the Franklin fault northwest of Walnut Creek is reasonably well constrained and more or less consistently portrayed on published geologic maps, there is significant uncertainty as to the exact location of the Franklin fault at the WCWTP and its relationship to other nearby faults in the vicinity of Walnut Creek and to the south toward Danville (Figure 2-2). Specifically, the relationship between the southern Franklin fault and the northern Calaveras fault, both of which occupy the same structural trend, is represented differently on published geologic maps of the region. The Franklin fault is inferred to be an active fault by Contra Costa County (1991) on the basis of a tectonic model. By virtue of its proximity and possible geologically young activity, this fault and any associated secondary deformation may pose a ground-rupture hazard to the plant site. To evaluate this potential hazard, Geomatrix assessed the location, activity, and geometry of fault traces traversing the WCWTP site by geologic mapping and trenching studies.

The following paragraphs summarize the pertinent findings and conclusions from our investigation of surface fault-rupture hazard at the WCWTP. The methodology, findings, and conclusions of our study are described in greater detail in the main body of this report.

FIELD INVESTIGATIONS

Field investigations for the assessment of the fault-rupture hazard at the WCWTP were conducted between December 30, 1996 and September 8, 1997, and included geologic mapping and trenching. The geologic mapping focused on the bedrock stratigraphy, Quaternary stratigraphy, geologic structure, and existing conditions at the plant site and vicinity. Pre-Quaternary bedrock and Quaternary alluvial geomorphic surfaces provide a stratigraphic framework for assessing the location, amount of displacement, and recency of faulting (Table 3-1). The trenching initially focused on the eastern and western zones of mapped faults (defined in Geomatrix, 1995) and then targeted specific faults and lineaments that were identified through the geologic mapping and initial trenching. The trenching program was designed to obtain continuous exposure of bedrock and Quaternary units along the western and northern sides of the WCWTP (Figure 1-2).

FINDINGS

Bedrock at the site and surrounding area findings consists of Oligocene to Miocene marine sedimentary rocks (Saul, 1973; Dibblee, 1980a). In general, the oldest rocks in the site vicinity are lower Eocene and upper Paleocene claystones and sandstones of the Meganos and Martinez formations located east of the site, on the east side of the Franklin fault (Plate 3). West of the Franklin fault, bedrock consists primarily of Miocene sandstone with subordinate siltstone and claystone of the Hambre, Briones and Neroly formations. A distinctive, fine-grained, white sandstone east of the site and immediately west of the Franklin fault may represent a fault-bounded slice of Oligocene San Ramon Formation.

Quaternary units at the WCWTP include the late Pleistocene geomorphic surface and associated alluvial deposits, Holocene colluvium on hillslopes, and Holocene alluvium along modern drainages (Plate 2). The geomorphic surface, a product of fluvial erosion and deposition, is an excellent "strain gauge" to evaluate young fault activity because of its antiquity and relatively planar character. The surface occurs directly west and north of the main plant site and lies about 30 feet above the modern drainage.

The main trace of the Franklin fault likely is located east of the plant site, as mapped by Dibblee (1980a), Graymer and others (1994), and Haydon (1995), because the identified faults in the plant site vicinity do not appear to exhibit significant stratigraphic separation to be the main fault and because uplifted geomorphic surfaces and possible fault-related photolineaments occur northeast of the site. The four northwest-trending secondary faults that occur within the site vicinity include the West fault directly west of the plant site, the Central fault at the plant site, and two East faults directly east of the plant site (Plate 2).

CONCLUSIONS

The WCWTP is located adjacent to the main trace of the Franklin fault, and lies within a zone of deformation characterized by secondary faulting, folding, and fracturing associated with the Franklin fault. Most of the plant site, however, has been cleared of active faults based on the Phase II trenching and mapping studies. These studies indicate that the main trace of the Franklin fault probably lies to the northeast of the WCWTP and, therefore, poses no to little fault-rupture hazard to the site, although it may be a source of strong ground motions. Secondary faults, however, pass through the plant site and may pose a ground-rupture hazard to some existing and planned facilities.

Given the relatively low slip rate estimated for the Franklin fault, we judge that a surface rupturing event on the Franklin fault is very unlikely during the useful life of the facilities. The activity of the Franklin fault has not been documented directly; however, a secondary fault

associated with the Franklin fault (the West fault of this study) has been active during the late Quaternary. This implies that the Franklin fault also is late Quaternary active. Only one previous paleoseismic study (Earth Science Associates, 1983) of the Franklin fault indicates the fault may be active. If active, the fault is expected to have a low rate of activity with a slip rate in the range of about 0.2 to <1 mm/yr based on comparison of its geomorphic expression with that of known active faults in the Bay Area. Therefore, the likelihood of a surface fault rupture event occurring on the main trace of the Franklin fault is judged to be very low.

A fault identified during this study, informally called the West fault, apparently branches from the Franklin fault and trends directly west of the WCWTP. Trenching studies have established that the fault has a right-normal-oblique sense of slip and that the fault displaces late Quaternary alluvial sediments that are dated as 31,410 radiocarbon years before present. Site geologic mapping indicates the West fault is tectonic in origin, and not related to landsliding. Therefore, the West fault is an "Active Fault" based on the DSOD's 35,000-year-old criterion (Fraser, 1995), but may or may not be an active fault based on CDMG's Holocene criterion (displacement in the past 11,000 years). The fault does not pass beneath the foundation of the existing clearwell, but it does cross the area of the proposed expanded clearwell and intersects both the influent water pipelines for the plant and the Mokelumne Aqueduct lines. Future slip on this fault does not appear to pose a ground rupture hazard to the existing clearwell, but it may pose a hazard to the pipelines and other utilities that are built across its trace.

The trenching studies and bedrock mapping of the site and vicinity have identified at least two other zones of northwest-trending secondary faulting at the site, two East faults and the Central fault. The East faults were intersected in two trenches near the northeastern boundary of the WCWTP site. Colluvium judged to be middle to late Holocene in age based on very weak pedogenic soil development is not displaced across the two East faults. The northwest-trending Central fault, located between the East and West faults, was identified based on truncated bedding in bedrock that was observed in a trench and was extended across the site based on strongly expressed photolineaments that are coincident with the fault and limited field mapping.

The Central fault passes close to the northeast corner of the existing clearwell and may underlie the area proposed for additional filters. The timing of the most recent slip on the East faults and Central fault is not known. Given their parallel and branching nature with respect to the main trace of the Franklin fault and the West fault, and given their location within the zone of deformation, late Pleistocene to Holocene surface-faulting events on the East and Central faults cannot be ruled out.

Faults that are secondary to the Franklin fault, like the West fault, Central fault, and East faults may rupture during an earthquake on the Franklin fault, but it is highly unlikely that they will rupture independently of the Franklin fault (i.e., the secondary faults are not separate seismic sources). Because the likelihood of a surface-faulting event on the Franklin fault is judged to be very low based on the available data, the likelihood of surface faulting on the secondary faults also has a very low likelihood.

The regional context of the active West fault and other secondary faults, specifically their relationship to the Franklin fault, has not been fully established with a high degree of confidence. The activity on secondary faults may be a result of strike-slip movement in a double releasing bend along the Franklin fault, or a result of extension in the hanging-wall block of a blind-thrust fault that either verges to the northeast or the southwest. The exact context of the controlling tectonic structure can not be determined based on the available data. However, when compared with other active Bay Area faults, the faults evaluated during this investigation are clearly minor, low slip rate features.

If a faulting event occurs on the Franklin fault, there may be movement on one or more secondary faults. Based on the trench exposures that support an interpretation of multiple slip events, it is reasonable to assume that the West fault probably has moved with the Franklin fault, but it is unknown if the East faults and the Central fault have a similar history of movement. The possibility that these faults move when the main Franklin fault moves cannot be ruled out. If the secondary faults do move, the expected size of the displacements will be smaller, perhaps much

smaller, than the displacement on the Franklin fault. Empirical relationships derived from studies of earthquakes worldwide indicate that the maximum displacement along the Franklin fault is expected to be about 4 feet, and the average displacement is expected to be about 2 feet (assuming a M_W 6¾ earthquake and a surface rupture length of 29 km). The expected displacement on the secondary faults is expected to be relatively small, on the order of 1 foot or less, although displacements as large as 2 feet cannot be ruled out.

FINAL REPORT
WALNUT CREEK WATER TREATMENT EXPANSION
SEISMIC STUDY – PHASE II

1.0 INTRODUCTION

This report presents the results of the Phase II Seismic Study conducted by Geomatrix Consultants (Geomatrix) for the proposed expansion of existing facilities (CH2M Hill, 1994) at the East Bay Municipal Utility District (District) Walnut Creek Water Treatment Plant (WCWTP). The principal goal of this study was to evaluate the existence of active faults beneath the footprint of proposed clearwell expansion alternatives. Evaluation of whether surface-fault rupture may pose a hazard to the Walnut Creek facility is an important objective of the District's Seismic Improvement Program, whose goals are to reduce seismic risk and improve system performance, as well as meet the current and future water needs of the Walnut Creek - San Ramon corridor.

The WCWTP is located on Larkey Lane in the City of Walnut Creek, California, about 1.3 miles northwest of the intersection of Highway 24 and Interstate 680 (Figure 1-1). The plant presently consists of an operations building and filters, a clearwell located directly west of the operations building, a settling basin to the north, and maintenance and storage buildings. Raw water is supplied to the plant from the Mokelumne Aqueducts, which are located about 1,000 feet to the north of the existing clearwell. Future expansion plans currently include two clearwell alternatives: (1) the installation of two 236-foot-diameter, 9,000,000 gallon capacity (each) steel water tanks whose proposed location is west of the existing clearwell; and (2) an expansion of the existing lined earthen clearwell. Both clearwell alternatives are shown on Plate 1. Flocculation and ozonation facilities, an ozone generation building, a chemical feed building, additional filters, and washwater decant basins also are planned.

The Franklin fault, a northwest-trending, steeply dipping fault that lies on trend with and north of the active Calaveras fault, has been mapped across or close to the plant site by state, federal, and local geologists (Geomatrix, 1995, Figures A-1, A-2, and A-3). The Franklin fault is inferred to be an active fault by Contra Costa County (1991) on the basis of a tectonic model. By virtue of its proximity and possible geologically young activity, this fault and any associated secondary deformation pose a potential ground-rupture hazard to the existing plant and the proposed plant expansion.

To evaluate this potential hazard, the District authorized Geomatrix to conduct a preliminary (Phase I) seismic hazard study in 1995. In that study, Geomatrix (1995) identified east and west zones of previously mapped fault traces traversing the site (Figure 1-2). This study concluded that the data available at that time were insufficient (1) to evaluate the activity of the Franklin fault, (2) to determine its dip, or (3) to determine whether traces of the Franklin fault cross the plant site and the existing or proposed expanded clearwell footprints or other proposed facilities. At that time, no geomorphic features or stratigraphic dislocations clearly indicative of Holocene or late Pleistocene age were observed along the Franklin fault during aerial reconnaissance, nor were geomorphic surfaces (soil-covered surfaces created by stream erosion) located near the plant site obviously disrupted by faulting. Geomatrix (1995) noted that the subdued topography along the Franklin fault contrasts sharply with the clear surface expression of nearby, active East Bay faults such as the Hayward, Calaveras, Concord, Green Valley, and Greenville faults. This lack of well-defined geomorphic expression indicates that the Franklin fault is either inactive or moves with a very low rate of slip. However, without additional supportive evidence, a subdued geomorphic expression is not sufficient to rule out a ground-rupture hazard stemming from the presence of the Franklin fault. Consequently, Geomatrix (1995) recommended that a Phase II seismic study be undertaken to evaluate the ground-rupture hazard at the site.

1.1 PURPOSE AND SCOPE OF PHASE II

In order to assess the surface-fault-rupture hazard at the WCWTP site posed by the Franklin fault, Geomatrix conducted a Phase II seismic hazards assessment program that focused on key

facilities of the plant site, including the existing clearwell and a proposed clearwell expansion. An assessment of the location and activity of the Franklin fault is essential for the safe operation of the existing clearwell and for the seismic design of new facilities to be constructed for the proposed water treatment plant expansion.

The following three tasks have been completed for the Phase II investigation:

1. **Assessment of Surface Faulting Hazard at the WCWTP Site** - Geomatrix assessed the location, activity, and geometry of fault traces traversing the WCWTP site by evaluating earth materials exposed in trenches and test pits. We also utilized photointerpretive, stratigraphic, structural, soils identification, and radiocarbon-dating techniques to assess the continuity of geologic deposits and surfaces that are potential "strain gauges" for the identification of geologically young surface faulting. The following work items were conducted as part of this task:

    - Excavation of a series of trenches to assess faulting conditions in the clearwell area across a western zone of mapped northwest-trending fault traces identified in the Phase I study;

    - Excavation of a trench across an eastern zone of previously mapped northwest-trending fault traces identified in the Phase I Study;

    - Assessment of the extent, age, and deformation of the geomorphic surface that lies directly west and north of the plant site;

    - Meetings with the District and the California Department of Water Resources, Division of Safety of Dams (DSOD);

    - Preparation of draft and final reports.

2. **Assessment of Fault Versus Landslide Origin for Shearing West of Existing Clearwell** - Reconnaissance geologic field mapping was conducted in the vicinity of the plant site to trace geologically young (late Pleistocene) faulting discovered during Task 1. As part of this effort, Trenches 9a, 9b, and 9c were excavated along the Mokelumne Aqueducts to locate faults identified in the roadcut exposure northwest of the existing clearwell, and Trenches 10a, 10b, 10c, and 10d were excavated west of the existing clearwell to evaluate a tectonic versus landslide origin for the late Pleistocene faulting (Plate 1 and Appendix A).

3. **Contingency for Additional Trenches** - Trenches 3, 4b, and 8 were excavated to further investigate the late Pleistocene faulting identified in Trenches 1 and 4a. Trench 11 was excavated to further investigate the lineament that occurs directly east of the existing clearwell (Plate 1 and Appendix A).

1.2 REPORT ORGANIZATION

The geologic setting of the WCWTP site, and previous investigations, are summarized in Section 2. Section 3 describes the field investigation of fault-rupture hazard including the results of the geologic mapping and trenching program. The potential for surface-fault rupture, including anticipated surface displacements, is presented in Section 4. Results and conclusions are summarized in Section 5. Appendix A presents the trench wall maps. Appendix B describes the assessment of Maximum Credible Earthquake (MCE) for the Franklin fault.

1.3 DEFINITIONS

To ensure a common understanding, definitions of geologic time periods, trenches and fault activity criteria are summarized. Terms for the youngest geologic era, the Cenozoic, are given in Table 1-1.

The excavations made for this study included both slot trenches on flat or gently sloping ground and bulldozer cuts along existing roadcuts. Both types of excavations are herein referred to as trenches. For example, Trenches 1, 2a-g, 3, 4b, 5, 6, 7, 9a-c, 10a-d, and 11 were slot trenches excavated with a backhoe, while Trenches 4a and 8 are roadcuts that were cleared with a bulldozer.

1.4 FAULT ACTIVITY CRITERIA

The criteria for classifying a fault as active differ depending on the use/purpose of an engineered structure and the potential consequences of its failure during an earthquake. For example, the California Division of Mines and Geology (CDMG) defines activity for structures that are constructed for human occupancy (Alquist-Priolo Earthquake Fault Zoning Act), and the DSOD defines fault activity for dam safety. The fault activity criteria for each of these state government agencies are given below. Note that the DSOD definitions are more conservative

than those used by the CDMG, a reflection of the life safety implications from a catastrophic dam failure.

1.4.1 Alquist-Priolo Special Studies Zone Criteria

The Alquist-Priolo Earthquake Fault Zoning Act serves to mitigate the ground-rupture hazard at facilities that are built for human occupancy (Hart, 1990, 1994). The CDMG has delineated Fault-Rupture Hazard Zones around faults that are "well-defined" and "sufficiently active." To be well defined, the trace of the fault must be clearly detectable by a trained geologist. A fault is sufficiently active if it has evidence of Holocene displacement, although the Act originally had provisions for potentially active faults. Fault activity criteria mandated by the Act and used by the CDMG are summarized below.

1. **Active Fault** - a fault that has "...had surface displacement within Holocene time (about the last 11,000 years)." (Hart, 1990).

2. **Potentially Active Fault** - a fault that "...showed evidence of surface displacement during Quaternary time (last 1.6 million years...)." (Hart, 1990).

1.4.2 Reservoir Siting (DSOD) Criteria

Because of their size and type of construction, both the existing clearwell and any proposed expansion fall within DSOD jurisdiction. Therefore, the goal in siting expanded clearwell facilities is to avoid faults that pose a ground rupture hazard. To accomplish this, the Phase II investigation was focused on locating faults at the WCWTP and evaluating whether they are "active," "conditionally active," or "inactive." The DSOD definitions of these fault activity categories are provided by Fraser (1996) below.

1. **Active Fault** - A fault is considered active by the DSOD if it has had at least one episode of displacement in the last 35,000 years. Active faults are considered seismic sources for dam design or reevaluation. Two subcategories of active faults include:

- **Holocene Active Fault** - "...is a fault on which surface or subsurface displacement has occurred within the Holocene Epoch." (Table 1-1); and

- **Late Pleistocene Active Fault** - "...is a fault on which no evidence of Holocene displacement is known, but which has experienced surface or subsurface displacement within the last 35,000 years."

Distinguishing between these activity classes is primarily for descriptive purposes; however, the DSOD may consider them distinct activity criteria that can be applied to different dam types or risk categories (Fraser, 1996).

2. **Conditionally Active Fault** -a fault that is either:

   - "A Quaternary active fault (one that has experienced surface or subsurface displacement within the last 1.6 million years) with a displacement history during the last 35,000 years that is not known with sufficient certainty to consider the fault an active or inactive seismic source."

   - "A pre-Quaternary fault which can be reasonably shown to have attributes consistent with the current tectonic regime."

   A **Conditionally Active Fault** is treated as an active seismic source for dam design or reevaluation because of incomplete or inconclusive evidence of recency of activity. It is understood that further study or analysis could change this designation.

3. **Inactive Fault** - "a fault which has had no surface or subsurface displacement within the last 35,000 years. Inactivity is demonstrated by a confidently-located fault trace which is consistently overlain by unbroken geologic materials 35,000 years or older, or other observation indicating lack of displacement. Faults that have no suggestion of Quaternary activity are presumed to be inactive." An **Inactive Fault** is not considered a seismic source for dam design or reevaluation.

1.5 ACKNOWLEDGMENTS

This geologic investigation was performed in accordance with the subcontract agreement for services between the District and Geomatrix dated December 16, 1997. Geomatrix received authorization to begin work in a letter dated, December 17, 1996 from Mr. David L. Pratt, Manager of Design for the District. Authorization to begin work on Task 2 was received in a letter dated, July 2, 1997 from Mr. Pratt. Task 3 funds were approved by Mr. Pratt in two increments, on February 10, 1997 and May 20, 1997.

The work described in this report was coordinated with the following District personnel:

- Ms. Marilyn Miller, Director of Engineering and Construction
- Mr. David Pratt, Manager of Design
- Mr. Xavier Irias, Senior Civil Engineer
- Mr. Fred Starr, Senior Civil Engineer
- Mr. Atta Yiadom, Associate Civil Engineer
- Mr. Dan Zelinski, Associate Civil Engineer

Geomatrix personnel who participated in the project include:

- Dr. N. Timothy Hall, Principal Geologist (Project Manager)
- Mr. Charles L. Taylor, Senior Consulting Geologist
- Mr. John R. Wesling, Senior Geologist (Trench Mapping and Field Coordinator)
- Mr. Michael M. Angell, Project Geologist (Geologic Mapping)
- Mr. Andrew P. Thomas, Project Geologist (Trench Mapping)
- Dr. Thomas F. Bullard, Senior Geologist (Trench Mapping)
- Mr. Phillip Frame, Consulting Geologist (Trench Mapping)

Excavation and grading services were provided by Lee's Backhoe Service. The Zahn Group provided support for preparation of the report.

1.6 LIMITATIONS

The conclusions presented in this report are based on the assumption that soil, bedrock, and faulting conditions at the Walnut Creek Water Treatment Plant do not deviate appreciably from those described herein, as disclosed by the exploratory trenches, interpreted from aerial photographs, and observed during the field geologic mapping. If any variations or conditions are known or subsequently discovered by others, Geomatrix should evaluate the effects these variations and conditions have on our conclusions and, if necessary, develop supplemental conclusions. Conclusions are made for the specific project elements described in this report.

In the performance of its professional services, Geomatrix, its employees, and its agents comply with the standards of care and skill ordinarily exercised by members of our profession practicing in the same or similar localities. This report may not provide all of the subsurface and geologic information that may be required by the District for assessment of faulting and landslide conditions at the Walnut Creek Water Treatment Plant. No warranty, either express

or implied, is made or intended in connection with the work performed by Geomatrix, or by the proposal for consulting or other services or by the furnishing of oral or written reports or findings. Geomatrix is responsible for the conclusions and recommendations contained in this report, which are based on data related only to the specific project and locations discussed herein. In the event conclusions or recommendations based on these data are made by others, such conclusions and recommendations are not Geomatrix's responsibility unless we have been given an opportunity to review and concur in writing with such conclusions and recommendations.

2.0 GEOLOGIC AND SEISMIC SETTING

The WCWTP site is located in the East Bay Hills of the San Francisco Bay Area. The geologic and geomorphic character of this region is strongly influenced by tectonic activity, both past and present. Understanding the regional- to local-scale tectonic and geologic setting is very important for assessing the location and activity of faulting. Faults in the Bay Area (Figure 2-1) kinematically interconnect and appear to systematically transfer slip between adjacent faults. The site area, for example, lies near the intersection of the Calaveras, Concord, and Franklin faults, and the Diablo thrust fault. Even though there has been considerable study of the tectonics and geology of the site area, the structural interaction and kinematic linkage of these faults are complex and incompletely understood. This section describes the previous investigations of the tectonic and geologic setting of the plant site and surrounding area, first focusing on the regional scale and then on the site-specific scale.

2.1 REGIONAL TECTONIC SETTING

The San Francisco Bay Area is a region presently characterized by high rates of tectonic activity. Basement bedrock between the San Andreas fault on the west and the San Joaquin Valley on the east consists primarily of the Franciscan Complex, a heterogeneous assemblage of deep-sea sediments and related oceanic crustal rocks of Mesozoic age (65 to 200 million years old), and their shallower-water age equivalent known as the Great Valley Sequence. Franciscan Complex rocks are a product of tectonic subduction, a process wherein an oceanic plate collides with and slides beneath a continental plate along a highly sheared interface. As a result of subduction, the Franciscan Complex is now highly disrupted and much of it forms a mélange, a tectonic mixture of rocks having a wide range of lithologies and degrees of deformation. Although folded and faulted, the sandstones, shales, and conglomerates of the Great Valley Sequence are considerably less deformed and maintain their general stratigraphic continuity because they have not undergone subduction.

Beginning about 30 million years ago in southern California, this subduction boundary began evolving into the San Andreas fault zone (Figure 2-1), the currently active transform (horizontally moving) system of faults that defines the boundary between the North American and Pacific plates. The Hayward fault, which is located more than 10 km west of WCWTP, and the Calaveras fault, located about 12 km southeast of the site, are major components of this plate boundary. The transition from subduction along a convergent plate margin to strike-slip faulting along a transform plate margin occurred in the Bay Area between about 9 and 14 million years ago. This transition caused uplift of the block of crust between the San Andreas and Hayward faults now occupied by San Francisco Bay. Sediment shed eastward from this elevated block formed the nonmarine Contra Costa Group, which includes the Orinda Formation and four other formations that have an aggregate thickness of more than 6500 feet. Prior to this change in the tectonic regime, the Walnut Creek area was the site of prolonged marine sedimentary deposition that is now represented by sandstones and finer-grained rocks of Paleocene to Miocene age. Included are units of the Miocene San Pablo Group (Briones and Neroly formations), Miocene Monterey Group (Hambre Formation), and older units such as the Oligocene San Ramon Formation and Paleocene/Eocene Meganos and Martinez formations.

Following deposition of the Contra Costa Group, and beginning about 3 to 4 million years ago, an increase in the component of compression across the San Andreas fault system (Harbert and Cox, 1989) caused local uplift and created the ranges and intervening valleys that dominate the topography of the Coast Ranges at the latitude of San Francisco, including the East Bay Hills near Walnut Creek, and Mount Diablo. The formerly elevated San Francisco Bay structural block subsided to its present low elevation, while the East Bay Hills were elevated and squeezed into large folds and cut by faults.

