GROUNDWATER STUDY AND WATER SUPPLY HISTORY OF THE EAST BAY PLAIN, ALAMEDA AND CONTRA COSTA COUNTIES, CA

for:

The Friends of the San Francisco Estuary
Box 791
Oakland, California

by:

S. Figuers

Norfleet Consultants
Livermore, California

Norfleet Consultants Project Number 971102

June 15, 1998

NORFLEET CONSULTANTS

Engineering
Geology
Geohydrology
Geophysics

1205 E. Stanley Blvd.
Suite B
Livermore, CA 94550
(925) 606-8595

June 15, 1998

Mr. M. Lozeau
Friends of the San Francisco Estuary
Box 791
Oakland, CA 94604

RE: East Bay Plain Beneficial Use Report

Dear Mr. Lozeau,

Norfleet Consultants is pleased to submit this report on the sub-surface geology, hydrogeology, and water supply history of the East Bay Plain. It presents our regional geologic analysis and historical review of groundwater uses of the East Bay Plain.

It has been a pleasure working on this challenging project. If you have any questions, please contact us at (925) 606-8595

Yours truly,

NORFLEET CONSULTANTS

Sands Figuers PhD, CE, CEG, CHG, RGp
Principal Geological Engineer

TABLE OF CONTENTS

TABLES

FIGURES (The Figures and Plates are located after the References)

PLATES

EXECUTIVE SUMMARY

This study provides a geologic, hydrogeologic, and historical framework of the East Bay Plain Groundwater Basin (Figure 1). The framework is based on a review of historical groundwater use in the East Bay area from 1860 to 1930, the identification of historic municipal well fields, an analysis of the sub-surface geology of the Study Area (including aquifers and aquitards), a search for wells and borings, an update of the Rogers and Figuers (1991) basement map of the area, an analysis of the nature and limitations of existing well data, an evaluation of the vertical interconnections between aquifers, and an identification/definition of basins and sub-areas within the Study Area.

We defined two basins (Figure 2). The San Francisco Basin extends north from the Dumbarton Bridge to the shoreline south of Richmond and the San Pablo Basin extends north of the San Francisco Basin. Both basins are tectonic depressions that filled primarily with a sequence of coalescing alluvial fans. These units consist of irregular lenses of sands, silts, and gravels eroded from the surrounding hills. During interglacial periods, seas entered the central part of the basins and deposited widespread estuarine muds. These muds are the primary aquitards that bound the major aquifers and control the vertical flow of groundwater. There are four or five estuarine muds within the central part of the basin, each with a different lateral extent. Along the southern part of the basin, there are laterally equivalent fine-grained layers that extend further inland. We created a series of lithofacies maps (Figures 11, 12, 13, and 14) and cross-sections (Plates 1 and 2) to illustrate the overall structural/stratigraphic/aquifer relationships.

Historically, stratigraphic units were given different names in different parts of the basin. In some respects, this nomenclature balkanized the basins, slowing recognition of the inter-connectedness of the units and water supplies. We redefined the stratigraphic names to be regionally consistent and to encourage a unified view of the basins.

The thickness of basin fill within the San Francisco Basin varies considerably. North of the Bay Bridge, there are 200 to 500 feet of sediments, while there are over 1000 feet of sediments beneath the cities of San Leandro/Hayward. The Bay Bridge also marks a significant change in the depositional style of the sediments. South of the Bay Bridge, the basin fill is relatively evenly layered; units are widespread and primarily have onlapping relationships. North of the Bay Bridge, basin fill is more chaotic. Periods of deposition were followed by deep erosion, causing large lateral and vertical variations in sediment type and distribution.

Individual aquifers and aquitards were historically defined in the Niles Cone, south of the study area (Figures 10 and 11). The aquitards (Newark, Irvington, and Mission) are equivalent to the estuarine muds (Young Bay Mud, Yerba Buena Mud, and deeper unnamed estuarine muds), and the aquifers (the Newark, Centerville, and Fremont) are equivalent to the San Antonio and unnamed alluvial units within the upper Alameda formation. The aquifers and aquitards can be mapped throughout the Study area. In the past, attempts have been made to subdivide the aquifers using existing well data. Our analysis indicates that the existing well data are too poor to allow such distinctions to be made at this time. Sub-divisions within the existing aquifers can be made, but to do so will require detailed, high quality geologic information.

We divided both basins into sub-areas based on geologic, geomorphic, and geographic factors (Figure 3). The eastern margin of the San Francisco Basin was divided into the Berkeley, Oakland, San Leandro, and San Lorenzo sub-areas, where as the central part of the basin forms the Central sub-area. The Central sub-area contains the classical stratigraphic section (Figure 8). The lower part of this sub-area filled with several hundred feet of fine-grained, alluvial fan deposits (Santa Clara formation). These were overlain by several hundred feet of interbedded alluvial fan and estuarine units (Alameda formation). The upper 100 feet or so of the Alameda had historically been divided into individual units (Yerba Buena Mud, San Antonio, Merritt Sand, Young Bay Mud), but these are now considered members within the Alameda formation. The sub-areas along

the eastern margin of the basin filled primarily with alluvial fan units (Santa Clara equivalent and younger units). Estuarine muds are found only along the western edges of those sub-areas.

Hydrogeologically, the sub-areas are distinct. The Berkeley sub-area is essentially a single hydrogeologic unit, containing numerous alluvial fan units. Individual wells provided water for most homes. There were no historic municipal well fields and no large-scale groundwater sources have been identified. The Oakland sub-area is also filled with alluvial fan material. It contains two main aquifers, the Merritt Sand and the deeper gravels. Both were primary sources of groundwater for over 60 years. A series of historical municipal well fields extended from the eastern end of Alameda, through the Oakland Coliseum, to 98th Street, and these mark a major hydrogeologic trend (Figure 18).

The San Leandro and San Lorenzo sub-areas have similar stratigraphic sections. There are two aquifers, a shallower one (0 to 200 feet deep) and a deeper one (deeper than 200 feet). These aquifers are composed primarily of alluvial fan material. The classical aquifer/aquitards, as defined in the Central sub-area, extend into the western part of these sub-areas. Even though the Yerba Buena Mud does not extend across these sub-areas, a laterally equivalent fine grained unit (50 to 100 feet thick) appears to act as an aquitard, dividing the stratigraphic section into the two aquifers. In the San Lorenzo sub-area, most wells pumped from the deeper aquifer, whereas in the San Leandro sub-area, most wells pumped from the upper aquifer. The Roberts Well Field was the only municipal well field in those sub-areas.

The Richmond sub-area is located in the southern end of the San Pablo Basin. The Richmond sub-area appears to have a similar stratigraphic section as the other sub-areas, but the estuarine clays do not appear to be as numerous or widespread. Several municipal well fields were drilled between the Wild Cat and San Pablo Creeks. Little is known about the stratigraphy or groundwater resources of the Basin north of the Richmond sub-area.

We researched and wrote an history of groundwater development between 1860 and 1930 in the East Bay Plain to provide guidance for beneficial use evaluations and to identify historic locations of large-scale groundwater supplies (Figure 24). Groundwater was a major part of the water supply for the East Bay area for almost 70 years, supplying up to 15,000,000 gallons of water per day. It was the sole supply for months on end during times of drought, and without it, the East Bay could never have developed. Approximately half of the groundwater was pumped from the Alvarado Well Field in Niles Cone, south of the study area (Figure 19). The majority of the remainder was pumped from a band of well fields stretching from the southeastern end of Alameda Island (the High Street Field) through the Oakland Coliseum (the Damon/Fitchburg Well Field) to 98th street (Kinsell Well Fields). The San Pablo well fields supplied water to Richmond, but they were over pumped and were shut-down twelve to fifteen years after being drilled.

There was a series of droughts between 1918 and 1929, and all of the municipal well fields were overpumped. This resulted in limited salt water intrusion into the upper aquifer in the Coliseum-eastern Alameda Island area, and caused the San Pablo fields to be shut-down in 1920. All of the municipal well fields were shut down in 1930, when Sierran water was brought into the area. Since then, groundwater levels have recovered, and it is likely that they are now at 1880 levels or higher.

We searched for historical private and municipal wells as part of our evaluation of aquifer-aquitard relationships. In addition to the municipal well fields, thousands of private wells supplied water to homes and businesses. In 1911, Mr. Dockweiler made an extensive survey of all private and public wells in the East Bay area, locating and mapping more than 3400 active wells (Figure 5). We estimate that in the range of 15,000 wells were drilled in the Study Area between 1860 and 1950. The majority of the wells were less than 50 feet deep, but many were 200 to 500 feet deep, with the deepest reaching 1000 feet below the ground surface. A few are still in use today, but most were abandoned and forgotten. Virtually none of these wells were properly destroyed.

GROUNDWATER STUDY OF THE EAST BAY PLAIN, RICHMOND TO SAN LEANDRO

INTRODUCTION

Location

The Study Area extends along the eastern side of San Francisco bay, between Richmond and San Leandro extending from the Hayward Fault west into the center of San Francisco Bay (Figure 1).

Purpose and Scope-of-Work

This study was performed to provide a regional current and historic hydrogeologic assessment of the East Bay Plain.

To achieve these goals, the following tasks were performed:

> Evaluate the subsurface geology of the East Bay plains. This included determining the overall depositional framework of the unconsolidated deposits, creating a subsurface bedrock map, identifying the major hydrologic sub-areas within the East Bay Plains, estimating the flow characteristics across the sub-area boundaries, and evaluating the nature of the major aquifers and aquitards.
>
> Research the historic groundwater uses in the East Bay plains from 1860 to 1930. This included locating the major well fields, wells, springs, and gathering information on historic water quality, pumping rates, and subsurface production zones.
>
> Based on the above data, prepare a report that provides recommendations for the division of the study area into sub-areas, evaluates the vertical interconnections between the upper and lower aquifers, and identifies locations of potential municipal or domestic well production or areas where such production is precluded.

The client and the consultant both recognized that completion of some of the tasks could be limited by the lack of information. We found that despite many turn-of-the-century anecdotal references concerning water quality, quantitative information was very limited. Interpretation of both the anecdotal and quantitative information was made more difficult by a lack of information about turn-of-the-century well construction methods and techniques, water analysis techniques, and pumping rates.

Methodology

The historical information was gathered by an in-depth search for and review of documents held in the Water Resources Center Archives, the Main Library, and the Bancroft Library at the University of California at Berkeley; the California State Library in Sacramento; the BART library in Oakland; CALTRANS archives in Oakland and Sacramento; the Oakland Historical Room at the Oakland Public Library; and the Alameda, Berkeley, Richmond, and Oakland Public Libraries. The historical review encompassed both groundwater use and previous geologic studies.

The volume of well data required that it be manipulated digitally. The data were entered in MapInfo (a geographical information system program). Data entered included: the well location, spud date, total depth, water levels, source of well data, and formation depth estimation (picks). That data were used to create the depth to bedrock map and other illustrations.

The basemaps used in this study were digital United States Geological Survey 7.5 minute quadrangles downloaded from the USGS web site. The basemaps were converted from the USGS SDTS format to the MapInfo format (MID/MIF). Where digital basemaps were unavailable, information was digitized from paper copies of the 7.5 minute quadrangles. Historic wells were located using the digital 1994 Tiger files.

Map Accuracy

Well data were located at a scale of 1:24,000 using the USGS quadrangles as basemaps. Plotting or viewing at scales larger than 1:24,000 will not provide more information, though it may reveal fine-scale irregularities. Such irregularities are a result of exceeding the resolution of the base map and are not real.

The accuracy of the well locations in the GIS database is generally in the range of 200-300 feet. This is a function of the basemaps used to locate the wells (1994 Tiger files) and the maps on which the wells were originally plotted (1910 to 1980 street maps). Even though well locations can be digitally determined to decimal places of a foot, such precision is meaningless.

Authorization

This study was performed in accordance with the Contract for Services between the Friends of the San Francisco Estuary and Norfleet Consultants. The work was performed for the Friends of the San Francisco Estuary as authorized on March 1, 1997.

Limitations

Official determination/delineation of basin or sub-area locations and boundaries is solely the responsibility of the Client. The basin/sub-area boundaries as discussed and illustrated in this report are approximate and are only intended to provide guidance to the Client. Boundary locations are subject to modification as new information becomes available.

The accuracy of the original well data was not verified, and it may contain inaccurate, incomplete, or be missing information. The Consultant provides this information on an "as-is" basis. Under the California Department of Water Resources regulations, access to water well information is restricted to the well owner or government agencies. It is not considered public information. Water well information contained within the database cannot be released to a private party without the written authorization of the well owner or a government agency.

The services performed by the Consultant have been conducted in a manner consistent with the level of care and skill ordinarily exercised by members of our professions practicing in the same or similar locations under similar conditions at the time the services were provided. This report may not provide all the information that may be required by the Client. No other representation, either expressed or implied, is included or intended in this report or in any opinion, documented or otherwise. Opinions provided in this report are subject to modification as additional information becomes available.

Acknowledgments

We would like to thank those who supported this project. The staff of the San Francisco Regional Water Quality Control Board, especially Linda Spencer and Greg Bartow for their support, and, most of all, their patience. Linda Sunnen and her staff at the University of California Water Resources Center Archives for their help in gathering historical information. The staff at CALTRANS, BART, Alameda County Flood Control District (Mr. A. Godfery), the Port of Oakland (Mr. J. Prall), the Alameda County Water District for allowing access to their well data, and all the others who provided help and information.

PREVIOUS GEOLOGIC STUDIES

There have been two periods of technical studies: 1890 to 1925 and 1955 to the present. The earlier studies used a wealth of detailed well and groundwater information that no longer exists today. Unfortunately, it appears that almost none of the recent studies were aware of the earlier studies. A review of the existing bits and pieces of the earlier studies suggests that in some respects, we are just beginning to reach the 1920's level of understanding of the nature of groundwater in the East Bay area. For example, earlier researchers had numerous wells that were available for long- and short-term pumping studies. The Union Water Company conducted 24-hour pumping tests in more than 100 of their wells scattered from Richmond to Alvarado in 1910. These tests included evaluation of individual wells, interactions between wells, and evaluation of individual aquifers. All of that information is gone.

Earlier Studies (1890 to 1925)

The majority of the earlier studies described the locations and amounts of ground water pumped (including numbers of wells and depths). The water-well drillers of the time knew the basin extremely well, and their descriptions of where and when various well fields were developed allows us to understand the nature and location of pre-development groundwater supplies, timing of sea water intrusion, locations of artesian wells, lowering of groundwater levels, and, indirectly, groundwater quality.

Important early reports that discuss the hydrogeology of the area are: Watts (1892), Miller (1903), Dockweiler (1912), and Forbes (1925).

Watts (1892) and Miller (1903) provide the first detailed description of the groundwater resources in the greater Oakland area (Berkeley to San Leandro). For each location, the authors provide information about well construction (depth, size, casing), pumping rates, type of sediments penetrated, and depths of aquifers and aquitards. We plotted much of the information, and it is shown on Figure 4.

Dockweiler (1912) provided a detailed snap-shot of water supply and usage in the East Bay area in the fall of 1911. A team of agents was sent into the field, and virtually every water well was located and water levels were measured. Driller's files were searched and more than 95 well logs were listed(Dockweiler, 1912, p. 152-176). Water companies were contacted, and descriptions of their water supplies (surface and subsurface) and distribution systems were compiled. The most important information is the private well map (Dockweiler, 1912, p. 141) and the water level information (Dockweiler, 1912, p. 177-506). The map identifies the location of 80 to 90 percent of the private water wells between Richmond and Hayward (3841 wells), and the water level information is listed at the rear of the report by street address. However, the water level information is identified by the 1911 street address but most of the streets in the greater Oakland area were renamed and renumbered between 1913 to 1915. We transcribed the well locations, and they are shown on Figure 5. The Dockweiler report shows that the engineers/geologists of the time had an intimate knowledge of groundwater conditions even though they may not have fully understood the geologic framework in which it was found.

Though the language is somewhat archaic, Forbes' (1925) report contains the first true hydrogeologic analysis of the East Bay area (Oakland to Alvarado). It provides a wealth of detailed well and groundwater information, but its usefulness is limited because the maps are missing from the only known existing copy of the report. Most importantly, Mr. Forbes understood the depositional nature/history of the area and analyzed the well information (lithology and groundwater) in that context. The tone of the reports suggests that the information was commonly known.

"*The wells of the east bay region draw water from three separate zones or aquifers lying at varying depths below the present ground surface, each zone or aquifer being distinct in manner and age of deposition, source of water, transmission of ground water, and quantity of ground water in storage, but these characteristics vary in the aquifers locally from the Alameda south to Irvington, as follows:*

1) The deep or lowest zone . . . comprisesd of more or less stratified alluvial deposits. . . as subsidence proceeded the alluvium became buried by a fine silt laid down in the sea water which entered and covered the land. This silt covering now lies as impermeable clay, sealing the aquifer. The wells of depths greater than 280 feet penetrate this zone. . . the source of the ground water which now penetrates the deep zone is principally that external water which seeps into the Santa Clara Valley and is transmitted northerly at depth.

2) The intermediate zone - is unlike the deep zone in character in that it is not stratified and varies in composition and method of deposition locally. San Leandro and San Lorenzo creeks built up short debris cones near their debouchures, dropping their heavier load, and carrying the lighter sand and silt to the bay through channels in the bay clays similar to those that exist at present in the salt marsh. These channels were left, with the shifting of the stream, as stringers of open porous material in a matrix of fine clay. With recurrent submergence the sea encroached upon the porous materials, to a limited extent, leaving blankets of clay within the zone. The depth of the intermediate zone varies from 50 to 300 feet. . . The intermediate zone varies in character with different localities. In the Niles cone, the zone consists of a buried mass of detrital material laid down by Alameda Creek - lenticular bodies of gravel, sand, and stream deposited silt - with but few and relatively thin tongues or blankets of marine clay. In the San Leandro and San Lorenzo Cones it consists of isolated stringers of sand and gravel enclosed in a matrix of marine clay as well as some shallow thicknesses of buried alluvial debris cones.

The source of water of the intermediate zone varies in each cone. The Niles cone intermediate zone materials are in direct contact with and a continuation of the materials which lie at the apex of the cone and extend to the present surface. . . The intermediate zone materials of the two northerly cones are imperfectly connected with their apexes and intercommunication between water yielding stringers is imperfect. These stringers have contained much water but when drawn upon the ground water moves slowly towards areas of depletion and replenishment is meager. The two deep wells in the Walker Field produce as much water as all the intermediate wells of the field combined.

3) Shallow or surface zone is made up by the recent alluvial cones of Alameda, San Lorenzo and San Leandro Creeks which coalesce with one another and with the limited cones of small intervening drainage area. The deposits are unconsolidated, porous and permeable, and absorb the water falling upon or flowing over their surfaces. [they were deposited] subsequent to a blanket-like clay body sealing the [intermediate] zone. This zone still is in the course of active aggradation.

With few exceptions, there is no transmission of ground water from one zone to another, in a state of nature. Draft upon the deep zone does not affect the ground water supply of the upper zones except where some deep well may be perforated at upper levels and allow drainage of water from upper levels down its casing." (Forbes, 1925)

[note: he studied the area for more than 10 years and one can see the progression of his thinking by reviewing his earlier study on Niles Cone (Forbes, 1914)]

South of the Study Area, several groundwater studies were done in the Niles Cone (Clark, 1915 and Bailey, 1920a and b) as part of the lawsuits by Alameda County Water District against the Spring Valley Water Company and the East Bay Water Company/EBMUD.

Later Studies

There have been three types of later studies: geotechnical, paleontological, and hydrological. From the 1930's to the 1960's, the studies were primarily concerned with the nature and distribution of the engineering properties of the subsurface sediments. There was a resurgence of these types of studies in the 1990's to evaluate the seismic properties of the bay area sediments. From the late 1970's to the early-1980's, a series of paleontological studies of the sediments beneath San Francisco Bay were published. These provided the first rational analysis of the depositional environments and geologic history of the basin. Hydrologic studies began in the 1960's and have continued to the present. At first, the focus was on identifying and quantifying groundwater resources. This focus evolved to integrate groundwater, the geologic framework (depositional environments), and mechanical properties (seismic and geotechnical). The current interest is to understand the relationship between groundwater resources and potentially hazardous sites.

Geotechnical Evaluations (1930-Present)

Planning for Salt Water Barriers across San Francisco Bay in the 1920's triggered a series of detailed engineering and geologic investigations in the northern Bay and Carquinez Strait (Young, 1929). Tolman (1931) summarized that geologic data in a report that was decades ahead of its time. His report contains a detailed geologic map, and identified all of the major faults (the San Pablo fault, Pinole fault, Franklin fault, Southampton fault, and the Sulphur Springs fault). Mt Diablo was identified as being bound by major thrusts. The Green Valley fault was mapped but not named.

Foundation exploration for the Bay Bridge began with the Hoover-Young (1930) report and culminated in the publication of Trask and Ralston's (1951) classic work that summarized 20 years of engineering subsurface evaluations of the bay between Oakland and San Francisco. These studies described the engineering properties of the sediments in the vicinity of the Bay Bridge and provided a fundamental litho-stratigraphic framework of the near surface sediments that is still in use today.

Between 1932 and 1954 there were investigations for additional crossings of the bay (California Division of Bay Toll Crossing, 1930, 1948, 1949, 1950, 1951, and 1955a and b; Joint Army-Navy Board, 1947; Stocks, 1932; DWR 1955a, b, and c; Department of Public works, 1947, 1957). Each proposed location required geotechnical investigations that generally included a series of deep borings. Samples from these borings provided the information for later paleontological studies. As part of this concept (additional crossing of the bay) the proposal to dam San Francisco Bay surfaced again (the Reber plan, see the Salt Water Barriers section), and there were associated plans to create a large harbor west of Berkeley. The resulting Army Corps of Engineers (1963) study evaluated the distribution of the near surface sediments (100 to 200 feet deep) from the western end of the delta to the southern end of the bay. Much of the data were derived from the Young (1929) report and private geotechnical reports (Woodward-Clyde, Dames and Moore, etc).

In the early 1960's, the planning for BART caused thousands of geotechnical borings to be drilled along the line of the tracks (Bechtel 1965 a,b,c,d, 1966a,b; Robert S. Cooper and Associates 1964, 1965a,b,c, 1966, 1967; Dames and Moore 1963, 1964, 1965a,b; Hawk Engineers, 1964, 1965; Harding Associates, 1965; PBQ&D, 1965; Woodward-Clyde 1963a,b, 1964a,b, 1967). The majority of these borings were less than 100 feet deep and were well described and analyzed. The reports containing the boring information north of Oakland contained excellent geologic cross-sections, identifying several basement channels. The BART tracks in Oakland were built below ground, and the reports for those sections contained several long-term, extensive groundwater tests (as well as the boring and cross-section information). The bay crossing section contained some subsurface information, but the cross-section (as drawn) was poor. A simplified regional stratigraphic section was published in Taylor and Conwell (1981, Figure 3).

Radbruch (1961 and 1967) published the engineering geological map of the Oakland West and Oakland East quadrangles. Both maps contained logs of selected borings throughout the Oakland area. A complete listing of all the boring can be found in Weaver and Radbruch (1961). For the past 30 years, Dr. E. Brabb of the USGS collected geotechnical boring information in the Bay area. The collection filled several file cabinets, but was placed in storage after Dr. Brabb's retirement in 1996. Access to that data is limited because of confidentiality agreements. The data were given to Dr. Brabb with the understanding that they would not be used outside of the USGS.

Goldman (1967 and 1969) published the first regional sub-surface geologic compilation of the greater San Francisco Bay area (Basement and Young Bay Mud maps and cross-sections) for the San Francisco Bay Conservation and Development Commission. The maps are limited in that the data were restricted to the rim of the bay. Goldman relied heavily on the 1963 Army Corps of Engineers study, but included more recent data from Alameda and Bay Farm Islands.

In the 1980's, there was a renewed interest in the subsurface nature of the Bay Area as it related to seismic hazards. Since then, a series of deep boreholes (200 to 300 feet deep) have been drilled at various sites throughout the bay area. The majority of the information has been published in a series of USGS open file reports (Fumal, 1978 and 1991; Fumal et al 1982; Gibbs and Borcherdt, 1974; Gibbs, et al. 1975; Gibbs et al, 1992; Gibbs et al, 1993; Gibbs et al, 1994; Gibbs and Fumal, 1994; and Powers and Fumal, 1993), in a report by Thiel and Schneider (1993), and in Wilson et al. (1978). Measurement of water levels in the Hayward area to estimate crustal strain was done by Quilty and Roeloffs (1994). Water quality measurements were done by King (1981). The seismic evaluation of the cross-bay bridges included a review of existing borings/stratigraphy (Geomatrix Consultants, 1992a, b, 1993a, b, c, d), and the drilling of new deep borings along the various bay bridges (personal communication, CALTRANS, 1997).

As part of the NEHRP studies into the collapse of the Cypress Structure, Rogers and Figuers (1991) created a series of sub-surface maps (isopach and isochor) along the eastern side of San Francisco Bay (basement, Alameda, Old Bay Mud, San Antonio, and Young Bay Mud formations). The maps were based on interpretations of water and geotechnical boring logs, and mapped horizons (Old Bay Mud and Continental Alameda) that had not been previously mapped.

Another source of subsurface information is individual geotechnical reports for major buildings in the area (as a rule of thumb, there is generally a boring as deep as a building is tall for buildings built after 1970). These sites are primarily located in downtown Oakland, but there are some in other areas. They are available through the building departments in each of the cities.

Caltrans drills a series of borings for each interstate overpass or underpass. This information (called a log of test borings) is located either in the Sacramento office (for the old borings) or in the Oakland office (for bridges under construction). Numerous deep borings were drilled in west Oakland as part of the Cypress Structure reconstruction and planning for a new Bay Bridge.

Paleontological Studies (1960-1980)

Arden (1961) published the first detailed paleontological study of samples in the Bay Area from a series of borings along the shore line from the eastern end of the Bay Bridge to Albany. The borings were drilled by the Santa Fe Railroad in 1950-51 as part of their investigation for an additional track. The original logs of the borings are in an un-numbered Caltrans file. Arden's evaluation study provided an excellent north-south view of the variations in the near surface sediments (0 to 75 feet deep) adjacent to the Berkeley shoreline. The current and earlier Temescal channels were well defined.

Between 1977 and 1981, a series of paleontological studies of the sediments beneath San Francisco Bay were published (Atwater et al. 1977; Ross, 1977; Bennett 1979; Sloan, 1981). These studies fundamentally altered how the subsurface was viewed. They identified the types and distribution of the various depositional environments and, for the first time, provided a geologic framework by which the location and nature of various units could be analyzed. All of these studies evaluated samples collected by Caltrans during their engineering evaluations for the various bay crossings (existing or proposed).

Atwater et al (1977) performed the first regional study of the bay sediments between the Dumbarton Bridge and the Bay Bridge. Additional details were provided in Atwater et al (1981) and Atwater (1979). Atwater was concerned with the timing, nature, and relationship between the various Pleistocene depositional environments, and was able to elucidate a detailed geologic history of the bay. This was a seminal paper that provided the first cohesive tectonic/depositional environment framework of the area.

Ross (1977), working under Atwater, analyzed boring samples from San Francisco Bay south of the Bay Bridge. The borings were drilled by Caltrans in the 1950's as part of their evaluation for a possible southern crossing of the bay between Hunters Point and Bay Farm Island. He evaluated the depositional environment/history of the samples based on microfossils, diatoms, sponge spicules, and plant fragments, as well as engineering properties. Based on that, he proposed a chrono-stratigraphic analysis of the middle section of San Francisco Bay.

Bennett (1979) analyzed depositional environments/history of samples from a bore hole at Ravenswood Point (the west end of Dumbarton Bridge). His analysis indicated that the site was underlain by a sequence of flood plain/estuarine sediments and alluvial fan deposits generally separated by unconformities. The earliest unit was about 600,000 years old. He also noted that the geotechnical properties of the various units were primarily controlled by post-deposition changes due to unconformities. He was unable to find a correlation between geotechnical properties and depositional environments.

Sloan (1981 and 1992) performed a paleostratigraphic analysis of the Yerba Buena Mud member (the Old Bay Mud) of the San Antonio Formation. The analysis was based on examination of well samples from borings across the San Francisco Bay south of the Bay Bridge. It was a detailed examination of a Pleistocene transgressive estuarine unit, more than 40,000 years old, and revealed the depositional details of a marine transgression.