2.2 REGIONAL GEOLOGY

Six published geologic maps cover the site area: Lawson (1914); Saul (1973); Dibblee (1980a); Graymer and others (1994); Crane (1995a); and Haydon (1995). Four of these maps that also show the WCWTP location are presented in Appendix A of Geomatrix (1995). The regional structure depicted on all four maps is similar. All show an intra-range fault (Franklin-

Southhampton fault) near the base of the eastern hill front separating a northwest-trending syncline of Upper Miocene shallow marine sandstone on the southwest from southwest-dipping Eocene-Oligocene shallow marine sandstone and shale on the northeast. The maps of Graymer and others (1994), Crane (1995a), and Haydon (1995) are regional compilation maps with some original input for local areas by the authors, whereas the maps of Saul (1973) and Dibblee (1980a) are based largely on their individual mapping efforts.

No geophysical data pertinent to the geology of the site was identified during our review of CDMG and USGS publications and maps.

2.2.1 Franklin Fault

The closest regional fault of potential significance to WCWTP is the Franklin fault, traces of which have been previously mapped across the WCWTP site (Figure 2-2). Geomatrix initially evaluated this fault while developing a comprehensive seismic source model for assessing the performance of Bay Area bridges for Caltrans (Geomatrix, 1993; Youngs and others, 1992). Responding to recommendations in the Geomatrix (1993) investigation of the Carquinez Bridge, Caltrans recently completed a study to evaluate the presence of traces of the Franklin fault near this bridge and to assess the fault's seismic activity. Caltrans acknowledged that this fault has been upgraded in status from inactive to potentially active by Contra Costa County (Woodward-Clyde Consultants, 1986). Based on discussions with S. Figuers, who mapped an eastern trace of the fault close to the bridge's southern approach (Figuers, 1991), and a reconnaissance geologic study, Caltrans found no evidence for a major fault in the vicinity of the structure and recommended against a full-scale fault study (Heyes, 1995).

The assessment of the Franklin fault is based on review of these previous investigations, the results of the Phase II trenching investigation and associated geologic mapping at the WCWTP site, and evaluation of geologic maps and reports covering the Walnut Creek-Lafayette area (e.g., Graymer and others, 1994; Haydon, 1995) published since development of the Bay Area seismic source model (Geomatrix, 1993).

It should be noted that although the location of the Franklin fault northwest of Walnut Creek is reasonably well constrained and more or less consistently portrayed on published geologic maps (e.g., Dibblee, 1980a), there is significant uncertainty as to the exact location of the Franklin fault and its relationship to other nearby faults in the vicinity of Walnut Creek and to the south toward Danville (Figure 2-2). Specifically, the relationship between the southern Franklin fault and the northern Calaveras fault, both of which occupy the same structural trend, is represented differently on published geologic maps of the region (e.g., Saul, 1973; Dibblee, 1980b,c; Graymer and others, 1994; Haydon, 1995). Part of this uncertainty can be explained by an inconsistent use of nomenclature in the geologic literature. To some extent this situation has arisen from the subtle, albeit significant, structural relationships among the major faults represented on the various geologic maps of the Walnut Creek-San Ramon Valley corridor. This inconsistency also reflects uncertainty in the northern extent of the Calaveras fault, a major active component of the transform boundary between the North American and Pacific plates that splays from the San Andreas fault south of Hollister. Slip on the Calaveras fault diminishes to the north, apparently by transfer of strain to adjacent strike-slip faults.

South of Danville, the Calaveras fault is clearly marked as an active structure by late Quaternary stratigraphic and geomorphic features, and by historical and instrumental earthquake data (Figure 2-2). From Danville north there apparently is insufficient slip on the northern Calaveras fault for it to have a clear geomorphic signal as a tectonically active feature either in the alluvium of the San Ramon Valley-Walnut Creek area or within the bedrock hills to the west. Neither the northern Calaveras fault north of San Ramon nor the Franklin fault is judged active by the California Division of Mines and Geology (Hart, 1988).

The Geologic Map of California (San Francisco Sheet) by Jennings and Burnett (1961) portrays the Franklin fault as divisible into northern and southern reaches–an interpretation based on early mapping by Lawson (1914). According to Lawson (1914), the northern part of the Franklin fault extends southeast from the Carquinez Strait near the Carquinez Bridge and is interpreted as being cut and offset by an unnamed east-trending fault just west of Walnut Creek. The southern part of Lawson's (1914) trace of the Franklin fault extends south along the crest

of the hills east of Tice Valley and west of Castle Hill and connects with the Calaveras fault along the west side of San Ramon Valley between the towns of Danville and San Ramon. More recent work by Saul (1973); Dibblee (1980a,b,c and 1981); Jennings (1975, 1994); Earth Sciences Associates (1983); Graymer and others (1994); and Haydon (1995) has refined the location of the Franklin fault, particularly the northern section. In general, their mapping supports subdividing the fault into northern and southern sections in the vicinity of Walnut Creek (Figure 2-2). The revised edition of the Geologic Map of California (San Francisco-San Jose Quadrangle) by Wagner and others (1990) does not show the east-trending fault, but is otherwise consistent with these more detailed geologic maps.

Northern Franklin Fault - As currently understood, the northern Franklin fault is a northwest-trending, northeast-dipping, high-angle reverse fault that extends continuously from the hills south of the Carquinez Strait to the Walnut Creek area, truncating the Southampton fault about a mile southeast of Alhambra Valley (Graymer and others, 1994). The northern Franklin fault lies almost entirely within bedrock, its trace weakly defined by aligned linear drainages, saddles, and ridges. West of Franklin Canyon, the geomorphic expression of the Franklin fault is relatively poor (Earth Sciences Associates, 1983). Major structural and stratigraphic discontinuities are mapped along the northern portion of the fault south of Carquinez Strait (Dibblee, 1980a; Sims and others, 1973; Wagner and Bortugno, 1982; and Graymer and others 1994). In this northern area, rocks of the Upper Cretaceous Panoche Formation on the northeast are juxtaposed against Eocene through Miocene rocks on the southwest. Major reverse dip-slip separation, with the east side up and a significant right-slip component, is believed to have occurred across the northern Franklin fault since Miocene time (Dibblee and Darrow, 1981; Earth Sciences Associates, 1983). Between the Southampton fault and Walnut Creek, the fault places Paleocene sandstone on the east against upper Miocene sandstone and shale on the west (Saul, 1973; Dibblee, 1980b; Graymer and others, 1994). Dibblee (1980b) identifies this structure as the Southampton fault, a convention not followed in this report.

Northern to Southern Franklin Fault Transition Zone - Approximately one-half mile northwest of the Highway 24 and Interstate 680 interchange, the southeast-trending northern portion of

the Franklin fault intersects or merges with a more northerly trending fault near the range front (Dibblee, 1980b; Saul, 1973; Jennings, 1975, 1994; Graymer and others, 1994). This north-trending fault is identified by Dibblee (1980b) as the Calaveras fault and is shown dying out within alluvium 4000 feet north of this structural intersection (Figure 2-2). Graymer and others (1994) also show a fault at this location that dies to the north, but have mapped it as a splay of the larger, more continuous Franklin fault. These latter authors interpret the Calaveras fault as a buried and queried feature lying about one-half mile to the east and extending north beneath alluvial cover to the active Concord fault (Figure 2-2). Saul (1973) shows a northwest-trending fault zone in the same general location as, and extending farther to the west of, Dibblee's (1980b) Southampton (Franklin) fault. Saul (1973) also shows this fault zone intersecting, and possibly being cut by, a more northerly trending fault near the range front at Walnut Creek; this latter fault dies to the north. Saul (1973) regards this entire system of faults as the (northern) Calaveras fault, and interprets it as a zone of vertical, right-lateral strike-slip faults.

Southern Franklin Fault - South of Walnut Creek, the Franklin fault (or the northern Calaveras fault of Dibblee [1980b] and Saul [1973]) crosses the alluvial valley of Las Trampas Creek as an apparent buried feature and reappears as a bedrock fault along the west side of Castle Hill between Tice Valley and the northern San Ramon Valley north of Alamo (Figure 2-2) (Dibblee, 1980b [Las Trampas Ridge Quadrangle]; Graymer and others, 1994). Here the fault places Paleocene and Eocene sandstone on the east against upper Miocene sandstone on the west, similar to the stratigraphic offsets mapped to the north near Walnut Creek. At this southerly location, the fault is identified by Dibblee (1980a) as the Calaveras fault, and by Ham (1952) and Graymer and others (1994) as the Franklin fault. The fault identified as the Calaveras fault by Graymer and others (1994) lies parallel to and east of the Franklin fault, and joins the Franklin fault at the southern end of Castle Hill near Alamo (Figure 2-2).

Immediately south of this branchline between the northern Calaveras and southern Franklin faults, the combined fault leaves bedrock and enters the alluvium of the San Ramon Valley. From here southward this fault is no longer referred to by any workers as the Franklin fault; all agree it is the northern Calaveras fault. Between Danville and San Ramon, Dibblee (1980a)

maps the northern Calaveras fault beneath a large landslide complex on the east flank of Las Trampas Ridge; Graymer and others (1994) depict the fault as a queried trace beneath the alluvium of San Ramon Valley east of the landslides. The Calaveras fault in the Danville area is only moderately to poorly expressed as a range front geomorphic feature, and as tonal and topographic lineaments within the alluvium of San Ramon Valley (Simpson and others, 1992). Based on analysis of bedrock structure in the region, Rodgers and Halliday (1992) and Geomatrix (1994) also locate the northern Calaveras fault within the San Ramon Valley in the vicinity of Danville.

South of San Ramon, the Calaveras fault has sufficient geomorphic expression and evidence for late Quaternary stratigraphic offsets to be considered active by the California Division of Mines and Geology (Hart, 1981 [Alquist-Priolo Fault Zone Map of the Diablo 7.5 minute Quadrangle]; Simpson and others, 1992).

Structural Setting of the Franklin Fault - A regional perspective of the structural geologic relationships along the east margin of the northern East Bay Hills offers some insight into the nature of the Franklin fault and its relationship to the Calaveras fault and other nearby faults. The northern Franklin fault between Carquinez Strait and the northern San Ramon Valley represents one of the most significant structural and stratigraphic discontinuities in the region. As indicated by the vertical stratigraphic separation in bedrock along this section of the fault, the east block has been uplifted between 4000 and 7000 feet. Horizontal displacements cannot be accurately judged without detailed investigations, primarily because much of the fault is subparallel to bedrock structure. Geomatrix estimates that horizontal displacements with a right-lateral sense may be at least 10,000 to 15,000 feet across the northern Franklin fault.

An important regional characteristic of the Franklin/Calaveras fault system is its along-strike geometry and relationship to adjacent faults. Between Carquinez Strait and its intersection with the Southampton fault, the Franklin fault follows a N35°W trend, parallel to the regional trend of the San Andreas fault system in northern California. Just west of the Southampton fault (at

the intersection with an unnamed north-trending fault), the Franklin fault swings to a more westerly (N45°W) trend for several miles then resumes a N35°W trend south to the range front in the vicinity of Walnut Creek. Between Walnut Creek and Castle Hill, the southern Franklin fault trends approximately N10°W, 25 to 35 degrees more northerly than adjacent sections of the fault. South of Castle Hill to San Ramon, the fault resumes a regional San Andreas trend of N35°W. This "zigzag" geometry in the mapped fault trace is closely mimicked by a neighboring fault to the west, the Lafayette fault, which branches from the northern Franklin fault at the Southampton fault intersection and rejoins the (northern Calaveras) fault just south of San Ramon.

The overall geometry and deformation style of the northern Calaveras, Franklin, and Lafayette faults define a structural geologic feature called a strike-slip duplex (Woodcock and Fischer, 1986). The concept of a strike-slip duplex applies terminology initially developed to describe fault geometries commonly observed in compressional fold and thrust belts. These features are isolated structural blocks bounded by sigmoidal (Z-shaped or S-shaped) faults that form a ramp/flat geometry. Duplexes are a fundamental geometry of fault systems that form under relatively high-strain environments by sequential linkage of ramp segments arranged en echelon (e.g., Butler, 1982). The recognition of this distinctive structural feature in the Walnut Creek area is important because it demonstrates a structural connection between the Franklin and Calaveras faults, and also indicates that significant amounts of lateral displacement may have been transferred between the two fault structures since the Miocene.

If the northern Calaveras and southern Franklin faults are structurally linked as bedrock features, as the preceding observations strongly suggest, the fundamental question to be addressed for a seismic hazard analysis is how this linkage is currently manifested as late Quaternary tectonic and seismogenic behavior. To answer this question, there must be an understanding of what happens to the Calaveras fault north of Alamo. Although strong evidence exists for Holocene activity on the Calaveras fault south of San Ramon near Calaveras Reservoir (e.g., Kelson and others, 1996; Geomatrix, 1994), and evidence for the presence of a

late Quaternary active Calaveras fault between San Ramon and Alamo is weak at best, unequivocal evidence for both the location and late Quaternary activity north of Alamo are lacking. The fault is neither "sufficiently active" nor "well-defined" to warrant inclusion into a California Fault-Rupture Hazard Zone (Hart, 1988). This could be explained partly by the observation that the fault, or faults, which extend along the trend of the Calaveras fault from Alamo to the northwest lie almost entirely within the bedrock of the East Bay Hills. Evidence for late Quaternary activity in this hilly terrain is notoriously difficult to assess due to a paucity of late Quaternary deposits and to the rapid rate that geomorphic processes typically overprint and obscure evidence of tectonic slip, particularly on steep slopes (e.g., Montgomery and Jones, 1992).

An alternative explanation is that active strike-slip displacement is transferred from the northern Calaveras fault westward to the Hayward fault across a restraining stepover expressed as the compressive structures (folds and thrust faults) and related uplift of the East Bay Hills (Aydin, 1982; Aydin and Page, 1984). Slip may also be transferred eastward across a releasing stepover to the Concord fault (Oppenheimer and Macgregor-Scott, 1992). This stepover is well expressed in the instrumental record by several northeast-trending seismic "lineaments" that extend from the northern Calaveras fault between Danville and Alamo and the southern extension of the Concord fault (Page, 1982; Oppenheimer and Macgregor-Scott, 1992; Simpson and others, 1992). No active geologic features, either within bedrock or Quaternary alluvium, have been identified within this stepover, however, even though Holocene right-lateral strike-slip is well documented along the northern Concord fault (Sharp, 1973; Wills and Hart, 1992). It is also possible that some minor slip might be transferred at a very low rate from the northern Calaveras fault northward to the Franklin fault, although no evidence for Holocene activity has been found on the traces mapped between Danville and Walnut Creek (Ridley and others, 1982).

It is important to note that evidence for Holocene deformation in this region (including seismicity) is restricted to the northern Calaveras fault (south of Danville) and to the Concord fault. Therefore, although bedrock relationships suggest that Tertiary deformation has

transferred from the northern Calaveras fault to faults within the East Bay Hills, including the Franklin fault, the available evidence for Holocene and historical tectonic deformation in the region suggests that most, if not all, of the remaining strain accumulated by the northernmost Calaveras fault is currently transferred north and east to the Concord fault.

2.2.2 Activity of the Franklin Fault

Subsurface investigations at two sites within the zone of faulting associated with the northern Franklin fault, one on Franklin Ridge south of Highway 4, and the other at the WCWTP, provide geologic evidence regarding the recency of fault activity. Based on this evidence, which is described below, the northern part of this fault could be considered "potentially active" according to CDMG criteria (i.e., has experienced possible slip within Quaternary time —the past 1,600,000 years) and is likely to be considered a "latest Pleistocene active fault" by DSOD (Fraser, 1997, oral communication). If this latter designation is applied to the northern Franklin fault, the DSOD will consider the fault a seismic source for dam design or reevaluation.

As part of their seismotectonic study of Martinez Dam for the U.S. Bureau of Reclamation, Earth Sciences Associates (1983) excavated two backhoe trenches across what appears to be a secondary trace of the Franklin fault on Franklin Ridge about 1 mile south of Highway 4 (Figure 2-2). This study concluded that in their trench F-3, a 35,000- to 40,000-year-old paleosol and the overlying colluvial soil are displaced by complex shearing that has a dip-slip component. The shears suggest multiple displacements "...with movement displacing the 35,000 to 40,000 year old paleosol and some recurrent offset of colluvium estimated to be on the order of 8,000 or 12,000 to about 20,000 years old", indicating possible early Holocene fault movement (Earth Sciences Associates, 1983). These age assessments were made by Dr. Roy Shlemon based on his observations of pedogenic soil development during a soil-geomorphic reconnaissance. No numerical-age methods, such as radiocarbon analysis, were used to confirm the estimated timing of most recent slip on the shears. Based on review of the report by Earth Sciences Associates (1983), Geomatrix (1993) suggested that the shearing that

disrupts the paleosol and the overlying colluvium in trench F-3 could be explained by landsliding as well as by tectonic faulting.

As part of revisions to the Safety Element of the Contra Costa County General Plan (1991), Woodward-Clyde Consultants (1986) changed the status of the Franklin fault from "inactive" to "inferred active" based on the late Pleistocene displacements at the Franklin Ridge Site reported by Earth Sciences Associates (1983) and based on a tectonic model. On the county's map of earthquake faults, the Franklin fault between Carquinez Strait and Pleasant Hill is depicted as a "fault with reported Late Pleistocene displacement." From Pleasant Hill south to its junction with the Calaveras fault at a point midway between San Ramon and Danville, the County depicts the Franklin fault as a "fault inferred active on the basis of a tectonic model," but queries the trace from just south of the I-680-Highway 24 interchange to the Calaveras fault. The Southampton fault is also depicted as a "fault inferred active on the basis of a tectonic model."

2.3 PREVIOUS STUDIES AT THE WCWTP SITE AND VICINITY

Geologic mapping and trench exploration were conducted at the WCWTP site by C. Marliave (1955, 1956) and B. Marliave (1963) prior to construction of the plant. This geologic mapping was conducted at a scale of 1 inch equals 1000 feet (i.e., 1:12,000) using existing U.S. Geological Survey topographic maps of the area. C. Marliave (1955) believed that differential weathering, rather than faulting, produced the topographic saddles and knolls at the WCWTP site. He recognized that the "Franklin Canyon fault" was mapped as traversing the general area and identified three possible fault locations: (1) a saddle situated between the operations building and the settling basin where Lawson (1914) had originally mapped the fault; (2) an upper saddle (probable fault trace) located within the "approximate location of mapped west fault traces," as shown in Figure 1-2; and (3) an eastern saddle (possible fault trace) located within the "approximate location of mapped east fault trace," as shown in Figure 1-2.

C. Marliave (1956) inspected two bulldozer trenches at the then prospective WCWTP site, one trench across the saddle between operations building and settling basin to the north and one

trench across the saddle to the south of the operations building. These original site exploratory trenches have been located based on Marliave's small-scale map and identification of trench scars (disturbed areas) visible on aerial photographs that were taken in 1959 (i.e., before plant construction) (see Plate 2). Marliave reports "...continuous bedrock exposed up both sides and across the bottom without any sign of faulting or rupturing." for both trenches. Marliave's letter report lacks any graphic trench logs or detailed description of the trench exposures.

Geologic mapping of the site was also conducted by B. Marliave (1963). Based on his work and the prior work of C. Marliave (1955 and 1956), B. Marliave believed that neither the main Franklin fault nor a branch fault traversed the site of the WCWTP. According to B. Marliave (1963), the Franklin fault passes along the west side of the saddle near the east edge of the property.

B. Marliave (1963) describes the sandstone on the site as jointed and fractured, a condition he attributed to local folding and the proximity to the Franklin fault. His site geologic map (scale 1 inch = 1000 feet) shows a lens of Rodeo Shale separating the Hambre and Briones formations from the area of the clearwell/operations building to the south. However, C. Marliave (1956) does not mention the presence of the Rodeo Shale in the bulldozer trench, nor is this unit shown on his geologic map.

Despite these inconsistencies, the initial site studies are generally in agreement with the geologic mapping of Dibblee (1980), Graymer and others (1994), and Crane (1995a), which indicate that the Franklin fault passes through the saddle east of the settling basin (Figure 1-2). However, these studies are not consistent with the work of Saul (1973), who maps two fault traces through the western saddle trenched by Marliave (1956) within the zone designated as the approximate location of mapped west fault traces. Neither the bulldozer trench work by C. Marliave (1956) nor the geologic mapping of B. Marliave (1963) suggests that a fault trace passes through this western saddle.

Fifteen boreholes were drilled at the site as part of investigations to characterize the geologic and geotechnical conditions for design of the WCWTP (East Bay Municipal Utility District, 1963). The boreholes provide information on the types of bedrock present and on their engineering and physical properties. Plate 2 shows the boring locations and the dominant lithology that was encountered in each borehole. These data indicate that a shale/siltstone unit underlies the central part of the site in the area of the operations building and to the south, and that sandstone is present on the periphery (i.e., to the northeast, southwest, and north of the operations building).

Geomatrix (1995) conducted a preliminary assessment of surface fault rupture hazard at the WCWTP based on a review available data and limited reconnaissance mapping of Tertiary bedrock and Quaternary soil units. This Phase I study identified two possible zones where traces of the northwest-trending Franklin fault have been mapped as traversing the plant site by Saul (1973), Dibblee (1980a), Graymer and others (1994), and Crane (1995a) (Figure 1-2). These locations are referred to as: (1) the approximate location (or zone) of mapped west fault traces (based on work by Saul, 1973; Marliave, 1956); and (2) the approximate location (or zone) of mapped east fault traces (based on work by Dibblee, 1980; Graymer and others, 1994; Crane, 1995a; Haydon, 1995). These zones were drawn by Geomatrix (1995) by enlarging the existing regional fault maps, transferring the fault locations onto a topographic map of the WCWTP site, drawing the zones wide enough to incorporate uncertainties of the fault locations, and finally tracing the zones onto the base map for Figure 1-2. The trace of the Franklin fault that was mapped by Haydon (1995) after the Geomatrix (1995) study falls within the zone defined by the approximate location of mapped east fault traces (Figure 1-2).

Other northwest- to north-trending fault traces are mapped east of the area shown in Figure 1-2 and the WCWTP property by Saul (1973), Dibblee (1980), Graymer and others (1994), Crane (1995a), and Haydon (1995) (Geomatrix, 1995, their Figures A-1 through A-4). In addition, Saul (1973) mapped short north- to east-trending fault traces in the site vicinity. If correctly located, one of these "cross fault" traces passes beneath the operations building and filters area. No north- to east-trending features are mapped beneath the existing clearwell.

The Phase I study (Geomatrix, 1995) indicated that the likelihood of Holocene activity on the mapped fault traces is low based on the absence of obvious geomorphic expression of young faulting and the apparent lack of vertical displacement of an elevated, planar, and gently sloping geomorphic surface located west and north of the site that was judged to be of Quaternary age (Plate 2). Modern drainages have incised into the geomorphic surface, indicating that relative uplift is occurring within the region. However, the cause, timing, and extent of the uplift could not be determined with the available data. The Phase I study by Geomatrix (1995) concluded that the available data were insufficient to classify the Franklin fault as active, or to demonstrate that major fault traces cross the WCWTP site, including the existing clearwell and the area of the proposed clearwell expansion. Given the limited available data, however, this Phase I study also concluded that the presence of faults traversing the site cannot be precluded with a high degree of confidence.

3.0 FIELD INVESTIGATIONS OF FAULT-RUPTURE HAZARD AT WCWTP

Field investigations to gather data for the assessment of the fault-rupture hazard at the WCWTP site were conducted between December 30, 1996 and September 8, 1997, and included geologic mapping and trenching. The geologic mapping focused on the bedrock stratigraphy, Quaternary stratigraphy, geologic structure, and existing conditions (cutting and filling) at the plant site and vicinity. The trenching initially targeted the eastern and western zones of mapped faults (defined in Geomatrix, 1995) and then targeted specific faults and lineaments that were identified through the geologic mapping and initial trenching. This section describes the existing site conditions and proposed expansion, site exploration program, results of the mapping and trenching programs, geologic structure, and origin of deformation at the plant site.

3.1 EXISTING AND PROPOSED SITE DEVELOPMENT

The WCWTP was built in the 1960s and consists of an operations building and filters built on top of an elongate and rounded northwest-trending ridge, and a clearwell that was constructed over a northwest-trending drainage located directly west of the hill, as well as other facilities (Figure 1-1). Cutting and filling activities during plant construction have significantly modified the original landscape. The top of the existing clearwell is as much as 75 to 80 feet above the floor of a former stream canyon. Significant quantities of fill were also placed on the part of the geomorphic surface (Geomatrix, 1995) that lies directly west to southwest of the existing clearwell (Plate 2). Additional fill was placed in the upper end of the drainages directly east and west of the geomorphic surface. Urban development has significantly modified the landscape northwest, north, and east of the site.

Additional facilities currently being considered by the District are shown on Plate 1. These facilities include steel tanks, settling basins, filters, and chemical treatment and storage buildings, as well as appurtenant facilities and pipes. These proposed additions are preliminary and subject to modification.

3.2 SITE EXPLORATION PROGRAM

Reconnaissance geologic mapping of exposed bedrock and Quaternary units in the site vicinity was conducted at scales of 1:1,200 (1 inch = 100 feet) and 1:6,000 (1 inch = 500 feet) (Plates 2 and 3, respectively) Stratigraphic and structural data exposed in trenches were incorporated in the geologic mapping as appropriate. The site exploration program at the WCWTP consisted of limited geologic mapping, interpretation of aerial photographs, and mapping of trench walls and road cuts.

The trenching program was designed to obtain continuous exposure of bedrock and Quaternary units along the western and northern sides of the WCWTP (Figure 1-2). Trenches 1, 2a-g, 4a and 8 (Plates A-1 through A-8, Appendix A) were excavated on the geomorphic surface west of the site to evaluate the location and recency of faulting in the "Approximate Location of Mapped West Fault Traces" (mapped by Geomatrix, 1995) (Figure 1-2), and Trench 6 was excavated to the north of the site to evaluate the location and recency of faulting in the "Approximate Location of Mapped East Fault Traces" (mapped by Geomatrix, 1995). The remainder of the trenches (3, 4b, 5, 7, 9, 10, and 11) were excavated and studied to further investigate shearing found in the above-mentioned trenches and to evaluate a landslide versus fault origin for the shearing.

Figure 1-2 and Plate 2 shows the locations of trenches (including roadcut exposures) that were excavated, studied and mapped at the WCWTP site. Individual trenches range in length from 24 to 546 feet, with a total combined length for all trenches of more than 2,800 feet (Appendix B). Trench depths ranged from about 2 to 19 feet and averaged about 7 to 8 feet. The goal was to dig deep enough to penetrate the surficial deposits and expose two or more feet of bedrock to assess the presence of bedrock fault zones. The activity of faults identified in these trenches was evaluated using overlying surficial (soil) deposits of late Pleistocene to Holocene age.

3.3 SITE STRATIGRAPHY

Pre-Quaternary bedrock and Quaternary alluvial geomorphic surfaces were mapped at the site and vicinity to provide a stratigraphic framework (Table 3-1) for assessing the location, amount of displacement, and recency of faulting. Bedrock units were identified and mapped according to their grain size, color and outcrop character. Formation names were assigned to the bedrock units based on comparison of our hand-specimen descriptions with lithologic descriptions of Saul (1973), Dibblee (1980a), Graymer and others (1994), and Haydon (1995). Quaternary units were mapped on aerial photographs and in the field. Descriptions of Quaternary units included texture, color, genesis, and pedogenic soil development.

3.3.1 Bedrock Stratigraphy

Bedrock at the site and surrounding area consists of Oligocene to Miocene marine sedimentary rocks (Saul 1973, Dibblee, 1980a). In general, the oldest rocks in the site vicinity are lower Eocene and upper Paleocene claystones and sandstones of the Meganos and Martinez formations located east of the site, on the east side of the Franklin fault. West of the Franklin fault, bedrock consists primarily of Miocene sandstone with subordinate siltstone and claystone of the Hambre, Briones and Neroly formations. A distinctive, fine-grained, white sandstone east of the site and immediately west of the Franklin fault may represent a fault-bounded slice of Oligocene San Ramon Formation. General lithologic descriptions of the rock units found at the site are provided below, and the general stratigraphy is shown in Table 3-1. The structural character of the formations and the relationships among them is discussed in section 3.4.

The WCWTP site is located within a tightly folded section of sandstone and clayey siltstone composed predominantly of fine to very fine, light brownish gray (weathered) to yellowish gray (fresh) sandstone (Plate 2). Primary structure is generally rare in this sandstone, although faint bedding defined by textural laminae is present at several trench and outcrop localities. Discontinuous, millimeter- to centimeter-scale beds of organic debris are a distinctive feature, but are present only at a few outcrops north of the site. Fossils are not uncommon, but typically are isolated molds within massive sandstone. Two fine-grained units are present at the plant

site. One, lying to the west consists of light yellowish gray, massive, fossiliferous silty mudstone. This unit is exposed at the southern edge of the site and transects the site in a north-northwest trending syncline defined in boreholes and outcrops and on aerial photographs (Plates 2 and 3). A second fine-grained unit is exposed west of the plant site and consists of gray, massive claystone and siltstone.

Exposures of the sandstone are moderately to intensely fractured, commonly with anastomose fracture patterns, and shear fabric developed within and adjacent to the fractures. Some of the fractures are filled with friable to soft, dark brown clay. A shear origin for the clay is likely because of the deformed condition of the surrounding rock, but could not be demonstrated. Intense deformation of this sandstone unit is indicated by the abundance of fractures, a strongly-developed cleavage at several locations north and south of the site, local silicified and brecciated zones, and the presence of high-angle, north- and northeast-trending shear zones. Syndepositional or early post-depositional deformation is indicated by the presence of common, mud-filled veins with apparently random orientation and no evidence of associated fracturing of lithified rock. Where exposed, the silty mudstone unit is moderately to intensely fractured.

Saul (1973) interprets this unit as the lower Oligocene San Ramon Formation. More recently published maps for the region, however, place this unit within the middle Miocene Hambre Formation. Based on a comparison between its lithologic characteristics in the site area and the lithologic descriptions from more regional geologic mapping, we consider this unit to belong to the Hambre Formation.

A distinctive gray-white sandstone crops out in roadcuts and in trench excavations directly east and southeast of the site. The sandstone is fine to very fine, massive, light yellowish gray (weathered), light gray to very light gray (fresh), friable to hard, weak to moderately strong and tuffaceous. Primary sedimentary structures are rare, and the unit is moderately to locally intensely fractured. The contact between this white sandstone and the Hambre Formation to the west was not observed in outcrop, but was exposed in the east end of Trench 6 where it is represented by a series of steeply dipping, northwest-trending faults and breccia zones. This

unit is tentatively assigned to the lower Oligocene San Ramon Formation and appears to be bounded to the east and west by steeply dipping faults (see section 3.2). The white sandstone is in fault contact to the east with lower Eocene to upper Paleocene rocks. The most recent published maps for this region (Graymer and others, 1994; Haydon, 1995) disagree as to the formation names of these units, but not their ages. Most maps agree on the presence of a fault at this location, but do not agree on fault name (see section 3.2). Outcrops of the lower Tertiary units east of the fault were not observed in the field. For this report, we have adopted the formation names of Haydon (1995) for the area east of the Franklin fault.

To the northwest, the Hambre Formation is in fault contact against sandstone, siltstone and mudstone of the middle to upper Miocene Briones Formation (Plates 2 and 3). The Briones Formation consists of a lower sandstone and an upper fine-grained unit. The lower Briones sandstone consists of fine- to medium-grained, orangish brown (weathered), massive to moderately well-bedded, locally fossiliferous, moderately hard, moderately strong sandstone. Exposures of this unit are rare in the site area, primarily due to residential development. The upper Briones consists of brownish gray to light olive gray, moderately strong to strong, hard, nonfossiliferous siltstone, mudstone and silty mudstone. Exposures occur only within shallow landslides on the northeast-facing slopes west of the site, and in trench excavations. The location of the upper contact between the Briones Formation and overlying lower Neroly (a.k.a. Cierbo) Formation is easily identified on aerial photographs as the lower limit of forested slopes. Because both formations dip into the slopes in this area, the less permeable upper Briones claystones and clayey siltstones may form an aquitard that allows groundwater to concentrate in the overlying porous sandstones of the lower Neroly Formation.

The upper Miocene Neroly Formation is the most distinctive bedrock unit in the vicinity of the site. As mapped for this study, it is composed of upper and lower sandstone members that are distinguished primarily on the basis of color, cementation, distribution of fossils, and grain size. The lower member conformably overlies the fine-grained upper Briones and forms the steep, northeast-facing slopes west of the site. The lower Neroly Formation sandstone is light reddish brown (weathered) to yellowish green (fresh), massive to cross-bedded, well sorted, and

medium grained with local minor gravel in the upper section. The unit is fossiliferous and contains distinctive isolated bivalve shells with crescent-shaped limonite-stained casts. Dark lithic fragments account for up to about 40% (typically 20%) of the rock mass. The rock is friable to moderately hard, weak to moderately strong, and exhibits exfoliation weathering of a 1 to 2 cm thick reddish brown rind. The lower Neroly is moderately to weakly fractured, and locally intensely fractured. This unit is correlative with the Cierbo Sandstone.

The upper sandstone member of the Neroly Formation is very distinctive. The rock is light blue-gray (weathered and fresh), medium to coarse-grained, with rounded to subrounded grains and dark lithic clasts that account for about 15-25% of the rockmass. The unit is massive to thickly bedded, abundantly fossiliferous, and contains strongly cemented fossil beds. It is moderately hard to soft (weathered and hard to very hard (fresh) and moderately weak to very strong, depending on degree of weathering. The tall and narrow peaks above the site to the west are underlain by the upper sandstone member of the Neroly Formation in the steeply east-dipping limb of the Briones syncline.

3.3.2 Quaternary Stratigraphy

Quaternary units at the WCWTP include the late Pleistocene geomorphic surface and associated alluvial deposits, Holocene colluvium on hillslopes, and Holocene alluvium along modern drainages (Plate 2). The geomorphic surface, a product of fluvial erosion and subsequent deposition, is an excellent "strain gauge" to evaluate latest Pleistocene and Holocene fault activity because of its antiquity and relatively planar character. Therefore, the geomorphic surface was the focus of our trenching studies. Holocene colluvium and alluvium are less reliable "strain gauges" because of their youthful age, limited distribution, and irregular geometry.

The geomorphic surface consists of an erosional surface that is cut onto older alluvium and Tertiary bedrock, and a younger terrace, which occurs as a discontinuous terrace along the small valley that trends northwest from the existing clearwell (Plate 2). The surface occurs

directly west and north of the main plant site and lies about 30 feet above the modern drainage. The geomorphic surface appears to be a remnant of a larger, regional scale surface based on interpretation of aerial photography and limited field reconnaissance (Plate 3). This regional geomorphic surface appears to extend from the plant site north and east to the edge of the hills near the trace of the Calaveras fault as mapped by Dibblee (1980a).

The top of Tertiary sedimentary bedrock beneath the geomorphic surface is undulatory, with relief of up to about 10 to 12 feet (Figure 3-1). This relief, called paleotopography, represents an ancient, buried landscape. This buried landscape consists of northwest- and northeast-trending, bedrock-floored drainages and intervening interfluves. These drainages have been filled with alluvium (Alluvium 1) comprised primarily of sand with lenses of sandy gravel and gravelly sand. A charcoal sample from a burn horizon in the upper three feet of this alluvium yielded a radiocarbon age of 31,410 ± 320 years before present (Beta-104148). Because this date was run on charcoal from the uppermost part of Alluvium 1, a late Pleistocene age is indicated for the alluvium (Figures 3-1 and 3-2).

The late Pleistocene age for Alluvium 1 is also indicated by the degree of pedogenic soil profile development (i.e., weathering profile that exhibits movement of weathering products into horizons of accumulation and/or depletion) on the fluvial deposits that comprise Alluvium 1. This soil is about 4.5 feet thick and has a very weakly developed, 2.0- to 2.5-feet-thick Bt horizon characterized by weak, moderate subangular blocky structure, and very thin clay films lining pores and bridging sand grains.

An erosional surface has been cut across the top of Alluvium 1 and bedrock (Figure 3-1) by lateral planation of a stream. This cut surface is generally abrupt and planar. There is typically very little to no erosional relief between where the surface is cut on bedrock and where the surface is cut on Alluvium 1. The erosive power of the stream appears to have been sufficient for the stream to plane off both bedrock and poorly consolidated sand deposits at about the same level. These relations indicate that the stream was meandering at the time the surface was

formed, and that very little to no downcutting (often the result of tectonic uplift) occurred during that period.

Alluvium 2 was deposited on this erosional surface (Figure 3-1). The contact between Alluviums 1 and 2 and between bedrock and Alluvium 2 is very abrupt, although locally it is gradual and/or mixed because of bioturbation. Alluvium 2 is comprised primarily of dark sandy to silty clay with occasional lenses of rounded gravel. The lenses of gravel indicate a fluvial origin for Alluvium 2; however, the strongly developed vertisol (i.e., a clay-rich pedogenic soil dominated by shrink-swell processes) and bioturbation have obliterated nearly all primary sedimentary structures and have homogenized the unit. Alluvium 2 is assigned a latest Pleistocene to Holocene age based on the radiocarbon date from the upper part of the underlying Alluvium 1, the strongly developed vertisol on Alluvium 2, and the relative deep (~30 feet) incision of the modern drainages below the geomorphic surface.

Small inset terraces occur along the canyon walls of drainages that have incised into the geomorphic surface. These terraces are included in the areas mapped as Qal on Plate 2. Incipient to no pedogenic alteration of the deposits associated with these terraces indicates they are of late Holocene to historical age. Alluvium along the bottom of modern drainage channels was undoubtedly deposited in recent years.

Although colluvium of probable Holocene age occurs on the hillslopes throughout the WCWTP Site, it was not differentiated as a separate unit on Plate 2.

3.4 BEDROCK STRUCTURE

The WCWTP site is located near the Franklin fault, where the fault enters the bedrock uplands of the East Bay Hills west of Walnut Creek (Figure 2-2). This reach of the Franklin fault lies at the northern end of a double-releasing bend in the right-reverse Franklin fault, and forms the northeast margin of a regional-scale, extensional strike-slip duplex discussed in Section 2.2.1 of this report. The main trace of the Franklin fault, as mapped at a scale of 1:24,000 by Dibblee (1980a) and Haydon (1995) and at 1:50,000 by Graymer and others (1994), lies near the range

front east of the plant site. Saul (1973) represents faulting east of the site near the range front as minor intraformational faulting (i.e., does not juxtapose different geologic formations) within the Eocene San Ramon Formation and discontinuous faulting along its contact with an unnamed, lower Eocene claystone. Saul (1973) mapped the site vicinity in greater detail (1:12,000) and places the main trace of the Franklin fault (referred to by him as the Calaveras fault) farther to the west, in the vicinity of the WCWTP.

Our investigations indicate the presence of a zone of northwest-trending faults and north- to northeast-trending cross faults between the range front on the northeast and an informally named West fault on the southwest. The main trace of the Franklin fault likely is located east of the plant site, as mapped by Dibblee (1980a), Graymer and others (1994), and Haydon (1995), because the identified faults in the plant site vicinity do not appear to exhibit significant stratigraphic separation and because uplifted geomorphic surfaces and possible fault-related photolineaments occur northeast of the site. The four northwest-trending secondary faults that occur within the site vicinity include the West fault directly west of the plant site, the Central fault at the plant site, and two East faults directly east of the plant site (Plate 2). Our studies suggest that the West fault, which initially was identified during the Phase II trenching study, is a tectonic feature related to the Franklin fault and that it forms the southwestern boundary of a zone of secondary deformation. The Central and East faults lie between the West fault and the main trace of the Franklin fault as mapped by Graymer and others (1994), Haydon (1995), and Geomatrix (this report).

The West and Central faults are nearly coincident with the main trace of the Franklin fault mapped by Saul (1973), (note that Saul called it the Calaveras fault), and the East faults are nearly coincident with the trace of the Franklin fault mapped by Dibblee (1980a). Because the West, Central and East faults appear to juxtapose similar lithologic units, these traces are considered to represent secondary deformation, and do not appear to be the main trace of the Franklin fault. The West fault and the bedrock structures within the zone of secondary deformation between the West fault and the Franklin fault are described in their structural

context below. Details of the secondary faults and associated zone of deformation as revealed in the trenches are presented in Section 3.6 below.

3.4.1 West Fault

Bedrock mapping of the West fault was conducted to determine if the observed deformation is due to tectonic faulting or landsliding and, if tectonic, to determine its relationship to the Franklin fault. In Trenches 4a and 4b, the West fault is a N35°W-trending, southwest dipping, right-normal oblique fault that juxtaposes sandstone of the Hambre Formation on the northeast against mudstone of the upper Briones Formation on the southwest (Plate A-8). Distinctive shale/siltstone of the upper Briones Formation thins to the south and is cut out entirely against the West fault on the north-facing slopes of the east-trending ridge south of the site (Plate 3). The West fault continues across the east side of this ridge, where it cuts out the lower Neroly Formation sandstone and juxtaposes Hambre Formation on the northeast against upper Neroly Formation on the southwest. South of the lower Neroly Formation and east to the Franklin fault, the location of the West fault is less certain. The West fault apparently intersects the main trace of the Franklin fault about 2000 feet southeast of the plant site. The southeastern end of the West fault was initially mapped by Lawson (1914) as a short west-trending fault that offset the trace of the Franklin fault.

Based on trench exposures and interpretation of pre-development aerial photographs, the West fault apparently joins the main trace of the Franklin fault about 4000 feet to the northwest of the plant site (Plate 3). Directly north of the plant site near the Mokelumne aqueducts, the West fault was exposed in Trench 9a where it separates sandstone of the Hambre Formation on the northeast and sandstone of the Lower Briones Formation on the southwest (Plate A-14). The location of the fault north of the Mokelumne aqueduct is less certain. The sparse outcrop pattern of the lower Briones Formation sandstone and a northwest-trending alignment of topographic saddles identified on predevelopment aerial photographs indicate the possible northwest extension of the West fault. Residential development, however, has significantly

altered the landscape, thus concealing and obscuring geologic relations in the region that includes the range front.

There is an overall step-like trajectory of the West fault trace across the Lower Briones Formation sandstone, along the less competent Upper Briones Formation shale/siltstone subparallel to bedding, and across the more competent sandstone of the Neroly Formation (Plate 3). This step-like trajectory and stratigraphic offset is consistent with strike-slip and down-on-the-west sense of displacement across the West fault.

3.4.2 Central Fault

A northwest-trending fault, informally named the Central fault, is present between the East and West faults (Plates 2 and 3). Based on geologic mapping and interpretation of aerial photographs, the Central fault was first identified as a structural discontinuity near the east side of the existing clearwell based on the several lines of indirect evidence. The west limb of the syncline that underlies the plant site appears to be truncated in the vicinity of a strong tonal and textural lineament (observed on predevelopment aerial photographs) that traverses the north-facing slope south of the site, and follows the west side of the hill upon which the WCWTP is located. This lineament is coincident with a north-northwest trending zone of strongly fractured bedrock having anomalous southwest and vertical dips that crop out between the south gate to the WCWTP and the channel of the stream north of the existing clearwell. The Central fault also is nearly coincident with the eastern margin of the fault zone mapped by Saul (1973) as the main trace of the Calaveras fault. As exposed in Trench 11, the fault is northwest-trending and steeply west dipping, and coincides exactly with the strongly expressed photolineament described above. Sandstone of the Hambre Formation is present on either side of the fault in this exposure. The exposure of the fault in Trench 11 (Plate A-16) is described in Section 3.5.2 below.

3.4.3 East Faults

The East faults comprise a zone of northwest-trending steeply dipping faults, shear fractures and breccia zones approximately 140 feet wide that extend from the crest to the base of Hill 340 at the northeast corner of the site (Plate 2). The internal structure of the East faults is discussed in Section 3.6.2. The East faults are truncated by, or merge with, the Franklin fault to the northwest. To the south, a sandstone unit within the Hambre Formation appears to be cut by the East faults (Plate 3). The orientation, intensity of deformation, and location of the East faults suggests that they are splays of the Franklin fault. The East faults are coincident with the main trace of the Franklin fault as mapped by Dibblee (1980a) and Haydon (1995), but sandstone of the Hambre Formation apparently crops out on either side of the fault (see discussion of Trenches 6 and 7 below, Plates A-11 and A-12). Therefore, the main zone of faulting along the Franklin fault was not crossed by the Phase II trenches and, on the basis of photointerpretation and stratigraphic relations, is inferred to lie east of the East faults.

3.4.4 Deformation Between Secondary Faults

The mapping and trenching investigations of this study demonstrate that cross faults, a tightly folded syncline, and very minor faults and fractures also occur within the zone of secondary deformation that lies southwest of the Franklin fault and northeast of the West fault. All of this secondary deformation is confined to lithologic units within the Hambre Formation. A south-plunging syncline identified from geologic mapping, boring data, and predevelopment aerial photographs transects the crest at the hill occupied by the WCWTP. The fold is bordered on its southwest side by the West fault and presumably by the Franklin fault on the northeast (Plates 2 and 3). The hinge of this fold is offset in an apparent right-lateral sense (and/or west-side-up sense) by a northeast-trending, steeply southeast-dipping cross fault that crosses the northern portion of the plant site. The southwestern and northeastern ends of this fault appears to be truncated against the Central and East faults, respectively. A north-northeast trending fault within the Hambre Formation was observed (by Geomatrix in March of 1995) in this vicinity in an excavation for a pipeline. If this fault is the same as the northeast-trending fault east of the Central fault, then it is offset in a right-lateral sense by the Central fault. Another cross fault located on the east side of the site, was observed in outcrop and on aerial photographs. This

north-trending vertical right-lateral fault cuts across and offsets the limbs of the syncline, but does not juxtapose different lithologic units (i.e., it is intraformational). The fault does not continue south of the Central fault and does appears not to continue north of the East fault. Minor faults and fractures having little to no discernible offset occur in the bedrock throughout the site. Some of these minor faults and fractures probably were inherited from a former episode of deformation. "Soft sediment" style of deformation is also evident in the bedrock, particularly in the Hambre Formation, but the majority of the minor faults and fractures appear to have a tectonic origin.

3.5 RESULTS OF TRENCHING STUDIES

The WCWTP Site lies within a zone of deformation bordered on the east by the main trace of the Franklin fault, and on the west by the West fault. This region (zone of deformation) lies within the Hambre Formation and is transected by the axis of a tightly folded syncline (i.e., a highly compressed, U-shaped folding of the rocks) that plunges steeply to the southeast and is cut by northwest- and north- to northeast-trending faults of tectonic origin (Plates 2 and 3). The northwest-trending faults include the West, Central, and East faults and are interpreted as secondary traces of the Franklin fault, which is judged to lie east of the plant site. The north- to northwest-trending faults are informally referred to as "cross faults." Minor bedrock faults, shear fractures, and joints also occur between the mapped faults. Table 3-2 summarizes the characteristics of secondary faults at the WCWTP. This section summarizes the results of the trenching studies and addresses the location and recency of activity of faulting at the WCWTP.

3.5.1 West Fault

The West fault is nearly coincident with the Franklin fault as mapped by Saul (1973) and was intercepted in Trenches 1, 3, 4a, 4b, 8, 9a, and 10c (Figure 3-3 and Plate 2; Plates A-1, A-7 to A-9, A-13 to A-15). The fault strikes N35°-40°W and dips 50 to 75 degrees southwest. The West fault juxtaposes claystone on the southwest against sandstone on the northeast in trenches 1, 3, 4a, and 4b, sandstone on the southwest against siltstone on the northeast in Trench 8, and sandstone against sandstone in Trench 9a.

The trace of the West fault is narrow (15 to 30 feet wide) and nearly linear to the northwest and west of the existing clearwell, but it changes to a more westerly strike to the south, where the zone is up to 80 feet wide (Figure 3-3). Several traces of the fault apparently pass through the eastern and western parts of the roadcut (Trench 8) south of the existing clearwell (Plate 2). A straight-line projection of the West fault to the southeast from Trenches 1 and 10c intersects the roadcut within 10 feet of one of the largest fault traces in the exposure (Plate A-13, stations 132 to 138 feet, Appendix A). Another trace apparently passes through the eastern end of the roadcut at about station 265 feet (Plate A-13), where sandstone on the southwest is juxtaposed against siltstone on the northeast.

Recency of Activity. The geomorphic surface and associated alluvial deposits directly north and west of the existing clearwell are used as strain gauges to assess the timing of the most recent slip along the West fault. The geomorphic surface and associated deposits are buried by locally thick artificial fill where the fault occurs west of the existing clearwell. However, they were exposed in Trenches 1, 3, 4a, 4b, and 10 (Plate 2). There is about 6 to 7 feet of down-on-the-southwest vertical separation of a charcoal horizon within Alluvium 1 in Trench 4a and the bedrock-Alluvium 1 contact in Trench 4b (Figure 3-2), and about 0.4 feet down-on-the-southwest vertical separation of a bedding contact within Alluvium 1 in Trench 10c (Figure 3-4). Photographs of the West fault within Alluvium 2 in the roadcut exposure (Trench 4a) are shown in Figure 3-5. Note the gravelly deposits on the northeast side of the fault and the sandy deposits on the southwest. Individual faults are locally filled with calcium carbonate and show as light colored bands.