Hydrogeologic Studies (1955-present)

Pierce (1948) evaluated salt water intrusion into the Niles Cone area. Patterson (1955, p. 9) indicated that it was known in the 1920's that pumping in the Niles Cone affected wells in Palo Alto, that water flow in San Leandro Creek recharged the Niles Cone aquifers, and that the Niles aquifers were hydrologically connected at their eastern ends (the aquifers all had the same head).

Between 1950 and 1975, the State Water Resources Board (1955b) and the Department of Water Resources (DWR) published a series of groundwater evaluations of the Niles Cone area (DWR, 1950, 1952, 1960, 1963a, 1963b, 1967, 1968, 1973, 1975, 1994). These were prompted by subsidence and sea water intrusion in the Niles Cone and northern Santa Clara Valley. These studies discussed the geologic framework, primary aquifers and their distribution, sea water intrusion, and flow regimes.

The State Water Resources Board (1955b) evaluated the Niles Cone area (north to San Lorenzo creek) and identified two primary aquifers separated by low permeability silts and clays. In the San Leandro and San Lorenzo cones, the Newark or shallow aquifer was approximately 200 feet thick, and consists of sand and gravel lenses which were not easily correlated in well logs. Water level measurements in the 1950's indicated that the upper aquifer in the San Leandro, San Lorenzo and Niles Cones were not interconnected. The shallow aquifer was underlain by the Fremont or deep aquifer (deeper than 200 feet). The deep aquifer appeared to be hydrologically connected throughout the east bay area. Water chemical analyses indicated that there was little water interchange between the two aquifers.

In the San Leandro cone, most of the wells (active in the 1950's) were completed in the shallow aquifer whereas the wells in the San Lorenzo cone were completed in the deep aquifer. These aquifers continued south into the Niles Cone, with the upper aquifer splitting into the '100 foot' (equivalent to the Newark) aquifer and the 'Centerville' aquifer. The '100 foot' aquifer extended from the ground surface to 100-120 feet below the ground surface; the 'Centerville' aquifer was located between the '100 foot' aquifer and the deep aquifer (below 200 feet). The 'Centerville' aquifer was limited in extent, thinning towards the bay and towards Alvarado. A blue clay layer separated the Newark from the Centerville aquifers, and it is likely that this is equivalent to the Yerba Buena Mud.

Salt water intrusion occurred in the upper aquifer as a result of over pumping in the mid-1920's, mid-1930's, and late 1940's. In the 1920's, salt water intrusion occurred in the shallow aquifer between Alameda and Niles Cone and extended as far east as the original location of Route 17. In the Niles Cone area, the salt front extended to Route 17, with localized contamination in Centerville. In 1930, water wells north of Niles Cone were shut down. Since then, salt water intrusion occurred primarily in the Niles Cone, with some intrusion in the San Leandro cone and minor intrusion in the San Lorenzo cone. The Department of Water Resources' analysis indicated that salt water reached the shallow aquifer via natural openings in the bay mud, abandoned wells, and through man-made openings in the bay mud such as those resulting from dredging. Limited intrusion into the deeper aquifer occurred in the vicinity of Centerville during the late 1940's and early 1950's. It was believed to have occurred as a result of salt water flowing down abandoned wells perforated in both aquifers, and salt water flowing around the eastern edge of the Yerba Buena mud. Heavy pumping in the deeper aquifer created a gradient reversal that allowed salt water to then flow west. The westward flow of salt water in the deeper aquifer was well documented in 1950-51.

Salt water intrusion in this area continued to be evaluated. A detailed analysis of the cause and source of the salt water intrusion was the subject of DWR (1960). That report also formally named the aquifers and aquitards. Chemical typing indicated that the groundwater in the Niles Cone area was a calcium bicarbonate to calcium-sodium bicarbonate-type with a variable salt content. Several boreholes were drilled to locate the eastern edge of the clay layer separating the Newark and Centerville aquifers, and the permeability of the aquitard was evaluated by both laboratory testing and pump tests (in the range of 0.006 gpd/ft^2 per foot of head).

In 1961, the Porter-Dolwig Ground Water Basin Protection Law was enacted, and DWR began to investigate and evaluate groundwater basins throughout the state. As part of those studies, DWR issued a revised/updated version of the State Water Resources Board 1955b publication in 1963 (Bulletin 13). A sequence of studies were published in the 1960's and 1970's (DWR 1963, 1967, 1968, 1973, and 1975; [Bulletin 118 series]), evaluating the Fremont (Niles Cone) and Northern Santa Clara Valley areas in detail. The 1963 report was the first regional sub-surface study of the southern part of the San Francisco/Santa Clara basins. This study included gravity, magnetic, seismic, and regional structural evaluations, drilling of 10 deep test holes (up to 600 feet deep), as-well-as evaluation of driller's logs and water levels.

Later studies evaluated specific sites in detail (Fremont and the northern Santa Clara Valley). The aquifers and aquitards were mapped by examination of driller's logs and using the USGS methodology (DWR, 1967, their Table 1). This indicated that there were other aquifers below the Fremont (deep) aquifer (the 400 and 500 foot aquifers). Water and chloride levels were measured, and a series of groundwater and salt intrusion maps were generated for each of the aquifers. These studies provided more details, but had the same basic conclusions as the State Water Resources Board (1955b) report.

Beginning in the early 1980's and continuing to the present, thousands of wells were drilled in the Study Area as part of environmental evaluations/remediation. Almost all of the wells were shallow (less than 50 feet deep) and contained little information that could be used in our study.

Todd (1986) performed a regional analysis of groundwater conditions in Alameda and Contra Costa Counties for EBMUD. The study outlined the major groundwater basins in both counties, and estimated water quality, annual yields, and recharge.

Hickenbottom and Muir (1988) evaluated the subsurface geology and water levels of the East Bay plains (Oakland to Hayward) for the Alameda County Water District. They analyzed driller's well logs to determine existing water supply (sources), recharge, water levels (and fluctuations), storage, and groundwater quality.

Beginning in the late 1980's, a series of masters and doctoral studies mapped and evaluated the aquifers in the study area and how they interacted. Maslonkowski (1988) evaluated well driller's logs to create a series of cross-sections and determine aquifer distribution in the San Leandro and San Lorenzo cones. His analysis was based on the USGS methodology developed in the eastern San Joaquin Valley in the early 1950's (Davis et al., 1959), and that used by DWR (1967) to evaluate the Niles Cone. The various driller's lithologic descriptions (sand, clay, gravel, silt, etc) were assigned an equivalent specific yield (clay is 3%, sand is 10%, gravel is 20%, etc.). Maslonkowski developed a computer program that read each of the descriptions for a well (averaged over a 10 foot thickness), and assigned it a specific yield value. The yield values were then plotted, evaluated within the geologic framework, and contoured to create subsurface depositional patterns at various depths.

It was an excellent analysis that drew together the geologic, hydrogeologic, and palentological information of the time. He used DWR's Niles Cone correlations, and determined that the major aquifers (Newark, Fremont, Centerville, and deep) and aquitards (Mission, Newark, and Irvington) extended north to San Leandro and west to the western side of Dumbarton Bridge almost without interruption. He recognized that the upper aquitards were estuarine muds whereas the deeper aquitards were alluvial fan, fine-grained, flood deposits. It appears that he accepted DWR's assessment that the San Leandro and San Lorenzo Cones were hydrologically distinct (his page 54), and his groundwater distribution map (his figure 22) reflected that. However, we believe his figure 22 could easily be redrawn as a single hydrological unit, sloping west.

Muir (1993) also used Davis et al.'s (1959) method to identify and map aquifers between Oakland and Fremont. His analysis was different in that he only mapped sand units. There was no attempt to fit sand units/aquifers into the geologic framework (formations) of the area. His analysis indicated that "there was little or no continuity between aquifers and there was no thick continuous aquifer beneath the East Bay Plain" (Muir, 1993, p.25).

Johnson (1994 and 1995) used the same methodology as Maslonkowski (assigned permeability values to driller's lithologic descriptions), but used a high level statistical analysis (variograms) in an attempt to finesse a geologically significant interpretation from the noise of driller's calls. A series of wells in the Santa Clara Valley were used as a test case (more than 10,000 lithology picks), but statistical analysis was only marginally better than a straight analysis of the driller's logs. As with most statistical analyses of well data, he was limited by the vagueness of the original data.

Koltermann (1993) and Koltermann and Gorelick (1992) developed a mathematical method to forward model the details of alluvial fan development. The model allowed her to 'turn on' various geologic factors and observe their effect on the growth of an alluvial fan in three-dimensions and over time (hence the term, forward model). Processes modeled included: stream flow (both low flow and flood), tectonic uplift, sediment input, sea level changes, subsidence, and compaction. The development of Niles Cone was used to validate the model. Unlike all the other evaluations and models of the area, this was a true forward (deterministic) analysis. Her model was detailed enough that specific aquifer/aquitard characteristics and groundwater flow paths could be reproduced.

Using the classical USGS methodology, Fio and Leighton (1995) and Leighton, et al. (1995) evaluated the regional geohydrology of the Santa Clara-San Francisco Basin. They identified sub-basins and created a series of computer-generated contour maps of the average fraction of coarse-grained sediments at various depths. There was no attempt to include local geological factors into their analysis. They recognized the regional nature of the study: "*the maps of coarse-grained sediments represent smoothed estimates of numerous well logs and are not intended to provide quantitative simulation of distinct aquifer units. The assumption that texture at a point is related to values several kilometers away is probably not valid*".

They also mapped probable well yields throughout the area (based on Webster's 1972 study). The maps are interesting in that the area with the largest percentage of coarse-grained sediments (Alameda Island) is identified as an area with small well yields, whereas the area with a small percentage of coarse-grained sediments (San Leandro-San Lorenzo Cones) was identified as having the larger estimated well yields. Historical well information indicates that the reverse is true. The Alameda area had some of the largest yielding wells in the bay area, and the San Leandro-San Lorenzo area had the lessor yielding wells.

In his study of wells in the Livermore Valley, Carle (1996) continued with the high-level statistical evaluation of well data using indicator geostatistics (Kriging and multi-dimensional Markov chains). He had access to a much higher quality of well information than was available in the San Francisco Bay area. The data came from the Lawrence Livermore National Labs in Livermore where a dense grid of borings was continuously logged and cored, and had a full suite of electric logs (Blake et al, 1995). It is the highest level mathematical evaluation to date that attempts to grapple with the lateral and vertical heterogeneity of alluvial fan aquifer systems. He found that "*geostatistical conditional simulations can provide realistic models of aquifer system heterogeneity . . . vertical hydraulic communication resulted primarily from interconnectivity of a network of moderate- to high-permeability levee and channel units, not leakage through low-permeability flood-plain aquitard materials*" (Carle, 1996, p. 164). It is unclear if his method would work with lower quality well data.

McCloskey and Finnemore (1996) used a more direct approach in the Coyote Valley. They combined evaluation of alluvial fan hydrogeologic facies, measurements of hydraulic conductivity values, and geophysical logs (mainly resisitivity logs) to estimate the distribution of relative hydraulic conductivity.

Metzger and Fio (1997) evaluated the relationship between the development of recent wells and groundwater quality and levels in Atherton, California.

Kessell (1997) analyzed well driller's logs and created a detailed longitudinal cross-section through the San Lorenzo Cone (Hayward to the east approach to the San Mateo Bridge). Her analysis was similar to Maslonkowski's (1988), but instead of assigning specific yields to driller's calls, she assigned facies types (alluvial clays, estuarine clays, indeterminate clays, and sands/gravels). She focused on mapping the clays, not the sands, and recognized the limitations of the driller's logs. She determined that the Yerba Buena Mud extended almost to the Hayward Fault. A review of her logs and cross-sections suggests that the Yerba Buena Mud extended as a continuous unit to her boring #3 (just west of Clawiter Road). There were indications of blue-green muds in other borings (#8 and #10), but they were discontinuous and could represent lakes or streams.

GEOLOGIC FRAMEWORK

The nature and distribution of groundwater in the East Bay Area is controlled by the geologic framework through which it flows, and is defined by configuration of basement (the structural framework) and the type of the materials (stratigraphy) that filled the basins. This framework provides a focus for future detailed geologic/hydrogeologic studies as well as help evaluate existing studies.

Structural Framework

The structural grain of the East Bay Area was outlined by Dr. B. Page in the late 1960's as well as in later papers (Aydin and Page, 1984; Prims and Furlong, 1995). Page postulated the existence of a series of northwest-southeast trending basement structures extending beneath the greater San Francisco Bay area. Some of these structures have been described/mapped in more recent studies (Fox, 1983; Zoback, et al, 1995; Wakabayashi and Hengesh, 1995; Wakabayashi 1992, 1996).

The regional tectonic features are shown on Figures 6 (map) and 7 (cross-section). San Francisco Bay rests in the core of a broad Franciscan (basement) synform. The Hayward Fault and the San Andreas Fault form the current eastern and western boundaries of the synform. Both faults are major tectonic features, with the Hayward Fault separating Franciscan units (on the west) from Cenozoic units (on the east). Basement structural trends exerted strong control over the initial depositional patterns, but their influence lessened as the basin filled.

Several faults have been defined within the basin fill (Figure 6). The San Pablo fault in Richmond was identified as a possible fault by Tolman (1931), and it has appeared on California Division of Mines and Geology geologic maps of the area ever since. Wakabayashi and Hengesh (1995), showed a fault in the same location, but called it the Point Richmond Fault. The original Silver Creek fault in San Jose was mapped as a thrust by Crittenden (1951), who also suggested that it might continue north beneath the basin fill. The northern sub-surface extension of the Silver Creek Fault into the Study Area was proposed by Taylor (1955) based on an alignment of gravity highs. The proposed fault extended from the original outcrop of the Silver Creek fault in San Jose, beneath the Santa Clara basin, and then north to the Coyote Hills in the Niles Cone. Based on additional gravity measurements, DWR (1967, their plates 3, 8 and 10) refined the location of the northern end of the fault to one and on-half miles east of Coyote Hills. However, in 1975, DWR (their figure 2) indicated that the Silver Creek fault was cut off by the Edenvale fault (also defined by gravity) just north of the Silver Creek area. They did not comment on whether or not they still believed that a buried fault still extended from the San Jose area north to the Coyote Hills area, but no fault was shown on their regional fault trace map (DWR, 1975, figure 4). Both the Silver Creek and the San Pablo faults have been referred to by many subsequent workers, and claims have been made that they could be potentially seismically active. Except for a possible alignment of gravity features, there is no direct evidence for their existence or seismic activity.

Basement

Basement rocks in the Study Area consist of tectonically emplaced bodies of graywacke, shale, sandstone, mafic volcanic rocks (greenstone), melange, and ultramafic rocks. Coherent depositional sequences of shale, sandstone, and conglomerate are commonly referred to as the Great Valley sequence, whereas the melanges, serpentines, and serpentinized ultramafic units are part of the Franciscan Complex. Both units are structurally complex, being the product of several periods of deformation. Limited fossils and age dates indicate that the Great Valley sequence ranges in age from late Jurassic (Tithonian) to Late Cretaceous (Fox, 1983; Wakabayashi and Hengesh, 1995).

Figure 8 is a structural contour map of the depth to basement of the study area as identified from drillers' well log data. The central part of Figure 8 is similar to the depth to basement map from Rogers and Figuers (1991). The information in the southern part of the map is derived from recent deep drilling by Caltrans along the San Mateo bridge. The data in the Richmond area were derived from drilling done for the Salt Water Barriers (Young, 1929; and Army Corps of Engineers, 1963), the San Rafael Bridge (Caltrans), BART exploration borings, Arden (1961), Howard (1962), water wells drilled at the turn of the century, borings for the City of Richmond (AGS, 1993a b), and wells drilled at the Chevron Refinery (Dames and Moore, 1980 and 1981).

North of Oakland, basement has been penetrated by a sufficient number of wells to demonstrate that a series of channels has been cut into it. The current major creeks in Berkeley/Albany/El Cerrito (Temescal and Cerrito Creeks) and Lake Merritt overlie well defined basement channels. It appears that these drainage systems are long lived and have not appreciably shifted laterally since their establishment. In Richmond, basement is deeper on the east side of Potrero Hill than on the west, but there are not sufficient data to demonstrate that there was an early (Santa Clara time) through-going stream from the San Pablo to the San Francisco Basin. It is likely that initially there was a divide between the two basins, and a through-going stream was not established until early- to mid-Alameda time. The basement contours near San Pablo are shown extending across the Hayward fault. The Orinda formation crops out in this area, with Franciscan basement being deeper. If the Orinda formation is considered non-water bearing, then the contours could be drawn on the west side of the Hayward fault.

Buwalda (1929), Radbruch (1957), Arden (1960) and Rogers and Figuers (1991) noted that the Yerba Buena Mud deepens from north (the Berkeley area) to south (the San Leandro area). Rogers and Figuers (1991, p. 21) suggested several possible causes, but the most reasonable now appears to be tectonic uplift of the north bay area (Oakland to Richmond). A regional structural analysis indicates that there had been local uplift west of the Hayward Fault in the Berkeley-Oakland area. This could be related to development of thrust splays (blind thrusts) extending from the western side of the Hayward Fault (Figures 6 and 7) or from localized, non-fault specific uplift. Wakabayashi and Hengesh (1995, their figure 2) postulated similar blind thrusts. Mapping in a structurally similar area in San Jose (Alum Rock area) suggests that it is un-likely that discrete fault planes developed close to the Hayward Fault.

The uplift of the Yerba Buena Mud and younger units suggests that these structures have been active throughout the Holocene. If discrete thrust planes exist, there is no indication at this time that they are seismogenic. Arden (1960, p. 83) noted that it appeared that the Berkeley water-front area appeared to have dropped several feet during the past several thousand years. This area is located in an incipient footwall syncline, and such dropping would be expected to occur.

Cross-Sections

Previous cross-sections of the study area all had vertical exaggeration in order to illustrate stratigraphic relationships. The exaggeration ranged between of 3:1 to 30:1, averaging 10:1 (for example: the Rogers and Figuers (1991) cross-sections had a 10:1 vertical exaggeration; the Goldman (1967) cross-sections had a 10:1 vertical exaggeration, and the recent Caltrans cross-section for the east section of the Bay Bridge was 2:1). In this study, we created a series of non-vertically exaggerated cross-sections in order to illustrate the overall geologic relationships (Plates 1 and 2). The location of the cross-sections is shown in Figure 9. Vertically exaggerated cross-sections (up to 30:1) were also created to illustrate stratigraphic relationships (Figures 16 and 17).

The geologic cross-sections reveal that the basins are wide and thin, similar to the shape of a pancake. The fill within the San Francisco basin has an overall thickness of 800 to 1000 feet, and it is asymmetrical, with the deepest part of the basin being below the current shore line in San Leandro/San Lorenzo area. On the west side of the basin, basement slopes gently up to the west, while basement on the east side of the basin has a steep slope. Basement is shown as being linear/smooth, but it is likely that there are scattered basement knolls, such as the one that exists beneath the San Francisco Airport. The lower 300 to 500 feet of the basin filled with continental units (Merced, Santa Clara and equivalent). The upper part of the basin filled with estuarine units.

South of the Bay Bridge, the interplay between estuarine and alluvial fan units controlled the location of the boundary between these two depositional environments, not basement topography. North of the Bay Bridge, it appears that basement topography was a locally a factor in controlling stratigraphic relationships. Downtown Oakland (west of Lake Merritt) was constructed on a topographic high. This topographic high appears to have been a high throughout basin history, and over-lies a basement knoll, 400 feet below the ground surface. Though minor, this high has effected the depositional patterns of both older and younger bay muds on top of this high. The stratigraphic variations across this high contributed to the collapse of the Cypress Structure during the 1989 Loma Prieta Earthquake.

Stratigraphic Framework

The depositional history of the San Francisco Basin has been well described in many previous studies (Rogers and Figuers, 1991, for example). The lower part of the San Francisco basin filled with several hundred feet of continental alluvial fan/plain deposits (Santa Clara or equivalent units). Outside of their approximate thickness, little is known about those units. Seas then encroached into the bay, filling it with several hundred feet of an alternating sequence of estuarine and alluvial deposits of the Alameda formation. The more recent units have been named: Yerba Buena or Old Bay Mud, San Antonio, Merritt, Posey, Young Bay Mud, and Temescal. Many of these units have been given informal formational status, but their limited extent both in distance and in time indicates that they should be referred to as units or members rather than formations.

There is little information about stratigraphic units within the San Pablo Basin. Information from the Richmond sub-area suggests that the stratigraphic units are similar to those found in the San Francisco Basin, but it appears that the marine units (Alameda formation) are thinner. It will require deep drilling in the central part of the basin to determine the nature of the units.

All of the basins (Santa Clara, San Francisco, and San Pablo) developed contemporaneously and have a common depositional history, but there are a plethora of stratigraphic/hydrogeologic names. Several stratigraphic nomenclature changes are proposed (and used) in this report (Figure 10). They are:

- The term Alameda Formation is restricted to the marine units beneath the bay (up to and including the Young Bay Mud). It does not include the alluvial fan units between the bay and the hills (bay plains).

- The Yerba Buena Clay (Old Bay Mud), San Antonio, Merritt, Posey, and Young Bay Mud are members within the Alameda Formation.

- The deeper continental section, identified as the continental Alameda by Rogers and Figuers (1991), is a combination/continuation of Santa Clara and Merced Formations (DWR, 1967; Brabb and Pamyeyan, 1983). Little is known about the nature of the deep units. (Only within the past year or so has this section been specifically sampled, as a result of the Caltrans borings along the San Mateo and Bay Bridges.)

- The deeper alluvial fan material along the east side of the bay has historically been mapped as part of the Alameda, San Antonio, or Temescal Formations. These units are equivalent in time, depositional environment, and lithology with the Santa Clara and/or Merced Formations. Correlations have not yet been made, but we suggest that these units are outcrops of the Santa Clara (and possibly the Merced) Formation. DWR (1967, p. 21) recognized this equivalence, but continued using the traditional names.

The Santa Clara, San Francisco, and San Pablo basins formed and filled in similar (if not identical) tectonic and stratigraphic environments. However, they have they been viewed as separate features, with each side of the basin being viewed as independent. The use of different names for the same units in each of the basins has helped maintain this fractured view. We suggest that geologists familiar with the lithologic units in each of the basins (San Jose, Oakland, San Pablo) meet and agree upon a common, basin-wide stratigraphic nomenclature.

The following is a synopses of the stratigraphic nomenclature in the Study Area:

Temescal - The Temescal is an early Holocene alluvial unit deposited along the east side of San Francisco Bay. The unit varies from 1 to 50 feet thick, thinning towards the bay. It consists primarily of silts and clays, but near the bay it contains graded sequences upwardly fining to clay. In the vicinity of Alameda Island, the base of the unit is a layer of gravel with cobbles up to 8 inches thick.

Young Bay Mud - The Young Bay Mud is the estuarine mud being deposited today in San Francisco Bay. It is a black, unconsolidated, saturated, organic rich clay, containing occasional gravel and sand layers, shell fragments/layers, peat, and organic debris. It ranges in thickness between 50 to 75 feet, but can be up to 150 feet thick in channels cut into the San Antonio/Merritt Sand during the late Wisconsin glacial stage.

San Antonio/Merritt/Posey - The San Antonio (first defined by Lawson, 1914) is a sequence of alluvial fans (0 to 120 feet thick) deposited between the Young Bay Mud and the Yerba Buena Mud. The lower San Antonio contains Franciscan pebbles, suggesting that it derived from the Berkeley Hills. As with all alluvial fan deposits, it contains a wide variety of lithologies, ranging from stream deposits to flood plains to lakes and swamps. Units are discontinuous and are difficult to correlate. In this report, the Merritt and Posey are considered facies within the San Antonio unit. Both Lawson (1914) and Trask and Rolston (1951) identified an erosional surface between the San Antonio and the Posey. Lawson kept the Posey as part of the San Antonio, where as Trask and Rolston created a separate unit.

The Merritt Sand (0-60 feet thick) is a fine grained, well sorted, aeolian sand deposit on Alameda Island and western Oakland. It was deposited contemporaneously with the upper San Antonio/Posey.

Yerba Buena Mud (Old Bay Mud) - This unit was originally called the Old Bay Mud (Trask and Rolston, 1951) until it was renamed the Yerba Buena Mud by Sloan (1981, 1990). It is a widespread, homogeneous estuarine mud deposited approximately 115,000 years ago. Like the Young Bay Mud, it was initially deposited within earlier stream channels and consists of an over-consolidated black, organic rich clay. It averages 25 to 50 feet thick, and typically has a gravel/sand/shell layer in the middle part of the unit.

Alameda formation - This is the main basin-filling unit (originally defined by Lawson, 1914), varying in thickness from 100 feet near Richmond to more than 400 feet near the San Mateo Bridge. It has been defined in the central part of the basin, but has not been described along the margins of the basin. In this report, the Alameda formation is restricted to the sequence of estuarine muds separated by alluvial fan deposits and includes the Yerba Buena, San Antonio, Merritt, and Posey. The estuarine units were first identified by Atwater (1979). Below it are the continental units of the Santa Clara/Merced formations (300-600 feet thick). They consist of alluvial fan units interfingered with lake, swamp, river channel, and flood plain deposits.

Sub-surface Correlations

One of the goals of this study was to evaluate the possible extension of the estuarine aquitards into the alluvial fans that fill the margins of the basins. Sub-surface correlations within alluvial fans is difficult and completely dependent on the quality of the boring information. Before correlations could be made, we evaluated the nature and quality of drillers' log (the basic information) in the study area. We also contacted other organizations that were evaluating similar geologic environments to determine if their techniques were suitable for use in this area.

All subsurface evaluations and interpretations are dependent on evaluation of drillers' logs calls. The appendix contains a critical review of drillers' logs as well as a review of the various sub-surface evaluation techniques that have been used in this basin and in other areas. Experience in other areas indicates that it is possible to identify hydrogeologic units within alluvial fans if high quality geologic information is available. Unfortunately, our evaluation indicates that the existing data in the study area does not allow such correlations to be made at this time.

Aquifer/Aquitard Correlations

The aquifers in the east bay area were described in the 1920's (Forbes, 1925) and in the 1950's (State Water Resources Board, 1955b), but were not formally named until 1960 (DWR, 1960). Three primary aquifers, the Newark, Centerville, and Fremont (from upper to lower), were identified in the Niles Cone area (Figure 11). All consist of alluvial sand and gravel lenses, separated by marine clay aquitards (bay muds). The Newark aquifer is 100 to 150 feet thick, and it was originally called the "100 foot aquifer". In the western part of the Niles Cone it is overlain by the Young Bay mud, while the eastern part is unconfined. The Centerville aquifer is approximately 100 feet thick. The Fremont aquifer (originally called the 200 foot aquifer) is a global term for a series of aquifers deeper than 200 to 250 feet. A few local, near-surface perched aquifers are found in the Niles cone (Valle Vista area).

Maslonkowski (1988) extended the Niles Cone aquifer and aquitard correlations into the San Lorenzo and San Leandro Cones. We agree with his interpretation that the San Lorenzo and San Leandro aquifers are the lateral continuation of the Niles Cone aquifers (Newark, Centerville, and Fremont), but our correlations are slightly different because of changes in formation definitions over time. Maslonkowski used an earlier definition in which the units below the Yerba Buena Mud were called the San Antonio formation (cv. Trask and Rolston, 1951; Maslonkowski, 1988, see his figure 18). We agree that the aquitard between the Newark and Centerville aquifers is the Yerba Buena mud (his Irvington Aquitard). He noted that the aquitard between the Centerville and the Fremont aquifers (his Mission aquitard) was a fine-grained flood plain deposit. It is likely that this unit grades into/correlates with an estuarine clay to the west. Aquifers deeper than 400 feet appear to correlate with the Santa Clara formation (or equivalent units).

Stratigraphic correlations with the Berkeley and Richmond sub-areas are poorly known at this time. The onshore units in the Berkeley sub-area consist of recent and older alluvial fan deposits. Some of the older units may be equivalent to the Santa Clara formation. What appears to be deep estuarine clays have been described in borings along the west side of the Richmond sub-area. It appears that they may be Yerba Buena clay equivalents, but this needs to be proven. It is likely that there will be noticeable lithologic differences between the San Francisco and San Pablo basins.

A continuing problem is the identification of hydrogeologic units/zones within the aquifers. There is extensive literature on the sub-division of alluvial units (Maill, 1985, 1992; Dalrymple et al, 1992; Blair and McPherson, 1994; and Neton et al., 1994), but alluvial aquifers are difficult to sub-divide even if there is a significant amount of three-dimensional data. Based on studies of alluvial fans in the Livermore Valley, the Lawrence Livermore Labs found that the only successful method to identify hydrogeologically distinct zones within alluvial fans was through detailed, closely spaced pump tests. Prior to the pump tests, they were unable to identify hydrogeologically distinct zones even though they had almost 100 continuously cored and logged borings (including a complete suit of oil field quality electric logs). The quality of their boring data was orders-of-magnitude better than the existing boring data in the East Bay area.

At this time, the available sub-surface information does not permit sub-division of the aquifers within the Study Area It is unlikely that meaningful sub-divisions could be made without a significant expenditure of time and money.

Groundwater Quality

While anecdotal information is numerous, there is little quantitative information concerning the quality of groundwater at or before the turn-of-the-century (see Tables 2, 5, and 6). The existing data are further complicated by the methods used to determine water quality as well as the water quality indicators themselves. Gillespie (1907) contains a description of the early water quality indicators (such as temporary hardness and albuminoid ammonia) and how they were measured. At the turn of the century, water quality was evaluated using gravimetric techniques. Metals were precipitated from a water sample, dried, weighted, and contaminant volumes were back calculated. These methods were accurate to parts per thousand or million. Today's methods are atomic based, and are accurate to parts per billion and trillion.

Historic accounts indicate that Alameda Island had the 'sweetest' water in the area. This is not surprising considering that the shallow aquifer (Merritt sand) received direct rainfall recharge with virtually no contribution from other sources. The remainder of the study area apparently had a similar quality groundwater. We did not encounter reports that indicated that water from one area was preferred over water from other areas.

As part of their regional groundwater quality studies, DWR (1958, pages 17-19, A-4, and B-4) collected and analyzed groundwater samples in the Niles, San Leandro, and San Lorenzo Cones. Sodium (Na) varied between 40 and 150 ppm with some wells being as high as 340 ppm. Total dissolved solids (TDS) varied between 430 and 460 ppm.

Todd (1986) collected groundwater quality information over the Study Area, and found that groundwater TDS values ranged between 500 and 1000 ppm. Specific chemical measurements were listed in Todd's Tables 2, 3, 4, and 7. Estimated permeability, transmissivity, annual recharge, and groundwater storage values for some of the sub-areas were estimated by Todd (1986) and are listed in Tables 1 and 2. These are sub-area wide values, and individual locations can have higher or lower values.

Table 1: Sub-area Permeability and Transmissivity values (Todd, 1986).

Sub-area	Aquifer name or depth	Permeability gpd/ft2	Transmissivity gpd/ft
Oakland	Merritt	100 (estimated)	6500 (estimated)
Richmond	10-100	-	1000 to 8000
San Leandro/	Newark	-	3000
San Lorenzo	Deep	-	60,000

Table 2: Estimated Annual Recharge and Groundwater Storage (Todd, 1986).

Sub-area	Recharge acre-feet	Groundwater Storage acre-feet
Oakland	2000	4500
Richmond	400	420
San Leandro/ San Lorenzo	14000	350

There were two general types of groundwater contaminants in the study area prior to world war II; sewer effluent and salt water. Until the 1890's, most of the houses and businesses had outhouses. Human and animal waste was dumped directly into the ground, and there are many accounts referring to contamination of shallow wells from outhouses (septic systems did not become common until the 1900's). Businesses located near the estuary or creeks so that waste could be dumped into them. The Brooklyn wells (the emergency water supply for Oakland in the 1880's) became contaminated from the nearby slaughter houses. Sewer systems began to be constructed in the 1880's with the untreated effluent flowing directly into the bay/estuary. Secondary treatment did not occur until World War II.

Salt water intrusion occurred in well fields near the bay that were overpumped. The High Street well field in Alameda was the first to experience salt/brackish water intrusion in 1892. The field was quickly abandoned. There was localized salt water intrusion into the Merritt sands along the east side of Alameda Island in the 1890's as a result of excavation of the tidal canal, and there was localized salt water intrusion into the shallow aquifer in west Berkeley in 1893. The next reported sea water intrusion occurred during the droughts of 1916-1919. The demands of World War I forced overpumping. As a result, the San Pablo Well Fields 1 and 2 in Richmond were abandoned, and the Fitchburg Field (Oakland) locally pumped brackish water. Water levels recovered over the next few years, but the drought of 1924 caused salt water intrusion in the Alvarado and Fitchburg areas. The combination of drought and overpumping caused groundwater levels to fall below sea level for the first time. When this occurred, there was widespread salt water intrusion through the young bay mud into the upper aquifer. In 1930, all of the commercial well fields north of Alvarado were permanently shut down. Even though the Niles Cone area continued to experience salt water intrusion in the 1930's, 1950's, and 1960's, there is no indication that salt water intrusion occurred to the north after the 1920's.

Salt water intrusion into the deeper aquifers occurred in the Niles cone in the 1950's, and may have occurred in Fitchburg in the 1920's. Near the bay, there were no natural flow paths into the deeper aquifers. Intrusion occurred as salt water in the upper aquifer flowed through the Yerba Buena Mud aquitard via man-made paths (abandoned wells) into the deeper aquifer. Pumping in the deeper aquifer contributed to the problem by de-pressuring the lower aquifer. All reports indicated that this was a localized problem in the Niles Cone area, and it is unlikely that deep aquifer intrusion occurred in the Study Area.

BASINS

We have identified two structurally separate basins beneath the northern San Francisco Bay, the San Francisco and San Pablo Basins (Figure 2). The San Francisco Basin extends from approximately the San Rafael Bridge (I-580) south to the San Mateo Bridge/Coyote Hills area, and the San Pablo Basin extends from Richmond north to the Petaluma area. The axial trend of both basins is similar, but the San Francisco Basin deepens to the south, while the San Pablo Basin appears to deepen to the north. South of Oakland, basement forms a single broad basin, with the deepest part of the basin being beneath the eastern shore line. Basement is mapped as being 1000 feet on Figure 8, but it is possible that it is as deep as 1100 to 1200 feet below sea level. A well defined basement ridge forms the boundary between the San Pablo and San Francisco Basins (Figure 3, and Plates 1 and 2). The ridge trends easterly-westerly, just north of I-580. The boundary between the San Francisco and Santa Clara Basins cannot be specifically defined at this time.

The San Francisco and San Pablo Basins (Figure 2) were divided into several sub-areas (Figure 3). The term sub-area was used instead of sub-basin because the term sub-basin implies a locally hydrological/geologically distinct area within a larger basin. Sub-area boundaries in the northern East Bay Plain were defined by Todd (1986, their figures 5, 6, 7, 10). Sub-area boundaries for the Niles Cone were identified by DWR (1967, their plate 11 and 1973, figure 1) and more recently by DWR under a contract with the RWQCB (shown in Figure 3 of DWR, 1994). All the Niles/San Leandro boundaries defined by DWR were different, but all were within an east-west trending zone bound by Route 92 on the north and Alameda Creek on the south.

In the Study Area, sub-areas laterally merge into one another, and there are few distinct topographic or geologic features that provide easily recognizable boundaries. The sub-area boundaries shown on Figure 3 were based on a combination of previously defined boundaries and geologic, hydrogeologic, and geomorphologic factors. The lack of distinct physical boundaries means that political and regulatory factors can be used to define the boundaries without comprising the integrity of the physical units.

The on-shore boundary between the San Leandro and Niles sub-areas follows the most recent DWR definition (DWR, 1994). The boundaries of the Richmond, Oakland, San Lorenzo, and San Leandro sub-areas follow that of Todd (1986). The boundaries of the Central and Berkeley sub-areas are new, being defined in this report.

The Hayward Fault has traditionally been thought to form the primarily ground water boundary along most of the eastern side of the San Francisco Basin. Our analysis indicates that Franciscan bedrock is the primary boundary, and that the Hayward Fault has little effect on groundwater in the sub-areas. The only locations were the Hayward Fault forms a groundwater barrier is at the apex of the Niles Cone and north of San Pablo where Orinda units are juxtaposed against basin fill.

Lithofacies Maps

We constructed a series of generalized lithofacies maps (Maill, 1984, p. 215) to better understand the depositional patterns and relationships of the study area over time (Figures 12, 13, 14 and 15).

Santa Clara/Merced, Continental deposits (Figure 12)

During this time, depositional environments were similar to those in the Sacramento Valley today. Streams carried sediments from the surrounding hills into a depocenter beneath San Leandro - San Lorenzo. Coarser-grained material was deposited in a band of alluvial fans that ringed the edges of the depocenter, while finer-grained material was carried into the center of the depocenter.

Well data suggest that basement north of the Bay Bridge was several hundred feet higher than the basement below the depocenter, forming table lands. Streams within the table lands flowed northwest to southeast, following the basement grain. Once the depocenter filled, the table lands would have filled from south to north. This depositional pattern has several implications. Long-lived lakes would have developed in the depocenter, but it is unlikely that they would have formed in the table lands until very late in Santa Clara time. Within the depocenter, sediments should have primarily an onlap configuration. The table lands will be more complex, with both onlap and erosional configurations. It is not known if there was a through-going stream connecting the San Pablo Basin with the San Francisco Basin, but the limited data suggest that it was unlikely. Like the Sacramento Valley, it is likely that a major stream flowed out of the San Francisco and Santa Clara basins. Previous workers have suggested that such a stream may have flowed out of the southern end of the Santa Clara Valley, eventually reaching Monterey Bay.

Mid-Alameda , Marine Incursion (Figure 13)

Depositional patterns were similar to those seen today, except for the location of the opening to the ocean. Instead of entering through the Golden Gate, the seas entered the bay via the Colma Channel. Estuarine muds were deposited in the bay, with alluvial fans forming around the edges of the basin. The Colma Channel is shown at its current location and size. It was originally wider, but was narrowed by subsequent movement on the San Andreas Fault. The southern exit to the bay meant that there was greater flushing of both water and sediments. It is likely that a through going connection between the San Pablo and San Francisco Bay had been established by this time, and it was likely the location of the salt-fresh water interface. Well data suggest that the connection between the two basins was located on the east side of the Potrero Hills in Richmond.

Mid-Alameda, Continental deposits (Figure 14)

The seas had withdrawn, but a through-going north-to-south major stream was still maintained. During withdrawal (sea level lowering), the northern table land area would have begun to erode, removing sediments deposited during the previous marine incursion. In the southern part of the bay, there would have been localized erosion along the major stream channel, but depositional patterns would still have been primarily conformable. Alluvial fans would have enlarged and expanded west into the bay. Over time, the build-out of these fans shifted the center of deposition west to its current location. The Coyote Hills have had a major effect on depositional patterns in the southeastern part of the San Francisco basin. They act as a barrier, diverting sediments to the north (currently) or south, as well as creating a sedimentary shadow behind them (to the west).

Present Time, Marine Incursion (Figure 15)

Depositional patterns today are basically similar to those in the past, with two changes. It is not known exactly when it occurred, but the connection between the San Pablo and San Francisco Bay switched to the west side of the Potrero Hills. It appears that growth of the San Pablo alluvial fan blocked the original channel, forcing it to the west. Movement on the San Andreas fault compressed the Colma Channel, closing off the southern entrance to the bay. Blockage of the Colma Channel fundamentally changed depositional patterns south of the Bay Bridge. The southern bay is now essentially hydraulically disconnected from the northern part of the bay, and is beginning to fill because there is no major through-going stream to transport sediments out of the bay.

San Pablo Basin

The depositional history of the San Pablo basin is poorly known. There are virtually no boreholes within San Pablo Bay proper. Although numerous deep wells were drilled in the southern end of the basin (Richmond sub-basin) in the early part of the century, almost none of the boring logs are extant. It was not until the early 1990's that deep boreholes were again drilled in the area. These borings suggest that the southern part of the basin filled primarily with alluvial fan deposits. There were some estuarine units, but they appear to be limited both in time and extent. The Hayward-Rogers Creek fault system crosses the basin, forming a primary structural boundary. The section of the basin west of the Hayward-Rogers Creek fault system is similar to the Santa Clara-San Francisco basins, whereas the section to the east formed as part of the footwall syncline from the

Franklin thrust. It is not known how development of that Hayward-Rogers Creek fault system or the footwall syncline altered/affected the nature and location of sedimentary units within the basin.

Richmond sub-area

The Richmond sub-area is located at the southern end of the San Pablo Basin. It is bounded by bedrock outcrops on three sides (Figure 3), and it opens and deepens to the north. There is no hard information concerning the depth to basement beneath the northern end of the sub-basin, but the depth of water wells suggests that basement is 600 feet or more below the ground surface. A series of basement outcrops and highs extend across the southern end of the sub-basin, and separate the San Pablo Basin from the San Francisco Basin.

The current bay extends along the west side of the Potrero Hills, but well data suggest that a deep (>300 feet) paleochannel extends along the east side of the Potrero Hills. West of the hills, basement is 200 to 250 feet deep, and east of the hills, basement is more than 300 feet deep. Buildout of the San Pablo alluvial fan obstructed the original channel, forcing the bay west to its current location. It appears that the Richmond sub-area may have been isolated from the San Francisco Basin until mid-Alameda time.

Existing boring logs suggest that this sub-area is filled primarily with alluvial material, but there may be estuarine clays between 60 and 125 feet below sea level (AGS, 1993a,b; Provenzano & Associates, 1993, 1994; and Dames and Moore, 1980, 1981). Both these clays and the young bay muds appear to have a limited aerial extent, being restricted to the western edge of the current alluvial fan. This apparently limited sub-crop may be artificial, caused by a lack of data in the eastern part of the area. The lack of widespread, shallow clay layers and the possible lack of widespread, deep clay layers suggests that the basin may not be vertically separated into distinct hydrologic units. Shear wave measurements (Provenzano & Associates, 1993, 1994), suggest that the boundary between the continental and marine sediments is 125 to 150 feet below the ground surface. It is not known if this boundary is local or regional in extent.

The description of the estuarine(?) clays in the Richmond area is somewhat different than the typical description of clays such as the Yerba Buena clay. The clays in Richmond are commonly described as green to grey-green, stiff, silty clays. Neither shells nor organics were described in the well logs even though Dames and Moore, 1981, stated that shells were common. The Yerba Buena is generally described as a green to blue-green clay. It ranges from soft to stiff, with shells or organics commonly encountered. It is possible that the deep clays in the Richmond sub-area were part of the Yerba Buena Mud, but were deposited in a high silt environment.

Several historic municipal well fields were located between San Pablo Creek and Wildcat Creek. This zone contained the San Pablo Well Fields 1 and 2 as well as major water supply wells/fields for the old Standard Oil refinery (now Chevron) and towns to the north (see the Richmond history section for the details). Some of the recent deep geotechnical wells drilled near the old San Pablo Well Field No. 2 (Provenzano & Associates, 1993, 1994) indicate that there is a significant gravel layer 100 to 150 feet below the ground surface. This zone was likely the primary aquifer for the well fields. The lateral extent of the gravel unit is unknown. The fields were overpumped and only lasted 12 to 16 years before they were shut down because of brackish/salt water intrusion. The remainder of the area supplied single family homes and smaller industrial sites. The original well field for the town of Richmond was located adjacent to the railroad between Ohio, Chanslor, Second, and Seventeenth Streets. It was never a large producer.

San Francisco Basin

The San Francisco Basin contains several sub-areas (Figure 3). The Central sub-area covers the central part of the basin (the bay), while others are located along the eastern margin of the basin.

The sub-areas along the eastern margin of the basin developed in similar depositional environments, and there is little lithologic variation between them. The boundaries between them (except for the Berkeley sub-area) are based on geographic and geomorphic factors rather than specific lithologic/geologic characteristics. The depositional edge of the Young Bay Mud forms the boundary between the Central sub-area and the other sub-areas. It is possible that the concept of sub-areas may not apply to the deeper Santa Clara units. It will require specific drilling and study to determine the nature and boundaries of the deeper units.

Central sub-area

The Central sub-area extends beneath the current bay (Figure 3). In many respects, it can be considered a sub-basin. It contains a well defined stratigraphic sequence, with all major units/beds being discernible on most well logs. The stratigraphic section discussed in Rogers and Figuers (1991) and in previous stratigraphic studies was derived from evaluation of the Central sub-area. Briefly, the lower part of the sub-area filled with several hundred feet of continental material (coalescing alluvial fans and plains). At this time, the depositional center appeared to be beneath the current eastern shoreline of the bay. The seas entered, and the remainder of the sub-area filled with up to 600 feet of an alternating sequence of estuarine clays and alluvial fans. As the sub-area filled, the depositional center shifted west towards the center of the bay. Only the upper 100 to 150 feet of the sedimentary section have been studied. Little is known about the deeper units.

The boundaries of the Central sub-area are based on the Young Bay Mud sub-crop. In some parts of the basin (ie: the Berkeley sub-area) there is a sharp edge to the Young Bay Mud, but in the other areas the boundary is sinuous and, at times, indistinct. The boundary shown on Figure 3 extends along the current western Oakland shoreline even though the Young Bay Mud extends further east in many of those areas (a result of wetlands filling/reclamation).

Alameda and Bay Farm Islands are located along the northeastern edge of the Central sub-area. Several artesian wells were drilled in the northern part (the original section) of Bay Farm Island in the 1880's, but overpumping stopped artesian flow by the early 1890's. Deep irrigation wells drilled in the Alameda County Golf course in the late 1980's did not encounter high quality aquifer units. The wells were 700 to 1000 feet deep; one was a dry hole and the others produced small amounts of water. During exploration drilling for the Bay Bridge, borehole 19 encountered artesian flows of water at a depth of 240 feet below sea level (Hoover-Young Commission, 1930, plate 23).

The earliest municipal well field, the High Street Well Field, was located at the eastern end of Alameda Island (see the Alameda history section for the details). The field was originally artesian. Overpumping caused salt water intrusion and lowering of the water table, and the field was shut down in the mid 1890's. The primary aquifer appears to have been gravel units just below the Yerba Buena Muds. High production wells were reported throughout the island.

The other aquifer was the Merritt Sands. These are up to 60 feet thick and were the major water supply for single family homes and businesses. On Alameda Island, the sands are surrounded by bay muds. There are no streams feeding the area, and it appears that rainfall was the sole source of the groundwater. This supply became locally contaminated by septic systems in the 1890's, and there was limited salt/brackish water intrusion along the southeast side of the island as a result of excavation of the tidal canal. There has only been minor pumping of this aquifer since 1900.

Berkeley sub-area

The Berkeley sub-area contains a series of alluvial fans deposited on top of a west sloping bedrock surface. A schematic section of the Berkeley area is shown in Figure 16. The alluvial units range from 10 to 300 feet deep, averaging 100 to 200 feet deep. There are no reported or identifiable significant clay (aquitard) units within the sedimentary section. The western edge of the sub-area is located at the pre-fill edge of the bay and does not appear to have laterally migrated since Yerba Buena times. The estuarine boundary is sharp, with the edges of the Young Bay Mud and Yerba Buena Mud being almost on top of each other. The estuarine clay-alluvial fan transition zone is also narrow, being 100 feet or so wide. This area was identified as the northern section of the East Side Alluvial Apron by Fio and Leighton (1995).

The BART boreholes and Arden (1961) revealed the presence of 6 alluvial filled valleys. Adjacent to the railroad track, the channels are up to 70 feet deep, cutting into the Yerba Buena Mud in north Berkeley, and through the Merritt Sand north of the Bay Bridge. The channels extend offshore, being marked by thickened zones in the Yerba Buena Mud (Trask and Rolston, 1951; Army Corps of Engineers, 1963).

These valleys suggest that throughout much of its life, the Berkeley sub-area consisted of exposed bedrock with a veneer of alluvial fan material. The age range of the alluvial material is unknown. Lithologically, it appears to be correlative with the Santa Clara, but it may not be time correlative (ie: the problem of chronostratigraphic vs. lithostratigraphic units).

Historically, ground water was pumped from near the bay, but pumping rates and volumes were low, and the area had to be supplemented by outside water supplies by the 1880's. The primary source of water was tunnels and springs in the hills east of U. C. Berkeley (see the Berkeley history section for the water history details). Even though the sub-area filled mainly with gravels and sands, it is unlikely that there are notable groundwater supplies. This appears to be due to the limited natural recharge. Wells will have a high initial pumping rate, but high pumping will quickly deplete the aquifer (small sustainable yields). Groundwater volumes appear to be suitable for single family homes and small industrial uses, but there is no historical evidence to suggest that groundwater supplies are sufficient for municipal use.

Oakland sub-area

The Oakland sub-area is similar to the Berkeley sub-area in that it consists of a sequence of recent to old alluvial fans. Basement is deeper, and the alluvial fill is thicker (300 to 700 feet). The majority of the Oakland sub-area is underlain by alluvial fan material and does not contain well-defined aquitards such as estuarine muds. Both the Young Bay Mud and the Yerba Buena Mud extend east towards I-880 and the site of the old Cypress structure, with the Yerba Buena Mud extending further east.

Lake Merritt is located in a drowned valley, similar to the valleys buried beneath the Berkeley sub-area. Drilling by Caltrans for construction of the I-580 overpass at Park Boulevard revealed black clays and shells 75 feet below the ground surface. It is possible that this material correlates with the Yerba Buena Mud, providing evidence that the Lake Merritt valley existed during Yerba Buena time.

The largest and deepest wells in the City of Oakland were located near Myrtle and 28th Streets and appear to be located in a basement channel. These wells pumped 1 to 2 million gallons per day, and were more than 200 feet deep. Surrounding wells were 30 to 100 feet deep. The upland areas east of Lake Merritt have historically shown little groundwater potential. The wells drilled in that area had only sufficient flows to supply single family homes. It is similar in nature to the Berkeley sub-area. The aquifer appears to have suitable physical characteristics, but the sustainable yield is low due to small recharge capabilities. The lowland areas have a variable ground water potential. The Merritt sand outcrop in west Oakland was a prolific shallow producer (up to 60 feet deep), and was an integral part of the early water supply of Oakland (both private and public). By the 1890's, septic systems contaminated many wells and there is some indication of limited salt/brackish water intrusion along the northwest part of the Merritt sand. Drilling records indicated that the deeper zones were quite variable. Some areas were quite prolific, others were dry.

There were a series of high yield wells along the Oakland waterfront and along a zone that stretched from the southwestern side of Alameda Island to the Oakland Coliseum (the Alameda-Fitchburg trend). The source for these wells was gravels below the Yerba Buena Mud. Our evaluation suggests that these gravels were deposited at the mouth of a series of valleys, one of which was the ancestral Lake Merritt valley (pre-Yerba Buena time). This suggests that similar gravel zones may exist west of the Berkeley shoreline, near the mouths of the buried valleys.

San Lorenzo and San Leandro Sub-areas

These sub-areas are discussed jointly because they have virtually identical geology. These sub-areas filled primarily with alluvial fans, but unlike the Niles Cone to the south, they were not fed by large streams. As a result, the sediments in these areas are finer grained, there are fewer gravel layers, and the transition zone between estuarine muds and alluvial units is wider and more complex (Figure 17). Basement is deep (700 to 1100 feet), and both sub-areas contain a complete Alameda section. None of the deeper continental units are exposed. It appears that this area has undergone continuous deposition. There have not been periods of uplift that would erode, remove, and rework sediments.

The boundary between these two sub-areas is based on surface geomorphology and follows the surface trace of the junction between the San Leandro and San Lorenzo alluvial fans. Unlike the sub-areas to the north, the Yerba Buena Mud extends west into the sub-area (almost to I-880). Boring logs and previous researchers (Forbes, 1925; Woodward-Clyde, 1993; Kessell, 1996) indicate that a thick (up to 100 feet?), fine-grained clastic section extends east of the Yerba Buena mud, forming an aquitard that reaches almost to the Hayward Fault. At this time, it does not appear that the fine-grained section is a direct lateral equivalent of the estuarine clays (genetic relationship). Instead, it was a long-term depositional sequence spanning several estuarine clay depositional periods. This section was the result of small streams that could not transport large material. Coarser-grained zones likely exist, but they are expected to be smaller, scattered, and disconnected. .

The Alameda-Fitchburg trend extends into the northern end of the San Lorenzo sub-area. Most of the Union Water Company's water supply wells were located at the eastern end of this trend (in the vicinity of 98th Street and 14th Avenue), and this area was proposed as an equivalent groundwater supply by Dockweiler during the 1910 lawsuit between Oakland and the Contra Costa Water Company. The only other groundwater supply was the Roberts Well Field at the edge of the bay. It produced from upper Alameda gravels. The Cherry Lynn Wells in the San Lorenzo Cone were pumped for a few years, but they were marginal producers. The remainder of the area was used for single family homes and small farms/commercial uses. There is little historical evidence for other large scale groundwater supplies in these sub-areas, and it is likely that the sustainable yield of these sub-areas is small even though high quality aquifers may exist. The largest groundwater supplies were the Alvarado Well Fields, but they were to the south, in the Niles Cone. In the mid-1990's, the City of Hayward drilled several emergency water supply wells in the vicinity of the Hayward Airport. Reportedly, these wells could produce in the range of 4,000,000 gallons per day during short well test. These wells are southeast of the Roberts Well Field, and may be a lateral extension of the Roberts Wells Field.

A WATER SUPPLY HISTORY OF THE EAST BAY AREA (1860-1930)

This section is intended to provide guidance for beneficial use decisions, and provide detailed information on the location and nature of historic well fields and groundwater uses. Early on in our research, we discovered that while there were descriptions/histories of specific events, no comprehensive, pre-1930 water supply history of the East Bay area had ever been written. We compiled this history so others could understand the desires, needs, and problems that drove the development of groundwater supplies.

All water supplies for the Bay Area were derived from wells and reservoirs until the entry of Sierran water into the area in 1930. The following is a history of the development of water supplies in the East Bay Area from their beginning to 1930. The information is shown graphically in figure 24, and Figure 19 illustrates the size of the various water supply sources in 1911 (in gallons per day). The water history of specific areas, Richmond, Berkeley, Alameda Island, Castro Valley, and Bay Farm Island, are described in the Municipal Well Field section. It must be remembered that the development of water supplies were intimately connected with the growth and development of infrastructure, scientific inventions, population, and, most importantly, personalities and luck. The history of water in the Oakland area is illustrative of what was occurring around the state, the nation, and other countries during the same time period (Mukhopadhyay, 1981).

One of the problems in elucidating the history of the water supply of the East Bay Area is the lack of hard information. The records of the Contra Costa Water Company (a predecessor of EBMUD) were burned in 1899. In 1929, Sierran water supplies had been brought into the area, and existing groundwater supplies were abandoned in 1930. By the late 1950's, everyone in EBMUD who was familiar with groundwater had retired, and corporate memory was lost. To make things worse, it appears that virtually all well and groundwater records were destroyed when EBMUD moved into its new building in downtown Oakland in the late 1980's. The information in this chapter was pieced together from: Anonymous (1886?, 1917, 1989); Bailey (1920); Bell (1947); Bowhill, T. (1895); Burgess (1948, 1992); Chamberlain, et al (1903); Commonwealth Club (1904, 1914, 1926, 1929); Cory (1914); Daniels (1921); Darling (1935); Davis (1924); Dawkins (1983); Dockwelier (1912, 1916); Forbes (1914); Ford (1923); Hanson (1903); Harroun (1908, 1920); Haviland, et al (1913); Hering (1924); Hodgenson et al. (1960); Hooker (1916); Hoover-Young Commission (1930); Huber (1931); Hyde (1944); Kuhn (1965); LeConte (1900); Lee (1905); Lefler (1910); LeVan (1924); Markwart (1910); McFarland (1926); McLean (1933, 1938); Merritt (1928); Miller (1903); Noble (1970); Oakland Chamber of Commerce (1923); Oakland Free Library (1930); Posey and Tibbetts (1924); Purcell (1940); Romanucci (1983); Sanborn Map Co. (1890 to 1925); Sander (1924); Sanders (1903); Schuyler (1886, 1900a, 1900b); Sloan and Stine (1983); Sturgeon (1913); Watts (1893); Weeks (1909); Wing (1951); Wood (1883); Young (1929) and numerous newspaper and magazine articles (1872-1930).