The age of the most recent slip event on the West fault is uncertain. It clearly postdates deposition of Alluvium 1 and apparently predates deposition of Alluvium 2, although minor fracturing may affect the base of this latter unit. The radiocarbon date and the geologic relations in Trench 4a demonstrate that the shearing occurred more recently than 31,410 years ago. The broad age estimate for Alluvium 2 (i.e., latest Pleistocene to Holocene) allows for a Holocene slip event. However, whether the most recent slip event is late Pleistocene or

Holocene matters little, because the West fault is an "Active Fault" according to the DSOD criteria (see section 1.3).

Alluvium 2 is not displaced significantly where it crosses the fault, but it may be fractured locally. Fractures in Alluvium 2 were documented above the bedrock fault on in Trench 1 (Plate A-1, stations 190 feet and 192 feet). Alluvium 2 was deposited directly on bedrock, and Alluvium 1 is absent in this part of Trench 1. It is important to note that the trend of the fractures in Alluvium 2 are about 65 degrees different than the trend of the fault zone. The fractures in Alluvium 2 strike N80°E and have vertical dips, whereas the underlying bedrock fault zone strikes about N35°W and dips 50 to 70 degrees to the southwest. However, there are minor shear fractures within brecciated bedrock along the fault, and these fractures have similar attitudes (N80°W, 90°) as the fractures in Alluvium 2.

Evidence of shearing of Alluvium 2 in Trench 4a (Plate A-8) is uncertain because the contact between Alluvium 1 and 2 is bioturbated (i.e., the mixing of soil by biological processes - such as burrowing by gophers), and the contact is gradational over 10 inches (Figures 3-2 and 3-5). Therefore, a slip event with less than 10 inches of apparent vertical displacement, if present, would be difficult to resolve. Two fault traces apparently extend into the bioturbated zone, but clearly do not affect the overlying Alluvium 2. No shearing or fracturing of Alluvium 2 was observed in Trenches 3 and 10.

Fractures within Alluvium 2 also can be explained by nontectonic causes, such as shrink-swell processes associated with wetting and drying in the clay-rich soil. The pedogenic soil formed in Alluvium 2 is classified as a vertisol, a clay-rich soil whose morphology and structure is dominated by shrink-swell processes. Fracture surfaces and shear planes are typical features of this soil type. Over a period of a hundred years or so, these processes can result in a more or less complete mixing of the soil materials and a destruction of stratification that renders radiocarbon age analyses almost meaningless.

Sense of Slip. As described above, the West fault has an apparent down-on-the-southwest vertical separation as indicated by displaced in situ "burn" horizons within Alluvium 1 and by the displaced contact of Alluvium 1 and bedrock (Figures 3-2, 3-4, and 3-5). Indicators of lateral offset include shallowly plunging slickenlines (grooves and scratches) in bedrock, small thickness changes of sand and gravel beds across some of the shears, and differences in the texture of Alluvium 1 on either side of the fault (i.e., primarily gravelly on the northeast side and sandy on the southwest side) (see Figure 3-5 and Plate A-8). The down-on-the-west displacement in conjunction with subhorizontal, slickenlines that plunge at a low angle to the northwest within the bedrock fault zone indicates that the lateral component of movement is probably right-lateral strike slip, which is consistent with the major northwest-trending, active plate boundary faults in the Bay Area.

Width of Fault Zone. The width of the fault zone in bedrock generally is 15 to 30 feet wide to the northwest and west of the existing clearwell, and it appears to widen to as much as 80 feet south of the clearwell (Figure 3-3). As described previously, the fault zone widens in response to changing strike direction. The width of the zone of faulting in the late Quaternary Alluvium 1 is about 10 to 15 feet; however, minor fractures were observed up to 30 feet from the main fault trace. The young shearing appears to be restricted to the main trace and a narrow area to the southwest. No young displacement was observed on faults the footwall (east) block in Trench 4a (Plate A-8).

3.5.2 Central Fault

A northwest-trending fault, the Central fault (Table 3-2), occurs directly east of the existing clearwell in the study area (Plate 2). This feature is nearly coincident with a bedrock fault mapped by Saul (1973) that forms the northeast boundary of a shear zone that he considers to be the Calaveras fault. The fault as mapped by Saul has a more northwesterly trend, however, that would intersect the geomorphic surface to the northwest of the WCWTP. No significant faulting was observed in trenches 2e and 2f across the geomorphic surface where Saul's fault

would project, although local zones of highly fractured rock and minor faulting were encountered in the trenches (Plates A-2 through A-7).

The Central fault was intercepted in Trench 11 to the south of the operations building, where it was found to be coincident with the strongly expressed tonal and textural lineament described previously (Plates 2 and A-16). The fault, therefore, can be well located based on the mapping the lineament on preconstruction aerial photographs. This mapping shows that the fault has a northwest strike from east of the existing clearwell and to the south, but it appears to have a more northerly strike from the clearwell and to the north. However, the lineament becomes indistinct to the north of the clearwell where it projects across a remnant of the geomorphic surface that occurs on the east side of the drainage north of the clearwell. The remnant of the geomorphic surface was identified on predevelopment aerial photographs, but is now buried by fill near the settling basin and appurtenant facilities on the north side of the site. The change in strike, or bend, in the Central fault is similar to the change in strike along the West and East faults and is consistent with close structural relations among these faults (Plate 3).

The Central fault separates interbedded sandstone, siltstone, and claystone of the Hambre Formation on the northeast against sandstone of the Hambre Formation on the southwest. Although the strike of the fault and bedding are nearly parallel, the fault cuts across bedding along its down-dip extension. For example, an interbedded sequence of siltstone, very fine sandstone, and conglomerate that is oriented N50°W, 75°NE is truncated by a fault that strikes about N20°W and dips 70 to 90 degrees to the southwest (Plate A-16, northwest wall, stations 44 to 46 feet).

The Central fault exposed in Trench 11 is a 6- to 8-foot-wide zone that strikes about N40°W and dips steeply (≥80°) to the west. Individual shears within the fault zone generally strike N20°-50°W and dip 70 to 90 degrees to the southwest. A fault trace lined with light gray to white, crushed siltstone forms the northeastern margin of the fault zone, while a fault trace containing thin (less than 2 inches thick), foliated clay gouge forms the southwestern margin.

Fine-grained sandstones and siltstones of the Hambre Formation within the fault zone are moderately to intensely fractured and locally brecciated. Faint slickenlines on faults within the zone plunge 15 to 30 degrees to the northwest. Additionally, small faults and fractures are common within 30 feet of the fault zone on the southwest side of the fault.

No natural soils or surficial deposits that can be used to assess fault activity overlie bedrock above the fault zone in Trench 11. However, the fault as mapped projects across a remnant of the late Pleistocene geomorphic surface that is now buried by fill in the northern part of the site. No disruption of this geomorphic surface was observed on predevelopment aerial photographs along the mapped trend of the Central fault. This indicates that the Central fault probably has either an equivalent or lower level of activity than the West fault, which also has no geomorphic expression across the late Pleistocene geomorphic surface.

3.5.3 East Faults

The East faults (Table 3-2) are nearly coincident with the Franklin fault as mapped by Dibblee (1980a), Graymer and others (1994), Crane (1995) and Haydon (1995), but evidence that tightly constrains their recency of activity was not found during the Phase II trenching studies. These two bedrock faults occur within the saddle area to the northeast of the site (Figure 1-2; Plate 2), one in the easternmost part of Trench 6 and one between stations 136 and 142 feet (Plate A-11, Sheets 1 of 4 and 2 of 4). The fault near station 0 to 2 feet has a more than 2-foot-wide breccia zone that is intensely fractured to crushed and deeply weathered. The southwestern margin of the fault zone strikes N48°W and dips 75 degrees to the southwest. The northeastern margin of the breccia zone occurs some unknown distance northeast of the trench. Very thin, late Holocene to historical colluvium that overlies the bedrock fault zone is undeformed.

The fault between stations 136 and 142 feet is about 6 feet wide and contains two 1- to 2-foot-wide breccia zones (Plate A-11). The overall zone is oriented N10°-23°W and dips 30 to 57 degrees to the east. The breccia appears to consist of locally derived lithologies that have been

crushed. No major stratigraphic break apparently occurs across this fault, an indication that the net amount of slip may be low. A less than 3-inches-wide fault trace filled with clayey fault gouge occurs at the western margin of each breccia zone. Slickenlines within the gouge zone indicate predominately dip-slip displacement. Very thin, late Holocene to historical colluvium overlies the bedrock fault zone and is undeformed.

Trench 7 (Plate A-12) was excavated to further evaluate the bedrock fault that occurs between stations 136 and 142 feet in Trench 6 (Figure 1-2). No breccia zones were observed in Trench 7, but a roughly 20-feet-wide zone of minor faults, spaced about 2 to 3 feet apart, occur in the northeastern part of the trench. The fractures do not disrupt the overlying middle to late Holocene colluvium in this trench.

3.5.4 Bedrock Deformation Between the West and East Faults

Smaller-scale bedrock shears occur locally in areas away from the East, Central, and West faults (Appendix A). These features appear to be very minor and do not significantly displace the bedrock units. No major lithologic or stratigraphic breaks occur across these minor shears, and there is no evidence that they have moved during the late Quaternary. However, some of the bedrock shear fractures are overlain only by late Holocene colluvium, making it impossible to rule out earlier Holocene and/or late Pleistocene activity.

The minor bedrock faults are more prevalent in the area directly northeast of West fault. This area was mapped as a "Shear Zone" by Saul (1973). Although minor faults in bedrock appear to be more prevalent within this zone, no young displacements were observed on minor shear fractures where they were observed with Alluvium 1 overlying them (see Plates A-2 through A-9). The "Shear Zone" mapped by Saul is shown to be bounded by discrete faults on the southwest and northeast. The fault on the northeast was not encountered in trenches of this study, and the fault on the southwest was mapped by Saul within 150 feet of the West fault.

3.6 ORIGIN OF OBSERVED DEFORMATION

Air photo interpretation, geologic mapping, and the trenching studies performed for this investigation have revealed much about a surface pattern of deformation (folding and faulting) at the WCWTP site. The data indicates the presence of a northwest-trending belt of structural deformation bounded on the northeast by the main trace of the Franklin fault and on the southwest by the West fault. Geologic structures within this zone of deformation, including the Central and East faults, appear contained within the Hambre Formation. No evidence was found that they extend beyond the limits of the zone.

The West fault is a late Quaternary active structure that persists unbroken along strike for more than two kilometers, from the rolling hills north of the site that contain remnant alluvial terraces (geomorphic surfaces), to the steep bedrock strike-ridges south of the site (Plate 3). The mapped geometry of this fault trace, its sense of displacement, continuity along strike, and persistence across different geomorphic and topographic "domains" all suggest a tectonic rather than nontectonic origin for the West fault. Evidence of right-normal oblique slip on the West fault is not consistent with a landslide origin, as some workers have postulated, but is consistent with bedrock relations across a long-lived tectonic fault. Bedrock at the plant site within the zone of deformation is stratigraphically older than bedrock exposed on the ridge above the site to the west, consistent with offset across the West fault. If the observed deformation were due to landsliding, bedrock within the zone of deformation northeast of the West fault would correlate with the bedrock exposed on the hillslopes to the west above the site. Based on these observations and the results of the trenching studies (especially trench T-10), Geomatrix interprets that deformation observed and documented along the West fault is not due to landsliding, but is tectonic in origin.

The regional tectonic context of how the West, Central, and East faults interact with the main Franklin fault at depth is not completely understood at present. It appears that the main Franklin fault was not encountered on the project site during this study and that its main trace lies further to the east as depicted on Plate 1. Trenching the fault offsite to refine its location and assess its dip and its sense and recency of slip was not part of the final work scope.

Similarly, determining the location (if present), activity, and dip of the Calaveras fault to the east of the plant site also was not part of this study.

To address these uncertainties, we have considered several kinematic models that assume different possible geometries for the Franklin and northern Calaveras faults. These models may explain the observed faulting at the WCWTP and help predict the likely future behavior of the west, central and east faults. The models include:

1. secondary contractual or extensional deformation associated with the right-reverse movement on a vertical Franklin fault located east of the plant site or similar slip on the northern Calaveras fault;

2. primary fault movement associated with a restraining bend in a southwest-dipping, predominantly right-lateral Franklin fault;

3. secondary hanging-wall deformation from sympathetic faulting on a northeast verging (southwest dipping) emergent or blind (concealed) thrust fault (Franklin fault); and

4. secondary deformation in the footwall of a southwest verging (northeast dipping) emergent or blind thrust fault (Franklin fault).

Based on the available evidence, it is our judgment that Model 1 best describes the folding and faulting condition observed at the plant site. First, although a normal component of slip is not consistent with the overall sense of slip on the predominantly right-reverse oblique slip Franklin fault, the plant site is located northwest of a large double releasing bend in the trace at the Franklin-Calaveras fault (Figure 2-2). Given its structural position relative to this releasing bend, right-normal (down-on-the-west) oblique displacement on the West fault is consistent with secondary faulting adjacent to the main trace of the Franklin fault. This right-normal (extensional) slip is inconsistent with the restraining tectonic geometry proposed by Model 2. Second, the West fault does not appear to be the main trace of the Franklin fault. The stratigraphic separation across the West fault is small (Middle Miocene Hambre Formation juxtaposed against Middle to Upper Miocene Briones Formation) when compared with the Franklin fault as mapped both north and south of the plant site (Graymer and others, 1994).

Similarly, the stratigraphic separation cross the Central and East faults is very small. Third, the relatively linear northwest-trending regional trace of the Franklin fault strongly supports it has a steep dip and a major component of right-lateral strike-slip like adjacent active plate boundary faults. The Franklin fault's trace geometry is inconsistent with Models 3 and 4, which portray the fault as a low-angle thrust.

4.0 ASSESSMENT OF SURFACE FAULT RUPTURE HAZARD AT WCWTP

This section summarizes the surface-fault-rupture hazard at the WCWTP. There are three important implications that arise from the geologic, paleoseismic, and structural interpretations developed from the data evaluated for this Phase II study. First, the majority of surface slip during a surface rupturing event is expected to occur on the main trace of the Franklin fault. Secondary faults, like the West, Central, and East faults, are expected to experience significantly less total slip than the primary fault rupture. Second, if a secondary fault within a larger fault zone is documented late Pleistocene active, such as the West fault, then by direct implication the main fault (i.e., the Franklin fault) within the zone must also be late Pleistocene active. Third, if both of these faults are late Pleistocene active, then there is a high likelihood of movement on other secondary faults located in the zone of deformation between the two faults during a surface rupturing event on the Franklin fault.

There are two distinct "environments" for the assessment of surface-fault-rupture hazard at the plant site. First is the regulatory environment of DSOD, which has jurisdiction over the existing clearwell and any proposed clearwell expansion. DSOD may not permit dams and dam-like water-retention structures to be built and/or operated where surface fault rupture has the potential to cause catastrophic failure of the dam. To mitigate the life-safety issues that can arise from catastrophic dam failures, DSOD uses a conservative, deterministic approach for the assessment of seismic hazards. As mentioned previously, the DSOD age criterion for fault activity is 35,000 years, in contrast to the 11,000 year criterion used by the CDMG and by many local and regional governmental agencies. When assessing ground-rupture hazards, DSOD does not consider the rate of slip manifested by the fault. As long as one episode of slip has occurred within the past 35,000 years, a fault with a slip rate of tenths of millimeters per year and a recurrence of thousands of years (e.g., the Franklin fault) is considered the same as one that slips at a rate of tens of millimeters per year and has a recurrence of tens to hundreds of years (e.g., the San Andreas fault). Both of these faults may be judged by DSOD as posing an unacceptable hazard to a dam.

By contrast, the District is not constrained to a deterministic-style assessment of rupture hazard for the entire WCWTP site. A probabilistic approach that considers likelihood of faulting as a function of fault recurrence and slip rate can be considered for assessing the surface-fault-rupture hazard, ground motions, and other geologic hazards, to existing and proposed facilities at the WCWTP, with the exception of the water storage facilities that fall under DSOD jurisdiction. Such an approach considers fault slip rate as it impacts anticipated ground motions and surface displacements associated with expected slip recurrence intervals, and identifies (and upgrades or protects) those facilities required to meet system performance goals. This probabilistic approach incorporates uncertainties, and is sensitive to fault slip rates.

4.1 METHODOLOGY AND ASSUMPTIONS

The expected location of future surface fault rupture at the WCWTP is assessed on the basis of near-surface deformation observed during the detailed geologic studies conducted for the Phase II Seismic Study. When assessing surface-fault rupture hazard, it is very reasonable to expect that future fault slip will occur at the same locations and in generally the same manner as past displacements. Future fault slip is typically assumed to occur on preexisting faults, and the likelihood of future displacements is related to the frequency and timing of the most recent displacements. The potential for new rupture in locations where it has not been previously observed is acknowledged by earth scientists, but is considered highly unlikely, except where the faults are buried beneath sediments that are young relative to the most recent surface faulting events.

The best estimates of the amount of displacement expected during a future earthquake on a fault are observations of actual displacements along historical ruptures on that fault, and from interpretation of paleoseismic data preserved along that fault. Unfortunately, there are no direct, reliable measurements of primary or secondary fault displacements per event for the Franklin fault, the West fault, and other faults in the plant site area. The data available on the West fault indicate that the fault has a very low vertical rate [i.e., on the order of 0.1 meters (about 4 inches) per thousand years or less]; however, typical amounts of displacement per

event and/or number of events that have occurred since the late Quaternary could not be determined from the available trench exposures. If the number of events that have occurred during an interval of time are known, the average displacement per event can be calculated using the total observed displacement. Additionally, long-term geologic slip rate and earthquake recurrence (from paleoseismic studies) data can be used to calculate displacement per event. However, because these data are not available for faults at the WCWTP site, relatively robust methodologies cannot be used to evaluate the expected displacement per event for the Franklin fault and its associated secondary faults.

Indirect, less robust methods to assess the expected magnitude of displacements during a ground rupturing event can be used. These are based on empirical relations of fault displacement versus maximum magnitude and fault displacement versus surface fault rupture length from observations of earthquakes worldwide (Wells and Coppersmith, 1994). These empirically based regressions are based on catalogues of displacements observed along primary surface fault ruptures. Although the observations are extremely valuable, there is considerable uncertainty associated with the data and it must be used with caution when evaluating the magnitude of displacement on secondary faults. According to one early study of historical faulting (Bonilla, 1970), individual secondary faults, like the West, Central, and East faults, are not expected to experience more than 30 percent of the total slip of the primary fault rupture. However, more recent work by Wells (1993) indicates the 30 percent may be too low of a value and that a range of 30 to 50 percent may be more realistic for faulting with a normal component of slip.

4.2 MODES OF COSEISMIC GROUND RUPTURE

Three modes of coseismic ground rupture are considered for a potential surface faulting event at WCWTP: (1) primary fault rupture and subsidiary faulting associated with the main trace of the Franklin fault; (2) secondary right-normal oblique faulting along secondary, northwest-trending branch faults like the West, Central and East faults; and (3) distributed secondary faulting and/or ground warping and block rotation in the area between the Franklin and West faults.

4.2.1 Primary Fault Rupture

Primary fault rupture is considered herein as coseismic fault displacement (i.e., an earthquake accompanied by surface fault displacement) expressed at the ground surface and directly related to differential slip on the causative earthquake-producing fault at depth. Primary rupture occurs along the main trace of the fault zone that carries all or a majority of the surface displacement. Observations of surface rupture along active faults worldwide reveal a wide range of styles. Primary surface rupture can occur along a very narrow zone of discrete faulting that repeatedly occupies only a few fracture traces, such as the San Andreas fault as exposed in paleoseismic trenches (Sieh and Jahns, 1984; Hall and others, 1995) or it can be expressed as a broad zone of shearing (>200 meters, 660 feet) such as occurred during the 1992 Landers, California earthquake (Johnson and others, 1993a,b).

The expected location and amount of primary ground rupture on the Franklin fault is characterized on the basis of trenching and mapping studies that indicate the main trace of the fault lies northeast of the site and on the regional assessment of the fault presented in Section 2.2. As described in Sections 3.4 and 3.5, the faults exposed in Trenches 6 and 7 are judged not to be the main trace of the Franklin fault. Therefore, apart from strong ground shaking, primary surface fault rupture along the Franklin fault is not expected to have a direct and significant impact to the WCWTP site.

4.2.2 Secondary Fault Rupture

Secondary fault rupture having a right-normal oblique component of slip concentrated within a discrete zone is possible along the northwest-trending West fault, Central fault, and/or the East faults. As described above, there is insufficient paleoseismic data to assess the actual displacement per event expected on the West fault. The long term slip rate for the Franklin fault is also unknown, because no paleoseismic studies have successfully addressed the slip rate on this fault. However, estimates based on geomorphic expression and comparison with other

faults with known slip rates indicates that the net slip rate of the Franklin fault is probably in the range of 0.2 to <1 mm/yr. The vertical rate of dip-slip displacement on the West fault as measured from Trenches 4a and 4b is about 0.07 mm/yr. based on displacement of the basal contact of Alluvium 1 and the more than 30,000 year age for the alluvium. The ratio of strike slip to dip slip for the West fault is unknown, but is estimated to be on the order of 2 (strike slip) to 1 (dip slip), based on total observed bedrock displacement across the entire Franklin fault zone of 4000 to 7000 feet vertical and 10,000 to 15,000 feet horizontal. These slip rate estimates are very low compared to major faults in the Bay Area, such as the San Andreas, Hayward, and Calaveras faults, and they may help explain the very poor geomorphic expression of the Franklin fault zone. Based on the available data, it is our judgment that the low rate of activity indicates that there is a very low likelihood of a surface rupturing event on the Franklin fault and its associated secondary faults during the useful life of the plant. A qualitative comparison of the fault-rupture hazard levels posed by the tectonic features at the plant site relative to other Bay Area faults is presented in Table 4-1.

4.2.3 Distributed Secondary Faulting

Distributed secondary fault rupture having an undetermined sense of slip is possible across the deformed zone between the Franklin and West faults. Fractures and small faults with very small cumulative displacement (i.e., less than a few feet) in Tertiary bedrock were observed between the secondary fault traces. This distributed faulting is considered to have a very low likelihood of occurrence, because no evidence of geologically young activity was observed on small faults and shear fractures during trenching investigations at the WCWTP. Many of these tectonic features have sufficiently old deposits overlying them to evaluate late Quaternary activity, but some features do not. Additionally, the very small cumulative displacements in bedrock on these features, if active, indicates that future displacements will probably be very small (i.e., less than 1 inch).

4.3 INTENSITY AND LOCATION OF GROUND RUPTURE

The amount and location of maximum ground rupture that may occur at the site is assessed on the basis of estimates of the total coseismic slip that would accompany a surface rupturing

event on the Franklin fault and the character of near-surface deformation observed during field investigations of this study. As described previously, primary surface fault rupture of the Franklin fault poses little to no threat to the WCWTP, because the fault apparently is located to the northeast of the site (Plate 3). The Franklin fault is considered in the estimation of fault displacement hazard, because displacements on the master fault will influence the movement on its associated secondary faults. A reasonable way to quantify the partitioning of slip from the main fault to secondary faults is through development of kinematic and mechanical models of the primary fault and its association with secondary faults. Because development of such models is beyond the scope of the present study (see Section 3.6), empirical methods will be used instead to estimate the amount of displacement on the primary and secondary faults.

4.3.1 Estimated Amount of Displacement

The amount of lateral and vertical ground movement associated with coseismic surface fault rupture on the Franklin fault is estimated using the empirical relationships of Wells and Coppersmith (1994) that relate maximum and average displacements to surface rupture length. The estimation of primary surface rupture on the main trace of the Franklin fault is based on using a maximum credible earthquake of M_W 6¾ (see Appendix B). According to the relation between maximum displacement and earthquake magnitude for faults of all slip types, the maximum displacement due to a M_W 6¾ earthquake is calculated to be 1.2 m (3.9 feet). Because the maximum displacement typically is observed along a limited length of the fault rupture, the average displacement using the relationship developed by Wells and Coppersmith (1994) is 0.7 m (2.3 feet) for a M_W 6¾ earthquake. The maximum and average displacement versus surface rupture length (Wells and Coppersmith, 1994), yield displacements of 1.3 m (4.3 feet) and 0.7 m (2.3 feet), respectively. Dividing the maximum displacement by the estimated rate of slip for the Franklin fault (0.2 to <1 mm/yr.) yields recurrence time estimates of 1,300 to 6,500 years for the maximum earthquake.

Secondary faulting has been observed in the trenches (e.g., the West, Central, and East faults) and data from the West fault provides some maximum constraints on the amount of displacement per event. The basal part of Alluvium 1 was displaced down-on-the-west about 7

feet in Trenches 4a and 4b. An unknown horizontal component of slip is indicated by the textural differences of Alluvium 1 across the fault and by abrupt thickness changes in some beds across small faults within the main zone of faulting. No indicators of multiple events within Alluvium 1 were identified from trench exposures. However, there are two indications of recurrent movement along the West fault: (1) there is a greater amount of deformation within the bedrock fault zone than in the overlying Alluvium 1; and (2) Alluvium 1 is displaced much more than Alluvium 2, which may be only fractured. Therefore, the amount of observed displacement of Alluvium 1 is probably a maximum, given that it was probably produced by multiple events.