PRIVATE WATER SUPPLIES

The earliest water supplies were from private wells drilled along the west side of Oakland (west of Lake Merritt), along the shore line adjacent to the estuary (Figure 4). These wells were shallow, generally less than 60 feet deep, and drinking water was found below a "hard pan" layer that was commonly encountered 4 to 20 feet below the ground surface. The water was reported as being potable but hard. Most of the houses had individual wells. There were scattered, small private water companies that supplied water to between 5 and 25 neighboring properties. In 1902, the largest private water company in Oakland was owned by Mr. Sicoth at Eighth and Willow streets. His well was 60 feet deep and supplied water to 25 houses. There were numerous private well companies. Little is known about these companies. The best source of information is the Sanborn maps. Private water companies were generally identified and located on the earlier, pre-1905, maps. For example, the Greater Oakland Water Company was located at the northwest corner of 73rd and Lockwood Streets; see Oakland Sanborn map, 1911, vol 5, sheet 571.

The primary source in the west Oakland area was the Merritt Sand (Figure 4). In this zone, wells were 40 to 60 feet deep, and virtually any well would produce a good supply of water. Initially, the water table was near the ground surface, but by the 1890's, pumping had lowered water levels 5 to 10 feet below the ground surface. The Merritt Sand extended from Alameda Island to 1-1/2 miles east of the estuary in West Oakland. Early descriptions indicate that there were artesian wells in the Merritt Sand near the bay. At that time, the term artesian had a slightly different meaning. It was used to describe a well in which water levels rose to within a few feet of the ground surface as well as a well in which water naturally flowed above the ground surface.

East of the Merritt Sand, wells were much deeper, and water was more difficult to find. Wells ranged between 150 and 250 feet deep, with some being 500 to 700 feet deep. The aquitard layers were well known (equivalent to our Young Bay Mud, Old Bay Mud and upper Alameda clay layers), but there was no widespread recognizable aquifer; "*there is no regularity in the depth of existing wells or in the depth and thickness of the water bearing sub-stratas*" (1903). Instead, water was found in isolated sand/gravel layers, 1 to 15 feet thick. These layers had various depths, but were in the range of 80 to 120 feet, 150 to 200 feet, and deeper than 250 feet. The best wells were found near the shore, with the risk of a low producer or dry well increasing towards the hills. It was also known that there was a one mile wide, high producing water zone extending from the south side of Alameda Island inland to what is now 98th Street (the Fruitvale area). Most of the major well fields were drilled in this zone.

Early on, it was known that wells in populated areas could become contaminated from outhouses and industrial wastes; "*wells in thickly settled neighborhoods are looked upon with distrust, and there have been instances where abandoned wells have been turned into cesspools. This would tend to poison every well in the vicinity, for the water evidently circulates freely beneath the hard-pan* " (1883). There was no outhouse effluent treatment. Waste was dumped into a hole in the ground. Conventional septic systems were invented in Europe in the 1880's, but did not come into use in the United States until the late 1890's. Sewer lines began to be installed in the East Bay Area in the mid-1880's, but all they did was transport raw sewage into the bay. Secondary treatment did not begin until the late 1940's.

By the 1880's, it was common for the upper 50 to 100 feet of a well in a densely populated area to be cased off to prevent near-surface contamination. The wells were pumped by windmills, but the lack of continuous winds required large water tanks (tank houses). Some of the windmills were still in existence in the 1940's, and some of the old tank houses are still visible today (the best preserved is just south of the intersection of I-580 and I-238 in Hayward).

The total number of wells (public or private) that have been drilled in the East Bay Area will never be known, but some estimates can be made. Based on the literature review for this report, we estimate that 12,000 to 15,000 wells were drilled in the East Bay area between 1860 and 1950 (when DWR began keeping records). An estimated 5,000 wells were drilled in the East Bay Area between 1860 and 1910. In 1912, Mr. Dockweiler surveyed all of the private wells between Richmond and Hayward, and found 3841 active wells (3431 private wells, 410 commercial wells, with the remainder being abandoned; Figure 5). He estimated that he identified 100 percent of the wells in Oakland and 80 percent of the wells in the outlying areas. The remaining wells were shallow (hand pumps) and did not significantly contribute to the water supply. Prior to circa 1910, the existing technology (cable tool rigs and 24 to 30 inch sections of casing that had to be riveted together) prevented the rapid drilling of wells. The largest well driller in 1910 reported that he drilled 100 to 120 wells a year in the area.

There was a series of droughts between 1918 and 1925, and it is likely that many wells were drilled in both the cities and in the outlying areas. We estimate that in the range of 6,000 wells were drilled between 1910 and 1930. This increased rate of drilling was also due to advances in technology: gasoline engines, rotary rigs, and the ability to set casing quickly.

In 1929, Sierran water supplies entered the area, and the drilling of new wells quickly dropped off. Probably in the range of 1,000 to 2,000 were drilled between 1930 and 1950, most of these in outlying areas where water lines had not yet been laid. DWR (1960) estimated that in 1960 there were about 4350 shallow wells in the San Lorenzo and San Leandro cones (one at almost every residence). Of these, approximately 4000 were less than 50 feet deep. Of the remaining deeper wells; 315 wells were between 50 and 200 feet, and 100 wells were more than 200 feet deep.

While all the wells were active at one time, it is likely that fewer than a thousand of the pre-1950 wells are active today (for example, there were 500 producing wells in Alameda in 1925, but only 135 producing wells in 1953). The remainder of the wells were abandoned in-place. In most cases, the casing rusted out and the well caved and collapsed. If the well had been over-pumped, the lower part of the well may have sanded up. There were reports from the early 1900's that some of the larger wells were back-filled with sand. Some wells were filled with grout, but this was only done in tidal areas to prevent salt water from flowing down an abandoned well and contaminating near by active wells.

There have been thousands of wells drilled in the area since 1950. The records for them are kept both at DWR and the Alameda County Department of Public Works.

PUBLIC WATER SUPPLY HISTORY

Individual wells were sufficient for household use but were unable to meet the demands for fire protection or large scale industry. Early on, the need for water companies was recognized, but there was no legal framework (under local or state laws) under which such a company could legally condemn land for water supply use. In a message to the Oakland City Council on April 29, 1854, Mayor Carpentier of Oakland regretted "that the charter confers no power on the City Council to authorize the construction of city water works by which some of the mountain streams might be brought into the city at a comparatively small expense, thereby affording an abundant supply of water both for common uses and for the extinguishment of fires."

On April 22, 1858, the state legislature passed "An Act for the Incorporation of Water Companies", allowing for the creation of water companies. Under this law, water companies had to furnish water to all who applied for it at a reasonable rate, but had to supply water for fire protection for free. In return, the companies acquired the power of eminent domain. This allowed the companies to force the sale of land from landowners for the construction of water mains, well fields, and reservoirs. By the mid 1860's, water companies were being formed all over the state. The first water company in the East Bay Area was the Alvarado Artesian Well Company. It was incorporated in 1860 for the purpose of boring an artesian well at Alvarado, in the Niles Cone. Its total capital stock was only $400, and the company apparently wanted water only for local irrigation. A company with the same name was incorporated in 1893. That company existed until 1899 when it was folded into the Contra Costa Water Company. It is not known if there was any relationship between the two companies.

In 1864, The Alameda Water Company was incorporated in Oakland by John Dwinelle. This company planned on damming Alameda Creek in Niles Canyon to supply water to Oakland and surrounding communities. They twice petitioned the courts to condemn the necessary land (in 1865 and 1866), but both petitions failed, primarily because of opposition from the Western Pacific Railroad whose right-of-way ran through Niles Canyon. In the late 1860's, it merged with the San Francisco and Alameda Water Company who had a small dam on Alameda Creek. They, in turn, were bought by the Spring Valley Water Company in 1875.

In 1865, the Oakland and Alameda Water Company was incorporated by Mr. Biddleman, who owned a large tract of land through which the south fork of Temescal Creek flowed and much of the land between Broadway Tunnel Road and Claremont Canyon. In late 1865, construction began on two dams across Temescal Creek, just downstream of the present Temescal Dam. The larger dam was to be 25 feet high and impound 100,000,000 gallons of water. They were under construction when runoff from a winter storm swept one dam away and severely damaged the other. In the Spring of 1866, the company began reconstruction of the dams, and began laying pipes. At the same time, they petitioned the Oakland City council for the right to lay water mains in the streets of Oakland, but the petition was held up in Committee. As it turned out, the chair of the committee, Mr. Shattuck, was a founder of a rival water company, the Amador Water Company. That company appears to have been organized for speculative reasons, not to supply water. It quickly disappeared, but it had a fundamental effect in that it delayed Mr. Biddleman's petition and allowed the Contra Costa Water Company to come onto the scene. The delay also caused financial difficulties for the Oakland and Alameda Water Company. Work on dam reconstruction stopped, and the company folded. It was purchased by the Contra Costa Water Company in 1868.

The Contra Costa Water Company was formed by Mr. Anthony Chabot on July 18, 1866, to supply water to Oakland under a charter granted by the City of Oakland. Mr. Chabot was an experienced water man who had recently sold a successful water company in San Francisco, and the new company was well financed. His name soon came to be synonymous with water and his water company. Many other water companies were created over the next 40 years. Some were to prosper, while others survived only a year or two. They all eventually merged into the Contra Costa Water Company which, in turn, was purchased by the East Bay Municipal Utility District (EBMUD) in 1927.

As soon as their petition was granted (a week after it was requested), the Contra Costa Water Company began work. Their charter required that they have 3000 feet of pipe in the ground and begin supplying water to Oakland within 18 months. The pipe was ordered, and by the spring of 1867, the piping system was installed and ready to supply water. The only problem was that there was no water supply. The company first wanted to dam Sausal Creek at the lower end of Diamond Canyon, but were unable to quickly secure the land or water rights. They then turned their sights to Temescal Creek (and Mr. Biddleman). However, to meet the charter requirements, Mr. Chabot made arrangements to use a well at the College School (Mr. Brayton's well). The well was pumped by a steam engine to an elevated tank, connected to the water mains, and in April, 1867, Oakland had its first public water supply.

The well had insufficient capacity to supply both the city and the College, and the pumps went dry on several occasions. In May, 1867, Mr. Chabot acquired rights to take water from Temescal Creek just south of the present intersection of Telegraph and Claremont Avenues. By June 1, the pipes reached the creek, and water from Temescal Creek replaced the well. The inlet was moved upstream in late June, 1867, to raise the water pressure (at the initial location there was only a 90 foot elevation drop over three miles in a 6 inch diameter pipe). Initially, there was a direct connection between the creek and the customers, but by early 1868, a million gallon reservoir was built on a hill near the intersection of Summit and 31st streets (initially called College Hill, now called Hospital Hill). Except for the occasional interruption, this water supply was satisfactory for six to eight months out of the year. Luckily, the winters of 1867-68 and 1868-69 were wet and there were no serious water shortages.

Mr. Chabot knew that this supply was only temporary. At the same time that he was preparing to pump from Temescal Creek (early 1867), he purchased the property that was to be the site of Temescal Dam and was contacting the owners of what was to be the reservoir, the surrounding lands (to protect the reservoir from pollution), and pipeline right-of-ways. Unlike his previous negotiations, he now had to deal with some of the largest land owners in the area (such as Mr. Biddleman of the defunct Oakland and Alameda Water Company). They had no intention of selling their land for a dollar and a water connection. It took a year and a court case or two, but by mid-1868 Mr. Chabot had acquired the necessary property.

In late 1867-early 1868, work began on the construction of the dam that formed Lake Temescal. This was the first great engineering work in the East Bay. When it was completed in 1869, the dam was initially 85 feet high, 600 feet long, and contained about 250,000 cubic yards of material. The reservoir covered 18 acres of land, was almost a mile long, and held 180,000,000 gallons of water. The initial dam was located at the narrowest part of the valley, approximately 300 feet upstream from the current dam (near the current boathouse). Unfortunately, construction was started without determining the subsurface nature of the site. Bedrock was much deeper than anticipated and the site was abandoned. Construction then began at the current location of the dam. This site was wider, but bedrock was much closer to the surface. The ground was scraped to bedrock (about 10,000 cubic yards of soil were excavated) on the bottom and the sides of the valley. A clay core was built up by spreading thin layers of clay that were wetted down and tamped (puddled) by horses before applying the next layer. The clay core was 30 feet wide at its base and contained more than 22,000 cubic yards. Using his experiences from the gold diggings, Mr. Chabot had the remainder of the dam constructed by sluicing dirt and gravel around the core instead of hauling it by horse and wagon. At the same time, an overflow channel was cut into the hill north of the dam, a regulating tower was constructed behind the dam, roads and bridges were built, and the vegetation was grubbed from the reservoir site. The tower was destroyed by a landslide and was replaced by a floating standpipe. Outside of a large aeration tank and a strainer, there were no other provisions for purifying the water. By mid-1868, the reservoir began to supply water to Oakland, but the dam was not completed until late 1868 (the reservoir did not fill until 1871). Over the next few years, the dam was raised to 105 feet. In 1911, the reservoir produced an average of 405,917 gallons per day. In 1925, it produced 152,000 gallons per day, supplying water to a small residential area in Piedmont and Berkeley. The reservoir was an active part of the Oakland water system until the arrival of Sierran waters in 1930. At that time, pumping from the reservoir stopped. The dam was lowered by 40 feet circa 1934, and it was given to the Park Department circa 1960.

During the early 1870's, the Company concentrated on building the infrastructure necessary to supply water. The pipe line system was expanded, old water lines were replaced, storage and maintenance facilities were constructed, and water rates were established. By mid-1869, more than 7 miles of pipelines had been installed. It quickly became apparent that the original mains (6 inches in diameter) were undersized and could not supply sufficient water. Within a year or so, many were removed and replaced with larger pipes. In 1870, Oakland embarked on a city-wide street improvement program that included grading. Unfortunately, most of the water mains were buried only a few inches below the ground surface, and many were damaged by the street improvement program. By 1871, more than 28 miles of pipeline had been installed, by 1874 more than 50 miles had been installed, and by 1876 more than 100 miles had been installed.

In 1869, the Oakland Fire Department was organized, and fire hydrants became an issue. The charter stated that water for fire service was free, but it said nothing about the fire hydrants. The Company offered to install them for 150 dollars each, but the City thought that was exorbitant. While they were arguing, a group of Broadway merchants purchased their own, and the first hydrant was tested on May 26, 1869. Apparently, it was not a complete success, and it was not until 1871 that additional hydrants were installed.

In a theme that would occur again and again, it became obvious that the area was outgrowing its water supply. Even as Temescal Dam was being completed, Mr. Chabot was contemplating additional sources. Temescal Dam could be physically enlarged, but the watershed was too small to provide more water than what was being collected. He then turned to San Leandro Creek. It had a suitable dam site and a sufficiently large watershed. However, it would require several years to construct, so intermediate water sources had to be found.

These intermediate supplies consisted of wells and the purchase of adjacent water companies. The first well was dug near the village of Temescal, at the present intersection of Claremont and Telegraph Avenues. A square well was dug about 30 feet deep, and then a bore was drilled in the middle of the well to a depth of 155 feet. It was a dry hole. The next well was at the west end of Commerce Street, now 14th Avenue. It struck water that rose to within a few feet of the ground surface. In 1871, it supplied 125,000 gallons of water per day.

A well was then drilled at the southwest corner of east 12th and 21st Avenue at the edge of the estuary (on the tide lands). Reportedly, the top of the well was below high tide level. Water was encountered at 100 feet, and good water was found at 160 feet below the ground surface. The well was deepened to 254 feet, with no additional water being encountered. Above the bore, a six foot square, 50 foot deep well was dug as a reservoir. The water rose to within a few feet of the ground surface. A few years later, a second well was drilled in the same area. These wells could produce 15,000 to 20,000 gallons per hour and were called the Brooklyn wells. They eventually became the emergency water supply for the City of Oakland and supplied water into the 1890's. There was a newspaper article in 1873 that indicated that the Brooklyn wells had became contaminated (temporarily?) from surrounding slaughter houses.

The Sausal Water Company was purchased in 1872. This company had been formed in 1869 to supply water from Sausal Creek to the Fruitvale Avenue area (then the town of Brooklyn). In June, 1870, the Sausal Creek Dam was built. This stone dam was located up the canyon near Moraga Road (now upper Park Boulevard). It formed a small lake about 25 feet wide and 60 feet long. Water flowed 4000 feet from the reservoir through a 7 inch diameter pipe to a reservoir on the west side of the lower end of the canyon at an elevation of about 325 feet. From there, water was piped to homes along Fruitvale Avenue. The Sausal Water Company was in financial difficulties. It did not have enough customers to cover its costs nor enough resources to extend the system. On April 5, 1872, Contra Costa Water Company purchased the Sausal Water Company (but it remained a separate corporate entity until 1890). Within a few weeks, the Sausal Water system was connected to the Contra Costa Water Company mains. A form of "Conjunctive use", a popular water management technique today, was used by Chabot. He used the deep wells at East 12th and 21st Avenues to fill the Sausal reservoir. These sources supplied Oakland during the winter and spring, allowing Lake Temescal to fill up for summer use. The original Sausal Creek dam was abandoned in 1906 because of pollution of the lower watershed. Two smaller wooden dams were constructed further up the creek. One was on Miller Creek (the east fork of Sausal Creek). The other was in Shepherds Canyon (the west fork of Sausal Creek). This dam produced about 80,000 gallons per day.

In 1871, Mr. Chabot obtained the water rights to Lyons Creek (adjacent to Mills College; now called Lions Creek) but did not develop this source until many years later.

In June, 1869, the Piedmont Water Company was formed. It anticipated using creeks and natural springs to supply the Piedmont area, but no water system was ever developed. The springs were well known to the local inhabitants. The Piedmont Resort Hotel was constructed adjacent to the sulfur springs in the canyon that is now Piedmont Park. By the early 1870's, the hotel drew clients from all over California to bathe in its mineral waters. In January, 1874, the large landowners in the area gave access to the springs to Contra Costa Water Company in exchange for reduced water rates. Piedmont was the first area in which all houses had water meters.

1870-1906

In early 1870, Mr. Chabot began planning for a dam across San Leandro Creek. At the same time, three other water companies were formed with the intent to build dams in the same area (the San Leandro Creek Water Company, the Oakland and San Leandro Water Company, and the San Leandro Water Company). None existed for more than a few months. It required 3 years and several lawsuits, but by early 1874, Chabot had acquired the necessary land. Construction began in 1874, and the reservoir filled in May, 1876. The dam was not constructed by the Contra Costa Water Company, but by a dummy corporation, the California Water Company, that had been set up by Mr. Chabot in August 14, 1873. Soon after construction (May 18, 1876), the dam was sold to the Contra Costa Water Company (Mr. Chabot made more than $100,000 on an initial investment of 10,000 dollars).

The dam was constructed in a similar manner to Temescal Dam. The site was excavated down to bedrock (varying between 10 and 30 feet deep), and three trenches were excavated into bedrock. The trenches extended the length of the dam and were filled with cement to prevent seepage beneath the dam. Above this, an impervious clay core, the "puddle wall" was constructed. The puddle wall was about 90 feet wide and more than 300 feet long. The clay was laid down in thin layers, saturated, and then trampled by horses. More than 75,000 cubic yards of clay were used in the core. Both sides of the core were then surrounded by sand and gravel that was sluiced from the surrounding hills (this was the slang term for hydraulic mining, which was apparently invented by Mr. Chabot in 1862). By 1886, the dam was 120 feet high (155 feet above bedrock), 450 feet long, 36 feet wide at the top, and contained 622,000 cubic yards of material. Sluicing continued for almost a decade after the dam was in use.

Even as the dam was being constructed, Mr. Chabot began planning to increase the water supply into the reservoir. In the early, 1880's, the Company purchased land near Pleasanton and began construction of canals to drain the Pleasanton swamps and direct the water into the reservoir. There were also plans to construct dams across the southern ends of Bollinger, Crow Canyon, and Cull Canyon Creeks to feed water into the reservoir. None of these plans were ever completed. The Pleasanton swamps were drained in the early 1900's as part of flood control and farm land reclamation.

When it was completed, San Leandro dam was the highest earthen dam in the world. A landslide occurred on the outside face of the dam in 1891. As part of the repairs, the dam was raised another ten feet in 1892. A cut stone spillway, 46 feet wide, at the north end of the dam contained stop-logs to increase the storage capacity. The capacity of the reservoir at high water, elevation 234, is 4,800,000,000 gallons. The reservoir was renamed Lake Chabot in 1889, after the death of Mr. Chabot, and is still an integral part of the present water supply system. A comprehensive geotechnical evaluation (including drilling) of the dam occurred in 1937.

A technical problem was the construction of tunnels through the hill north of the dam. The lower tunnel (tunnel #1, elevation 149 feet) was 30 feet above the original level of the creek, and 862 feet long. The first 500 feet consisted of a 5x7 foot tunnel. From that point, water could continue through the tunnel or be diverted into two 24 inch diameter water mains. This tunnel was abandoned in 1932. The second tunnel (#2, 193 feet elevation) is much higher up and closer to the dam. It is about 400 feet long and 9x9 feet square. Water enters this tunnel through a vertical shaft near the north side of the dam. A third tunnel (10x10 feet) was built in 1889 to handle overflow. It was further north and was more than 1500 feet long.

The reservoir covered about 333 acres of land. As with Lake Temescal, all vegetation was to be removed before being covered with water. This apparently was not properly done, and the effects of rotting vegetation were to plague the Company for years. The construction of Lake Chabot marked the end of large water projects until the advent of the Sierran water supplies in the 1920's.

From the beginning, water quality and high consumer costs (water rates) were problems. Water quality was a function of two factors, sediment in the reservoirs and bacterial growth in the piping system. During the winter, the rains would transport large amounts of fine sediment into the reservoirs. The particles were so small that the water stayed muddy even during the summer. In the heat of the summer, the lack of oxygen caused eutrophication, and the water would begin to stink from growing algae and dead fish. Even as early as 1867, the water coming out of the pipes looked like mud (and smelled just as bad). The primary health problem was water stagnation in the mains. At this time, the technology was only sufficient to filter large particles from the water (fish, bugs, globs of muck). The original filters were cloth, and they had to be removed and hand scrapped every few minutes. Sand filters and alum were introduced in 1894, but there was no feasible method to kill bacteria until the introduction of chlorination just before World War I (the first use of chlorination in the U.S. occurred in Chicago in 1908). Remember, it was only in 1854 that Dr. Snow (in his study of deaths near water pumps in London) demonstrated that contaminated well water could spread disease. Typhoid was a continual worry. Between 1886 and 1894 (pre-filtration), there were 30 to 50 deaths per 100,000 people per year in Oakland (the highest rate was 79 deaths per 100,000 in 1893). The rate dropped to 15 to 20 after filtration began (1894).

As long as the water flowed through the mains, there were generally few problems. However, dead end pipes caused stagnant water which allowed the rapid growth of bacteria. The growth of bacteria was also compounded by low water pressure. Acceptable water pressure was 10 to 20 psi. If too many people turned on their taps, there was no water in the end of the pipe and leaks from adjacent cesspools could enter the mains. One of the health evaluation methods used by the Oakland Health Department in the 1880's was to map deaths with water main locations. There were higher death rates in areas where mains dead-ended. One of the solutions was to aerate the mains.

In 1870, a newspaper article stated:

> *If the water used in San Francisco were of a quality like that furnished Oakland, the cry over there would be for less instead of greater supply. Here, it has such an offensive smell that, to say nothing of drinking it, it is not even "goot vor vash" and it is feared that the increased use of substitutes for the natural beverage of mankind will seriously affect not only the physical, but also the mental condition of the community. . . . At any rate the muddy condition and terrible stench of the water now served to Oaklanders renders it fearfully nauseating to the strongest stomachs. Is there no remedy?*

After an inspection of Lake Temescal in 1872, the local newspaper stated that charges against the purity of the water by "irresponsible parties" was "all bosh". The article also mentioned that there was a dairy farm on the main stream above the lake, but that the barn was at least a hundred yards from the stream, so that any pollution from that source would be negligible. The building of Lake Chabot in the mid-1870's reduced the complaints for a few years, but there was renewed agitation about water quality in the 1880's.

The Company charter specified that the rates were to be set by an independent commission, but this was done by the Oakland City Council from the early 1870's. Homes were generally not metered, but were charged on the basis of the number of stories and square feet. This was only the basic rate. If there were more than 5 people in the house, there was an additional 25 cents per person per month charge. A bathtub entailed an additional dollar per month charge. Yard watering cost one cent per square yard of lawn and garden. There were additional fees for washing sidewalks, horses and carriages, boarders, etc. Commercial rates include similar items but at a higher cost. In 1870, an average residential water bill was 5 to 7 dollars a month at a time when wages were less than a dollar a day. Even though yard watering was based on the size of the yard, the lack of meters meant the owner could use as much water as desired. Oakland had large, well-maintained yards, and it was common for sprinklers to run all night long. During the summer months, sprinklers were generally banned by the Company. Over the next 30 years, the Company installed meters on all water connections

The Company had a huge investment in infrastructure (it is estimated that it cost between 285,000 and 375,000 dollars to build Temescal Dam and more than 600,000 dollars to built Chabot Dam), but the presence of numerous private wells and small water suppliers reduced the number of water connections. The main problem (as far as the Company was concerned) was that the water rates were set by the Oakland City Council. The Company could request rate hikes, but the actual rates were determined by politics. This meant that the Company could not always charge enough to cover their costs. This was also the primary reason why competing water companies eventually merged with the Contra Costa Water Company and why it was replaced by the East Bay Municipal Utility District in 1928.

These issues sparked a debate that is ongoing today -- private vs. public ownership of water utilities. On January 19, 1874, the City passed a resolution that the City should create a bill that would be presented to the State legislature authorizing the City to issue bonds for the purpose of acquiring the Company (the bill passed). In March of that year, Mr. Chabot proposed selling the Contra Costa Water Company to the City at a value to be fixed by an independent commission. The deal fell through for several reasons. The bill passed by the legislature was financially flawed (too low an interest rate, no method to guarantee payment, etc.); the commission and Chabot failed to reach an agreement on the selling price; and there was ultimately a lack of political will. The City and the people began to doubt if the City could provide more or better water than the Company could. The initial success of Lake Chabot in supplying good water also reduced the public's desire for a change (ie: reduced political will). The inadequate water supplies and poor water quality from Lake Temescal mobilized the citizens, but the creation of Lake Chabot mollified them.

There were proposals to bring Sierran water to the Bay Area as early as 1875 by Colonel von Schmidt, who owned the Lake Tahoe and San Francisco Water Company, and the Mount Gregory Water and Mining Company. Colonel von Schmidt planned to tap Lake Tahoe and transport the water via large tunnels. The Mount Gregory Water and Mining Company was going to tap rivers and lakes and transport the water via aqueducts. Both ideas were seriously considered, but never went beyond the planning stage. In the early 1900's, Lake Tahoe was proposed as a water supply for San Francisco. A deal was cut between Tahoe land owners and Boss Ruef (the kingpin boss of San Francisco at the turn of the century). The idea was to build a water system and sell it to San Francisco at a profit of three million dollars with one third of the profit going to Ruef. Before this could occur, the Mayor, Ruef, and his supervisors were caught up in corruption scandal that lasted 10 years and eventually sent Ruef to jail.

In the early 1880's, four artesian wells were drilled by the Central Pacific Company near Fifth and Kirkham streets. Apparently, good water was found. An artesian well was also completed by Mr. O. Lindsley in West Oakland.

During the 1880's, there was continuous agitation concerning the water rates and quality that culminated in the "Citizens Committee of One Hundred of Oakland" in 1890. Over several months in the fall of 1889, the chairman of the Oakland Board of Health, Dr. Pardee, issued a series of reports describing the putrid and hazardous nature of the waters of Lake Temescal and Chabot. In a series of measurements, the water in Lake Chabot had albumenoid ammonia levels in the range of 0.33 to 0.44 parts per million. Albumenoid ammonia is a poison formed from the decomposition of organic and nitrogenous matters, and levels above 0.10 were thought to be hazardous to health. At that time, water samples from Strawberry Creek and the Sacramento River had albumenoid ammonia levels of 0.13 and 0.10 respectively. Dr. Pardee believed that the water should be purified by extensive filtration (sand filters and aeration). At the time, the only filtration consisted of a series of cloth strainers that were removed, scraped, and scrubbed every few minutes.