Another method to estimate the amount of displacement per event for the West fault and other northwest-trending faults at the site that are secondary to the Franklin fault is to calculate the displacement from the observation by Bonilla (1970) that a secondary fault is not expected to experience more than 30% of the total slip of the primary fault rupture. Assuming this relationship between the Franklin fault and secondary faults at the WCWTP implies maximum and average displacement values of about 1.3 feet (16 inches) and 0.7 feet (8 inches), respectively. Based on Bonilla's (1970) relationship, individual displacements along secondary faults are expected to be on the order of 1 foot or less. However, more recent work by Wells (1993); indicates that the maximum displacement on a secondary fault is between 5 percent and 80 percent of the slip on the main fault. For strike-slip faults, however, his data indicates that the secondary displacement is typically less than 20 percent of the primary faulting. The upper limit of 80 percent is primarily controlled by normal faulting events, and as described previously, the Franklin fault near the plant site is in a double releasing bend and a normal component of fault slip may be likely. However, few data occur above 50 percent. Therefore, a 30 percent to 50 percent assumption may be reasonable for strike-slip faults with a normal component of slip. This 30 percent to 50 percent assumption yields an estimated maximum surface displacement of 1.3 to 2.1 feet on the West, Central, and East faults. Cross faults (north- to northeast-trending secondary faults) are not parallel to the Franklin fault, and it is assumed that displacements on cross faults will be less than northwest-northwest-trending

faults. The estimated maximum displacements for plant site faults identified in this study are summarized in Table 3-2.

4.3.2 Locations Of Future Displacements At WCWTP

The location of future surface-fault displacements is expected to be at the same locations and in the same manner as inferred past displacements: along the main trace of the Franklin fault; and along secondary faults like the West, Central, East, and Cross faults. Distributed secondary faulting between the main trace of the Franklin fault and the trace of the West fault is judged to have a very low likelihood of occurrence. This section describes the expected locations of future fault displacements at the WCWTP.

Franklin Fault. Because the primary trace of the Franklin fault is inferred to the northeast of the WCWTP (Plate 1), future surface fault rupturing events on this fault should not directly impact the site. However, the estimated maximum displacement of about 4 feet may adversely impact utility lines, pipelines, and other District facilities that cross this zone.

Secondary Faults. Displacement on one or more secondary faults (e.g., the West fault, Central fault, East faults, and the cross faults) is possible during a surface faulting event on the Franklin fault. The West fault has experienced at least one and probably several surface fault displacements in the past 31,400 years, and will probably experience surface-faulting events in the future. However, the likelihood of surface rupture events during the useful life of the WCWTP is judged to be very low based on the apparently low slip rate of the Franklin fault.

Future displacements on the West fault are estimated to be 1 to 2 feet or less based on the above assumption that displacement on individual secondary faults will have less than 30 percent to 50 percent of the maximum slip of the Franklin fault (Table 3-2). However, larger displacements cannot be ruled out. Detailed mapping of the West fault indicates that it crosses the footprint of the proposed expanded clearwell (CH2M Hill, 1994), the raw water line for the plant, and the Mokelumne Aqueducts, but the fault does not intersect the existing clearwell

(Plates 2 and 3). The West fault also does not intersect the proposed locations of the 9,000,000 gallon steel water storage tanks, but it would intersect the new inlet and outlet lines between the tanks and the plant site. Given that the West fault is a southwest-dipping right-normal oblique fault, minor fracturing and faulting is likely to occur in the hanging-wall block (i.e., southwest side of fault where the tanks will be located). It appears that most of the zone of faulting (related only to the West fault) was captured within the trenches, but small fractures and shearing having very small displacements (i.e., < 1 inch) below the tanks cannot be ruled out.

Future displacements on the Central fault may potentially impact the site. The fault trace is located about 30 feet east of the existing clearwell liner at the closest approach and underlies the northeast corner of the clearwell's embankment (Plates 1 and 2). The Central fault trace as mapped misses the footprint of the expanded clearwell proposed by CH2M Hill (1994). However, several existing and planned water lines at the site, as well as the filters that are proposed to be installed directly south of the operations building do cross the mapped trace of the fault. Slip on the Central fault may adversely affect these structures. Slip on the Central fault could displace the base of the fill at the northeast corner of the existing clearwell, but does not underlie the clearwell liner. The expected displacement on the Central fault will probably be very small (perhaps a few inches), but displacements as large as those expected on the West fault (up to 1 to 2 feet) cannot be ruled out based on the available data.

The East faults are assessed as posing a very small surface-fault-rupture hazard to the existing and planned facilities at the WCWTP, because they are located northeast of the existing and planned facilities. These faults were intersected in Trenches 6 and 7, where unfaulted middle to late Holocene colluvial sediments overlie the bedrock fault zones. Older sediments suitable for evaluating late Pleistocene activity were not encountered in the trenches. Consequently, little is known of the late Quaternary displacement history of these faults. Future surface fault rupture on the East faults is judged to have a very low likelihood of occurrence and is unlikely to impact the facilities at the site.

Cross faults at the WCWTP site are assessed as posing a very small surface-fault-rupture hazard to the plant site (Plate 1). The faults do not trend beneath the existing and planned facilities. However, they do cross existing pipelines and other utilities and may represent a small hazard to them. The cross faults probably have a very low rate of activity and very small expected displacements (i.e., less than several inches). The rupture hazard from cross faults is judged to be very low because displacements are likely only when the Franklin fault and secondary faults rupture (low likelihood in lifetime of facilities), and because the cross fault do not pass beneath important facilities.

Distributed Faulting. As described above, smaller-scale bedrock faults occur locally in areas between the East and West faults. These small-scale features appear to be minor, and do not significantly displace the bedrock units. Although the origin of these features has not been systematically assessed, most of these minor features are probably tectonic in origin. It is likely that many of them probably formed during development of the syncline, because the orientation and morphology of some fracture sets appear consistent with cleavage development during folding. No major bedrock lithologic or stratigraphic breaks occur across these minor faults, and there is no evidence of late Quaternary displacements where such faults are overlain by Alluvium 1. Because some of the faults are overlain by late Holocene colluvium, earlier Holocene and late Pleistocene activity cannot be precluded. If the fractures are in fact active, future displacements across them during a surface fault rupture event on the Franklin fault are expected to be significantly less than the displacements on both the primary and secondary faults (i.e., << 1 foot).

5.0 SUMMARY AND CONCLUSIONS

This section summarizes the results of the Phase II Seismic Study to evaluate surface fault rupture hazard at the District's WCWTP in Walnut Creek, California. This evaluation is based primarily on a review of existing geological data and an extensive trenching program. The principal goal of this study was to evaluate the existence of active faults beneath the footprint of proposed clearwell expansion alternatives. Another goal was to evaluate the existence and activity of northwest-trending faults within two zones of previously mapped fault traces that cross the plant site (Geomatrix , 1995). The following are key observations, judgments, and conclusions regarding faulting and related surface-fault-rupture hazards at the WCWTP.

1. The WCWTP is located adjacent to the main trace of the Franklin fault, and lies within a zone of late Quaternary deformation characterized by secondary faulting, folding, and fracturing associated with the Franklin fault. Most of the plant site, however, has been cleared of active faults based on the Phase II trenching and mapping studies. These studies indicate that the main trace of the Franklin fault probably lies to the northeast of the WCWTP and, therefore, poses no to little fault-rupture hazard to the site, although it may be a source of strong ground motions. Secondary faults, however, pass through the plant site and may pose a local hazard to some existing and planned facilities.

2. Given the relatively low slip rate estimated for the Franklin fault, we judge that a surface rupturing event on the Franklin fault is very unlikely during the useful lifetime of the facilities. The activity of the Franklin fault has not been documented directly; however, a secondary fault associated with the Franklin fault (the West fault of this study) has been active during the late Quaternary. This implies that the Franklin fault also is late Quaternary active. Only one previous paleoseismic study (Earth Science Associates, 1983) of the Franklin fault indicates the fault may be active. If active, the fault is expected to have a low rate of activity with a slip rate in the range of about 0.2 to <1 mm/yr. based on comparison of its geomorphic expression with that of known active faults in the Bay Area. Therefore, the likelihood of a surface fault rupture event occurring on the main trace of the Franklin fault is judged to be very low.

3. A fault identified during this study, informally called the West fault, apparently branches from the Franklin fault and trends directly west of the WCWTP. Trenching studies have established that the fault has a right-normal-oblique sense of slip and that the fault displaces late Quaternary alluvial sediments that are dated as 31,410 radiocarbon years before present. Site geologic mapping indicates the West fault is tectonic in origin, and not related to landsliding. Therefore, the West fault is an "Active Fault" based on the DSOD's 35,000-year-old criterion (Fraser, 1996), but may or may

not be an active fault based on CDMG's Holocene criterion (displacement in the past 11,000 years). The fault does not pass beneath the foundation of the existing clearwell and the proposed tanks, but it does cross the area of the proposed expanded clearwell of CH2M Hill (1994) and intersects both the influent water pipelines for the plant and the Mokelumne Aqueducts. Future slip on this fault does not appear to pose a ground-rupture hazard to the existing clearwell and the water tanks alternative, but it may pose a hazard to the pipelines and other utilities that are built across its trace.

4. The trenching studies and bedrock mapping of the site and vicinity have identified at least two other zones of northwest-trending secondary faulting at the site, two East faults and the Central fault. The East faults were intersected in two trenches near the northeastern boundary of the WCWTP site. Colluvium judged to be middle to late Holocene in age based on very weak pedogenic soil development is not displaced across the two East faults. The northwest-trending Central fault, located between the East and West faults, was identified based on truncated bedding in bedrock that was observed in a trench and was extended across the site based on strongly expressed photolineaments that are coincident with the fault and limited field mapping. The Central fault projects beneath the northwest corner of the existing clearwell embankment and may underlie the proposed area for additional filters. The timing of the most recent slip events on the East faults and Central fault is not known, but given their parallel and branching nature with the main trace of the Franklin fault and the West fault and given their location within the zone of deformation, late Pleistocene to Holocene surface-faulting events cannot be entirely ruled out. Therefore, these faults are probably "conditionally active" according to DSOD criteria.

5. Faults that are secondary to the Franklin fault, like the West fault, Central fault, and East faults may rupture during an earthquake on the Franklin fault, but it is highly unlikely that they will rupture independently of the Franklin fault (i.e., the secondary faults are not separate seismic sources). Because the likelihood of a surface-faulting event on the Franklin fault is judged to be very low based on the available data, the likelihood of a surface-faulting event on the secondary faults also has a very low likelihood.

6. The regional context of the Franklin Fault and the active West fault and other secondary faults (specifically their relationship to the Franklin fault), has not been fully established with a high degree of confidence. The activity on secondary faults may be a result of movement in a double releasing bend along a predominantly strike-slip fault (the active Franklin fault), or a result of extension in the hanging-wall block of a blind-thrust fault (the Franklin fault) that either verges to the northeast or the southwest. The structural context of the Franklin Fault (i.e., the nature of the underlying controlling tectonic structure) can not be determined based on the available data. In either case, the activity on the West fault indicates that the Franklin fault is also late Pleistocene active. When compared with other active Bay Area faults, the faults evaluated during this investigation at the WCWTP are clearly minor, low slip rate features.

7. If a faulting event occurs on the Franklin fault, there will likely be movement on one or more secondary faults. Based on the trench exposures that support an interpretation of multiple slip events, it is reasonable to assume that the West fault probably has moved with the Franklin fault, but it is unknown if the East faults and the Central fault have a similar history of movement. The possibility that these latter faults move when the main Franklin fault moves cannot be ruled out. If the secondary faults do move, the expected size of the displacements will be smaller, perhaps much smaller, than the displacement on the Franklin fault. Empirical relationships derived from studies of worldwide earthquakes indicate that the maximum displacement along the Franklin fault is expected to be about 4 feet, and the average displacement is expected to be about 2 feet (assuming a M_W 6¾ earthquake and a surface rupture length of 29 km). The expected displacement on the secondary faults is expected to be relatively small, on the order of 1 foot or less, although displacements as large as 2 feet cannot be ruled out.

6.0 REFERENCES

Aguirre, E., and Pasini, G., 1984, The Pliocene-Pleistocene Boundary: Episodes, v. 8, no. 2, International Union of Geological Sciences, Herndon, Virginia, p. 116-120.

Aydin, A., and Page, 1984, B.M., 1984, Diverse Pliocene-Quaternary tectonics in a transform environment, San Francisco Bay region, California: Geological Society of America Bulletin, v. 95, no.11, p. 1303-1317.

Ayers, E.W., 1994, Draft fault activity guidelines: California Department of Water Resources, Division of Safety of Dams, personal communication, May 15,1995.

Bonilla, M.G., 1970, Surface faulting and related effects; in Wiegel, R.C., ed., Earthquake Engineering: Prentice-Hall, Inc., Englewood Cliffs, N.J.

Butler, R.W.H., 1982, The terminology of structures in thrust belts: Journal of Structural Geology, v. 4, no. 3, p. 239-245.

CH2M Hill, 1994, Walnut Creek water treatment plant expansion feasibility study final report: Unpublished Consultants Report for East Bay Municipal Utility District.

Contra Costa County, 1991, Safety element (Section 10.0) in Contra Costa County General Plan 1990-2005, January 1991.

Crane, R.C., 1995, Geologic Quadrangle Maps prepared for the Walnut Creek area, personal communication.

Dibblee, T.W. Jr., 1980a, Preliminary geologic map of the Walnut Creek quadrangle, Contra Costa County, California: U.S. Geological Survey Open-File Map 80-351, scale 1:24,000.

Dibblee, T.W. Jr., 1980b, Preliminary geologic map of the Las Trampas Ridge quadrangle, Alameda and Contra Costa counties, California: U.S. Geological Survey Open-File Report 80-545, scale 1:24,000.

Dibblee, T.W. Jr., 1980c, Preliminary geologic map of the Briones Valley quadrangle, Alameda and Contra Costa counties, California: U.S. Geological Survey Open-File Report 80-539, scale 1:24,000.

Dibblee, T.W. Jr., 1981, Preliminary geologic map of the Port Chicago quadrangle, Solano and Contra Costa counties, California: U.S. Geological Survey Open-File Report 81-106, scale 1:24,000.

Dibblee, T.W. Jr., and Darrow, R.L, 1981, Guidebook to the regional geology of the East Bay hills and the northern Diablo Range-Livermore Valley area, *in* Frizzell, V., ed., Geology of the Central and Northern Diablo Range, California: Society of Economic Paleontologists and Mineralogists.

Earth Sciences Associates, 1983, Seismotectonic Study of Martinez Dam and Vicinity: Unpublished Consultant's Report for the U.S. Bureau of Reclamation.

East Bay Municipal Utility District, 1963, Walnut Creek Filter Plant, Earthwork Drawings Nos. 5000-G-1 through 5000-G-8: Oakland, California, scale 1:720.

Figuers, S., 1991, The Tectonics of Western Solano County: Field Trip Guide to the Geology of Western Solano County, Northern California Geological Society and Association of Engineering Geologists, October 12.

Fraser, W.A., 1996, Seismic Source Characterization for Dam Site Analysis in California: ASDO Western Regional Technical Seminar on Earthquake Engineering for Dams, April 11-12, Sacramento, California, 15 p.

Geomatrix Consultants, 1993, "Seismic Response Study for Proposed Carquinez Bridge: Unpublished Consultant's Report Prepared for CALTRANS, Division of Structures, February.

Geomatrix Consultants, 1994, Seismic stability evaluation of Danville Reservoir embankment: Unpublished Consultant's Report for East Bay Municipal Utility District.

Geomatrix Consultants, 1995, "Final Report, Walnut Creek Water Treatment Plant Expansion Seismic Study - Phase I": Unpublished Consultant's Report for East Bay Municipal Utility District, September, San Francisco, 2 Appendixes, 24 p.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1994, Preliminary geologic map emphasizing bedrock formations in Contra Costa County, California, U.S. Geological Survey Open-File Report 94-622.

Hall, N.T., Wright, R.H., and Clahan, K.B., 1995, Paleoseismic investigations of the San Andreas fault on the San Francisco Peninsula, California: Final Technical Report, Award No. 14-08-0001-G2081, U.S. Geological Survey.

Ham, C.K., 1952, Geology of Las Trampas Ridge, Berkeley Hills, California: California Division of Mines Special Report 22, 26 p.

Harbert, W., and Cox, A., 1989, Late Neogene motion of the Pacific plate: Journal of Geophysical Research, v. 94, no. B-3, p. 3052-3064.

Hart, E.W., 1981, Evidence for recent faulting, Calaveras and Pleasanton faults, Diablo and Dublin quadrangles, California: California Division of Mines and Geology Open-File Report 81-9 SF, sheet 1 of 2.

Hart, E.W., 1988, Fault-Response Hazard Zones in California, Alquist-Priolo Earthquake Fault Zoning Act with index to earthquake fault zones maps, California Division of Mines and Geology, Special Publication 42, Revised 1994.

Hart, E.W., 1990, Fault-Rupture Hazard Zones in California: California Division of Mines and Geology Special Publication 42, 26 p.

Haydon, W.D., 1995, Landslide hazards in the Martinez-Orinda-Walnut Creek area, Contra Costa County, California: California Division of Mines and Geology Open-File Report OFR 95-12, 4 plates, scale 1:24,000.

Heyes, D.G., 1995, Reconnaissance level study of the Franklin fault in the vicinity of the Carquinez Bridge: Geotechnical Report for State of California, Department of Transportation, District 4, 23 p.

Hopkins, D.M., 1975, Time-stratigraphic nomenclature for the Holocene epoch: Geoderma, v. 14, no. 1, p. 2.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., Shackleton, N.J., 1984, The Orbital Theory of Pleistocene Climate: support from a revised chronology of the Marine O record *in* Berber, and others, eds., Milankovitch and Climate, Part I: Reidel Publishing Company, Netherlands, p. 269-305.

Jennings, C.W., 1975, Fault map of California: California geologic data map series, map no. 1 - faults, volcanoes, thermal springs, and wells: California Division of Mines and Geology, scale 1:750,000.

Jennings, C.W., 1994, Fault activity map of California and adjacent areas: California Division of Mines and Geology, Geologic Data Map No. 6, scale 1:750,000.

Jennings, C.W., and Burnett, J.L., 1961, San Francisco sheet, geologic map of California (Olaf P. Jenkins edition): California Division of Mines and Geology, scale 1:250,000.

Johnson, A.M., Fleming, R.W., and Cruikshank, K.M., 1993a, Broad belts of shear zones as the common form of surface rupture produced by the 28 June 1992 Landers, California, Earthquake: U.S. Geological Survey Open-File Report 93-348.

Johnson, A.M., Fleming, R.W., and Cruikshank, K.M., 1993b, Shear zones formed along long, straight traces of fault zones during the 28 June 1992 Landers, California, Earthquake: Bulletin of the Seismological Society of America, v. 84, no. 3, p. 499-510.

Kelson, K.I., Simpson, G.D., Lettis, W.R., and Haraden, C., 1996, Holocene slip rate and earthquake recurrence of the northern Calaveras fault at Leyden Creek, northern California: Journal of Geophysical Research, v. 101, no. B3, p. 5961-5975.

Lawson, A.C., 1914, Description of the San Francisco District; Tamalpais, San Francisco, Concord, San Mateo and Hayward quadrangles: U.S. Geological Survey, Geology Atlas San Francisco Folio # 193.

Lazarte, C.A., Bray, J.D., Johnson, A.M., and Lemmer, R.E., 1994, Surface breakage of the 1992 Landers earthquake and its effects on structures: Bulletin of the Seismological Society of America, v. 84, no.3, p. 547-561.

Marliave, B., 1963, Preliminary report on Walnut Creek Filter Plant Site No. 2 (now Walnut Creek Center), report to Mr. J.D. DeCosta (EBMUD), April 24.

Marliave, C., 1955, Filter Plant Site on Sousa Property along Mokelumne Aqueduct near Walnut Creek (now Walnut Creek Center), letter to Mr. R.C. Kennedy (EDMUD), December 13.

Marliave, C., 1956, Sousa Filter Plant Site (now Walnut Creek Center), letter to Mr. R.C. Kennedy (EDMUD), April 6.

Montgomery, D.R., and Jones, D.L., 1992, Contemporary deformation in the California coast ranges and the preservation of evidence for Holocene offset, in Borchardt, G., et al. (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 281-288.

Oppenheimer, D.H., and Lindh, A.G., 1992, The potential for earthquake rupture on the northern Calaveras fault, Calaveras Reservoir to Walnut Creek, in Borchardt, G., and others (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 233-240.

Oppenheimer, D.H., and Macgregor-Scott, N., 1992, The seismotectonics of the eastern San Francisco Bay region, Calaveras Reservoir to Walnut Creek; in Borchardt, G., and others (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, P. 11-16.

Page, B.M., 1982, Modes of Quaternary tectonic movement in the San Francisco Bay region, California, in Proceedings of the Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 62, p. 1-10.

Ridley, A.P., Alt, J.N., and Taylor, C.L., 1982, Investigation of the activity of the Franklin fault and reported Quaternary fault traces near Tice Valley, Walnut Creek, California, in Proceedings of the Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology, p. 227.

Rogers, J.D., and Halliday, J.M., 1992, Exploring the Calaveras-Las Trampas fault junction in the Danville-San Ramon area, Calaveras Reservoir to Walnut Creek, in Borchardt, G., and others (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 261-270.

Saul R.B., 1973, Geology and slope stability of the southwest quarter of the Walnut Creek 7½ minute quadrangle, Contra Costa County, California, California Division of Mines and Geology Map Sheet 16.

Sharp, R.V., 1973, Map showing recent tectonic movement on the Concord fault, Contra Costa and Solano counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-505, scale 1:24,000.

Sieh, K.E., and Jahns, R.H., III, 1984, Holocene activity of the San Andreas fault at Wallace Creek, California: Geological Society of America Bulletin, v. 95, no.8, p. 883-896.

Simpson, G.D., Lettis, W.R., and Kelson, K.I., 1992, Segmentation Model of the Northern Calaveras Fault, Calaveras Reservoir to Walnut Creek, in Borchardt, G., and others, eds., Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Department of Conservation, Division of Mines and Geology Special Publication 113, p. 253-259.

Sims, J.D., Fox, K.F. Jr., 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, scale 1:62,500.

Sowers, J.M., Unruh, J.R., Lettis, W.R., and Rubin, T.D., 1994, Relationship of the Kickapoo fault to the Johnson Valley and Homestead Valley faults, San Bernadino County, California: Bulletin of the Seismological Society of America, v. 84, no. 3, p. 528-536.

Wagner, D.L., and Bortugno, E.J., 1982, Geologic map of the Santa Rosa quadrangle, California, sheet 1 of 5, Regional Geologic Map series; Map showing recency of faulting, sheet 5 of 5; Santa Rosa quadrangle Map No. 2A (Geology): California Division of Mines and Geology, scale 1:250,000.

Wagner, D.L., Bortugno, E.J., and McJunkin, R.D., 1990, Geologic map of the San Francisco-San Jose quadrangle: California Division of Mines and Geology Map No. 5A, scale 1:250,000.

Wells, D.L., 1993, Analysis of primary and secondary surface faulting associated with historical normal and strike-slip earthquakes: Geological Society of America Abstracts with Programs, Reno, Nevada.

Wells, D.L., and Coppersmith, K.J., 1994, New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement: Bulletin of the Seismological Society of America, v. 84, no. 4, p. 974-1002.

Williams, P.L., Taylor, P., Wilhelm, R., and Buell, R., 1995, The BRIDGE project--high resolution seismic reflection study for the Caltrans toll bridge retrofit program: Abstracts with Program, AEG/GRA Annual Meeting.

Wills, C.J., and Hart, E.W., 1992, Progress in understanding the Concord fault through site-specific studies, in Borchardt, G., et al. (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publications 113, p. 311-317.

Woodcock, N.H., and Fischer, M., 1986, Strike-slip duplexes: Journal of Structural Geology, v. 8, no. 7, p. 725-735.

Woodward-Clyde Consultants, 1986, Revision of portions of Contra Costa County Seismic Safety Element: Consultant's report to Contra Costa County Community Development Department.

Youngs, R.R., Coppersmith, K.J., Taylor, C.L., Power, M.S., DiSilvestro, L.A., Angell, M.M., Hall, N.T., Wesling, J.R., and Mualchin, L., 1992, Comprehensive seismic hazard model for the San Francisco Bay region, in Borchardt, G., and others (eds.), Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 431-441.