Dr. Pardee's findings were not universally accepted. A champion for the water company, Dr. Woolsey, fought back with a series of articles that challenged the scientific basis and the professional ethics of Dr. Pardee. Eventually the issue landed in the lap of the Oakland City Council. The Council waffled and the newspapers, the *Times*, *Tribune*, and the *Enquirer* began a series of articles and editorials on the problem (with the Tribune on the side of the Company, and the *Times* and the *Enquirer* on the side of Pardee). A spokesman for the Company stated that the cloth filters worked fine. The Company procrastinated, but public pressure finally forced the Company to announce that it would build a large settling reservoir. Pardee responded that he could not see what advantage there would be in drawing stagnant water from Lake Chabot, removing part of the living and dead organisms from it by cloth strainers, mixing a little air with it, and leaving it exposed to the summer heat so conducive to the growth of water life.

A few days after the Company announcement, the City Council met to consider water rates for the coming year. Initially, the rates were going to be reduced 15 percent, but after a series of parliamentary maneuvers and multiple versions of ordinances, the water rates were kept the same by a vote of 6 to 5 (the Collins ordinance). The newspapers praised the "honest five", and denounced the "rotten six" who had been disloyal to their duty, and branded them as men making no pretense of honesty -- therefore men from whom nothing good was to be expected. There were charges of payoffs, and the ring leader of the six, Mr. McAvoy, was called a liar and a coward.

The citizenry exploded. On February 24, 1889, the day after the City Council meeting, a mass meeting of the citizenry was held, complete with bonfires and bands. On the stage were eleven jars of water, each representing a City Councilman. Six of the jars were filled with a greenish fluid representing the water from Lake Chabot, while the other five contained clear, filtered water. The jar representing Councilman Collins contained a snake. Three resolutions were passed. The first resolution dealt with the right of the people to have pure water, the responsibility of the water company to provide clean water, and the ultimate need for municipal ownership. The second condemned the water company and the rotten six, and the third organized a Committee of the One Hundred to carry on the fight for pure water at reasonable rates. On March 3, 1890, the second mass meeting was held on the steps of the Oakland City Hall at the same time the Council was meeting. They passed a resolution that called for the Council to rescind the Collins ordinance and pass one in keeping with the will of the citizens. The request was presented to the Council that night; and by a vote of 6 to 5, the Council declined.

The company saw the handwriting on the wall and quickly began construction of state-of-the-art filters and a large holding tank (the Highland Park reservoir). Heavy rains that winter also helped improve water quality. Dr. Pardee was elected to the City Council in the next election and then became Mayor (he eventually became Governor of California, and in 1921 he was brought back as head of the campaign to sell the concept of public ownership of water supplies, ie: the creation of the East Bay Municipal Water District, and then became chairman of the board). The Committee of the One Hundred was active for the next few months, but slowly disappeared over the next year. The Committee had three important effects. It collected information from cities from all over the United States regarding their water supplies and issued that information in a pamphlet just prior to the City Council determining water rates in the next year. It contacted the Alameda County Board of Supervisors and provided them with information to help them set water rates for areas outside of the city limits. Most importantly, it collected information on the local sources of water supply (artesian wells). It also recommended consideration of the proposal to bring Sierran water to the City by the Blue Lakes Water Company. A common thread in all these actions was the concept of municipal ownership of the entire water works system, but that was not to occur for another 35 years.

In April, 1890, the sub-committee reported on artesian wells in the area. Wells that flowed at high tide were found at: Bay Farm Island, at the old narrow-gauge pier, Butchertown, San Pablo, and at Sobrante. Wells with continuous flows were found at Klinknerville, near Temescal, near Oak Street, at Fruitvale, near Fitchburg, and three wells at Alvarado (that yielded 3,000,000 to 5,000,000 gallons per day). In addition, there were nearly 100 wells which did not flow, but were good producers.

These events marked a turning point in how water was viewed by the citizens, the government, the newspapers, and the water companies. Prior to this time, the water companies did pretty much as they pleased. The citizens grumbled, the newspapers were generally mute, and the politicians never acted. After this, the governments became much more independent of the water companies and took an active/critical roll in linking water rates with water quality/service. The newspapers began to report water issues in a more critical light, and the citizens stopped viewing water supplies as a privilege and more as a right (to the dismay of the Company, citizen's groups would appear periodically until the 1920's). Never again would the water companies be able to ignore the desires of the citizens with the impunity that they had long had.

In the 1890's, the Company faced the one thing that it had never had to contend with before: competition. In early 1891, the Company turned down an application for water by Mr. Dingee, who had a large estate in the Montclair-Piedmont hills area. Following the advice of a local civil engineer (Mr. Boardman, who had a theory that large amounts of water could be found by drilling into the hills above Oakland just below the summit), Mr. Dingee began to bore two tunnels (the Boardman and the Giles) into the southern side of Moraga peak in May, 1891. When the Boardman tunnel was 210 feet into the hill side, a "beach formation" (containing shells, sand, pebbles, etc.) was encountered, and a large volume of water gushed forth. The initial flow was 1,000,000 gallons per day, but it reduced to 250,000 gallons per day a few days later. At about 250 feet, the Giles tunnel encountered a volcanic ash zone that also produced a large flow of water. In August, 1891, Mr. Dingee formed the Piedmont Springs and Water Company. By January, 1892, an eight million gallon reservoir had been constructed, and 10 tunnels had been bored which initially produced more than 670,000 gallons per day (Table 3 and Figure 23). The tunnels were 3 feet wide and 6 feet tall.

Table 3: Piedmont Springs and Water Company Tunnels.

Tunnel	depth (feet)	initial production (gallons per day)
Boardman	318	200,000
Giles	268	350,000
Tubbs #1	125	80,000
Gibson	150	30,000
Old Tunnel	n/a	10,000
Henshaw 1+2	100	none

There were eventually 17 tunnels in the group that supplied water to the Kohler Receiver (reservoir). They ranged in depth from 45 to 400 feet. There was a 1095 foot long tunnel that was driven to allow flow from the tunnels on the east side of the ridge to drain by gravity. The long tunnel was dry. Between 1902 and 1911, the average annual production was 134,200 gallons per day. Six of the tunnels had gone dry by 1910. The Boardman tunnel caved in 1898, and it was shut down in 1904. It produced little water in 1896, and no water in 1904. The Tubbs tunnels 1, 2, and 3 and the Henshaw tunnels 1 and 2 produced no water after construction and were never hooked up. The water flow from all of the Piedmont tunnels declined significantly within a year or so after construction. Several small dams were constructed in near-by streams, and the flow from those streams was combined with the tunnel flow. Even though the flow from the tunnels decreased with time, the total flow from the complex increased with time because of stream diversions. (Note: the tunnels were plugged with cement by EBMUD between 1945 and 1954.)

Another tunnel used for water supply was the Inter County Tunnel. This was the wagon road tunnel that connected Oakland with Orinda (Tunnel Road, built in 1906). Water was collected from a trench on one side of the roadway in the tunnel. It primarily supplied the Claremont Hotel. A photograph of the tunnel is shown in Blow (1920, p. 133)

Mr. Dingee quickly discovered that the Company had tied up the Piedmont customer base with long-term contracts, but that the southern part of Oakland was poorly served. Over the next year, water mains were laid, customers signed up, and plans were made for his company to serve all of Oakland. To do so would require more water and capital. He teamed up with "unnamed San Francisco capitalists", bored more tunnels, and began to investigate the Alvarado wells. On December 15, 1893, the Piedmont Springs and Water Company reorganized into the Oakland Water Company. The Company had two well fields in west Oakland. One was at 26th and Myrtle Streets. This field consisted of 3 wells on a 50 foot wide lot. The wells were connected to a tunnel that was 15 feet below the ground surface. The tunnel served as a reservoir. These wells were in the range of 200 to 250 feet deep and produced approximately 1 million gallons per day. The other field was near 5th and Union streets. It consisted of 4 wells, 58 feet deep. These wells yielded about 5,000 gallons per hour each. Water was also pumped from a well in a vegetable garden at Fifteenth and Willow street. It was estimated that these three sources produced 1.5 million gallons per day.

Since the 1860's, the Alvarado area had been noted for its artesian wells. By 1890, it had 40 artesian wells that produced more than 10,000,000 gallons of water per day, some of which had been flowing continuously since 1865. One of the members of the Committee of the One Hundred, Mr. Farwell, purchased the Glue Factory Well in 1892 with the intention of drilling more wells and supplying the City of Oakland. He let some options lapse, and in March and April, 1893, Mr. Dingee purchased the adjacent Granger Tract and the Poorman Tract, upon which some of the oldest and most prolific of the Alvarado wells were located (a lawsuit then ensued with the result that Mr. Farwell's interests in those lands were bought out on December 15, 1893).

In early May, 1893, Mr. Dingee began service to 28 blocks in east Oakland with water from his tunnels, and service to west Oakland from local wells. In late May, the first of the new Alvarado Wells was completed, producing 1,500,000 gallons per day (but it was not until December, 1894, that water from the Alvarado Wells reached Oakland). In the summer of 1893, Mr. Dingee claimed to have a daily water production of 4,500,000 gallons of water per day from 15 to 20 wells, and he invited the Oakland Council members to visit.

This had an immediate effect. In October, 1893, the Oakland City Council issued a memorandum requesting bids to supply water to the City at rates 10 percent lower than the previous year. After several months of political wrangling (including input from citizen's committees), the new rates were set at 30 percent lower than the year before. Neither Mr. Dingee nor the Company liked it, but they had no choice. The Council then passed an ordinance stating that the Oakland Water Company would supply water to all of the fire hydrants and public buildings west of the center line of Broadway, and instructed the Contra Costa Water Company to disconnect themselves from that area. The Contra Costa Water Company was alarmed by this competition. They kept close track of Mr. Dingee's activities and assigned an employee to keep a list of all connections to his water system.

The next year, 1895, the City demanded another 20 percent rate reduction. This was a 50 percent reduction in two years. By this time, both companies were losing thousands of dollars per month, and the stock of the Contra Costa Water Company had declined more than 50 percent. The City

Council continued to be partial to Mr. Dingee and proposed to give the Oakland Water Company all of the fire hydrants west of Lake Merritt. Complaints from insurance companies nixed that plan (they liked the idea of multiple water supplies in an area).

The first shot of the water war occurred on February 28, 1895, when Mr. Dingee sent a letter to the Oakland City Health Officer, Mr. F. Adams. In that letter, Mr. Dingee informed Mr. Adams of dead cows on the shores of Lake Temescal, and that barnyards of certain dairies drained into Temescal Creek (and the reservoir). This was picked up by the newspapers and a sensational article, complete with illustrated pictures of bacteria cultures and water analyses, appeared in the Oakland Tribune in April, 1895 (also see Bowhill, T., 1895). The Company fought back with articles by prominent chemists that certified that the Company's water was as pure as the driven snow whereas the water of the Oakland Water District was unfit for human consumption. During the summer, similar articles appeared in all the newspapers. About this time (August, 1885), the Oakland Water Company began to have water quality and water pressure problems (water had to be hand carried to the second floor in the City Hall). Mr. Dingee replied that "someone" had bored holes in the side of his water mains and that another water main had been connected to a sewer where it poured millions of gallons of water into the Bay.

The Alvarado Artesian Well Company, incorporated in June, 1893, was a dummy corporation set up by the Company for the express purpose of damaging Mr. Dingee's wells. It purchased the Glue Factory property/well adjacent to Mr. Dingee's wells in Alvarado, and drilled 15 additional wells. Instead of using them for water supply, the Company began pumping more than three million gallons of water per day into the Bay in an attempt to destroy the supply to the Dingee wells. The Alvarado Artesian Well Company was folded into the Contra Costa Water Company in 1894. During the summer of 1895, Mr. Dingee took several parties of Oakland citizens to witness this "alleged villainous behavior on the part of his rival". On August 16, 1895, a mass meeting was held at the Tabernacle where the Company was roundly denounced by all. The pumping stopped soon after the meeting.

Disparaging reports and articles about their rival's water continued to appear during the fall of 1895 and all of 1896. In the summer of 1896, the Company again commenced pumping adjacent to Dingee's Alvarado wells. This time they were not apologetic, but asserted their right to pump whatever they pleased from their own wells. In an interview in the Oakland Times in July, 1896, Mr. Dingee said:

> *"The Contra Costa Water Company have hired newspapers to libel me, they have spies out dogging the footsteps of my men, they have lied about the quality of our water, they started the water-back fake on us and I believe it was the Contra Costa Water Company that has put lime into our pipes, the same statement allies to the matter of cutting our mains and blowing them up last July. The Contra Costa Water Company, to get business from our Company, has cut its rates to 25 cents per month for houses they used to get 4 dollars for before the new company began business."*

By the spring of 1897, it was believed that neither company was receiving more than half the legal rates. It was a Pyrrhic battle that neither side was winning. The Company had suspended dividends for several years, and the stock had fallen from 100 dollars to between 20 and 30 dollars. Most knowledgeable people believed that the two companies would have to merge. Unknown to them, two factions had developed within the Contra Costa Water Company. One faction, the anti-combiners, hated Mr. Dingee and wanted to destroy him at all costs. The other faction was more pragmatic. They had not received dividends in several years and wanted to be paid. When Mr. Chabot died in 1888, the Pierces took control. By the 1890's, they held the principal offices and held a majority on the board of directors. In general, the anti-combiners were aligned with the Pierces, and the combiners were supporters of the Chabot interests. In order to prevent a merger of the two companies, the anti-combiners entered into a private agreement that prevented any merger of the two companies for two years. The general public knew nothing about this, and on April 20, 1897, the City Council passed a resolution authorizing the Mayor to appoint a committee of fifty citizens for the purpose of investigating the water situation and presenting plans for acquisition by the City of a municipal water works.

For the next two years, things were at a stalemate. The Contra Costa Water Company had the greater financial resources, but their water supply (and quality) was subject to the vagaries of the weather. The Oakland Water Company had a plentiful, high quality, year-round supply, but lacked the financial resources to withstand an extended period of low water rates. There were continuing issues about fire hydrants, water quality, and water pressure, but it was a matter of who would blink first. In 1898, the water rates were raised twenty-five percent (the City recognized that the companies were slowly going broke). The rate increase was costly to the politicians. One councilman resigned, the mayor was followed by mobs with cries of "lynch him", "tar and feather him", etc., and he was expelled from the Grand Army League (a fraternal order). A grand jury investigation was started, but no links between the council and the water companies were discovered.

The fact was that as long as the anti-combining faction held power, nothing would change. Then nature stepped in. Eighteen ninety-seven marked the beginning of a three year drought. Over the next two years, the water levels in Lake Temescal and Lake Chabot fell precipitously. The Company tried to expand its resources. It drilled additional wells in its Alvarado holdings, pumping the water to Oakland, and it drilled wells along the route of its water mains in the San Leandro area. These efforts were not enough. The drought continued, and there were minimal rains in the fall of 1898. At the stockholders' meeting in February 15, 1899, it was stated that the water levels in Lake Chabot stood at 15 feet when the reservoir should have been full (75 to 80 feet). This was the straw that broke the camel's back. The stockholders voted to purchase the Oakland Water Company, and this occurred in May, 1899. It was ironic, but there were heavy rains in March and the reservoirs filled up. If it had rained a few months earlier, the merger might never have occurred. After the merger, the Contra Costa Water Company was headed by Mr. Dingee, the Pierces having resigned. (Note: very few pre-1899 records exist, because almost all of the company records were burned soon after the merger.)

At this time, there were five water companies in the East Bay Area. The Contra Costa Water company had a virtual monopoly in Oakland, the Artesian Water Works supplied Alameda Island, the Alvarado Artesian Water Company supplied the Contra Costa Water Company with water from the Niles Cone area, the Pinole Water Company supplied the Pinole area, and the Alameda Water Company supplied Berkeley.

The Contra Costa Water Company began to expand in order to provide better service with less duplication of infrastructure. In the fall of 1899, the Company purchased the Artesian Water Works that supplied the island of Alameda. This included the Fitchburg Well Field (now the location of the Oakland Coliseum) that could provide several times the needs of Alameda. The Company also turned their sights north. They bored wells in San Pablo (Fall, 1899), and purchased the Alameda Water Company that supplied water to the Berkeley area (Spring, 1900). There were legal problems with the articles of incorporation of the Alameda Water Company, so a short-lived corporation was formed, the East Shore Water Company, to transfer the assets. In 1903, the Pinole Water System was purchased. This purchase included 32 square miles of watershed and the site of the future San Pablo Dam.

The perennial problem of water quality reared its head again. In early 1900, the Oakland City Council passed a resolution requesting that the Company correct the problem. The Company said it was working on a solution and it would be fixed as soon as it could. The Council then passed a new ordinance that cut rates by 25 percent. In March, 1900, the Company sued the City over the rate cut in one of the most famous trials in the State (the Hart Case). The Company argued that they were entitled to make a reasonable profit on their investment. The City countered that the recent merger between the Contra Costa Water Company and the Oakland Water Company was illegal, and that the current value claimed by the company ($8,500,000) was more than double its actual value. The suit reached the California Supreme Court, and the Company won. The court said that the City had lowered the rates without justification. On the witness stand, several council members stated that they had voted to lower the rates because they were peeved at the company. The City had to rescind the rate cut and, instead, implement a 30 percent rate increase (the transcripts of the case are more than 10,000 pages long and are in the Oakland Library History Room). The case was appealed to the United States Supreme Court which overturned the original decision in 1910.

In 1900, there was a proposal to build a dam across Santa Isabel Creek near Mt. Hamilton by the Mt. Hamilton Water and Power Company. It was originally designed to be a hydroelectric dam, but the water shortages in the East Bay Area caused the water supply potential to be evaluated. The dam was never built, but as part of the planning studies, the water supply of the East Bay was briefly reviewed by Dr. L. J. LeConte. He noted that the annual consumption of Oakland was about 12,000,000 gallons per day, Alameda was 1,600,000 gallons per day, and Berkeley was 1,000,000 gallons per day. During the summer, demand exceeded supply. The uptown sections of Oakland were habitually without water during the day. Water was pumped at night and stored in vessels for use during the day. During the winter, supply was only a little in excess of demand. "*The possibility of future expansion are none. The Company has spent large sums in fruitless attempts to get more water by new tunnels and wells, but to no purpose. . . The only well known supplies capable of further development along the East side of San Francisco Bay, are San Lorenzo Creek Catchment system, and the groundwaters at the mouth of Alameda Creek.. Both of these sources have already been largely appropriated and are in use today.*"

The water quality problems also caused an increased agitation for public ownership of the water supply that was to culminate in the creation of EBMUD in 1921. In 1899, a citizens committee recommended that Oakland purchase the Roberts Well Field. The wells were on 350 acres of land at Roberts Landing (on the edge of the bay, west of San Leandro). Tests of the wells were disappointing (they had been poorly maintained and had sanded up). Two additional wells were drilled in 1900, and they were prolific, producing 764,000 gallons of water per day with no noticeable drawdown in adjacent wells. By this time, the City had become embroiled in the Hart case, and the Roberts Well Field purchase was dropped. The wells were eventually purchased by the Peoples Water Company.

The rise in rates caused numerous private wells to be drilled. Newspapers of the time indicated that windmill and well-boring companies did a land-office business. It was well known that near surface waters were unsuitable. The following is a water analysis from a 16 foot deep well at 1714 Linden Street, Oakland, circa 1899 (Table 4).

Table 4: Well Water Analysis in Oakland, circa 1899.

Potassium sulphite	11.39	(grains per gallon)
Sodium chloride	13.52	
Sodium Carbonate	2.50	
Calcium and magnesium Carbonate	12.53	
Mineral matter	39.94	
Organic matter	9.62	

The battles between the City and the Contra Costa Water Company did not end with Judge Hart's ruling. In 1903, the Bay Cities Water Company began selling water in the Oakland area. The City Council played the two firms against each other in an attempt to force a 25 percent reduction in water rates in 1904. The Contra Costa Water Company took the City back to court, where an injunction was granted preventing the City from lowering the water rates.

The public's desire for municipal ownership of a water company was still strong, and it appeared that the City attempted to drive down the price of the Contra Costa Water Company's stock to help the City purchase the Company. This was unsuccessful, and the focus turned to the Bay Cities Water Company. On January 16, 1905, a special election was held to determine if the City should purchase the Bay Cities Water Company. The proposal was defeated. The Bay Cities Water Company was eventually purchased by the Peoples Water Company.

In early 1906, the Syndicate Water Company was incorporated. It was an offshoot of the Realty Syndicate, a major land owner in the Richmond area (one of the Directors was "Borax" Smith, the borax tycoon-real estate developer). The Syndicate Water Company purchased control of the Richmond Water Company and began to improve the water supply in that area. It constructed pumping plants, water mains, reservoirs, and drilled the San Pablo Well Field 1. It then looked south and claimed that they had purchased water rights on Sausal Creek, its branches, and tributaries (this included most of the Piedmont area). At the same time, they filed claim to water rights on San Pablo creek (the site of the future San Pablo Dam). The Contra Costa Water Company immediately fought back and took the Syndicate to Court.

By 1906, the Contra Costa Water Company was near bankruptcy. On August 30, 1906, (after the earthquake) the Peoples Water Company was formed (with Mr. Dingee still in control), combining the Contra Costa Water Company, the Richmond Water Company, and the Syndicate Water Company.

The Company faced major problems. Prior to the 1906 San Francisco earthquake, the average population growth in the Peoples Water Company service area was about 20,000 people per year (Oakland grew at 3000 to 4000 people per year). After the earthquake, the population growth was 80,000 to 100,000 people per year. Studies of the water supply by the Contra Costa Water Company in 1903-04 pointed out that the margin between water supply and demand was small. The effects of the earthquake caused an even greater squeeze on supplies, and the Peoples Water Company tried to increase their water supply by 100 percent. Over the next 8 to 10 years, considerable land was purchased in the hills to the east, in anticipation of building more dams. Groundwater supplies were increased by drilling additional wells and increased pumping. They drilled the San Pablo Well Field 2, built the Central Reservoir, increased the size of the Alvarado well field, and built several pumping plants. The Company planned on purchasing additional water from the Spring Valley Water Company, but Spring Valley Water Company did not have the water to spare.

The other problem was the condition of the distribution system. The Company inherited a piping system that was badly outdated, poorly maintained, and undersized (50 percent of the water mains in Berkeley were less than 4 inches in diameter). The Company had to embark on an expensive and extensive upgrade of their distribution system.

1906-1920

A fundamental conceptual change occurred in the early 1900's. In the 1800's, the water business was localized. There was little interaction between major cities and the companies were controlled by personalities such as Mr. Dingee and Mr. Chabot. By 1900, water had become big business. Firms consolidated/merged and the personalities disappeared. It was soon recognized that cost of new water supplies required greater resources than private firms could provide, and by 1913, eighty-four municipal water companies had been set up throughout the state. The struggle for new water supplies also forced regional solutions both on a local and state level. Planning for the state water project began in the mid-1910's and was approved in 1930. It took another 30 years for it to be funded and constructed.

There was also a major change in the way water was viewed both legally and by the general populace. In the 1800's, appropriative rights were the rule. This was based on the miners code: first in time, first in right. If you needed water, you could pump it. When California joined the United States, the concept of riparian rights (ownership of land meant ownership of water) was also brought in. These two concepts were diametrically opposed, and resulted in numerous lawsuits and even bloodshed. In the 1880's, Mr. Miller, the largest landowner in the country (controlling more than 22,000 square miles), championed the riparian theory, and eventually was able to convince the California State Supreme Court (though its four-to-three decision was tainted with a suspicion of bribery). His power and stance caused him to become one of the most unpopular men in California, and a political party, the irrigationists, was organized to fight him. For the next fifty years the riparian theory remained law, though it was largely ignored and settlers tended to appropriate water when needed.

The public also began to understand the concept of conservation of natural resources and in 1908, many of the large public parks were set up. California was slow to act, but on December 19, 1914, the Water Commission Act was passed (it was modeled after Oregon's 1909 Act). For the first time, there was a legal framework to arbitrate, define, record, and permit water rights. As part of the development of the State Water plan, the Water Commission became the Division of Water Resources (within the Department of Public Works) in 1921. [The Division of Water Resources expanded and became the Department of Water Resources circa 1956 in preparation for construction of the Feather River Project (Orville Dam and the California Aqueduct).]

Sometime between 1905 and 1910, the legislature transferred the authority to set water rates to the State Railroad Commission. This removed much of the local political pressure and infighting that had traditionally occurred every year when the water rates were set. In 1910, the Union Water Company was incorporated, and began to supply water to the Richmond, San Leandro, and Newark areas from wells in Richmond, Fitchburg, and Alvarado. In 1912, the Marin Municipal Water District was formed and became the first utility district in the state to supply water to more than one city.

At the turn of the century, San Francisco also began searching for Sierran water supplies, and they focused on the Hetch Hetchy reservoir site. This required Congressional approval, and it was granted in the Garfield permit of May, 1908. In 1910, the Secretary of the Interior ordered the City of San Francisco to show cause why the Hetch Hetchy should not be eliminated from the filings of the Garfield permit. As a result of this action, President Taft ordered an evaluation of the various possible water supply sources for the entire Bay Area, with the Army Board of Engineers to be the advisory committee. In July, 1912, the Freeman report was submitted (the 1911 Dockweiler report on the East Bay Area was one of the studies done as part of the Freeman evaluation). The report evaluated all of the available water supply sources and recommended the Tuolume River as the best source. This conclusion was approved by the Army Board of Engineers, and the water rights were granted by Congress on December 19, 1913 (the Raker Act or Hetch Hetchy Grant). In their approval, the Army Board of Engineers suggested the formation of a metropolitan water district that could include the East Bay cities.

In the early part of the 1900's, the agricultural methods in the Niles Cone area changed from orchards, oats, hay, and pasture (they did not require significant irrigation) to crops such as alfalfa that required extensive irrigation (ie: groundwater). By 1910, the Peoples Water Company was pumping 5 to 10 million gallons of water per day, the Spring Valley Water Company was pumping 15 to 20 million gallons per day, and the farmers were pumping 5 to 15 million gallons per day. This caused noticeable drops in groundwater levels and a fear of sea water intrusion.

In December, 1913, the County Water District Act was passed by the legislature which allowed the formation of a municipal water company outside of a city's limits. Its main limitation was that it only allowed single county organizations. As a result of dropping groundwater levels, the farmers in the Niles cone area united, and the Alameda County Water District became the first water district in the state to be organized under the County Water District Act (December, 1913). Unfortunately, they were unable to secure water rights on Alameda Creek, and had to rely on groundwater (the Spring Valley Water Company had acquired most the Alameda Creek water rights for the Calaveras Reservoir that was then under construction). Within a year, the new District filed suit against the Peoples Water Company and the Spring Valley Water District to reduce their pumping and to allocate Alameda Creek water. It required 20 to 25 years, but the suits were eventually successful. The lawsuits had one important side effect; they were the cause of a series of groundwater investigations of the Niles Cone such as those by Bailey (1920) and the USGS study by Clark (1916).

In 1914, the formation of a municipal water district to service the East Bay Area was defeated at the polls (10,711 for, 13,688 against, with the City of Berkeley having the only favorable vote). The primary problem appeared to be that the plan for organizing the district was defective, and the belief that it was not the responsibility of the public to bail out the water company from problems of its own making. At this time, the Peoples Water Company appeared to be more of a land syndicate (owning more than 44,000 acres of land) than a water company. As a result of this defeat, several civic bodies and clubs (such as the Commonwealth Club) employed engineers and agitated for municipal ownership. The most notable report (Harroun, 1919) evaluated the Eel River, Hetch Hetchy and McCloud River projects.

In 1916, the Peoples Water Company, likes its predecessor, was in severe financial difficulties. It was sold to Mr. Heller on November 29, 1916, under the decree in action entitled the "Mercantile Trust Company of San Francisco vs. Peoples Water Company", and was reincarnated as the East Bay Water Company. Mr. Dingee was not included in the new organization. He had become a multi-millionaire while the two water companies that he controlled went bankrupt (however, when he died in Sacramento in 1941, his assets consisted of $150 dollars, a suit of clothes, and a cemetery plot). On January 1, 1917, Mr. Heller conveyed all of the properties which he purchased from the Peoples Water Company to the East Bay Water Company. Mr. Heller was a good manager, and his company built San Pablo Dam, several tunnels, several large water purification/filtration plants, and purchased the Union Water Company in 1921.