TABLES

GEOMATRIX

TABLE 1-1

CENOZOIC BOUNDARY DATES[a]

Period	Epoch	Boundary Dates (years before present)
Quaternary	Late	Historic – 3,000
	Middle	3,000 – 7,000 ka
	Early	7,000 – 10,000[b]
	Late	10,000 – 128,000[c]
	Middle	128,000 – 736,000[d]
	Early	736,000 – 1,600,000[e]
Tertiary	Pliocene	1,600,00 – 5,300,000
	Miocene	5,300,000 – 23,700,000
	Oligocene	23,700,000 – 36,600,000
	Eocene	36,600,000 – 57,800,000
	Paleocene	57,800,000 – 66,400,000

[a] Modified from Emily Taylor (U.S. Geological Survey, written communication, 1995); Quaternary time scale based on Imbrie and others (1984).

[b] Arbitrary age suggested for Pleistocene-Holocene boundary (Hopkins, 1975).

[c] Astronomical age of marine oxygen-isotope substage 5e boundary.

[d] The Brunhes-Matuyama geomagnetic reversal.

[e] Provisional age of proposed Pliocene-Pleistocene boundary at the end of the Olduvia polarity subchron (event) in the Vrica stratotype, southern Italy (Aguirre and Pasini, 1984)

TABLE 2-1

CHARACTERISTICS OF THE FRANKLIN FAULT

Characteristic	Franklin Fault
Activity	Late Pleistocene Active
Length	> 29 km
Down-Dip Width[1]	15 to 18 km
MCE[2]	M_W 6¾
Slip Rate[3]	0.2 to <1.0 mm/yr (Geomorphic Expression)
Sense of Slip	Right-Oblique (E Side Up?)
Dip at WCWTP	Steep (>60°) (Poorly Defined)
Slip per Event[4]	Maximum 4.3 feet, Average 2.3 feet

1 Estimated from regional seismicity data.

2 MCE = Maximum Credible Earthquake. See Appendix B for assessment of MCE.

3 Slip rate was estimated by comparing the geomorphic expression of the Franklin fault to the expression of other Bay Area faults with known slip rates.

4 The slip per event is calculated using the empirical relations of Wells and Coppersmith (1994) that relate Maximum and Average Displacement per Event with Maximum Magnitude.

TABLE 3-1

STRATIGRAPHIC SEQUENCE AT WCWTP

Unconsolidated Soil Units	
Historical	Artificial Fill
Latest Holocene	Modern Alluvium and Colluvium
Latest Pleistocene to Holocene	Alluvium 2
Latest Pleistocene	Alluvium 1
Bedrock Units – West of Franklin Fault	
Upper Miocene	Neroly Formation (aka Cierbo Formation)
Middle to Upper Miocene	Briones Formation (Upper and Lower Members)
Middle Miocene or	Hambre Formation or
Lower Oligocene	San Ramon Formation
Bedrock Units –East of Franklin Fault	
Lower Eocene	Meganos Formation
Upper Paleocene	Martinez Formation

TABLE 3-2

CHARACTERISTICS OF SECONDARY FAULTS AT WCWTP

	West Fault	Central Fault	East Fault	Cross Fault
Location	Well-located	Moderately well-located	Moderately well-located	Approximately located
Attitude	NW strike SW dip	NW strike steep SW dip	NW strike SW & NE dips	NE & N strike unknown dip
Sense of Slip	Right-normal oblique	Probable right-normal oblique	Probable right-normal oblique	Right-lateral and/or down on west
Recency	Late Pleistocene (<31,410 years)	Presumed late Pleistocene	Presumed late Pleistocene	Unknown (post-Miocene)
Estimated Maximum Displacement per Event	1.3 to 2.1 feet	1.3 to 2.1 feet	1.3 to 2.1 feet	<1.3 to 2.1 feet

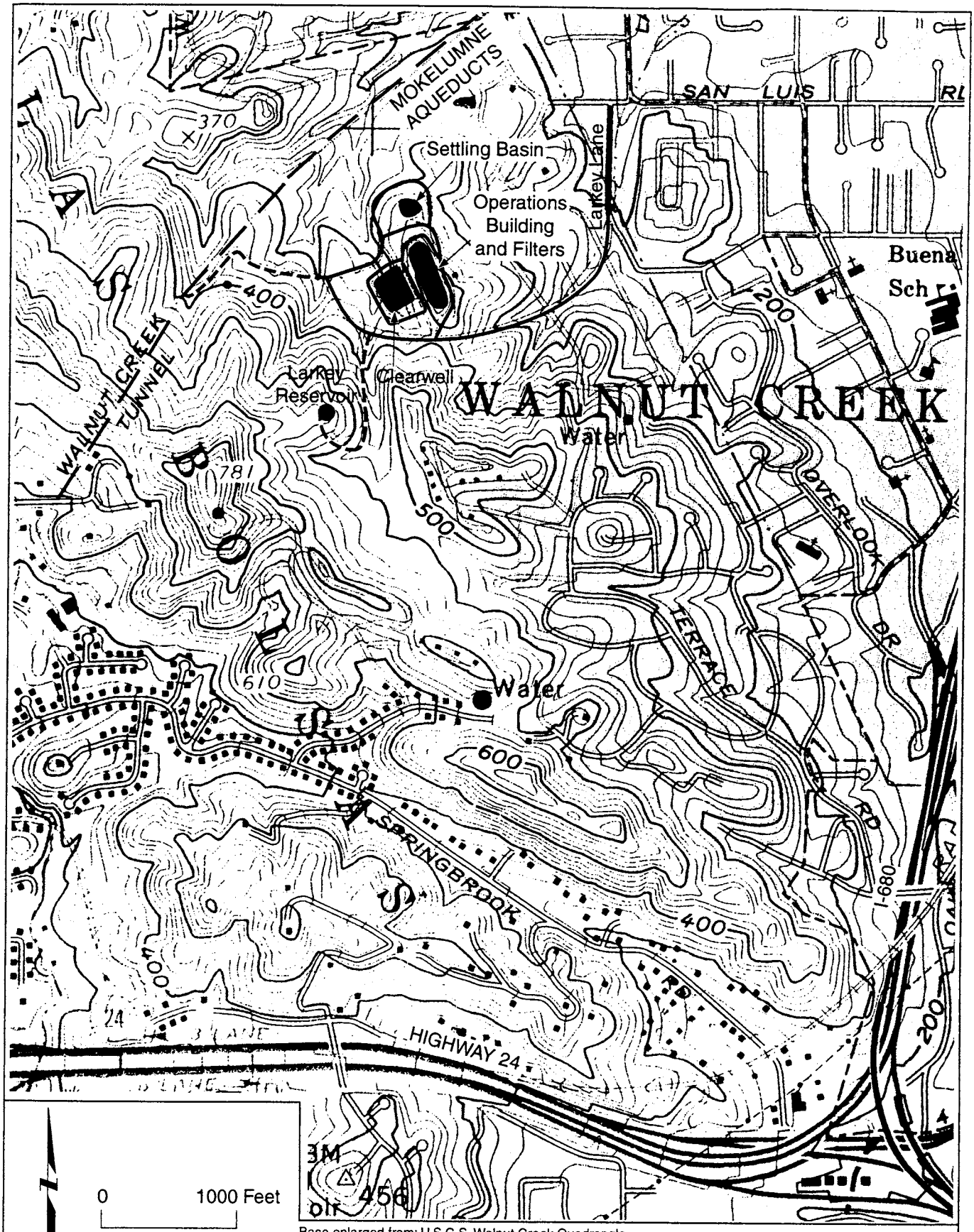
[1] Maximum displacement per event for secondary faults is calculated from the maximum displacement on the main trace of the Franklin fault (estimated to be 4.2 feet using empirical relations of Wells and Coppersmith (1994) and a Maximum Credible Earthquake of M_W 6¾) by assuming that the displacement on secondary faults in 30% to 50% of the displacement on the primary fault. See discussion in text.

TABLE 4-1

COMPARATIVE ASSESSMENT OF FAULT-RUPTURE HAZARD IN THE BAY AREA

Relative Hazard[1]	Example
Lowest ↓ Highest	Unfaulted bedrock away from active faults
	Ground between mapped faults at WCWTP
	Cross faults at WCWTP
	West, Central, and East faults at WCWTP
	Franklin fault (main trace)
	West Napa fault
	Green Valley and Greenville faults
	Concord fault
	Calaveras fault (south of San Ramon)
	Hayward and San Andreas faults

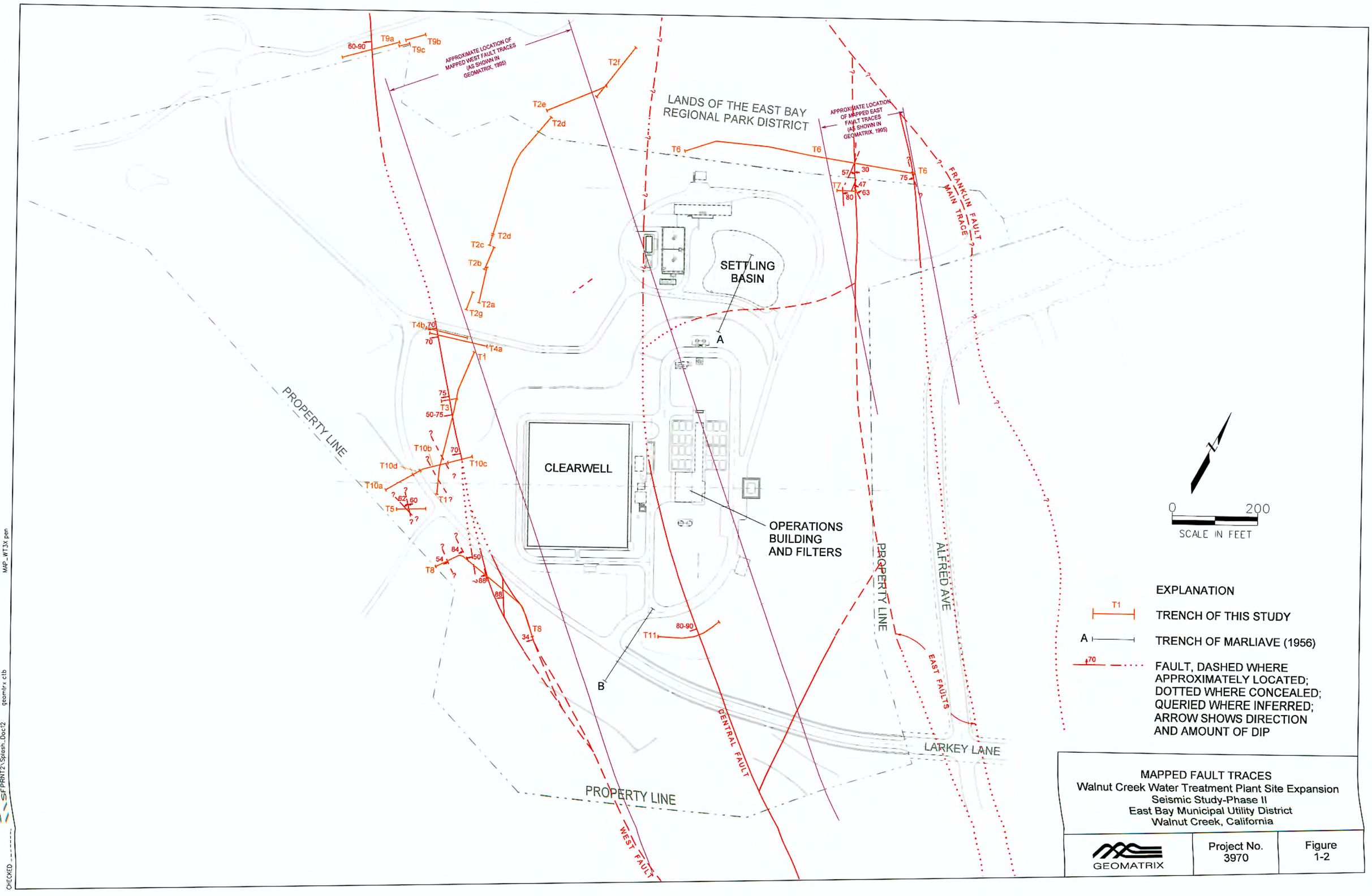
1 Assessment of relative hazard is influenced by the expected frequency (rate of activity), geometry, width of deformation zone, and amount of fault slip. This relative hazard can be expressed both numerically, using a nonlinear scale of 1 to 10 (from lower hazard to higher hazard, respectively), or by descriptive terms like low, moderate, and high.

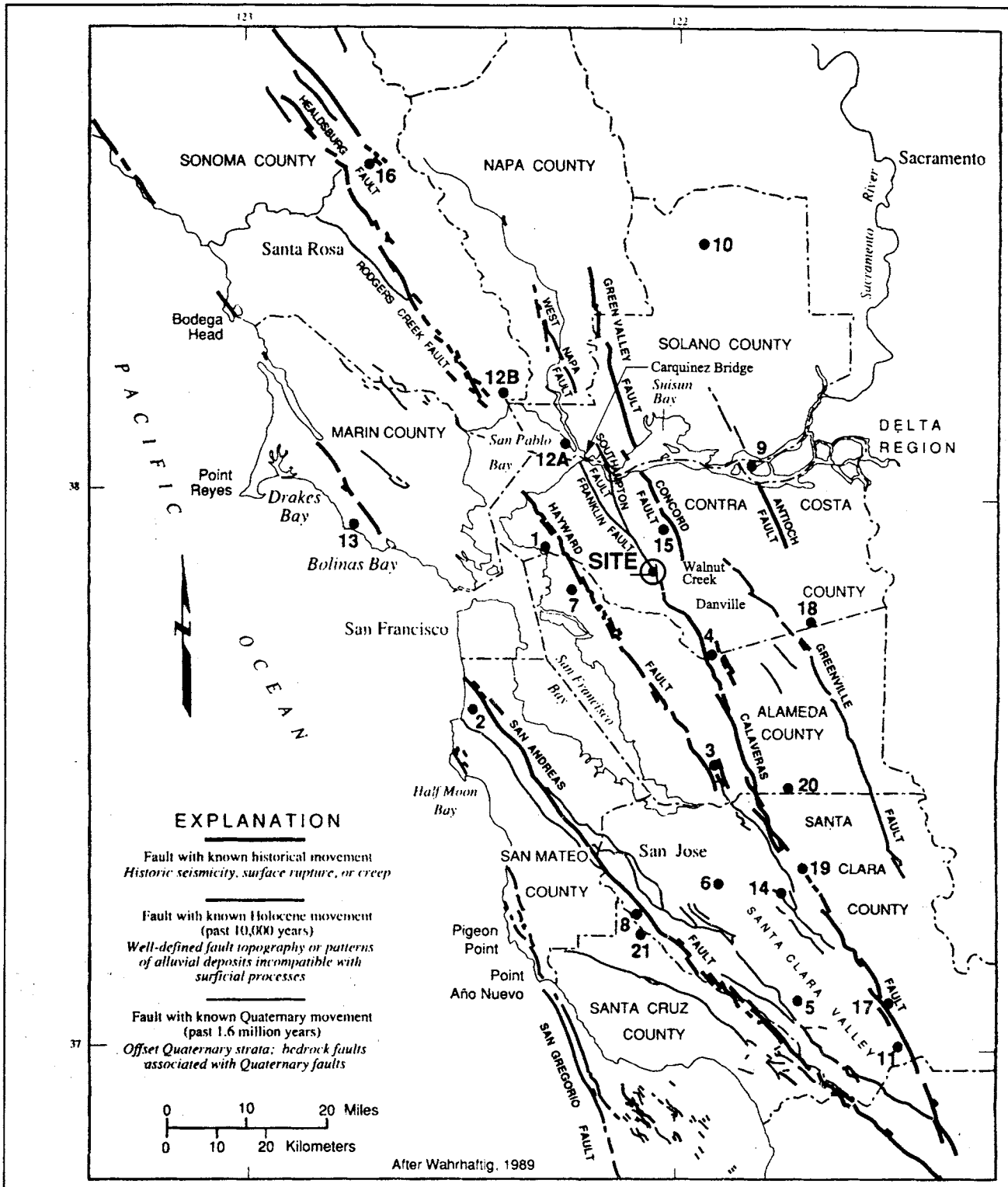


Base enlarged from: U.S.G.S. Walnut Creek Quadrangle
7.5 Minute Series (Topographic)

GEOMATRIX	LOCATION MAP Seismic Study - Phase II Walnut Creek Water Treatment Plant Expansion East Bay Municipal Utility District Walnut Creek, California	Figure 1-1 Project No. 3970

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T9a
T9b
T9c
60-90
APPROXIMATE LOCATION OF MAPPED WEST FAULT TRACES (AS SHOWN IN GEOMATRIX, 1995)
T2f
T2e
T2d
LANDS OF THE EAST BAY REGIONAL PARK DISTRICT
APPROXIMATE LOCATION OF MAPPED EAST FAULT TRACES (AS SHOWN IN GEOMATRIX, 1995)
T6
T6
T6
57
30
75
T7
47
80
63
FRANKLIN FAULT MAIN TRACE
T2d
T2c
T2b
T2a
T2g
SETTLING BASIN
A
T4b
70
70
T4a
T1
75
T3
50-75
PROPERTY LINE
CLEARWELL
T10b
70
T10c
T10d
T10a
62
60
T5
T1?
OPERATIONS BUILDING AND FILTERS
84
54
50
T8
88
88
T8
34
B
T11
80-90
PROPERTY LINE
ALFRED AVE
EAST FAULTS
CENTRAL FAULT
LARKEY LANE
PROPERTY LINE
WEST FAULT
N
0
200
SCALE IN FEET
EXPLANATION
T1
TRENCH OF THIS STUDY
A
TRENCH OF MARLIAVE (1956)
70
FAULT, DASHED WHERE APPROXIMATELY LOCATED; DOTTED WHERE CONCEALED; QUERIED WHERE INFERRED; ARROW SHOWS DIRECTION AND AMOUNT OF DIP
MAPPED FAULT TRACES
Walnut Creek Water Treatment Plant Site Expansion
Seismic Study-Phase II
East Bay Municipal Utility District
Walnut Creek, California
GEOMATRIX
Project No. 3970
Figure 1-2
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Historical Earthquakes

1. Hayward, 1836
2. San Francisco, 1838
3. Hayward, 1858
4. Calaveras, 1861
5. Santa Clara Valley, 1864
6. Santa Clara, 1865
7. Hayward, 1868
8. San Andreas, 1870
9. Antioch-Collinsville, 1889 and 1965
10. Vaca-Winters, 1892
11. Calaveras, 1897
12A. Mare Island, 1898
12B. Mare Island, 1898
13. San Francisco, 1906
14. Morgan Hill, 1911
15. Concord, 1955
16. Santa Rosa, 1969
17. Coyote Lake, 1979
18. Greenville, 1980
19. Morgan Hill, 1984
20. Mount Lewis, 1986
21. Loma Prieta, 1989

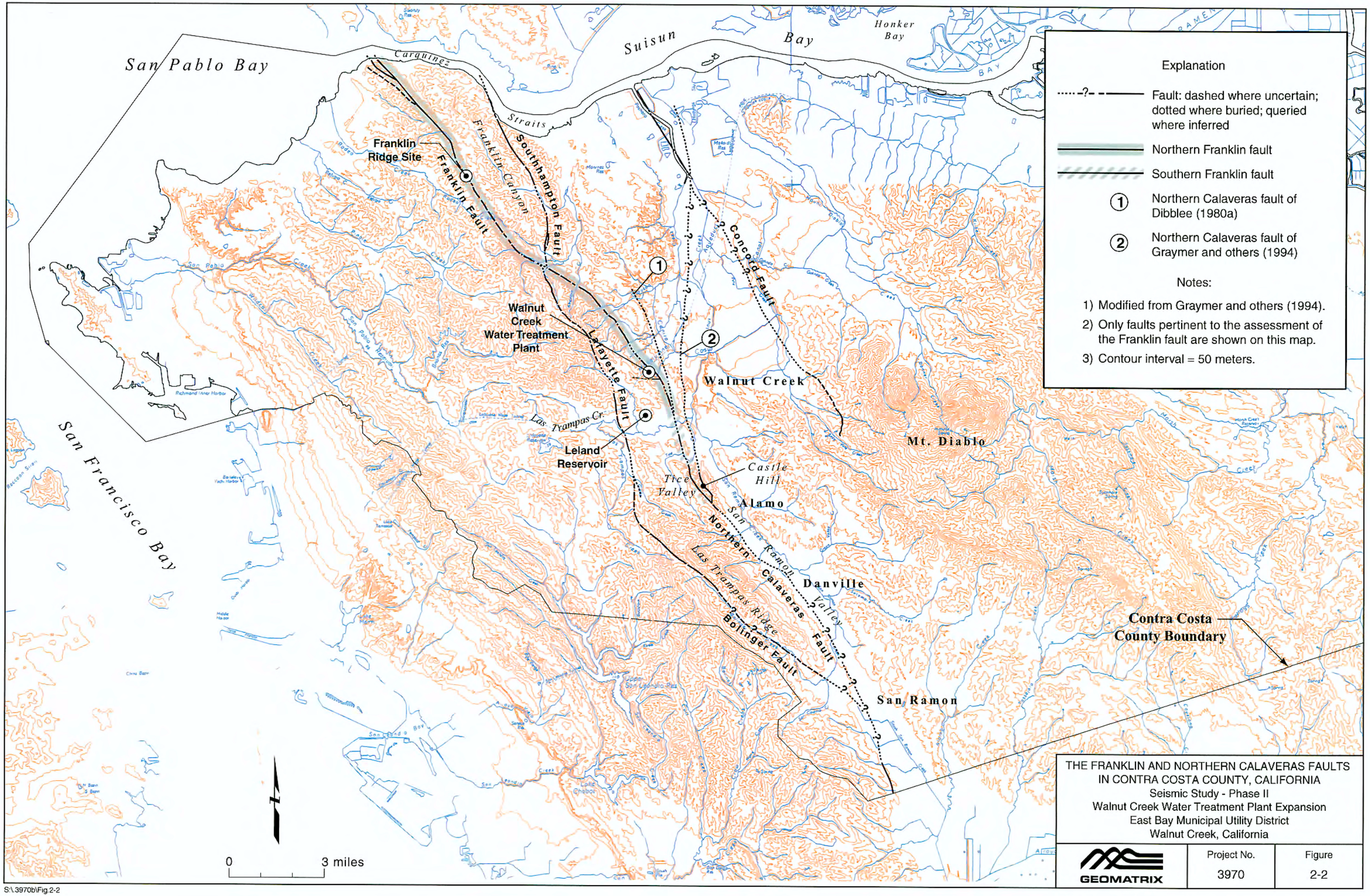
GEOMATRIX

REGIONAL ACTIVE FAULTS AND SELECTED EARTHQUAKES WITHIN THE SAN FRANCISCO BAY AREA
Seismic Study - Phase II
Walnut Creek Water Treatment Plant Expansion
East Bay Municipal Utility District
Walnut Creek, California

Figure 2-1

Project No. 3970

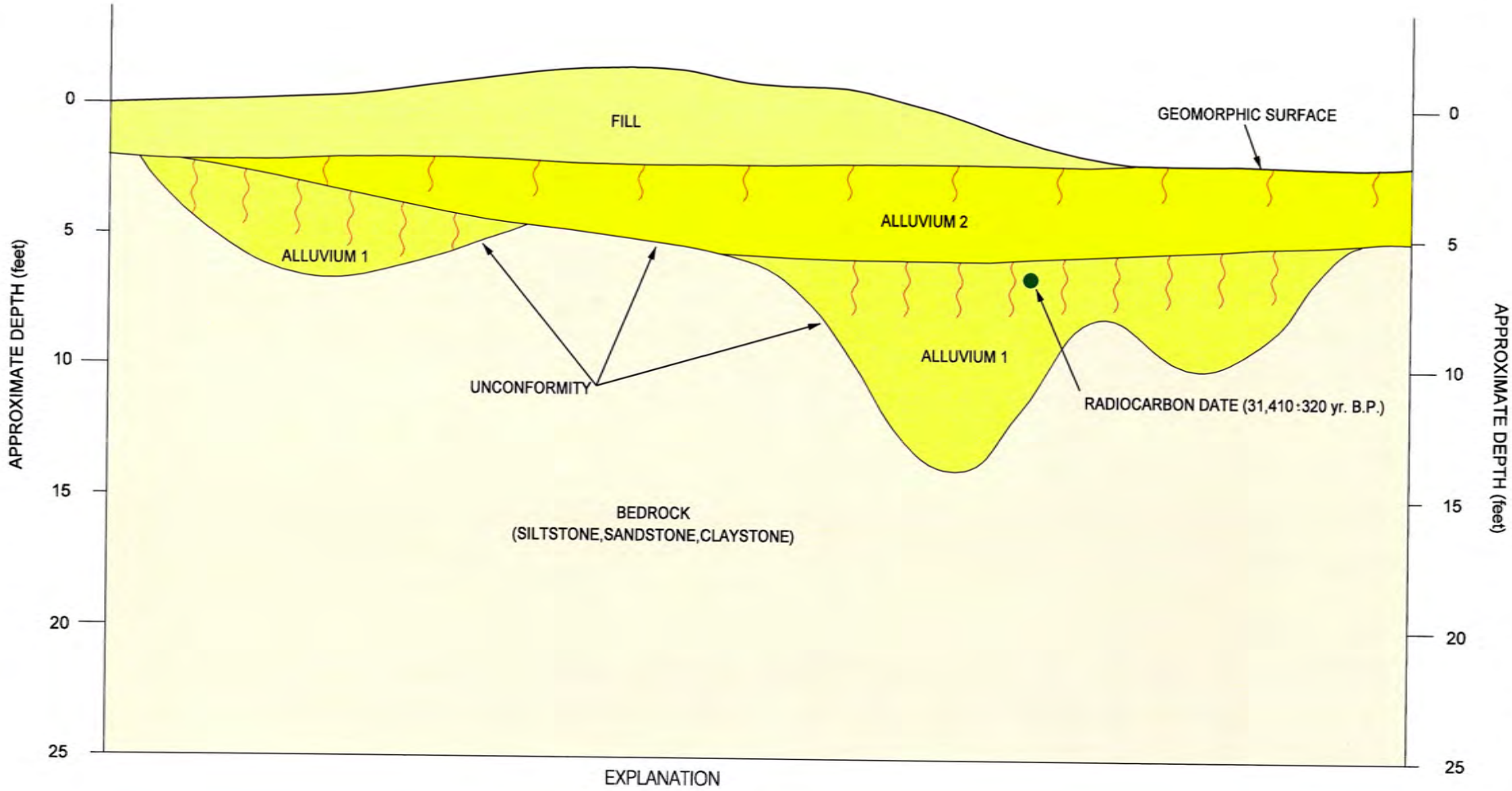
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THE FRANKLIN AND NORTHERN CALAVERAS FAULTS
IN CONTRA COSTA COUNTY, CALIFORNIA
Seismic Study - Phase II
Walnut Creek Water Treatment Plant Expansion
East Bay Municipal Utility District
Walnut Creek, California

GEOMATRIX	Project No. 3970	Figure 2-2

S:\3970b\Fig.2-2



EXPLANATION

UNIT	INFERRED AGE
FILL	MODERN
ALLUVIUM 2	LATEST PLEISTOCENE-HOLOCENE
ALLUVIUM 1	LATE PLEISTOCENE
BEDROCK	TERTIARY

NOTE:
Wavey lines indicate pedogenic soil profile development; longer closely spaced lines indicate stronger development.

0 6
SCALE IN FEET
NO VERTICAL EXAGGERATION

GEOMATRIX

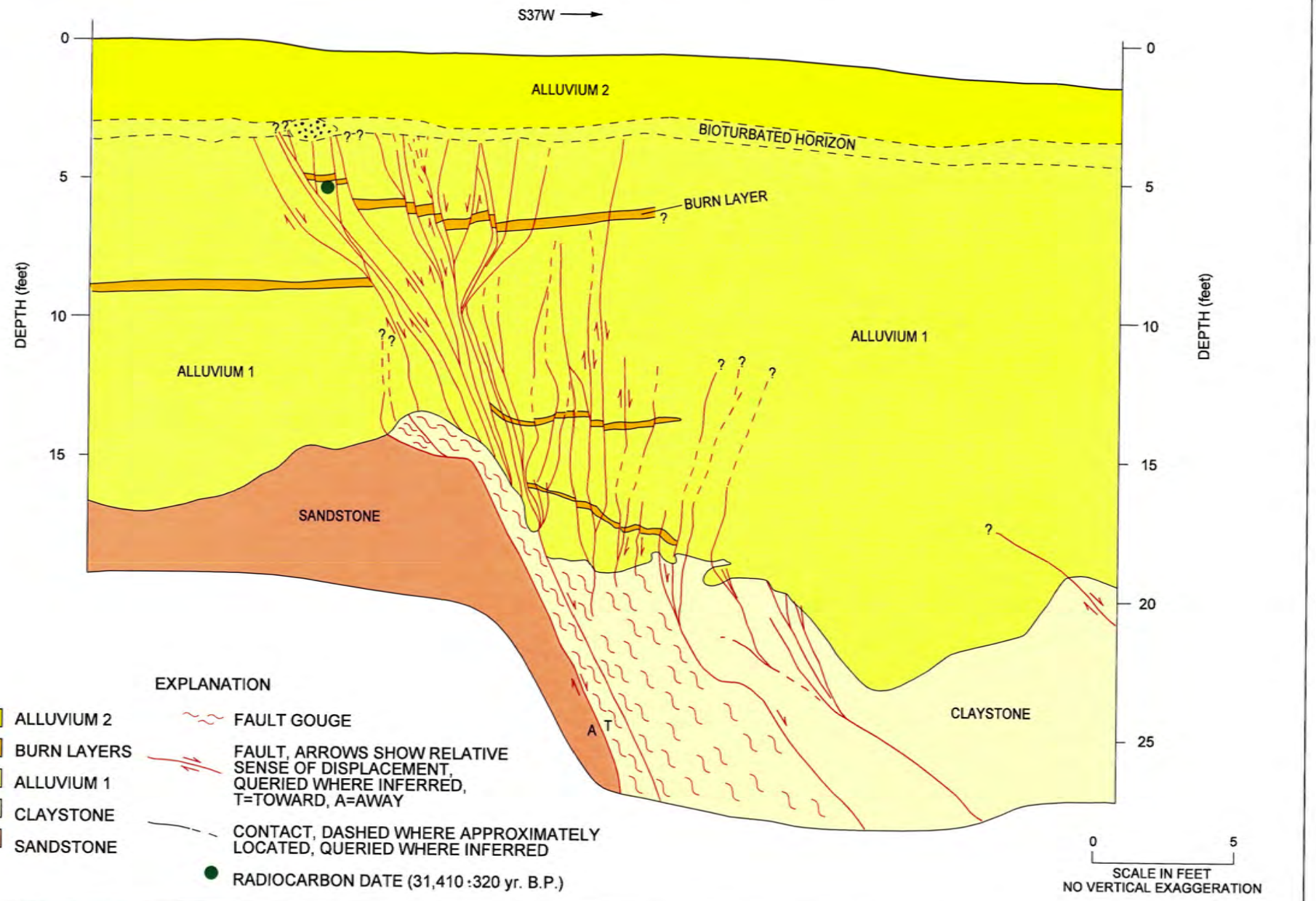
DIAGRAMMATIC SECTION SHOWING STRATIGRAPHIC RELATIONS ASSOCIATED WITH THE LATE PLEISTOCENE GEOMORPHIC SURFACE

Walnut Creek Water Treatment Plant Expansion
Seismic Study - Phase II
East Bay Municipal Utility District
Walnut Creek, California

Figure 3-1

Project No. 3970

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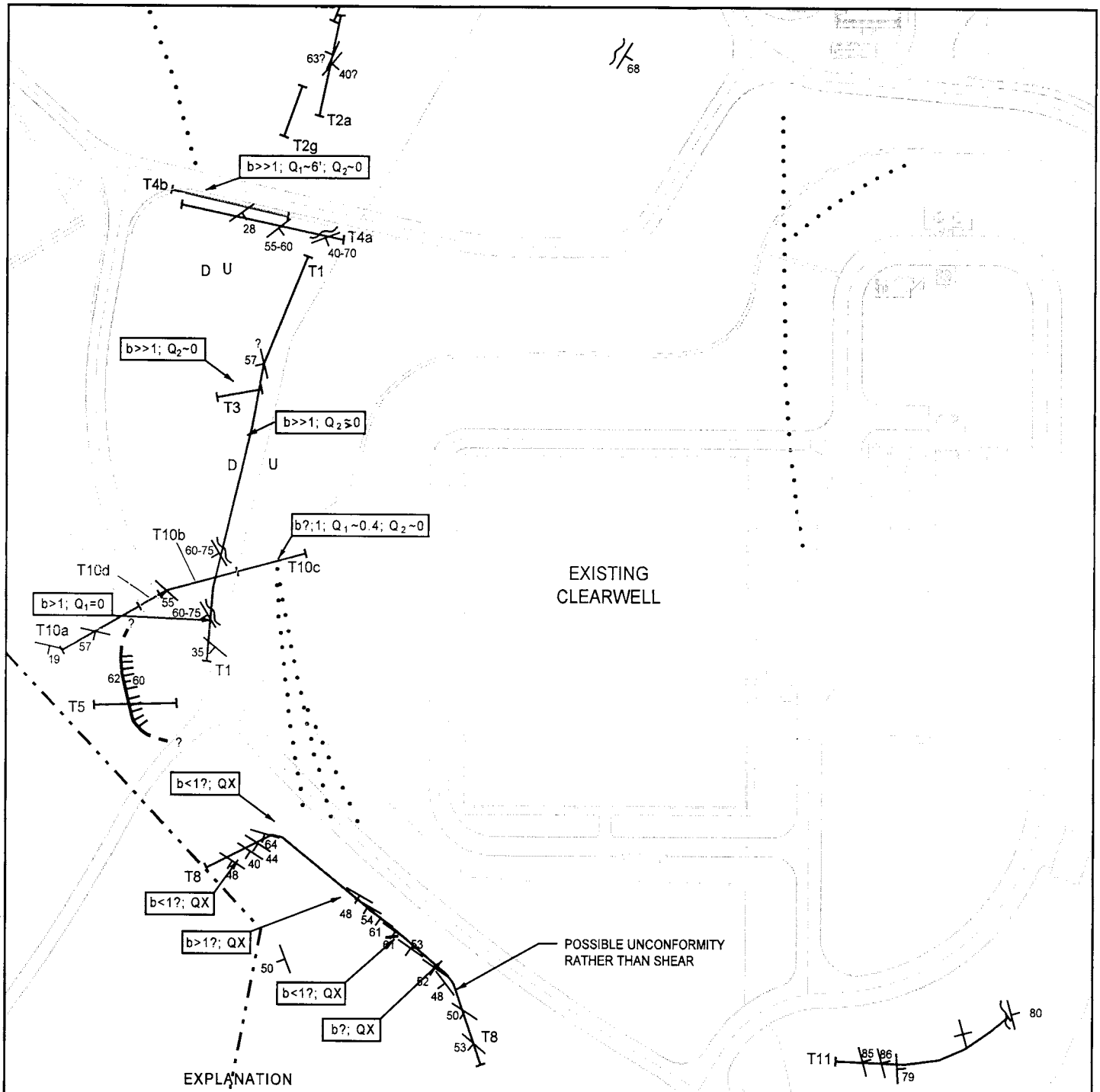
GEOMATRIX

COMPOSITE TRENCH WALL SKETCH MAP OF THE SHEAR ZONE EXPOSED IN TRENCHES 4a AND 4b

Walnut Creek Water Treatment Plant Expansion
Seismic Study- Phase II
East Bay Municipal Utility District
Walnut Creek, California

Figure 3-2

Project No. 3970



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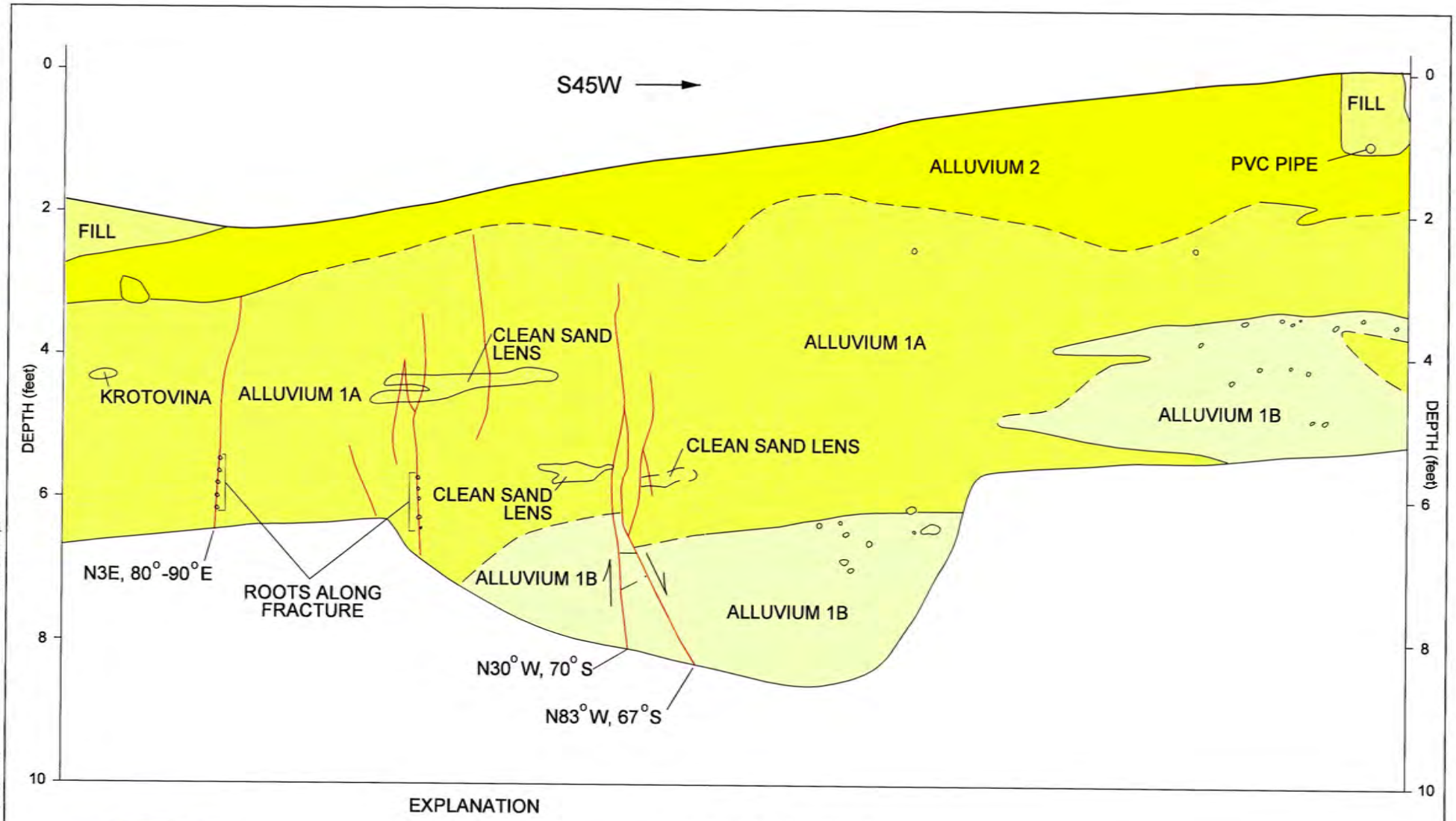
GEOMATRIX

FAULT DISPLACEMENTS IN BEDROCK AND QUATERNARY DEPOSITS

Walnut Creek Water Treatment Plant Expansion
Seismic Study - Phase II
East Bay Municipal Utility District
Walnut Creek, California

Figure 3-3

Project No. 3970



EXPLANATION

- FILL
- ALLUVIUM 2
- ALLUVIUM 1A, SAND FACIES
- ALLUVIUM 1B, GRAVELLY SAND FACIES

SHEAR OR FRACTURE, ARROWS SHOW RELATIVE SENSE OF DISPLACEMENT

CONTACT, DASHED WHERE APPROXIMATELY LOCATED

0 2
SCALE IN FEET
NO VERTICAL EXAGGERATION

GEOMATRIX

TRENCH-WALL MAP OF SHEARS AND FRACTURES EXPOSED IN TRENCH 10C
Walnut Creek Water Treatment Plant Expansion
Seismic Study- Phase II
East Bay Municipal Utility District
Walnut Creek, California

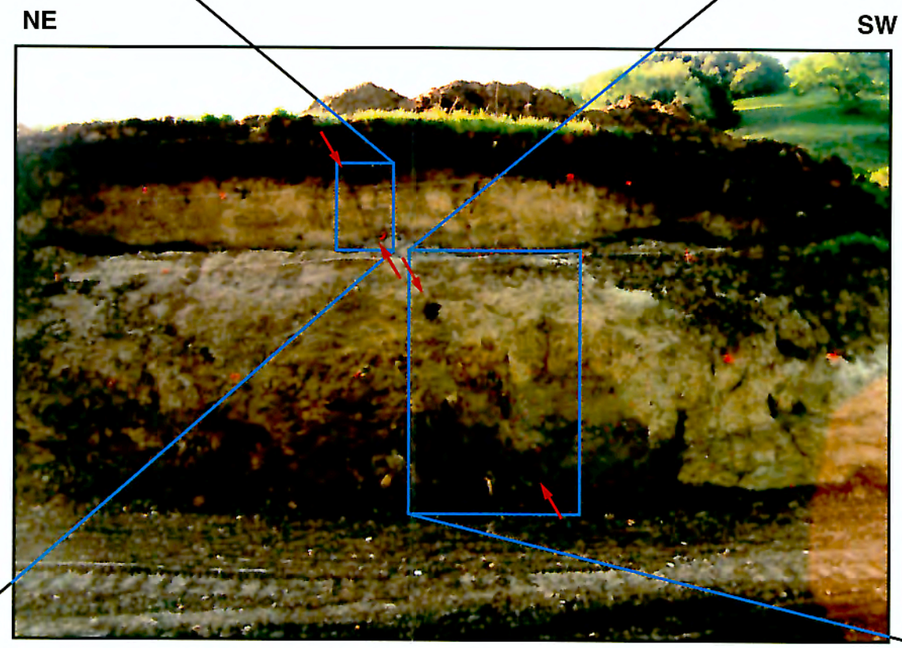
Figure 3-4

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Detail A: Close-up of West Fault at top of trench exposure 4a showing truncated gravel beds and offset burn horizons. Scale is 1 foot.



Southwest end of trench (roadcut) exposure 4a showing southwest dipping west fault. See Plate A-8 for detailed map of the exposure. Exposure is approximately 15 feet high. View is to the southeast. Arrows indicate fault trace.



Detail B: Close-up of West Fault at base fo trench exposure 4a showing faulted contact between claystone bedrock and alluvium #1. Note calcium carbonate lined shears. Burn horizons (dark colored areas in lower right part) are truncated by shears directly to right (southwest) of scale. Scale is 1 foot.

TRENCH EXPOSURE OF WEST FAULT
Seismic Study - Phase II
Walnut Creek Water Treatment Plant Expansion
East Bay Municipal Utility District
Walnut Creek, California

GEOMATRIX

Project No.	Figure
3970B	3-5

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PLATES

LIMIT OF MAPPING

LIMIT OF MAPPING

LIMIT OF MAPPING

FRANKLIN FAULT MAIN TRACE

Tem

Qt

Tmh

Qal

Tmbl

Tmbu

Tmnl

Tmnu

Fill

9 MG

OVERFLOW ELEV. = 374.0
WATER DEPTH = 28.0'
BOTTOM ELEV. = 346.0
DIAMETER = 235.0'

9 MG

OVERFLOW ELEV. = 374.0
WATER DEPTH = 28.0'
BOTTOM ELEV. = 346.0
DIAMETER = 235.0'

PROPOSED STEEL TANKS ALTERNATIVE

PROPOSED CLEARWELL EXPANSION ALTERNATIVE

REALIGN RAW WATER LINE

NEW OUTLET LINE

NEW INLET LINE

RELOCATE EXISTING FENCE

RELOCATE ROAD

PROPERTY LINE

FILL/DECANT BASINS

SOLIDS HANDLING

RETAINING WALL

NEW 66" RAW WATER INFLUENT

BYPASS CHANNEL

COLLECTION CHANNEL

RAPID MIX IN CHANNEL

FLOCCULATION CONSTRUCTION

DISTRIBUTION CHANNEL

EXISTING 66" RAW WATER INFLUENT

EXISTING CLEARWELL OUTLET

NEW 66" CLEARWELL OUTLET

EXISTING 78" FILTER EFFLUENT

66" FILTER EFFLUENT

ELECTRICAL SUBSTATION

CHEMICAL FEED BUILDING

DRAINAGE GENERATION BUILDING

EAST FAULTS

CENTRAL FAULT

WEST FAULT

T6 T5 T30 T30c T30a T30d T7a T7d T7b T7c T20 T20c T20d T29 T29a T40 T40a T10 T10c T10d T10a T11 T11a T8 T8a T8b T8c T8d T8e T8f T8g T8h T8i T8j T8k T8l T8m T8n T8o T8p T8q T8r T8s T8t T8u T8v T8w T8x T8y T8z T8aa T8ab T8ac T8ad T8ae T8af T8ag T8ah T8ai T8aj T8ak T8al T8am T8an T8ao T8ap T8aq T8ar T8as T8at T8au T8av T8aw T8ax T8ay T8az T8ba T8bb T8bc T8bd T8be T8bf T8bg T8bh T8bi T8bj T8bk T8bl T8bm T8bn T8bo T8bp T8bq T8br T8bs T8bt T8bu T8bv T8bw T8bx T8by T8bz T8ca T8cb T8cc T8cd T8ce T8cf T8cg T8ch T8ci T8cj T8ck T8cl T8cm T8cn T8co T8cp T8cq T8cr T8cs T8ct T8cu T8cv T8cw T8cx T8cy T8cz T8da T8db T8dc T8dd T8de T8df T8dg T8dh T8di T8dj T8dk T8dl T8dm T8dn T8do T8dp T8dq T8dr T8ds T8dt T8du T8dv T8dw T8dx T8dy T8dz T8ea T8eb T8ec T8ed T8ee T8ef T8eg T8eh T8ei T8ej T8ek T8el T8em T8en T8eo T8ep T8eq T8er T8es T8et T8eu T8ev T8ew T8ex T8ey T8ez T8fa T8fb T8fc T8fd T8fe T8ff T8fg T8fh T8fi T8fj T8fk T8fl T8fm T8fn T8fo T8fp T8fq T8fr T8fs T8ft T8fu T8fv T8fw T8fx T8fy T8fz T8ga T8gb T8gc T8gd T8ge T8gf T8gg T8gh T8gi T8gj T8gk T8gl T8gm T8gn T8go T8gp T8gq T8gr T8gs T8gt T8gu T8gv T8gw T8gx T8gy T8gz T8ha T8hb T8hc T8hd T8he T8hf T8hg T8hh T8hi T8hj T8hk T8hl T8hm T8hn T8ho T8hp T8hq T8hr T8hs T8ht T8hu T8hv T8hw T8hx T8hy T8hz T8ia T8ib T8ic T8id T8ie T8if T8ig T8ih T8ii T8ij T8ik T8il T8im T8in T8io T8ip T8iq T8ir T8is T8it T8iu T8iv T8iw T8ix T8iy T8iz T8ja T8jb T8jc T8jd T8je T8jf T8jg T8jh T8ji T8jj T8jk T8jl T8jm T8jn T8jo T8jp T8jq T8jr T8js T8jt T8ju T8jv T8jw T8jx T8jy T8jz T8ka T8kb T8kc T8kd T8ke T8kf T8kg T8kh T8ki T8kj T8kk T8kl T8km T8kn T8ko T8kp T8kq T8kr T8ks T8kt T8ku T8kv T8kw T8kx T8ky T8kz T8la T8lb T8lc T8ld T8le T8lf T8lg T8lh T8li T8lj T8lk T8ll T8lm T8ln T8lo T8lp T8lq T8lr T8ls T8lt T8lu T8lv T8lw T8lx T8ly T8lz T8ma T8mb T8mc T8md T8me T8mf T8mg T8mh T8mi T8mj T8mk T8ml T8mm T8mn T8mo T8mp T8mq T8mr T8ms T8mt T8mu T8mv T8mw T8mx T8my T8mz T8na T8nb T8nc T8nd T8ne T8nf T8ng T8nh T8ni T8nj T8nk T8nl T8nm T8nn T8no T8np T8nq T8nr T8ns T8nt T8nu T8nv T8nw T8nx T8ny T8nz T8oa T8ob T8oc T8od T8oe T8of T8og T8oh T8oi T8oj T8ok T8ol T8om T8on T8oo T8op T8oq T8or T8os T8ot T8ou T8ov T8ow T8ox T8oy T8oz T8pa T8pb T8pc T8pd T8pe T8pf T8pg T8ph T8pi T8pj T8pk T8pl T8pm T8pn T8po T8pp T8pq T8pr T8ps T8pt T8pu T8pv T8pw T8px T8py T8pz T8qa T8qb T8qc T8qd T8qe T8qf T8qg T8qh T8qi T8qj T8qk T8ql T8qm T8qn T8qo T8qp T8qq T8qr T8qs T8qt T8qu T8qv T8qw T8qx T8qy T8qz T8ra T8rb T8rc T8rd T8re T8rf T8rg T8rh T8ri T8rj T8rk T8rl T8rm T8rn T8ro T8rp T8rq T8rr T8rs T8rt T8ru T8rv T8rw T8rx T8ry T8rz T8sa T8sb T8sc T8sd T8se T8sf T8sg T8sh T8si T8sj T8sk T8sl T8sm T8sn T8so T8sp T8sq T8sr T8ss T8st T8su T8sv T8sw T8sx T8sy T8sz T8ta T8tb T8tc T8td T8te T8tf T8tg T8th T8ti T8tj T8tk T8tl T8tm T8tn T8to T8tp T8tq T8tr T8ts T8tt T8tu T8tv T8tw T8tx T8ty T8tz T8ua T8ub T8uc T8ud T8ue T8uf T8ug T8uh T8ui T8uj T8uk T8ul T8um T8un T8uo T8up T8uq T8ur T8us T8ut T8uu T8uv T8uw T8ux T8uy T8uz T8va T8vb T8vc T8vd T8ve T8vf T8vg T8vh T8vi T8vj T8vk T8vl T8vm T8vn T8vo T8vp T8vq T8vr T8vs T8vt T8vu T8vv T8vw T8vx T8vy T8vz T8wa T8wb T8wc T8wd T8we T8wf T8wg T8wh T8wi T8wj T8wk T8wl T8wm T8wn T8wo T8wp T8wq T8wr T8ws T8wt T8wu T8wv T8ww T8wx T8wy T8wz T8xa T8xb T8xc T8xd T8xe T8xf T8xg T8xh T8xi T8xj T8xk T8xl T8xm T8xn T8xo T8xp T8xq T8xr T8xs T8xt T8xu T8xv T8xw T8xx T8xy T8xz T8ya T8yb T8yc T8yd T8ye T8yf T8yg T8yh T8yi T8yj T8yk T8yl T8ym T8yn T8yo T8yp T8yq T8yr T8ys T8yt T8yu T8yv T8yw T8yx T8yy T8yz T8za T8zb T8zc T8zd T8ze T8zf T8zg T8zh T8zi T8zj T8zk T8zl T8zm T8zn T8zo T8zp T8zq T8zr T8zs T8zt T8zu T8zv T8zw T8zx T8zy T8zz