The war effort resulting from World War I, in the years 1914 to 1918, greatly increased the need for water. Groundwater usage increased from 9,000,000 gallons per day in 1916 to 19,000,000 gallons per day by 1918. The war hastened the building of San Pablo Dam (completed in 1918; the land had been purchased in March, 1903, and initial surveys done in 1908). The reservoir was designed to hold 14,000,000,000 gallons of water, far beyond the yield of the basin in average years. It was designed to hold floods from wet winters (every 4 to 5 years). It didn't fill until the 1930's, when water from the Molkomne River flowed into the reservoir. Damming Bollinger Canyon, Crow Canyon, and Cull Canyon creeks was again proposed (first proposed in the mid-1880's), but never went beyond the concept stage.

There were eight years of water shortages beginning in 1918. During the summer of 1918, the reservoirs were empty, and for 5-1/2 months groundwater was the sole supply of water to the area. The heavy pumping caused the water levels in some of the Alvarado wells to go just below sea level. This had never happened before. All lawn and garden irrigation in the East Bay area was stopped, and the call for municipal ownership appeared again. Groundwater supplies had to be augmented. Twelve new wells were drilled at Fitchburg (approximately 400 feet deep), three new wells were drilled at 92nd Avenue (approximately 300 feet deep), five new wells were drilled at Roberts Landing (approximately 600 feet deep), the Alvarado well field was overhauled, and water was to be purchased from the Alameda Sugar Mill in Alvarado (3,000,000 gallons per day). The output of Fitchburg was increased by 3,000,000 gallons per day (from the new wells), and the Alvarado output was increased by 1,500,000 gallons per day. An injunction prevented use of the Alameda Sugar Mill water. The Alameda Sugar Mill had 5 wells, 350 to 550 feet deep, that produced up to 4 million gallons of water per day.

The water levels recovered in 1919, but Oakland lost the Goodyear Company manufacturing plant because the Peoples Water Company could not guarantee 8,000,000 gallons per day water supply. The plant went to Los Angeles. This water shortage also prepared the way for the passage of the Municipal Utility District Act by the legislature in May, 1921.

1920-1930

In 1920, pumping caused water levels in the Alvarado area to drop to 7 feet below sea level. Water levels slightly recovered in 1922 and 1923. The winter of 1923-1924 was so dry that increased pumping caused well water levels to drop to 15 to 20 feet below sea level. This resulted in widespread sea water intrusion from Oakland to Roberts Landing.

These dry years also resulted in construction of the Upper San Leandro Dam (15,000,000,000 gallons capacity) which was completed in 1927 by the East Bay Water Company. Local industries also responded, primarily by drilling private wells. The California Hawaii Sugar Company drilled wells (up to 1000 feet deep, the log is listed in the 1929 Young report) and barged water from the Delta. In 1920, they contracted with the Marin Water Company to pipe water in from Marin (a volume not to exceed 500 million gallons per year for five years). The size and scope of the Berkeley fire of September, 1923, was partly caused by the inadequacy of the water distribution system.

In 1921, Dr. Pardee was made head of the committee for public ownership of water utilities (he later became the president of the board of directors of EBMUD) and Mr. A. Davis was the chief engineer. At that time (May, 1921), the State Legislature amended the utilities act, allowing a district to cover two counties as well as incorporated and unincorporated areas. The issue was put before the voters, and the District was approved on May 8, 1923 (28,733 for, 16,217 against). Richmond and Piedmont did not approve EBMUD and were not initially part of the organization. They were allowed to join a few months later.

The first problem facing the new District (EBMUD) was where to get more water. The safe yield of the water supply was estimated to be 30,000,000 gallons per day (20,000,000 from the reservoirs and 10,000,000 from wells). The average water use in 1924 was 27,500,000 gallons, and the rate of growth indicated that the water supply would run out by 1930. The only possible source for additional water was from the Sierras.

The District turned down an offer to join in San Francisco's Hetch Hetchy project, which was fortunate because it was not completed until 1934. After an extensive evaluation, the Mokelumne River was chosen to be the site of Pardee dam in September, 1924, and a vote on the construction bonds (39 million dollars) was approved in November, 1924. As had happened so many times in the past, a lawsuit was filed challenging the vote. The vote was upheld by the Supreme Court of California in August, 1925, and contracts were issued in September, 1925. In 1927, the citizens approved another bond measure (26 million dollars) to either construct a water distribution system or purchase the East Bay Water Company. The East Bay Water Company tried to stay in business, but was forced to sell out to the District in September, 1928, (for 34.7 million dollars), when the District announced that it would lay pipes on top of the East Bay Water Company's lines.

The drought of the early 1920's rekindled the Alameda County Water District's lawsuit against the water companies in the east bay area that had been languishing since 1914 (they had concentrated on the Spring Valley Water Company first). In 1922 the lawsuit was re-filed against EBMUD, and sought to limit the amount of groundwater pumping. Another dry year was recorded in 1927. EBMUD increased pumping in the Alvarado area, and salt water was detected in the Alvarado wells. After years of wrangling, EBMUD agreed in late 1927 to limit its pumping at Alvarado to 4.5 million gallons per day (down from 9 million gallons per day).

Pardee Dam was finished in early 1929, and water from the dam flowed into the San Pablo Reservoir on June 23, 1929 (but it did not fill until May, 1930). It could not have come at a more critical time. There had been two years of low rainfall, the reservoirs were noticeably low, and groundwater supplies had been severely over pumped for more than a decade. Filling of San Pablo Reservoir meant that the area no longer had to face the vagaries of the weather. It is difficult to evaluate what would have happened if Sierran water supplies had not been brought to the area when they had.

In early 1930, EBMUD virtually stopped pumping ground water (shutting down the Fitchburg Well Field and the Jones Avenue well fields), and transferred ownership of the Newark, Alvarado, and Mt. Eden water distribution systems and the Alvarado wells, the mainstay of their groundwater supplies, to the Alameda County Water District (the purchase had been negotiated in August, 1929 for $290,000. ACWD did not want the water distribution systems, but a local Niles water company was also bidding and ACWD had no choice but to accept what was offered). More than anything else, this action signaled the end of an era that began in 1860: the reliance on groundwater. The Alameda County Water District modernized the Alvarado pumping plants, refurbished the wells and continued supplying water to Newark and Alvarado. The field was pumped for a few years, but it appears that it was abandoned sometime the mid-1930's. In the late 1930's, ACWD purchased/annexed the Centerville, Irvington, and Mission San Jose water systems. In the early 1970's, ACWD located the old Alvarado wells and plugged almost all of them.

The departure of EBMUD from the Niles Cone did not stop overpumping in the Niles cone area. The winter of 1933-34 was very dry, groundwater levels in the Niles Cone area dropped to 40 feet below sea level, and sea water intrusion threatened even the deep aquifers (at one time, water levels were dropping one inch per day). The purchase of Hetch Hetchy water from San Francisco in 1934 and above average rainfall allowed the basin to recover. Beginning in 1944, water levels began to drop again. By 1950, water levels were 50 to 80 feet below sea level. Wide-spread sea water intrusion occurred throughout the upper aquifer, extending as far east as Centerville. This was approximately the eastern edge of the Yerba Buena clay and salt water was able to enter the lower aquifer and flow west towards the bay. This prompted a series of studies by ACWD and DWR that resulted in construction of a series of recharge/conservation structures. By the 1980's, the groundwater basin had recovered, with artesian conditions again widespread (up to 6 feet of head in some locations).

SALT WATER BARRIERS

Proposals to dam San Francisco Bay surfaced periodically for more than 100 years. Even though damming the bay was never part of the water supply plans of the East Bay Area, it is briefly discussed because of its notoriety.

The great floods of January and February, 1862, prompted the first proposals to dam the bay. Mr. Byron briefly discussed building a dam across the Carquinez Straits as part of his flood control report to the Legislature in 1866. In 1880, Mr. Grunsky, who was an Assistant State Engineer at the time, again proposed building a flood control dam across the Carquinez Straits. Additional analysis revealed that the surface area of Suisun Bay (28,000 acres) was insufficient, and that a dam could worsen the effects of a flood. The idea was quickly dropped.

Damming San Francisco Bay sounds heretical today, but the water quality of the Sacramento River was much different in the 1800's. Up to about 1910, there was little water diversion from the upper Sacramento River, and the geometry of the delta had not been significantly altered. This meant that there was sufficient flow down the river to keep out the tides almost the entire year. As a result, the river water was fresh and drinkable down to Suisun Bay and suitable for industrial use down to Oleum. The presence of fresh water was the reason why there was large scale industrial development adjacent to the river between Crockett and Antioch. The water quality in the Carquinez Straits would change slowly over a year, becoming brackish during the late summer. To enhance water quality during the late summer, pumping would occur during low tide when the water would be least brackish, and large cisterns would be filled in the early summer to be used during the late summer-early fall.

The delta itself was very different. It consisted primarily of a tule marsh of boggy peat (about 500,000 acres in extent) over which the water surface oscillated with the tides in Suisun Bay. The rivers divided into numerous winding waterways, creating low islands (exposed at low tide) that were a few hundred to a few thousand acres in size.

This began to change in the late 1800's. In 1850, Congress passed the Arkansas Act which granted all swamps and overflow lands to the states. In 1855, the California legislature passed the California Swamp Act. This provided a mechanism to transfer swamp lands (wetlands/ tule lands) to individuals and create reclamation districts to convert delta wetlands to farm lands through the construction of levees. By 1860, practically all of the wetlands east of the Suisun and Goodyear Sloughs were being reclaimed. As farming increased, pumping and water diversions from the delta increased. It was estimated that during the summer of 1919 and 1920, the water flow in the vicinity of Sacramento was mainly seepage and return drainage from irrigated fields.

Hydraulic mining in the Sierras caused tailings (silt and debris) to be stored in the canyons just below the workings (It was reported that hydraulic mining was invented by Anthony Chabot during the spring of 1852 to work his claim on Buckeye Hill above Nevada City). Large volumes of this material washed out into the Sacramento Valley during the floods of 1862, covering farmers fields. The valley farmers complained, saying the flood waters were "too thick to drink and too thin to plow". The farmers filed lawsuits and continued to do so for the next 20 years. The battles between the farmers and the miners culminated in 1884 with Judge Sawyer's decision, which prevented the placing of mining debris in water courses which were tributary to navigable streams. This essentially stopped hydraulic mining, but the damage had been done. For the next 20 to 30 years, debris continued to be carried into the delta, and it is estimated that one-and-one half billion cubic yards of material washed out of the Sierras.

The farmers immediately began to press for reclamation/rehabilitation. In 1888, Congress passed a bill that funded a commission of three Corps of Engineers officers to study the problem and provide recommendations. In 1891, they recommended the construction of large permanent stone barriers across the major tributaries of the Sacramento River. These would trap debris and allow its removal. Some of these recommendations were enacted in 1893 with the signing of the Caminetti Act. This act created the California Debris Commission, composed of three officers from the Army Corps of Engineers. The Commission was "*empowered and required to adopt plans for improving the navigation of the Sacramento and San Joaquin Rivers, project and construct works for impounding detritus and preventing the deterioration of the rivers from the deposit of hydraulic mining and other debris, and devise means and issue permits for resuming and carrying on hydraulic mining operations under conditions that will not injure other interests in the State.*" Since then, more than 3000 hydraulic mining permits have been issued, but it has proved impossible for private individuals to construct restraining works that would accomplish even moderate rehabilitation. Essentially, hydraulic mining ceased in 1893. However, the Debris Commission's most important function was overseeing levee construction throughout the Delta.

In the 1870's, Congress began to fund projects to improve navigation in the delta and tributary rivers. The early projects were designed to improve the depths over bars by construction of wing dams, scraping, closing of levee breaks, and removal of snags. The first major project occurred in 1899 with the construction of Sacramento Channel, a 7 foot deep channel that extended through the delta to Sacramento. Channels were also constructed to Chico Landing and to Colusa. While these were being constructed, the Debris Commission constructed two debris dams near where the Yuba River emerged from the foot hills. These only lasted a few years and were destroyed in the flood of March, 1907. Expansion of navigation channels continued. By 1920, the Port of Stockton was developed, the dredging of the Fremont channel and McLeod Lake near Stockton were completed, and numerous cut-offs had been dug. The Reclamation Board was created in 1912 to oversee reclamation plans in the delta.

The overall result of these activities was that river channels were straightened, obstructions were removed, and two of the natural flood storage basins, the Yolo and the Sacramento, were destroyed. These actions significantly reduced the flood storage capacity of the delta. They increased the peak flows down the rivers during the winter months and reduced the flow through the delta during the summer months. This was noted by Foote (1921, p. 229-231) who stated "*that work done for navigation alone is fatal to flood protection because it contracts the drainage channels in order to give depth at low water, and thus prevents the free passage of the floods. Works for irrigation alone takes water needed for navigation. Mining is stopped because the debris fills the drainage channels and spreads over the farm lands. Drainage is blocked by the levee system built for flood protection; and to build levees for flood protection alone is hopeless. . . Fifty years of mishandling natural riches and spurring natural laws have so far injured it that now it may be said . . . the Great Valley is lost to the world*."

The effect in the Bay Area was that during the summer, the salt/brackish water interface moved further and further east into the Delta (reaching Stockton in 1931). The upstream shifting of this interface caused more than 25 million dollars of damage to shipping infrastructure (wharves, hulls, etc.) from teredo worms between 1913 and 1921 (the worms do not live in fresh water, they require water with 450 to 500 ppm salt). The wharves at Mare Island were significantly damaged in 1914, 1917, and 1920. As a result of this and other damages, the American Wood Preserver's Association commissioned a study in 1920 to determine the extent of damage to marine pilings in San Francisco Bay (San Francisco Bay Marine Piling Committee, 1921, 1922, 1923). The study found that the increased salt content of the river allowed teredo worms to survive as far east as Carquinez, and some marine species were found as far east as Walnut Grove.

The loss of water quality (increase in salt content) caused damage to both public and private water users. San Francisco rejected the San Joaquin River as a source of water supply in 1911 because of the salinity of the water during the fall. Richmond also rejected it as a supply in 1913 for the same reason. In 1906, the California Hawaiian Sugar Company was able to pump water directly from Carquinez straits for use in their plant. Within a few years, the increase in water salinity forced them to barge water from the upper reaches of the delta during the late summer (each of the barges carried 500,000 gallons of water). This continued until 1920 when the limits of navigability had nearly been reached (they had to go almost 40 miles into the delta to find fresh water). At that time they made arrangements to purchase water from the Marin Water District. The District laid pipelines to Point San Quinten, and the company barged water from there. The water District ran out of surplus water in 1930, forcing the Company to drill wells in the Napa Valley at Suscol. It cost more than $1,000,000 to drill the wells and lay pipelines to the plant. Unfortunately, this supply could not provide enough water. It was overpumped, eventually causing some of the wells to become brackish. In 1935, the Company was able to connect to EBMUD, ending their water problems.

Since their founding, the river had been the sole water supply to Antioch, Pittsburg, and heavy industry, and the only cost was pumping. The continued reduction of fresh water flow between

1913 to 1918 changed all that. After 1915, virtually no major industries were located between Oleum and Antioch because of the worsening water supply. During the major drought of 1918, sea water intrusion caused millions of dollars of damage to industry (the Pioneer Rubber Mills in Pittsburg had to rebuild its boilers to withstand salt water, the dry kilns of the Redwood Manufacturing Company had to be rebuilt, and several industries barged in water from Marin and other areas). In 1919, Antioch sued 27 upstream delta diverters (10 to 200 miles above Sacramento) to prevent them from diverting water. Antioch was granted an initial injunction, but the lower court decision was reversed by the California State Supreme Court in 1924. During June, July, and August of 1924, no fresh water passed the mouth of the Sacramento and San Joaquin Rivers. By 1925, both cities had to find alternative water supplies. Pittsburg drilled wells and Antioch constructed reservoirs. The Contra Costa Water district was formed in 1936, and provided water to those areas.

These problems prompted several studies. Preliminary salinity studies were first done in October, 1916, and again in 1919. A delta-wide study was done by Mr. G. V. Rhodes in 1920 and by Mr. F. Boezinger in 1921 under the auspices of the State Water Commission. Salt levels were measured at one to three week intervals at 28 locations throughout the delta. These measurements revealed that in 1920, the river salinity (chloride) at Martinez was 1100-1200 ppm, 850-1000 ppm at Pittsburg, and 550-750 ppm at Antioch (at the H Street wharf).

The nineteen twenty's were the zenith of the salt barrier concept. Captain Jarvis of the Army Corps of Engineers proposed the building of a salt water barrier across the Carquinez Straits in 1921 (it had been conceptually proposed by Colonel Marshall in his report to the Governor in 1919). The proposal was warmly received, and the State Legislature authorized funds for a feasibility study. The study was finished in 1923 (by Mr. Kempkey), and it concluded that a dam was feasible but that extended studies of all possible sites should be made before a final selection was made. In 1924, the Legislature, in conjunction with the Federal Government (Department of the Interior), the Sacramento Valley Development Association, and the Delta Land Syndicate contributed $76,000 to do a detailed technical evaluation of possible dam sites. The study was done by Mr. Walker Young for the California Reclamation Service and was known as the Walker Young report (Young, 1929). The study was extensive even by today's standards. Three sites were evaluated. The evaluation included a physical study of the various barrier sites, topographic and geologic studies, drilling more than 322 boreholes (most more than 100 feet deep) to evaluate the engineering properties of the proposed dam sites, basic designs for the dams at each site, studies of tides, floods, navigation, water storage, salinity, silting, and shipping studies. The study did not select a specific site, but indicated that damming the bay was technically feasible.

The Walker Young report was completed in 1927, but political in-fighting kept the report from being released until 1928. The 600 page report was so popular that it was reprinted 3 times. Several well organized private groups, such as the Salt Water Barrier Association, were organized to garner public support, while other groups, such as the City of Stockton, were vehemently opposed. A bill was introduced in the legislature by Assemblyman Sharkey in 1927 to construct the barrier. It failed by one vote, the two-thirds majority rule causing the defeat. The barrier concept continued to be pushed, but it had lost favor with the state bureaucracy. In 1931, the State Engineer announced that the salt water barrier "*is not now necessary or economically justified as a unit of the State Water Plan*" (Division of Water Resources, 1931, p. 44). Salt water control was to be done via construction of dams in the Sierras (the Central Valley project). The barrier plan was officially scrapped in 1933 when the Central Valley Project was approved by the voters, but a few supporters never lost hope. The most ardent was Mr. Reber, a retired school teacher and theatrical producer. During the 1930's and 1940's, he traversed the state, speaking to whoever would listen about the benefits of damming the bay. He became so closely associated with the barrier concept, that it was soon called the Reber plan.

The proposal to build a second crossing over the bay in 1940 revived interest in the salt water barrier. Preliminary economic analyses indicated that the costs to bridge or dam the bay were about equal. Mr. Reber re-doubled his efforts, and aroused such public interest that the California Legislature requested the Congress to fund a study of the barrier concept (the Reber Plan). The plans were shelved during the war, but in 1947, a Joint Army-Navy Board submitted a report on additional crossings of San Francisco Bay that discussed 29 different crossing plans, including salt water barriers. Other plans were soon published. Mr. Savage published his ideas in 1951 (the Savage Plan), and Mr. Weber also proposed a variant. The salt water barrier still had its critics. Mr. Hyatt, the State Engineer in 1949, publicly stated that the Reber Plan would not work even though it might be technically feasible.

The plethora of plans caused the State Legislature to pass the Abshire-Kelly Act in 1953. The act created the Water Project Authority to formally investigate the feasibility and economic value of barriers across San Francisco Bay. Besides evaluating the various barrier plans, the Authority retained Mr. Biemond, an engineer from the Netherlands, as a consultant. In March, 1955, the Board of Consultants for the Authority found that "*no plan for construction of a barrier across San Francisco Bay or any of its arms would be functionally feasible because the water conserved thereby could not be relied upon as a source of supply . . . The Board also finds that the plan outlined by Mr. Biemond . . .is functionally and economically feasible; that it would accomplish the major objectives of a barrier; and it best provides for flood protection of the Delta*." Mr. Biemond's plan is now known as the peripheral canal. He was not the first to propose a canal through the delta. It had been discussed in 1931 by DWR and in 1945 by the Bureau of Reclamation, but he was the first to integrate both water supply and flood control.

MUNICIPAL WELL FIELDS

This section contains information about the history, development, and production of individual municipal well fields. The information is fragmented, but, unfortunately, much of the original source material has been destroyed. The location of the major well fields is shown on Figure 18.

Niles Cone - *Alvarado Well Field*

The Alvarado Well Field was located in the north side of the Niles Cone, near the outlet of Alameda Creek. It is outside of the Study Area, but it is discussed because it supplied almost 50 percent of the groundwater used in the Oakland area. From the 1860's, the Alvarado area was noted for its artesian wells. By 1890, there were 40 artesian wells that produced more than 10,000,000 gallons of water per day, some of which had been flowing continuously since 1865. One of the better known was the Glue Factory Well. In the 1890's, one group of wells was purchased by Mr. Dingee (the Contra Costa Water Company) and the other by the Alvarado Artesian Water company. Both fields were absorbed by the Peoples Water Company by 1909.

The field consisted of two groups of wells on adjacent lots. The Dingee group contained 36 wells (most were 10 to 12 inches in diameter, but some were 20 inches in diameter). The wells were 180 to 884 feet deep with the average being 350 feet. The early wells produced water from a gravel layer 170 to 175 feet deep. The later, deeper wells produced water from 3 gravel layers. Thirty-one wells were drilled in 1894, and the remainder in 1910-11. About 28 were operational in 1910. They were located on 372 acres of land. This field first supplied water to Oakland on November, 1894, from 15 wells. At the turn of the century, the water level was 5 to 6 feet below the ground surface and the wells were not pumped. Air lift was installed circa 1908 to increase the volume of water pumped. Table 5 contains construction details on some of the Dingee group wells (as of 1912).

Table 5: Wells in the Alvarado Well Field, 1912.

Well Name	Diameter (inches)	Total depth (feet)	
Old Poorman Well	14	258	
Barron Well	14	185	
Granger Well	14	170	
Farwell Well	14	392	
Crosby Well	14	181	(double cased)
New Poorman Well	14	184	
Dingee Well	14	192	
Rose Well	14	178	(double cased)
Barrows Well	14	178	(double cased)
Rogers Well 1	10	399	(double cased)
Healey Well 1	20	197	(double cased)
Rogers Well 2	20	421	(double cased)
Healey Well 2	14	242	(double cased)
Rogers Well 3	12	517	(double cased)
Healey Well 3	12	519	
Healey Well 4	12	394	(double cased)
Healey Well 5	12	356	(double cased)
Healey Well 6	12	186	
Healey Well 7	10	196	(double cased)
#20	10	202	(double cased)
#21	10	422	
#22	10	203	

#23	10	253
#24	10	379
#25	10	536
#26	16	523
#27	15	714
#28	20	260
#29	14	91
#30	14	884

(Conversations with ACWD indicate that 10 to 15 additional wells were drilled between 1915 and 1930)

The other group was called the Glue Factory group, located on 4.5 acres of land. It contained 15 wells that were drilled in 1898. The wells were 8 and 10 inches in diameter, averaged 200 feet deep, and had no surface casing. An additional well was drilled several years later. In 1904, they produced approximately 2-1/2 million gallons per day. In 1908, six of the wells were double cased and those were still operational in 1910. The remainder had caved in and were plugged with cement in 1908. The land of both groups is below high tide level, and an earthen levee extended around the lots.

In 1895, the Alvarado Well Field had 15 to 20 wells, supplying 5,000,000 gallons per day. Many of the wells were artesian. At the turn of the century, it was estimated that the safe yield of this field was 6,500,000 gallons per day. In 1910, the wells produced 8,000,000 gallons per day. In 1915, there were 36 wells producing 8,000,000 gallons per day, and the water level had dropped 10 to 12 feet below sea level. In 1920, nineteen wells were in use. In 1925, the average daily supply was 7,569,000 gallons. The maximum supply, 9,000,000 gallons, was limited by the capacity of the pumps (one downhole electric, the remainder were air lift). The pumping station was built in 1894 and enlarged in 1912. The field was sold to the Alameda County Water District in 1930. It was used for a few years, but then was abandoned. Most of the wells were plugged in the 1970's.

San Leandro Cone - *Roberts Well Field*

The Roberts Well Field was located on 350 acres of land at Roberts Landing (on the edge of the bay, west of Alvarado). The first well was drilled by Captain Roberts to supply water for steamers landing at Roberts Landing. Four wells were drilled between 1870 and 1885, and at that time, two of them were artesian. Tests of the wells in 1889 were disappointing (they had been poorly maintained and had sanded up). The well field was purchased by the Peoples Water Company in the 1890's, and the original wells were refurbished. The field was again evaluated for the City of Oakland in 1900 by Mr. J. Schuyler (the well test report still exists and appears to be the earliest extant well evaluation report in the Bay Area). At that time, there were 4 active wells (Table 6).

Table 6: The Roberts Well Field.

Well	Diameter	Original depth (feet)	1900 depth	Flow (gal/day)
A	10	258	156	<200
B	8	506	?	183000
C	8	300	?	110000
E	6	425	246	25-30000

Well E was located a considerable distance out in the salt marsh and was said to have been artesian. Mr. Schuyler's evaluation revealed that the wells had silted up and that there may or may not have been an adequate water supply at this location. It appears that two additional wells were drilled later in 1900, and they were prolific, producing 764,000 gallons of water per day with no noticeable drawdown in adjacent wells.

The field was purchased by the Union Water Company circa 1909. In 1925, there were 8 wells in service. The wells were 12 inches in diameter and 300 to 800 feet deep. The average daily pumping was 2,000,000 gallons with an available yield of 5,000,000 gallons. By 1913, it was known that pumping of the Roberts and Alvarado Well Fields caused a noticeable depression in the Niles Cone water table. In 1995, the site of the well field was developed for a housing tract. Most of the old wells were located and destroyed.

Oakland Area Well Fields

Fitchburg/Damon Well Field

In 1887, Mr. Thompson, owner of the Alameda Water Company, purchased the 2-1/2 acre Damon Property, north of the town of Fitchburg (adjacent to Damon Slough). (This was also the site of a major train wreck on November 14, 1869 in which 15 people were killed and 27 injured). In early 1888, 11 wells were drilled on the Damon property to depths between 60 to 250 feet (8, 10, and 12 inch diameter). One of the wells produced 8,000 gallons per hour, but three were weak producers and they were shut off. Total production from the remaining wells was 44,000 gallons per hour. Twelve more wells were drilled in April, 1888, because of a scarcity of water in Alameda. The deepest of these was 485 feet deep. The Damon Well Field came on line in May, 1888, and was abandoned in the early 1900's.

In 1893, additional land was purchased about one mile southwest of the Damon Wells. This new site became the Fitchburg Well Field (Figure 20; it is now the site of the Oakland Coliseum). A pumping station was built, and fifty-one, 10 inch diameter wells were drilled (42 to 140 feet deep) in 1893 which produced about 500,000 gallons per day (this line of wells is adjacent to the current flood control canal). The wells were spaced 100 feet apart. At the time, the land was tidal and was surrounded by levees to prevent flooding. The primary water-bearing layers were between 70 to 80 feet, 150 to 175 feet, and 240 to 260 feet. In 1894 an additional 19 wells were drilled a mile south. Sixty-six of these wells were 42 to 100 feet deep, and the remainder were 101 to 141 feet deep. Each well was reportedly cased off to produce from a separate sand/gravel layer. The field continued to be enlarged until it had 72 operational wells in 1903, producing 1 million gallons per day. By this time, some of the wells were 270 feet deep. In 1911, there were more than 90 wells producing more than 1,000,000 gallons per day. When the field was pumped hard (3 million gallons per day) between 1899 and 1904, it produced some salt water, but did not do so when pumped at 1.5 million gallons per day. In 1925, there were 11 operational wells, each with downhole electric pumps. The daily average output was 912,000 gallons, with an estimated maximum supply of 2,000,000 gallons. The field was shut down in early 1930.

The Union Water Company

The Union Water Company began service in the East Bay Area circa 1910, supplying water to Newark, Richmond, and Piedmont. In 1912, the Company had 103 wells scattered throughout the East Bay Area. A 24-hour test of those wells in 1912 indicated that they could produce 16,186,000 gallons per day. At that time, the Company only produced 3,445,000 gallons per day. The Company was purchased by the East Bay Water Company in 1921.