EXPLANATION

SURFICIAL GEOLOGIC UNITS

- Fill — FILL (HISTORICAL), SANDY TO SILTY CLAY, SOME SMALL AREAS OF FILL ARE NOT SHOWN (FILL NEAR FILTERS FROM EBMUD DRAWING 5001-G-23.01)
- Qal — ALLUVIUM (HOLOCENE TO HISTORICAL), SANDY CLAY, SAND, AND SANDY GRAVEL
- Qt — ALLUVIAL GEOMORPHIC SURFACE (LATE PLEISTOCENE), SANDY CLAY, SAND, AND SANDY GRAVEL

BEDROCK UNITS

- Tmnu — UPPER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE
- Tmnl — LOWER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE AND SHALE
- Tmbu — UPPER BRIONES FORMATION (UPPER MIOCENE), SHALE MEMBER
- Tmbl — LOWER BRIONES FORMATION (UPPER MIOCENE), SANDSTONE MEMBER
- Tmh — HAMBRE SANDSTONE (MIDDLE MIOCENE), FINE-GRAINED SANDSTONE
- Tem — MEGANOS FORMATION (LOWER EOCENE), CLAYSTONE MEMBER

LITHOLOGIC ABBREVIATIONS

- CGL — CONGLOMERATE TERTIARY (?)
- SS — FINE-TO VERY FINE-GRAINED SANDSTONE
- MSS — MEDIUM-GRAINED SANDSTONE
- SH — CLAYSTONE
- SLTS — SILTSTONE

SYMBOLS

- FAULT, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED, QUERIED WHERE INFERRED; ARROW INDICATES DIRECTION AND AMOUNT OF DIP OF FAULT
- CONTACT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE INFERRED
- AXIS OF SYNCLINE
- MARKER BED
- PALEOCHANNEL, SHOWING FLOW DIRECTION
- LANDSLIDE; ARROW SHOWS DIRECTION OF MOVEMENT
- EBMUD PROPERTY BOUNDARY
- STRIKE AND DIP OF BEDDING
- STRIKE AND DIP OF VERTICAL BEDDING
- STRIKE AND DIP OF BEDDING PARALLEL SHEAR
- STRIKE AND DIP OF BEDROCK FAULT EXPOSED IN TRENCH; FULL ARROW INDICATES DIP OF FAULT; ARROWS INDICATE RELATIVE SENSE OF DISPLACEMENT
- STRIKE AND DIP OF FRACTURE
- VERTICAL FRACTURE
- BOREHOLE, LITHOLOGY
- TRENCH, THIS STUDY (1997)
- TRENCH, C. MARLIAVE (1956)
- LIMIT OF TYPE "A" STRUCTURAL EMBANKMENT FILL (FROM EBMUD DRAWING 5000-G-8)

100 0 100
SCALE IN FEET

SITE GEOLOGIC MAP
WALNUT CREEK WATER TREATMENT PLANT EXPANSION SEISMIC STUDY-PHASE II
East Bay Municipal Utility District
Walnut Creek, California

GEOMATRIX	October 1998	Project No. 3970	Plate 1

(C)GEOMATRIX 1998
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By: steve

LIMIT OF MAPPING

LIMIT OF MAPPING

LIMIT OF MAPPING

FRANKLIN FAULT MAIN TRACE

EAST FAULTS

CENTRAL FAULT

WEST FAULT

REALIGN RAW WATER LINE

9 MG
OVERFLOW ELEV. = 374.0
WATER DEPTH = 28.0'
BOTTOM ELEV. = 346.0
DIAMETER = 238.0'

9 MG
OVERFLOW ELEV. = 374.0
WATER DEPTH = 28.0'
BOTTOM ELEV. = 346.0
DIAMETER = 238.0'

PROPOSED STEEL TANKS ALTERNATIVE

PROPOSED CLEARWELL EXPANSION ALTERNATIVE

Tem Tmh Fill Qal Qt Tmbl Tmbu Tmnl Tmnu

100 0 100
SCALE IN FEET

EXPLANATION

Fill FILL (HISTORICAL), SANDY TO SILTY CLAY, SOME SMALL AREAS OF FILL ARE NOT SHOWN (FILL NEAR FILTERS FROM EBMUD DRAWING 5001-G-23.01)

Qal ALLUVIUM (HOLOCENE TO HISTORICAL), SANDY CLAY, SAND, AND SANDY GRAVEL

Qt ALLUVIAL GEOMORPHIC SURFACE (LATE PLEISTOCENE), SANDY CLAY, SAND, AND SANDY GRAVEL

BEDROCK UNITS

Tmnu UPPER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE

Tmnl LOWER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE AND SHALE

Tmbu UPPER BRIONES FORMATION (UPPER MIOCENE), SHALE MEMBER

Tmbl LOWER BRIONES FORMATION (UPPER MIOCENE), SANDSTONE MEMBER

Tmh HAMBRE SANDSTONE (MIDDLE MIOCENE), FINE-GRAINED SANDSTONE

Tem MEGANOS FORMATION (LOWER EOCENE), CLAYSTONE MEMBER

LITHOLOGIC ABBREVIATIONS

CGL CONGLOMERATE TERTIARY (?)

SS FINE-TO VERY FINE-GRAINED SANDSTONE

MSS MEDIUM-GRAINED SANDSTONE

SH CLAYSTONE

SLTS SILTSTONE

SYMBOLS

FAULT, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED, QUERIED WHERE INFERRED; ARROW INDICATES DIRECTION AND AMOUNT OF DIP OF FAULT

CONTACT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE INFERRED

AXIS OF SYNCLINE

MARKER BED

PALEOCHANNEL, SHOWING FLOW DIRECTION

LANDSLIDE; ARROW SHOWS DIRECTION OF MOVEMENT

EBMUD PROPERTY BOUNDARY

STRIKE AND DIP OF BEDDING

STRIKE AND DIP OF VERTICAL BEDDING

STRIKE AND DIP OF BEDDING PARALLEL SHEAR

STRIKE AND DIP OF BEDROCK FAULT EXPOSED IN TRENCH; FULL ARROW INDICATES DIP OF FAULT; ARROWS INDICATE RELATIVE SENSE OF DISPLACEMENT

STRIKE AND DIP OF FRACTURE

VERTICAL FRACTURE

BOREHOLE, LITHOLOGY

TRENCH, THIS STUDY (1997)

TRENCH, C. MARLIAVE (1956)

LIMIT OF TYPE "A" STRUCTURAL EMBANKMENT FILL (FROM EBMUD DRAWING 5000-G-8)

NOTE:
Photographic base is from aerial photograph AV-334-12-15 taken on 7/1/59.

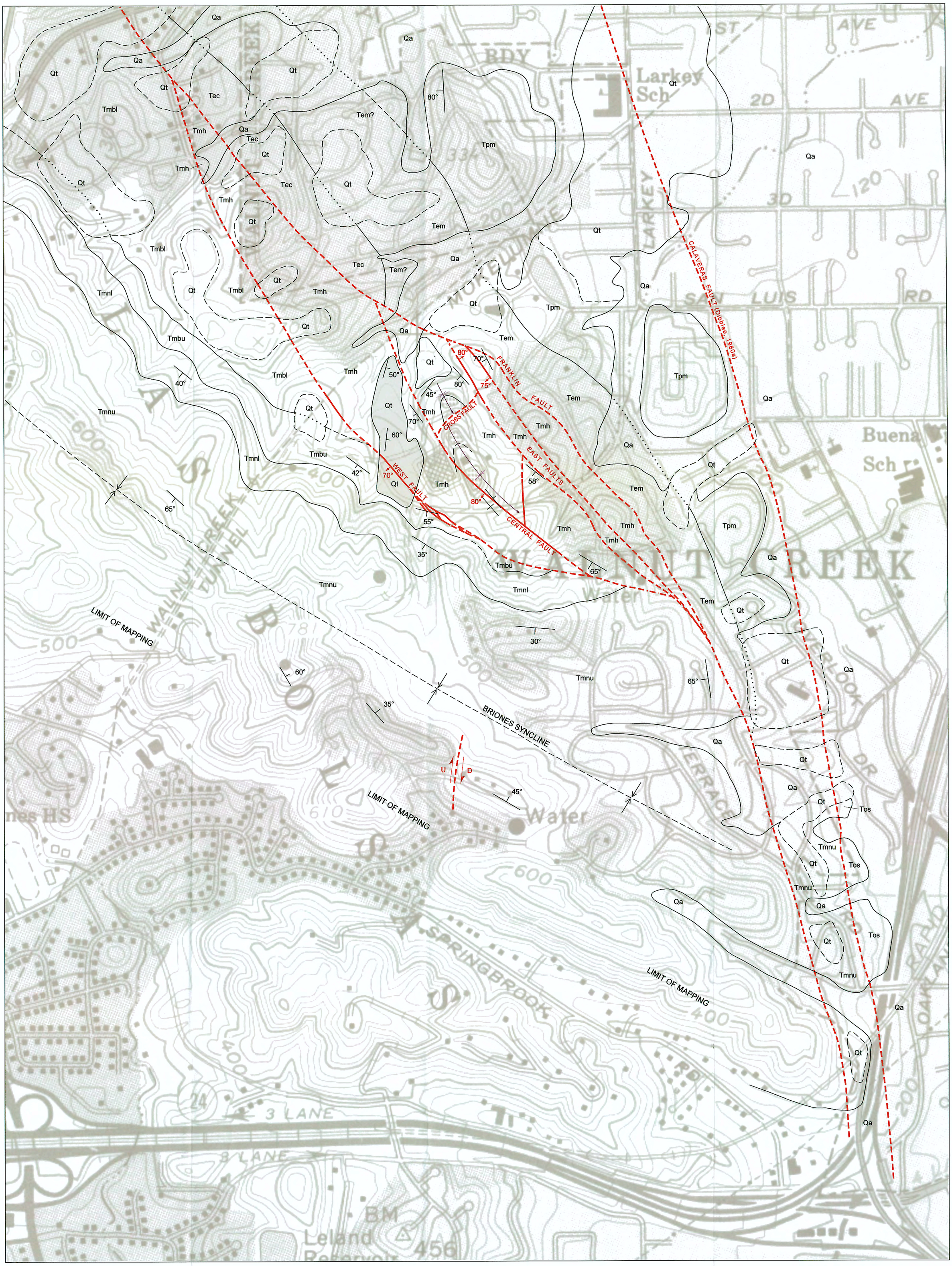
SITE GEOLOGIC MAP
WALNUT CREEK WATER TREATMENT PLANT EXPANSION
SEISMIC STUDY-PHASE II
East Bay Municipal Utility District
Walnut Creek, California

GEOMATRIX	October 1998	Project No. 3970	Plate 2

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EXPLANATION

GEOLOGIC UNITS

Qa	ALLUVIUM (HOLOCENE TO HISTORICAL), SANDY CLAY, SAND, AND SANDY GRAVEL
Qt	ALLUVIUAL GEOMORPHIC SURFACE (LATE PLEISTOCENE)
Tmnu	UPPER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE
Tmnl	LOWER NEROLY FORMATION (UPPER MIOCENE), SANDSTONE AND SHALE
Tmbu	UPPER BRIONES FORMATION (UPPER MIOCENE), SHALE MEMBER
Tmbl	LOWER BRIONES FORMATION (UPPER MIOCENE), SANDSTONE MEMBER
Tmh	HAMBRE SANDSTONE (MIDDLE MIOCENE), FINE-GRAINED SANDSTONE
Tos	SAN RAMON FORMATION (LOWER OLIGOCENE), SANDSTONE
Tec	UNNAMED CLAYSTONE (LOWER EOCENE), CLAYSTONE, MINOR SANDSTONE
Tem	MEGANOS FORMATION (LOWER EOCENE), CLAYSTONE
Tpm	MARTINEZ FORMATION (UPPER PALEOCENE), SANDSTONE AND CLAYSTONE

SYMBOLS

70° U D ? — FAULT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE INFERRED; FULL ARROW INDICATES DIP OF FAULT HALF ARROWS INDICATE RELATIVE SENSE OF SLIP; U=UP; D=DOWN

CONTACT, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED, QUERIED WHERE INFERRED

AXIS OF SYNCLINE

44 — STRIKE AND DIP OF BEDDING

STRIKE AND DIP OF VERTICAL BEDDING

N

400 0 400

SCALE IN FEET

REGIONAL GEOLOGIC MAP
Walnut Creek Water Treatment Plant Expansion
Seismic Study-Phase II
East Bay Municipal Utility District
Walnut Creek, California

GEOMATRIX	October 1998	Project No. 3970	Plate 3

GEOMATRIX

FINAL REPORT
WALNUT CREEK WATER TREATMENT PLANT EXPANSION SEISMIC STUDY – PHASE II

APPENDIX B - FRANKLIN FAULT—ASSESSMENT OF MAXIMUM CREDIBLE EARTHQUAKE

Prepared for

East Bay Municipal Utility District
375 Eleventh Street
P.O. Box 24055
Oakland, California 946o7-4240

October 1998
Project No. 3970

FRANKLIN FAULT
ASSESSMENT OF MAXIMUM CREDIBLE EARTHQUAKE

Assessment of the maximum credible earthquake (MCE) for the Franklin fault is based on applying the appropriate empirically based magnitude/fault parameter relationships of Wells and Coppersmith (1994) to estimates of fault rupture length and fault rupture area. Estimates of these parameters are derived from existing data (e.g., geologic maps, seismicity, analysis of fault activity) and reconnaissance-level investigation conducted by Geomatrix for this and previous projects (Geomatrix, 1993, 1995).

The location of the northernmost extent of the Franklin fault is not well defined. As mentioned previously, the Geologic Map of California (Jennings, 1994; scale 1:750,000) and the San Francisco-San Jose and Santa Rosa quadrangles (Bortugno and others, 1991; Wagner and Bortugno, 1982; scale 1:250,000) place the northern tip of the fault at the southern bank of Carquinez Strait near San Pablo Bay. The Franklin fault may extend an unknown distance into San Pablo Bay to the northwest, but there is no geologic evidence that it reaches the north shore of the bay. It is possible to postulate a structural link between the northern Franklin fault and the West Napa fault across a right (releasing) stepover within San Pablo Bay, but such a connection has not been established. Geomorphic and structural geologic evidence also suggest it is possible that the Franklin fault may persist northward along the west coast of Mare Island, but there is no firm evidence that currently supports this possibility. The Franklin fault was not imaged on recently acquired geophysical data gathered across the northern projection of the fault (Williams and others, 1995). However, because technical problems affected data quality in this area, the fault may not have been identified even if it were present. For purposes of this study, the northern end of the Franklin fault is assumed to be located on the south shore of Carquinez Strait, the northernmost location that is supported by available geologic data.

The southernmost extent of the Franklin fault is located at the southern end of Castle Hill, in the northern San Ramon Valley, where the southern Franklin fault (northernmost Calaveras fault of Dibblee 1980a,b) joins a more northerly trending fault that lies to the east (the

northernmost Calaveras fault of Graymer and others, 1994). This interpretation is supported by bedrock mapping that indicates the style and amount of displacement in bedrock is characteristic of the Franklin fault to the north (Ham, 1952; Graymer and others, 1994). It is also supported by the Quaternary geologic, geomorphic, and seismicity data that indicate the northern Calaveras fault does not extend north of this location (e.g., Simpson and others, 1992). The interpretation of Graymer and others (1994) that the Calaveras fault extends as a buried feature north of this location and east of the Franklin fault is apparently based on their interpretation of a major discontinuity ("stratigraphic assemblage" boundary) in bedrock beneath the alluvium of the Walnut Creek basin.

Several lines of evidence also suggest that even though the northern Calaveras and southern Franklin faults appear connected as post-Miocene bedrock structures, they are not necessarily linked as Quaternary active faults. There are significant differences in the style and activity of Quaternary deformation between the northern Calaveras and Franklin faults that indicate they have different slip histories. The Franklin fault, particularly the northern part, is a high-angle, northeast-dipping reverse fault that lies primarily within bedrock terrain, whereas the Calaveras fault is a vertical, right-lateral strike-slip fault that lies primarily at or near the base of the East Bay Hills within Quaternary deposits. The geomorphic expression of the entire Franklin fault is very subtle or nonexistent, with possible evidence for late Quaternary displacement currently limited to just two locations. However, there is no evidence for Quaternary activity on the Franklin fault where its projected trend crosses the alluviated valley floor or channel walls of Las Trampas Creek west of Walnut Creek. These observations indicate that, if active, the Franklin fault has a low to very low (<1 mm/yr) rate of slip.

The geomorphic expression of the northern Calaveras fault is also subtle, but is significantly stronger than that of the Franklin fault. Recent paleoseismic investigations indicate that south of San Ramon in the vicinity of Sunol, the northern Calaveras fault has a dextral slip rate of 3 to 5 mm/yr (Kelson and others, 1996). Finally, even though the rate of seismic activity on the northern Calaveras fault is very low relative to the fault farther to the south, diffuse microseismicity is present northeast of its trace. This microseismicity is associated with the northeast-trending earthquake swarms that are cited as evidence for a right en echelon link to

the active Concord fault (Oppenheimer and MacGregor-Scott, 1992). In contrast, no seismic activity is clearly associated with the Franklin fault. There is a very diffuse alignment of microseismicity that extends north of Walnut Creek along the range front, but this activity is spatially closer to the northernmost Calaveras fault as mapped by Graymer and others (1944) than to the Franklin fault. All of the existing evidence for Holocene fault activity (including seismicity) in the vicinity of the Walnut Creek area supports the hypothesis that in the current tectonic setting, dextral fault slip is transferred from the northern Calaveras fault northeastward to the Concord fault.

In addition to these observations of the differences in the Quaternary tectonic character between the northern Calaveras and Franklin faults, two structural features in the region also suggest these faults are separate structures with respect to fault rupture. Foremost is the strong evidence that in the current tectonic setting, displacement is transferred from the northern Calaveras to the Concord fault across a right stepover. This stepover is reflected in the spatial (en echelon) relationship between the two faults, clear evidence for Holocene slip on both the Concord and northern Calaveras faults south of Danville, presence of the Walnut Creek basin in the stepover region, strong expression in the instrumental seismicity, and presence of a cluster of approximately north-trending faults in bedrock within the stepover (e.g., Graymer and others, 1994). A second, although less convincing, structural argument for the lack of seismogenic continuity between the Calaveras and Franklin faults is the double releasing bend associated with the strike-slip duplex that forms the bedrock connection between the faults as discussed previously. The southern bend in the duplex is a 25 to 30 degree, right-releasing bend that lies just north of the southern tip of the Franklin fault at Castle Hill. The northern bend in the duplex is a 20 to 25 degree, left-restraining bend located near the range front at Walnut Creek. The northward step, or offset, in the bedrock trace of the northern Calaveras and Franklin faults associated with the duplex is about 2.5 km. The ability of such along-strike discontinuities to arrest earthquake rupture has been demonstrated from observations of active fault systems worldwide (Sibson, 1989); their effectiveness as segment boundaries is related to the width of the stepover and the geometric severity of the fault bend. The 1992 Landers, California, earthquake, however, ruptured across several such along-strike discontinuities linking Holocene fault traces across regions that manifested only weak evidence for Quaternary

fault activity (Sowers and others, 1994). The ground rupture associated with Landers earthquake suggests that, for deterministic assessments of maximum earthquake magnitudes, segmentation of faults based on along-strike discontinuities may be misleading.

Based on the geologic observations presented above, the southern extent of the Franklin fault is considered to be its intersection with the Calaveras fault at the southern end of Castle Hill near Alamo. From here the fault extends 29 km to the southern shore of Carquinez Strait. Although the dip of the fault is not well constrained, its nearly linear trace through hilly terrain suggests it is a relatively high-angle feature (>50 degrees). This interpretation is supported by the structural cross sections of Figuers (1991) and by the field observations of Haydon (1995). For assessment of fault width, a dip of 60 degrees is assumed. The regional base of the seismogenic zone is between 15 and 20 km, becoming deeper to the north and east along the northern Calaveras and Concord faults (Oppenheimer and Lindh, 1992). The Birds Landing Seismic Zone, located north of Pittsburg, extends to an anomalous depth of 24 km. The cluster of seismicity associated with the Concord fault lies at a depth of 15 to 16 km. For calculation of fault width, a somewhat conservative seismogenic depth of 18 km is assumed for the Franklin fault.

Based on these fault parameters, maximum earthquake magnitudes calculated using the relationships of Wells and Coppersmith (1994) are MW 6.78 for a total fault rupture length of 29 km and MW 6.79 for a total fault rupture area of 603 sq. km. Despite the poor geomorphic expression of the Franklin fault, reflecting a very low slip rate and/or absence of Holocene activity; significant along-strike variations in trend, geomorphic expression, and structural geologic associations; and observations that faults of moderate length like the Franklin fault seldom rupture their entire mapped trace during major earthquakes, a 29-km-long rupture of the Franklin fault, although judged unlikely, cannot be ruled out. Future geologic research in the Walnut Creek area may resolve some of the ambiguities associated with the Franklin fault and increase understanding of its role in the tectonic environment of the East Bay Area. Such research is unlikely, however, to shorten the estimated rupture length of this fault. Based on these considerations, the Maximum Credible Earthquake (MCE) on the Franklin fault is judged to be MW 6¾.

SLIP RATE

The Franklin fault is poorly expressed geomorphically, and few direct data exist regarding the slip rate. In the absence of slip data clearly related to the Franklin fault, Geomatrix estimates its slip rate by assessing the degree of activity of the Franklin fault relative to other faults having known slip rates. The geomorphic features of various faults in the San Francisco Bay Area show that those faults having slip rates on the order of several to tens of millimeters per year (such as the San Andreas and Hayward faults) usually are clearly expressed geomorphically along most of their length. In these cases, the rate of development of fault-related geomorphic features exceeds the rate of destructive geomorphic processes, such as landsliding and erosion, which tend to obscure evidence for fault activity. At slip rates of about 1 mm/yr (such as the Greenville fault in the eastern Livermore Valley), the geomorphic evidence for activity is much more scattered and subdued, although locally the fault may display clear evidence of activity. At rates of tenths of millimeters per year, faults in the Bay Area usually are poorly expressed geomorphically and difficult to recognize except locally under favorable topographic and stratigraphic conditions. The Franklin fault is not well expressed geomorphically; considerable uncertainties apply to its location and extent as documented above. Based on comparisons with other faults, Geomatrix concludes that the fault has a slip rate on the order of tenths of millimeters per year, certainly no higher than 1 mm/yr, and probably no higher than the lower limit (0.1 to 0.5 mm/yr) estimated for the Greenville fault (Geomatrix, 1993).