The Union Water Company had 14 wells on 4 tracts of land in the Niles Cone (in the town of Newark and at Alvarado, producing almost 5,000,000 gallons per day). In the town of Newark, there were two wells that were 160 and 280 feet deep. There were 12 wells at Alvarado.

There were also approximately 65 wells in 7 well fields in the San Leandro Cone (east of the Fitchburg Well Field). These were called the: Kinsell Well Field, the Jones Avenue Well Field, the Walker Well Field, the Dinsen Well Field, the Broadmore Well Field, and the Stonehurst Well Field.

The Kinsell pumping plant was between 89th and 92nd Avenues, north of G street in Oakland. It was supplied by 5 nearby well fields.

> The *Kinsell Well Field* surrounded the pumping plant (this field was also called the Elmhurst Field). Twenty-three wells were drilled on 7 acres of land between 1910 and 1912, but it appears that only 13 wells were active in the 1920's. The wells were 10 and 12 inches in diameter, 122 to 430 feet deep, and spaced 100 feet apart. Upon completion, the water level was 22 feet below the ground surface. Each of the wells tested at 100 to 200 gallons per minute. There is some indication that there were 10 to 12 additional shallower wells (less than 100 feet deep).
>
> The *Jones Avenue Well Field* was located on 22 acres of land at the southeast corner of the intersection of 98th Avenue and the Western Pacific Railroad right-of-way (adjacent to San Leandro Street). Thirty-nine wells were initially drilled. There were 15 shallow wells (10 inch diameter, 35 to 60 feet deep) and 24 deep wells. The deep wells were 12 inches in diameter and 200 to 340 feet deep, and produced from the same gravel layer. The shallow wells produced 40 to 60 gallons per minute, and the deep wells produced 150 to 200 gallons per minute. Of the 23 wells, 7 wells were hooked up, supplying 400,000 to 500,000 gallons per day. Six more wells were drilled in the mid-1910's (166 to 920 feet deep), and in 1925, two wells were drilled that yielded 322 and 377 gallons per minute.
>
> The *Walker Well Field* was adjacent to the Jones Avenue Field and had 8 wells (up to 417 feet deep) on 4 to 5 acres.
>
> In the vicinity of 92nd and C Streets (no field name) three 12-inch wells were drilled in the early 1910's. They tested at 150 gallons per hour and were capped, to be developed as a future water supply. As of 1920, this field was active, with 6 wells.
>
> Just to the north, near Peralta Avenue, was the *Dinsen Well Field* (13 wells, 122 to 300 feet deep).

The *Broadmore Well Field* was located on 13 lots in the Broadmore Tract, San Leandro. Fourteen 12 inch diameter wells were drilled in 1909-10, 73 to 190 feet deep. These were adjacent to Mr. Hellerman's private water plant. This was the first well field of the Union Water Company. There was not sufficient water here, and the well driller, Mr. Ough, recommended that the Company purchase the Jones Avenue property for an new well field.

The *Stonehurst Well Field* was located on lots 83 and 84 in Stonehurst. There were two 12 inch diameter wells, 160 and 240 feet deep. They tested at 80 gallons per hour.

The *West Stonehurst Well Field* contained three wells on 8 acres of land. The field was 1/2 mile west of the Southern Pacific railroad track, on line with 98th Avenue. The wells were 12 inches in diameter, 200 to 340 feet deep, and produced 180 gallons per minute. Well drillers of the time indicated that the producing gravels in the West Stonehurst Well Field were at different depths than the producing gravels in the Fitchburg Well Field.

Other wells included: the Downer well (southwest of Key Boulevard, 425 feet north of Glen Avenue); the Dover Villa wells (60 feet east of Hyde Street, between Dover Street and Wildcat

Creek); the Mira Vista wells (Johnston Avenue, east of Harris); and the Nevin Avenue wells (near Nevin street, between 23rd and 24st).

Other Union Water Company well fields included:

The *Fremont Well Field* which was located on a single 50 x 200 foot lot in the Fremont Tract in East Oakland (Sutter Street and Eastman Avenue). It contained three wells, one 12 inch and two 10 inch diameter wells between 155 and 300 feet deep.

The *Cherry Lynne Well Field* which had two wells at Cherry Street between 1st and 2nd Streets in San Leandro. It appears that this was the only well field on the San Lorenzo Cone.

A series of well fields in Richmond (see the Richmond section).

Alameda Island

From the 1850's, Alameda Island had been known for its abundant, pure water supply. Early wells varied in depth from a few feet to hundreds of feet deep. Even in the early days, it was common knowledge that artesian waters would be found along the southwestern side of the island at a depth of 100 feet or so. The water would rise in the bore holes to about high tide level.

The first record of an attempt to create a public water supply was the purchase of a lot and the drilling of a water supply well (no deeper than 185 feet) by the Town in early July, 1872. It was located on Central Avenue near Park Street. Evidently, little water was found, and it was abandoned. On July 23, 1872, an alternate site was chosen on Central Avenue between Euclid Street and West End Avenue. No information is currently known about that well.

A well drilled at the corner of Buena Vista Avenue and Walnut Street produced about 2 gallons a minute. The well was 113 feet deep, but the water came from a gravel layer at a depth of 80 feet. At about the same time, Mr. Norton drilled a well on his property on the west side of Grand Street between Santa Clara and Lincoln Avenues (near the old Encinal Station). The well produced so much water that his neighbors asked if they could hook up to his well. About 18 months later, in 1874, Mr. Norton obtained a franchise to supply water to the town, and went into the water business as the Alameda Water Company. The well was approximately 250 feet deep, 11 inches in diameter, and produced about 200,000 gallons per day. The water was reportedly soft, clear, and the 'sweetest' in the Bay Area. This well remained in use well into the 1900's, and was called the Old Norton Works. The Company eventually had 3 miles of wooden pipe lines (20 to 22 psi) but could only supply a limited number of residences. The population of Alameda at that time was about 1700.

A report from 1877 indicates that there were more than 30 artesian wells in Alameda In 1875, artesian wells were drilled at the Yosemite Hotel and on the property of Conrad Leise. Mr. Leise's well was 218 feet deep, and water rose to within 12 feet of the ground surface.

A year or so later, the Town entered into negotiations with Mr. Chabot, of the Contra Costa Water Company, with the idea of connecting the Island to Mr. Chabot's Oakland water system. They could not agree on terms, and the city fathers did not like what they saw at Lake Chabot when they toured the facilities.

In late 1879, Mr. Thompson founded the Artesian Water Works (a franchise was granted on July 30, 1880). He purchased the Alameda Water Company and immediately began drilling additional wells on a 12-1/2 acre lot on the east side of High Street between Alameda and the Bay. It was located just south of the intersection of High Street and Thompson Avenue. For many years, this was referred to as the *High Street Well Field*. Originally, there were four 11-inch diameter production wells drilled in a square pattern, 15 feet apart. All were artesian. One drew water from a depth of 150 feet (producing 12,000 to 16,000 gallons per hour), two from 115-120 feet (each producing 18,000 to 20,000 gallons per hour from a 6 foot thick gravel bed), and one from 95 feet (producing 4,000 to 7,000 gallons per hour from a 6 foot thick gravel bed). Reports also indicate that the initial test well produced 1600 gallons per hour from an 8 foot thick gravel layer at 45 feet. The total supply was more than 1,000 gallons per hour from a series of gravel beds. After completion, a brick-lined cistern more than 30 feet in diameter and 30 feet deep was constructed around the wells. These wells were the sole water supply for more than ten years. The water was pumped to a large reservoir on Park Street. The reservoir was unusual in that the 240,000 gallon tank was on the top floor of the water works office building. The first telephone line in Alameda connected the High Street Wells with the Park Street Building. The Park Street Building was torn down in 1955.

In 1880, artesian waters were thought to be derived from a "*subterranean river bed, half a mile or a mile in width, extending from the southern extremity of the Encinal [Alameda] along the shore line towards San Leandro*". At this time, Alameda had about 5000 inhabitants.

By the mid-1880's, population growth was beginning to outstrip the water supply, and Mr. Thompson began to search for additional water. Two additional wells were drilled in the High Street Well Field in August, 1885. At a depth of 87 feet, one of them produced 12,000 gallons per hour. At the bottom of the brick opening, 5 shafts, 1500 feet long, were dug in different directions.

In 1887, more than 14 two inch diameter wells were drilled to a depth of 60 feet on the High Street property. Each was expected to produce 500 gallons per hour. None did, and the project was abandoned. By November, 1888, the High Street Well Field had been shut down, but it was occasionally used whenever extra water was needed or other wells were shut down for repairs. By 1889, there were problems with the wells. The original deep well caved in and had to be abandoned. Another deep well was drilled (150 feet), but it had to be abandoned because it drained two wells several hundred feet away. There is some information that indicates that the High Street Wells had become contaminated with salt water in 1887-88. Analysis of the well water in June, 1890, revealed that it contained 34.07 grains of salt per gallon. The High Street Well Field was abandoned in May, 1901, and the pump house burned down in August, 1901.

In 1885, Mr. Thompson purchased 11 acres at Buena Vista Avenue and Oak Street where he drilled four 22 inch diameter wells to a reported depth of 150 feet. These were spaced 100 to 200 feet apart. It appears that this location was chosen because there were several existing artesian wells in the vicinity producing from an average depth of 70 feet. No other information is currently known about those wells, and it appears that they were unsuccessful.

In March 17, 1885, a well was drilled by the Harmony Borax Works. It was at 285 feet when it encountered a thick gravel layer that produced several fine specimens of gold bearing quartz. This was not the only gold found in borings. In 1879, in a well being bored by Mr. Henry Smith in San Lorenzo, gold was found at 200 feet in a gravel bed 10 feet thick. It prospected at 3 cents to the pan. The exact location of the well is unknown.

In 1887, Mr. Thompson purchased the 2-1/2 acre Damon Property, north of the town of Fitchburg (adjacent to Damon Slough), and in early 1888 drilled the Damon Well Field (see Oakland Area well fields for a complete discussion). The Damon Well Field came on line in May, 1888. At that time, total water consumption in Alameda was 90,000 gallons per hour (about 333 gallons per day per person). The field was abandoned in the late 1890's.

In 1893, additional land was purchased about one mile southwest of the Damon wells (now the site of the Oakland Coliseum). This was the Fitchburg Well Field (see Oakland Area well fields for a complete discussion). A pumping station was built, and fifty-one 10 inch diameter wells were drilled (42 to 140 feet deep) in 1893 which produced about 500,000 gallons per hour. In 1894 an additional 19 wells were drilled a mile south. The field was shut down in 1930.

In 1894, Mr. Dingee, owner of the Oakland Water Company, offered to supply water to the Town of Alameda at a cheaper rate than Mr. Thompson. Pipes were brought in, but they were never installed and the plan was apparently dropped.

In December, 1894, Mr. Thompson offered to sell the water works to the Town. There were disagreements over the price, with the Town not wanting to pay the asking price. On November 16, 1899, the Artesian Water Works were sold to the Contra Costa Water Company for $600,000. All water to Alameda was then supplied by the Fitchburg Well Field.

There was minor well drilling after 1900. In 1903, it was reported that there was an old well beneath the middle of the Webb Avenue fire house. The well was covered up when the fire house was extended. In 1905, the City drilled a replacement well at the lower end of the City Park (which Park is unknown but it was originally used for an electric works). The water had a salt content of 6 grains of salt per gallon. Water from the old well had a salt content of 96 grains per gallon. Circa 1925, there were 500 producing wells in Alameda. In 1953, there were 135 producing wells.

An unusual event occurred in February, 1909. Between February 12 and 14, 1909, almost 40 percent (8700 people out of 22,700) of the residents of Alameda became sick with gastro-enteritis. No other areas of the East Bay Area were affected. The cause was defective well casings in the Fitchburg Well Field. Several days earlier, there was a large storm that, combined with high tides, caused sewage-polluted water to flood the Fitchburg Well Field. As many as 27 wells were under water. At that time, the Fitchburg Well Field was the sole water supply for Alameda. The attack was sudden. On the evening of the 12th, there were numerous cases of gastro-enteritis. Cases continued to occur on the 13th and 14th, but few occurred after that. There were no deaths, but most experienced severe nausea, vomiting, a slight fever, abdominal pain, and diarrhea. The outbreak was investigated by the Sanitation Department who made a systematic house-to-house survey. The results clearly pointed to the water supply. The wells were repaired and placed back into service.

As a side note, in August, 1884, Mr. Thompson's recently constructed $160,000 mansion burned down just before he moved in. It was a total loss, and there was no insurance. The house was built on 8 acres adjacent to his water works on High Street. For several years before this, Mr. Thompson had vocally opposed a tax levy for fire purposes and claimed that he had trained his staff to put out fires that might start on his property. The property was eventually sold to the City where it is now known as Lincoln Park. He moved to San Francisco in the early 1900's where his new house burned down in the fire from the 1906 quake.

Bay Farm Island

In the early 1870's, the majority of the island was tidal flats and wetlands. There was a small area, several hundred acres, just south of Alameda Island that was above tide level. In 1877, there were 3 to 4 artesian wells on Bay Farm Island (117 feet deep). Some of them flowed 2 to 3 feet above the ground surface, and one was more than 250 feet deep. At the turn of the century, a drainage district was formed to drain the entire Bay Farm Island for agricultural purposes. Some drainage tile was laid and about 300 acres were reclaimed (this area is now the Alameda Municipal Golf Course). However, constant flooding due to poor levees and the salty soils reduced the farming potential, and the district slowly disbanded. In the early 1920's, the Oakland Airport was constructed and reclamation began again as the airport expanded. Several wells, up to 800 feet deep, were drilled for the old airport. Several of the wells are still being used by the golf course and the original Oakland Airport. Since then, much of Bay Farm Island has been reclaimed.

Castro Valley Water District

From the mid-1800's, groundwater was the sole water source for the Castro Valley Area. The Hayward fault was recognized as a water bearing zone: "*there is a streak of water-bearing formation extending through the town [Hayward] in a northwest and southeast direction extending nearly parallel to the foothills. Along this streak, which does not exceed 20 feet in width, there are many springs and abundant supply of water can be obtained from dug wells at a depth of about 10 feet. At the time of an earthquake, 1868, a crack opened along this streak, and from it a small stream of sand and water flowed for several hours*".

In 1930, the area was a bedroom community of 2000 (there were 1200 residents in 1926). The primary local industry was poultry raising and fruit orchards. From the late 1910's, groundwater levels had steadily dropped, and in several locations, wells had gone dry. In response to this, the Castro Valley Water District was formed by a vote of the residents (656 to 110) in late 1930, and bonds were issued in order to construct a water distribution system. It was known that the local water supplies were insufficient, and the residents planned on acquiring water from either the Niles Cone area, from the San Francisco Hetch Hetchy Aqueduct, or from EBMUD (Mokelumne River water). In May, 1931, the Castro Valley Water District was acquired by EBMUD.

Richmond

In the 1830's, the Franciscan outcrop on the west side of Richmond (Potrero Hill) was an island, and it was reported that deep water ships could navigate the slough east of the hill. Filling of the slough began in the 1850's and was completed in the 1920's. Even though it had an excellent port, it was not developed until 1900 because of clouded land titles and threats of lawsuits.

Richmond, as we know it, developed as a direct result of the railroads and the 1906 San Francisco earthquake. In 1899, the Santa Fe Railroad selected the area to be the deep-water port in the East Bay and a major railway repair station. Prior to this, the area was grazing/farm land with small towns, San Pablo, Rust (the name was changed to El Cerrito circa 1911), and Stege Junction (soon shortened to Stege) near the eastern hills. There were approximately 1805 people in the entire area in 1899. In 1901, ferry traffic was first initiated; in 1902, the Standard Oil Company refineries were established. In the beginning, there were two settlements: Point Richmond (the western hills) and the City of Richmond (the plains east of the hills). The two sections incorporated as the City of Richmond in 1905. A few years later, the town of Pullman developed east of Richmond, adjacent to the railroad tracks. As with Oakland, the 1906 earthquake cause a massive population increase after 1906 (the earthquake also created Albany, which was incorporated in 1908.) By 1913 there were 15,585 people in the Richmond area.

The first water company, the Richmond Water Company, was created by landowners as an inducement to home buyers at Point Richmond. Between 1900 and 1906, water was obtained from a series of wells in the vicinity of Castro Street, just north of I-580, and piped to a reservoir on top of Point Richmond. The field contained ten 12-inch wells, 118 to 250 feet deep. In 1906, there were 398 customers. The Richmond Water Company was purchased by the Syndicate Water Company in February, 1906, which in turn was purchased by the Peoples Water Company in 1907. During its one year existence, the Syndicate Water Company drilled the Richmond Well Field and developed the San Pablo Well Field 1. By 1910, The Peoples Water Company provided approximately 90 percent of the water to the area with the remainder by the smaller firms. All of the smaller firms were eventually purchased by the Peoples Water Company or disbanded.

Even as early as 1910, it was recognized that the pumping rate (3 to 4 million gallons per day) of the San Pablo alluvial fan was significantly more than the annual replenishment of the aquifers (the safe yield was estimated to be in the range of 2 million gallons per day). On May 11, 1911, the Richmond Municipal Water District was created for the express purpose of developing additional water supplies. It was approved by a vote of the residents (797 to 511) on December 3, 1912. Over the next several years, various water sources were studied and evaluated. These included development of surface water supplies in the hills east of the City (dams), or pumping water from the Sacramento River from either Martinez or Toland's Landing (at the mouth of the delta). Circa 1916, the issue was submitted to the voters (ie: the authority to issue bonds). The bond issue failed, and the District disbanded.

Water to the area was pumped from five major well fields. Four of these were located adjacent to the San Pablo and Wildcat Creeks, while the fifth was located in downtown Richmond. In 1913, there were approximately 350 wells in the District. Of that number, 240 were privately owned with the remainder being owned by private and public water companies. These wells supplied a total of 3 to 4 million gallons per day. In 1913, the average daily use was 71 gallons per day per person.

The groundwater in the Pullman District and in the vicinity of Cerrito Hill was near the ground surface (Cerrito Hill is a low hill in the central part of the southern Richmond plain). Wells in this area were generally 100 feet deep, and many gently overflowed. In the area northeast of Cerrito Hill, in the area east of Wall Street, and from Cutting Boulevard north to Grand View Terrace, the wells were drilled 100 to 140 feet deep and water stood 16 to 20 feet below the ground surface. The wells between Wildcat and San Pablo Creeks were drilled 170 to 500 feet deep. Over-pumping caused the water level in the San Pablo Well Fields to drop 30 feet between 1907 and 1911.

The groundwater in this area normally had a higher mineral content than other parts of the East Bay Area, and had to be treated by industrial users. Overpumping exacerbated the situation by causing sea water intrusion. In November, 1913, the Richmond wells had chlorine levels as high as 660 ppm. At that time, 100 ppm was thought to be the upper limit for human consumption. Test results from several groundwater samples are listed below (Tables 7 and 8). (Chlorine was listed in the tests, not chloride.)

Table 7: Analysis of Richmond Well Water (November 1, 1913), values in parts per million

Impurity	Union Water Richmond	Peoples Water Richmond	Peoples Water San Pablo	Sacramento River
$SiO_2+Al_2O_3+Fe_2O_3$	21.8	21.4	19.4	19.2
Ca	45.6	150.2	84.0	16.0
Mg	19.0	52.8	33.4	7.8
Na	48.0	98.7	46.6	14.0
Cl	34.1	399.0	129.2	12.8
CO_3 (equiv to HCO_3)	139.9	129.0	127.2	46.6
SO_4	17.1	31.1	50.4	6.4
Total dissolved matter	322.5	882.2	490.2	122.8
HCO_3	278.4	262.3	258.7	94.7
$CaCO_3$ (temp. hardness)	228.2	215.0	212.0	77.6
$CaCO_3$ from calcium	114.0	376.0	210.0	40.0
$CaCO_3$ from magnesium	78.0	217.0	137.0	32.0
Total	192.0	593.0	347.0	72.0

Table 8: Chlorine Content of Various Richmond Wells, September to October, 1913

Well Location	Chlorine Content (ppm)
Richmond Wells	660.0
San Pablo No. 1, Composite	61.2
San Pablo No. 1, well B	39.6
San Pablo No. 2, well 5	41.6
Single well	55.4
San Pablo No. 2, wells 6, 8, 10	47.2
Standard Oil Company, No. 2 (230 feet)	36.8
Standard Oil Company, No. 12 (290 feet)	44.2
Standard Oil Company, No. 16 (397 feet)	38.6
Southern Pacific Well (300 feet)	33.2
Santa Fe Company	45.0
Hercules Powder Company	34.2
Santa Fe Wells	399.0
Sacramento River (Toland's landing)	12.8
Curry Bottling Works	82.0

Richmond Wells - This was a group of seven to nine 12 inch wells drilled north of the Santa Fe Railway, between Ohio, Chanslor, Second, and Seventeenth Streets. The wells were 115 to 203 feet deep. The estimated capacity was 500,000 gallons per day, but the 5 year average yield (1907-1911) was 306,000 gallons per day (Table 9). This was the first well field in the area and was drilled in the early 1900's. The field was abandoned in the mid-1910's.

Table 9: Water Levels in the Central Richmond Well Field.

Well No.	Depth (feet)	Water Level, well idle	Water Level, well operating*
1	132	15	20
2	138	15	21
3	115	15	22
6	118	16	20
7	118	17	-
8	153	12	-
9	203	12	-

* Field was pumping 16,000 gallons per hour. When pumping 25,000 gallons per hour, the water level dropped to 38 feet from the ground surface

San Pablo Well Field No. 1 - This field was located in the town of Old San Pablo, between Wildcat and San Pablo Creeks (Alvarado Street and Church Lane). The tract of land on which the wells were drilled (lot 137) was approximately 1 mile long, with the creeks being approximately 1/4 mile apart at the west end, and 3/4 mile apart at the east end. (Reports of the day indicate that the 1/4 mile wide part of the land was at the east end of the lot. We switched the compass descriptions because we was unable to reconcile the original directions with the actual lot location/orientation.)

There were ten, 10 inch wells that were 134 to 359 feet deep. Nine of them were active. Half were drilled in 1906 and the remainder in 1910-1911. An additional well was drilled in the late 1910's. Their estimated capacity was 550,000 gallons per day, but the 5 year average yield (1907-

1911) was 348,000 gallons per day (Table 10). There are some reports that indicate that wells were drilled in this area as early as May, 1899. The field was abandoned in September, 1920.

Table 10: Water Levels in the San Pablo Well Field No. 1

well no.	depth (feet)	water level, well idle	water level, well operating
1	180	38	58
2	183	26	89
3	179	28	63
4	170	28	61

San Pablo Well Field No. 2 - This field was located at the northwest corner of the intersection of the Southern Pacific railroad tracks and Parr Boulevard (now the site of the old Crown Cork facility, Figure 21). There are eleven 10 inch wells varying in depth from 265 feet to 510 feet. Nine wells were drilled in 1907, and 2 more in 1910. In 1907, these wells yielded almost 2 million gallons per day. Because of overpumping, the yield decreased to 600,000 gallons per day in 1912 (a reduction of almost 70 percent), and to 300,000 gallons per day in 1918. In 1913, some of the wells were producing saline water, suggesting that there had been sea water intrusion. The field was abandoned in January, 1919. Hickey (1907) contains photographs of wells being drilled in this field.

San Pablo Creek Wells - As a result of the significant decline of the San Pablo Well Fields 1 and 2, 25 wells were drilled along the axis of the narrow valley in which San Pablo Creek flowed. Twenty-three of the wells were 50 to 100 feet deep, three were over 100 feet deep, and one was more than 200 feet deep. There was a 10 inch well, six 12 inch wells, and eighteen 14 inch wells, which produced approximately 300,000 gallons of water per day and were brought on-line in August, 1912. Provisions were made to allow pumping of water from San Pablo Creek into the well supply line. This was rarely done because there was only sufficient water during high water flows and the water was generally too muddy to be put into the system.

Wildcat Wells - These wells were located near the head of Wildcat Creek, where the old County road from Berkeley to Orinda crossed the creek (at Wegner Road). While these wells were technically within the Richmond District, the water generated by this system was used in Berkeley. None was used in Richmond. Within a small area 11 wells were drilled, 100 to 250 feet deep, and two 12 inch wells 275 and 293 feet deep. The water in the majority of the wells rose to near the ground surface. Four of the wells were drilled in 1911. There was also an 800 foot long tunnel. Water was only found in the first 200 feet. During the winter, water was also diverted from the creek. The wells, tunnel and creek diversion structures were connected to a small brick reservoir (15,000 gallons) at elevation 950 feet. The average yield of this system between 1902 and 1911 was 413,000 gallons per day. When the Claremont tunnel was driven in the late 1920's, the upper section of Wildcat Creek was diverted into the tunnel.

Other Richmond Area Water Companies

Other local water companies included the Union Water Company, the Fred Meyers Water Company, the McEwen Brothers Water Company, the Herbert Brown Water Company, the West San Pablo Water Company, and the Hercules Water Company. The larger industrial companies (such as the refineries) had private wells to supplement purchased water.

The *Union Water Company* supplied three areas in the Richmond area. One was Stege, one was west of the railroad tracks at Pullman, and the third was the subdivision at the Macdonald Avenue-Civic Center tract and the Grand View Terrace area. Water was pumped from a 12-inch diameter, 330 foot deep well at the west end of the San Pablo Well Field #1, and wells at each of Pullman

Stations #1, #2, #3, and #4. The Pullman Station #1 well was 120 feet deep on a 50 x 150 foot lot. The Pullman Station #2 well field was located on a triangular shaped, 21 acre lot on which 12 wells were drilled, with depths varying between 100 and 150 feet deep (Porter at Union Avenue). Pullman Stations #3 and #4 reportedly had single wells each, with depths less than 50 feet. Pullman Station #4 was southwest of 32nd Street, about 200 feet north of Portero Avenue.

There were tunnels at Bay View Park near Stege. The tunnels were located on a 50 x 175 foot lot and consisted of an 80 foot deep shaft from the bottom of which the tunnels were driven 100 feet north and south. The water was pumped to holding tanks at the top of Cerrito Hill. The tunnels produced up to 15,000 gallons per day.

The *Fred Meyers Water System* supplied water to two areas, a 400 acre area northeast of Pullman and the area south of Grand View Terrace. The supply to the area northeast of Pullman was provided by several (3?) wells that were approximately 100 feet deep. The other area was supplied by on-site wells.

The *McEwen Brothers Water System* supplied water to an area south of the Oakland Branch of the Santa Fe Railroad, between 1st and 16th Streets (the Santa Fe Tract). Water was pumped from 4 wells. The pumping plant and some of the wells were located on 5th street south of Ohio, and other wells were located north of 13th street at Ohio. The Company was purchased by the Peoples Water Company on February 15, 1907.

The *Herbert F. Brown Water System* supplied water to the 40 acres of the Brown-Andrade Tract. Water was pumped from one well. No other information was available.

The *West San Pablo Land and Water Company* supplied water exclusively to the Standard Oil Company. They had 12 wells ranging from 170 to 325 feet deep on lot 190 in San Pablo Rancho. They had 4 other wells closer to town. In 1911, they supplied about 450,000 gallons per day to the refinery.

The *Hercules Water Company* supplied water to the town of Pinole, primarily to the Hercules Powder Company. They had 3 wells on lots 179 and 183 in Rancho San Pablo (at the point where San Pablo Creek and Wildcat Creek are closest). The wells were 181 to 335 feet deep. Between 1908 and 1915, they pumped 46,000,000 gallons per year (130,000 gallons per day). Pumping continued until the early 1930's. They also had a small dam on Pinole Creek from which they drew water.

In 1912, the *Standard Oil Company* used 500,000 gallons per day from the West San Pablo Land and Water Company and 500,000 gallons per day from the Peoples Water Company. They also used about 25,000,000 gallons of salt water per day for condensing purposes. In 1907 they used 327,000 gallons of water per day.

The *Pullman Car Shops* purchased water from the Peoples Water Company. They also had several wells and two tunnels. The tunnels were 35 feet below the ground surface. One was 64 feet long; the other was 42 feet long.

The *Santa Fe Railroad* provided all their needs from wells drilled adjacent to the tracks at various locations. They had 6 wells in 1910, 11 wells in 1921, and 10 in 1923. Between 1910 and 1920, they pumped an average of 105,000,000 gallons per year.

Water Usage - Water usage in the Richmond area in 1912 is listed in Table 11:

Table 11: Production and Use of Water in Gallons per Day in Richmond, 1912.

Source	Production	Mfg.	Domestic	Sent outside of District
Private Wells (250)	533,500	---	533,500	---
Factory Wells	771,500	771,500	-----	---
Hercules Water Co.	130,000	----	----	130,000 to Pinole
Small Water CO's	39,000	----	39,000	-----
Main Well Fields	1,396,430	882,260	271,670	242,500 to Berkeley
Wild Cat Creek	312,600	---	----	312,600 to Berkeley
Sunset View Cemetery	55,000	55,000		
Union Water Co.	150,000	1,540	148,460	
Total	3,388,030	1,710,3000	992,630	685,100

Berkeley

In the early years, the Berkeley area contained two unincorporated towns, the college and the new town of Berkeley (founded in 1866) at the foot of the hills, and the town of Ocean View along the Bay. They were separated by several miles of open fields. The two towns merged on April 1, 1878.

The College of California (U.C. Berkeley) constructed the first water supply for the college and the surrounding town. The company, called the College Water Works (or the University Water Company), was incorporated on July 27, 1866, and water was first delivered in August, 1867. The water came from a dam on Strawberry Creek that was located at the foot of Panoramic Way, near Memorial Stadium. Two years later, the college decided it was not proper for them to operate a private company. In 1869, the college water works and water rights were sold to the Berkeley Water Works Company, owned by Mr. Berryman and Mr. Chappelle. Mr. Berryman bought out Mr. Chappelle in 1877. This firm constructed a series of tunnels and small dams on Strawberry Creek and Wildcat Creek (fall, 1877), and the Berryman reservoir, holding 8,000,000 gallons in North Berkeley. The California Institution for the Education of the Deaf, Dumb, and Blind (now the Kerr Center) was supplied by water from 2 private water tunnels (1000 feet long), a well, and a large spring in the hills behind the school.

This was not the end of the attempts by the University to produce its own water. Between 1883 and 1886, the University bored a 1400 foot long tunnel that produced about 3000 gallons per day. In 1890, they drilled 73 wells in the hills north of the University. The wells were 10 to 73 feet deep. Only one produced water. A short tunnel was bored at that site. It produced water for a few days, but quickly dried up. In 1892, a 120 foot deep, 6 inch diameter well was drilled in the bed of Strawberry Creek within 40 feet of the eastern boundary line of the university property. A second well, 500 feet deep, was drilled about 30 feet further up the canyon. Between 1900 and 1910, there was a series of student reports analyzing the building of dams across Strawberry and Claremont Creeks. Foundation evaluation test pits were dug in Claremont Canyon in the late 1890's.

Little is known about the water supply of Ocean View. All of the houses had private wells, but it appears that a small private water company, the Land and Town Improvement Association existed. In 1877, it laid 2,600 feet of pipe and offered to sell water from its well. One of the early wells is still in use. It was drilled prior to 1868, and is used by the Safeway located at Shattuck Avenue and Rose Street.

In 1882, Mr. Berryman sold out to Mr. Hopkins, though the company continued under the same name. In June, 1883, Berkeley experienced a water shortage, the first of many over the next 20 years. Garden watering was limited to one day a week. Soon after, the citizens suggested that water be brought in from Lake Temescal or that artesian wells be drilled. In 1884, the Berryman reservoir was enlarged to 23,000,000 gallons, and the Hopkins reservoir was constructed south of the California Institution for the Education of the Deaf, Dumb, and Blind (2,500,000 gallons). The Berkeley Water Works was transferred to the Alameda Water Company (also owned by Mr. Hopkins) in 1885.

Mr. Hopkins died at the age of 70, leaving the business to his wife who became an absentee owner living in San Francisco. She neglected the business, refusing to expand or improve the water supply. As a result, Berkeley suffered through a series of water shortages throughout the 1890's. The Contra Costa Water Company, which serviced Oakland, indicated that it would relieve the Berkeley situation if the Alameda Water Company would give up its franchise or buy available water. The Alameda Water Company would do neither. In 1896, the company admitted that it could not continue to adequately service West Berkeley. It gave up its franchise to service that area to the Contra Costa Water Company.

There was such a water shortage in Berkeley during 1898, that on July 15, the town trustees made watering a lawn or a garden a misdemeanor. This created such a stir that it was repealed at the next board meeting. This shortage prompted the citizens to seriously consider municipal ownership. In December, 1899, a Citizens' Syndicate was ready to submit to the town trustees a proposal to fund bonds for the purchase of the Alameda Water Company and for the development of additional water supplies. The proposal was reviewed, and on January 27, 1900, the committee in charge of reviewing the proposal reported against it. The engineers' evaluation of the proposed water supplies (a dam across Pinole Creek and the drilling of wells in the San Pablo Creek area) suggested that these would only provide sufficient water for a few years (very prophetic, see the San Pablo wells discussion) and that it would be unwise for Berkeley to commit itself to any project relying solely upon these wells. Berkeley drilled a test well in San Pablo that tested 4800 gallons per hour. A few months later (June, 1900), the town trustees approved the sale of the Alameda Water Company to the Contra Costa Water Company. The holdings included pipelines, 800 acres of land in Alameda and Contra Costa Counties, and three reservoirs: the Summit (40,000,000 gallons), the Berryman (30,000,000 gallons), and the Garber (10,000,000 gallons) It also included 174 acres of land at the head of Claremont Canyon. In 1961, those lands were transferred to the University of California as open space.

In 1911, water supplied to Berkeley was produced from the following (Figure 22):

Berryman Tunnel

Five hundred feet long, north of the head of Cordonices Creek (on Queens Road about 150 feet south of Quail Lane). It was 3 x 5 feet and heavily timbered. In 1938, the outlet pipes had rotted, and flow from the tunnel had been significantly reduced. The tunnel was opened up, and it was observed that the original timbering had rotted and the tunnel had filled with caved material. Approximately 210 feet of the tunnel were cleaned out. At that point, a concrete plug was installed and a 4 inch cement lined cast iron pipe was laid to direct the flow of water to the sewer in Quail Lane.

Average yield	1902-1911	91,200 gallons per day
Maximum yield	1906	123,200 gallons per day
Minimum yield	1908	63,800 gallons per day

Summit Tunnel

Three thousand feet long, 500 feet north of the Tunnel Road (Fish Ranch Road) at 1000 foot elevation. The tunnel was 6 feet high and 4 feet wide.

Average yield	1902-1911	726,000 gallons per day

Pfeiffer Springs and Tunnels

Six springs and 3 tunnels near the head of Strawberry Creek, 1/4 mile south of the county line at a 700 foot elevation. The tunnels were 3 feet wide, 6 feet high, and 40, 75, and 150 feet long. The springs were developed by the excavation of wells. The wells were about 4 feet in diameter and 20 feet deep with stone walls.

Average yield	1902-1911	45,900 gallons per day

CONCLUSIONS

Groundwater was a major part of water supply to the East Bay area from the 1860's to 1930. During that time there was a continuous struggle to locate and develop both ground and surface waters to serve the growing population. By the early 1920's, it was recognized that local groundwater and surface water supplies had reached their limits, and water would have to be brought in from outside the Bay Area. After years of planning and construction, Sierran water entered the area in the spring of 1930. However, instead of continuing to be part of the water supply, municipal well fields were shut down and forgotten.

We estimate that in the range of 15,000 wells were drilled in the Study Area between 1860 and 1950. The majority of these were shallow (less than 100 feet deep), but some were up to 1000 feet deep. Few of these wells were properly destroyed.

Our historical review indicates that there were only three areas in the East Bay Plain that historically supported municipal well fields: the Alvarado, San Pablo, and southern Oakland trends (Figure 18). The Alvarado Well Field was located south of the Study Area on the northern side of the Niles Cone. This trend had the most prolific wells and supplied about one-half of the groundwater to the East Bay Area (Figure 19). There were 8 to 10 individual well fields in the southern Oakland trend. The first well field in this area was drilled on Alameda Island (the High Street Field) in the 1880's. Within 10 years, the field was shut down because of water quality problems and casing failures. Additional well fields were drilled to the west (Fitchburg, 98th Street, etc.), following the trend of the aquifer. These fields were an integral part of the water supply system until they were shut down in 1930. There were three well fields in San Pablo. They were drilled in the late 1900's to supply water to the rapidly growing Richmond area. Overpumping and intrusion of brackish water caused those fields to be shut down by 1920.

There is little specific information about historic groundwater quality, but the existing information indicates that groundwater had a relatively similar quality throughout the East Bay Plain. Total dissolved solids (TDS) varied between 500 and 1000 ppm.

Salt/brackish water intrusion occurred along the eastern end of Alameda Island (early 1890's), in the Fitchburg Well Field (late 1920's), and in San Pablo (late 1910's). Existing information indicates that the intrusion was restricted to the upper aquifer (above the Yerba Buena Mud) and was caused by overpumping. All of these fields were shut down by 1930. Overpumping continued to occur in the Niles Cone for the next 30 years. This resulted in intrusion of the deeper aquifers by the 1950's. Evaluation of that intrusion revealed that there were no natural direct pathways to the deeper aquifers. Intrusion occurred via abandoned wells and reverse hydrostatic head from high pumping rates.

There appear to be sufficient groundwater supplies for individual domestic and light industrial users but limited locations for long-term municipal water supplies. This is more due to the lack of recharge than a lack of aquifer quality. Existing groundwater supplies can be used for emergency water use. Large volumes of groundwater could be pumped for several months to a year, but the aquifers could be noticeably drawn down and might require several years to recover.

We propose that the term Alameda formation be restricted to the marine units beneath the bay, and that the names Yerba Buena Mud, San Antonio, Merritt, and Posey should be used to refer to members within the Alameda formation. We suggest that geologists familiar with the lithologic units in each of the basins meet and agree on a common, basin-wide stratigraphic nomenclature.

Existing well data is sufficient to identify and map the various bay muds and the overall characteristics of the alluvial/continental units bounded by those muds. At this time, the data are not sufficient to identify individual flow units or specific geologic trends within the alluvial fan units. Well logs are only a guide to the subsurface and must be evaluated within their geologic context. It is possible to define meaningful sub-divisions within alluvial fan units, but it would require a significant expenditure of time and money to do so. We recommend that the RWQCB or the appropriate agency begin to require the submittal of digital well data for wells greater than 150 feet deep, and that a full suite of high quality electric logs be required for wells deeper than 200 feet.

The eastern boundaries of the estuarine muds are poorly known. Identifying their boundaries can be difficult because of the problem of separating estuarine muds from continentally derived clays (crossing depositional environmental boundaries). Separating the two types of clays can be done either using high quality electric logs or microscopic evaluation of samples.

Over the past 10 to 15 years, there has been an effort to mathematically evaluate alluvial fan aquifer trends both here and around the country. Typically, these models are run when the data are poor. The models generally have a sound theoretical basis but are completely dependent on the quality of the original data. Before accepting the results of a model, one has to be aware of the quality of the original data and if the theoretical limitations of the model are satisfied (all geo-mathematical models have limitations).

The basins need to be viewed as a whole both geologically and hydrogeologically. The basin is not composed of isolated areas. Sufficiently large pumping in one area can affect groundwater conditions in other areas.

APPENDIX

Well Log Evaluation

All subsurface evaluations and interpretations are dependent on evaluation of drillers' logs calls. In the past 10 years, there has been an increase in geotechnical logging and electrical logging, but driller's logs still provide the only data over large sections of the study area.

There are several problems with driller's well logs. Identification of alluvial facies is based on lithologic component analysis and numerous three-dimensional features such as: types of laminations, cross-bedding, slumping, lateral variations in sediment types, bed forms, and orientation of bed surface (Miall, 1994; Kraus and Aslan, 1993; Burnes et al, 1997; Webb, 1994; and Nadon, 1994). Conventional drilling destroys virtually all of the physical relationships. All that remains is a finely-ground mixture of sand and gravel. This problem is compounded by how the cutting information is recorded. Historically, cuttings have been described by water well drillers because they have been required by law since 1949 to submit driller's logs to DWR. Only in the past 10 to 20 years have well logs begun to be described by geologists.

Well drillers are not geologists, and few have had formal training in lithologic evaluation/identification. As a result, there is no consistency as to how and when cuttings are sampled/described. Some drillers look at the cuttings every 5 feet while others look at them 'whenever'. As with any profession, there are drillers who make a conscientious effort to accurately record the sub-surface conditions and there are those who do not. Sample descriptions are strongly influenced by drilling characteristics and the drilling method. If these problems are not kept in mind, it is easy to misinterpret what the driller is trying to describe.

The following definitions are based on conversations with several bay area well drillers.

Pebble	1/8 to 3/4 inches in diameter.
Gravel	3/4 to 2 inches in diameter.
Boulder	larger than 2 inches. When a drill bit hits a "boulder", it will either drill through the "boulder" or push it aside (roll).
Hard Pan	a hard/dense clay layer.
Hard/Soft	these refer to drilling characteristics and they vary with the drilling method.
Cement clay/ cement gravel	a very hard, very dry clay that is difficult to drill through.
Clay vs. shale	If a driller sees numerous pieces of shale (50 percent or more of the sample), then he will make a shale call. However, if there are only a few pieces, it will typically be called clay.
Sand vs. Sandstone	The distinction between the two is based on the drilling difficulty.
Colors	These are the wet colors. Dry colors can be very different. Drillers are generally very accurate as to the color of the samples as long as the hole was not drilled with mud. If it is a rotary rig (using drilling mud), the samples are not washed and the colors are always brown. [see Myrow (1990) for a good discussion about mudrock colors]

Some drillers only recorded clay or sand, with sand being anything other than a clay.

An example of the Sand vs Sandstone distinction can be seen in boring log 82 of Robert S. Cooper and Associates (1965b). That boring was drilled at the northern end of the Richmond BART segment, near the Chevron refinery. It was 60 feet deep and sandstone was reported to have been encountered at 50 feet. This was the only boring to encounter sandstone. Surrounding deep borings indicate that bedrock is more than 400 feet deep.

Another problem is the method used to describe the samples. Since the 1930's, boring samples have been visually described using some type of engineering description (ie: the United Soil Classification System). These systems are based primarily on grain size; they have no ability to record geologic information such as composition, texture, bedding, etc. It has been rare for samples to be cleaned and dried, to be observed under magnification, to be analyzed for microfossils/pollen, or to be analyzed for grain distribution or type. These types of classification systems were specifically developed by civil engineers to standardize the description of soils to allow them to be more consistent in describing the engineering properties of soils (Abdu-Nur, 1950; Burmister, 1950; and Willis, 1950). They were not intended or designed to record geologic information.

Prior to the mid-1950's, there was no universally recognized engineering soil classification system. Each engineer/geologist/driller used a slightly different terminology. One has to be careful when translating earlier sample descriptions to current standards. One should not assume that pre-1950's terminology, such as stiff clay, has the same meaning as it would today (see Stocks, 1932, p. 1).

The volume of borehole cuttings presents a problem if particle-size is going to be analyzed for either engineering purposes (Rowe, 1971) or depositional environmental analysis (Gale and Hoare, 1992). Both authors evaluated the relationship between sample size and particle-size analysis and found that truncated distributions resulted from too small of a sample size. Particle-size evaluation of alluvial fan material was especially sensitive to sample size; several kilograms of material were needed if the maximum particle diameter was 10 millimeters, and the mass increased logarithmically as the maximum particle diameter increased. The other problem is that the vertical variations in particle size needed to analyze alluvial fans (ie: graded bedding, determination of point bars, etc.) are also destroyed.

Oil Companies have dedicated years of research and training to develop methods of describing/logging geologic information from samples. The majority of these methods are described in internal company documents, but some have been published: Swanson (1981), the EXLOG manuals (EXLOG, 1980), and Berg (1970). Sedimentary geologists have developed specific methods for the hand-sample description of alluvial material (Brewer, et al, 1990; Brown and Harrell, 1991; Sutter, 1989 for example), and there is an extensive literature on alluvial facies interpretation (basic references include: Miall, 1984, 1985, 1992, 1994; Dalrymple et al, 1992; Blair and McPherson, 1995; Nadon, 1994; and Neton et al, 1994). North (1996) contains an excellent review of the philosophy and methodology of evaluating fluvial stratigraphy.

Evaluation of the subsurface geology in the Study Area is dependent on the evaluation of well driller's logs and scattered geotechnical borings. This is beginning to change as electric logging is becoming more common, but no significant analysis of bay area electric logs has yet occurred. A preliminary evaluation (Rogers and Figuers, 1991, their figure 20) identified wide spread, well defined E-log signatures for many of the marker units (estuarine muds, continental units)

Electric logs typically run in water wells are SP, resistivity, and sometimes gamma. They are generally used as water quality indicators, not for lithologic identification. For example: water-well borehole fluids generally have the same salinity as drinking water. This means that the SP will only deflect when there are saline formation waters. There are three types of resisitivity logs that are typically used: the single point log, the normal (16 or 64 inch electrode spacing), and the lateral log (6 foot electrode spacing). These tools generate an asymmetrical signature, with the peak at the base of the bed. In the oil field, these are called ancient logs, and there is a sub-specialty of experts who know how to interpret these logs (Society of Professional Well Log Analysts, 1985; Hilchie, 1985). Hudson (1995) provided a review of the use of electric logs in evaluating groundwater quality in alluvial fans.

Burow et al (1997) combined ground penetrating radar (GPR) and seismic surveys with borehole lithologies to estimate hydrogeologic facies in the upper 300 feet of alluvial fans near Fresno, California. Their analysis suggested that the combination of techniques provided a reasonable estimate of alluvial fan facies.

Interpretation of Well Logs

There have been many attempts to overcome the inherent limitations of drillers' logs. The most common, and still the most successful, is to place the logs in their geologic context and use them as a guide to the subsurface. The key is to pick the correct geologic environment and not to over interpret the logs. As noted by Forbes, "*well logs are not self explanatory and are dependent entirely upon the recorder's interpretation of the materials penetrated. Reported materials, especially clay and so-called water bearing and dry strata, are given a wide variation in interpretation by drillers, but, coupled with a knowledge of the origin of the materials penetrated and geologic history of their deposition, well logs or drillers penetration records are of great aid to the hydrologist . . . However, correlation or exact determination of the extent and course of lenses through alluvial deposits are seldom justified from well logs. . . Only in lake bed formations can the depth and character of the principal water yielding strata at any place be predicted with any confidence.*" (Forbes, 1924, p. 188-189).

There are two ways to analyze well logs. One is to analyze/map the clays (aquitards) and the other is to analyze/map the sands (aquifers).

It is easier to map clay/mud units. They are deposited in a well defined depositional environment over a relatively long time period, they are widespread, and they are generally adequately described in well driller's logs. This type of mapping was done by Sloan (1981), and Rogers and Figuers (1991). The primary correlational problem with clays is in identifying their depositional environment. Clays deposited in one environment have little genetic relationship to clays deposited in adjacent environments. Unfortunately, there is a tendency/desire to assume that clays correlate. Unknowingly extending clay correlations across depositional environments/boundaries can seriously effect a geologic/hydrogeologic interpretation. In our opinion, this is the problem with Kessel's (1997) extension of the Yerba Buena Mud to almost the Hayward Fault. It is unlikely that the Yerba Buena Mud extends that far east. Instead, it appears that a marine clay was correlated with clayey soil zones. This does not mean that the two types of clay cannot form a continuous aquitard, just that the problem has to be recognized and taken into account.

If samples are available, microscopic analysis can provide a wealth of information about the units. This is easily done if samples are available, but, if they are not, coarse determinations can be made from log descriptions. The State Water Resources Board (1955a, p. 100-102) provided an excellent practical description of the differences between the various types of clays in the Bay Area.

> *Clays fall into three broad genetic classifications. The two most common are stream-or flood-deposited clays, and clays which have been formed as the result of weathering. The other type of clay is marine- or tidal flat-deposited clay. The depositional clays may be blue, yellow, or brown. The last two colors being most common. Some of the yellow clays may represent oxidized blue clays. The yellow clays of the drillers include clays which are actually red, brown, and yellow. The blue clays of the drillers generally include blue, greenish blue, blue-grey, and gray clays. Nearly all of the clays described by the drillers contain only a relatively small proportion of true clay, the remainder of the material being silt , sand, or gravel.*
>
> *The clays which are the result of weathering are brown, red, and yellow. They can be differentiated from the deposition clays by the pitted surface of the enclosed sand grains and pebbles. Most of the cement gravels and tight gravels of the drillers are actually weathered gravels, sands, or gravely silts.*
>
> *Individual beds of gravels are very irregular and lenticular. Groups of these can often be correlated from place to place, but correlations of individual beds is generally impossible. Clean gravels may*

grade into any combination of gravels, sands, and clays, which in turn may eventually pinch out or grade into either sands or clays.

What is usually termed a ten-foot gravel bed actually consists of perhaps two to twelve inches of clean gravel, the remainder being clay and gravel or sand and gravel. A thick clay bed usually consists of only one-third to two-thirds silt and clay, the rest being a mixture of these with sand and gravel.

The location and nature of clays being deposited today in the Study Area provides a guide to the past deposition of clays. A continuous marine clay layer is being deposited throughout San Francisco Bay (the Young Bay Mud). The on-shore deposition of clays is variable. Clays are being deposited within wetlands, lakes, and streams, but those units are discontinuous and have a limited lateral extent. In the southern part of the Study Area (San Leandro/Lorenzo), the soils are primarily expansive clays. In the northern part of the study Area (Berkeley -Albany), the soils are silty.

It is more common to map sand units, but the analysis is much more difficult because little of the necessary information is described on drillers' logs. Sands can deposited in many depositional environments (alluvial fans, eolian, floodplain, various types of channel deposits, etc). Identification of the specific depositional environment requires some knowledge of the tectonic setting, the scale and geometry of the sand unit, and its petrography. This can be further complicated because sand units are typically time transgressive and interfinger with other units.

In California, it has historically been the practice to estimate the permeability/conductivity of sand units without trying to determine their depositional environment. This is a form of sand counting, and it has been used successfully for many years by both oil companies and the USGS. Oil companies found that in the shallow section of the Gulf of Mexico the best reservoirs occurred when the sand percentage was 25 to 35 percent. They would determine the percentage of sand in well logs and would create a sequence of sand percentage maps. Many oil fields were found with this technique.

DWR (1967) used a classical technique, a peg model, to visually map the sub-surface in the Niles Cone area. Wells logs were evaluated using the USGS methodology (DWR, 1967, their table 1). Computers were in their infancy, so a physical model was used to interpret the data. They cut wooden dowels to a scaled length of the well, and painted color bands on the pegs (at their scaled depth and thickness) corresponding to the type of sediments reported on the drillers log. Colors used were red for gravel, yellow for sand, green for sandy clay, blue for silt or clay, and vertical stripes for combinations. The pegs were then placed vertically on a map of the area (there was a 40:1 exaggeration), and the model was visually analyzed and correlated (the datum was 600 feet below sea level, with the pegs pointing up). Forty three cross-sections were drawn using this model. This may sound primitive, but it was an excellent method by which to qualitatively evaluate the sub-surface.

The USGS used this concept in their analyses of the eastern San Joaquin Valley (Davis, et al., 1959), in San Francisco Bay (Fio and Leighton, 1995), in their regional study of the High Plains aquifer in Colorado, Nebraska, and New Mexico (Gutentag, et al. 1984; Weeks et al. 1993), in the western San Joaquin Valley (Phillips and Belitz, 1991), and in southwestern Ohio (Sminchak et al., 1996). It was also used by DWR (1967). The USGS procedure was simple. The various driller's lithologic descriptions (sand, clay, gravel, silt, etc) were assigned an equivalent specific yield (such as: clay = 3%, sand = 10%, gravel = 20%, etc.). Individual logs were averaged over varying intervals (10 or 20 feet) and the resulting yield values were plotted and contoured. In the High Plains aquifer study, Gutentag, et al. (1984) used a slightly modified version of this technique. After assigning various specific yield values to the driller's picks, the specific yield values within a well were statistically analyzed using the method of moments. This was done to estimate the vertical variability of aquifer parameters. All of these analyses were regional, on the scale of 50 to 100's of miles. On this scale, sand counting provided a reasonable first order approximation of the sedimentary units because the scale was orders of magnitude larger than the stratigraphic features being evaluated (both vertically and horizontally).

It is difficult to use this technique to evaluate small areas. This method relies on the concept that the aquifer (as defined by the percentage of sand and gravel) has been sufficiently sampled by wells and is widespread. It is difficult to identify small aquifers, such as stream channels using this technique because they will not appear to be statistically significant. At the scale of the Study Area, the lateral stratigraphic inhomogenities overpower the discriminatory ability of the technique.

Similar techniques were used by Maslonkowski (1988), Muir (1993), and Johnson (1994 and 1995) with varying results. Muir (1988) used a pure sand counting method without geologic input. He identified various sand bodies within individual wells, but was unable to determine their relationships within a well or between wells. The most successful analysis was Maslonkowski (1988), who used sand counting, but only as part of an overall geologic interpretation. Johnson (1994 and 1995) recognized the inadequacy of the well log descriptions and used a statistical analysis (variograms) in an attempt to finesse a geologically significant interpretation from the noise of driller's calls. The concept was reasonable, but was not really successful because the well log descriptions were so poor.

With the advent of computers, numerical analysis of well logs has become more common (Mehta et al., 1990; Zacek and Krivanek, 1991; Bardossy, Bogardi, and Kelly, 1990). This type of analysis has two underlying assumptions: the data have been properly recorded (though they may be obscured by noise) and the method used to describe the data is adequate. Unfortunately, it is rare for these assumptions to be valid, and even rarer for a study to analyze the suitability of the basic data.

The problems that most statistical analysis of well data face are that they try to identify a signal in data that are fundamentally flawed (eg: Johnson). Some studies try and get around this problem by analyzing lots of data, but increasing the volume does not improve quality. In geophysical terms, this is called the problem of downward continuation or aliasing. That is, one cannot create data where none exists. This does not mean that statistical analysis is wrong or should not be utilized, but the limitations of the original data and how they affect subsequent analyses must be recognized.

The same problem was faced by the Kansas and New Mexico Geological Surveys in their hydrogeologic analyses of alluvial filled basins similar to San Francisco Bay. The New Mexico Geological Survey (Hawley and Lozinsky, 1992; Hawley and Haase, 1992; and Hawley, personal communication, 1997) were able to divide alluvial basin fill in the Mesilla and Albuquerque basins into ten mappable lithofacies subdivisions with distinctive geophysical, geochemical, and hydrologic attributes. These units were defined through well log correlations, geologic analysis, sand-fraction petrographic analysis of cuttings (grain-size distribution, mineralogy, sediment structure, and degree of post-depositional alteration [cementation]), and a full suite of borehole geophysical logs.

The Kansas Geological Survey (MacFarlane et al., 1994; Gutentag personal communication, 1997; and the Survey web site 'www.kgs.ukans.edu') performed a state wide hydrogeologic analysis of the Dakota Aquifer. Delineation of hydrostratigraphic units was based on the evaluation of five factors:

- deriving a conceptual lithostratigraphic and sequence stratigraphic framework of the study area, including diagenetic processes and tectonics;
- mapping and evaluation of outcrops;
- subsurface mapping using cores, driller's logs, and geophysical logs;
- laboratory testing of core samples; and

- in-situ hydraulic testing of aquifer and aquitard units.

The analysis relied on the evaluation of thousands of electric logs. These logs provided the information necessary to evaluate the depositional environment of the units and estimate the porosity/permeability of the various aquifer and aquitard units. Temperature logs (standard thermal logs and high-resolution distributed optical fiber logs) were also used to define aquifers/aquitards. Stochastic modeling was used to develop a high-resolution model of aquifer (lithic) heterogeneity in the Terra Cotta Clay Member of the Dakota Sandstone. The mapping (contouring) appeared to be based on either a minimum curvature spline or Kriging.

Kriging is used in many geologic statistical analyses. It involves the fitting of a three-dimensional surface (a high order polynomial equation) to the data using a criterion of minimum variance or covariance (variograms) between the data and the surface. Kriging assumes that there is a form to the underlying surface and that the data are a probabilistic approximation of this surface. A variogram is a measure of the similarity between data values as a function of the separation between their locations. The differences between the various types of kriging are based on the nature of the equations (variogram, semivariogram, covariance, autocovariance) used to predict a value at a location. Other types of analyses, Triangle, Rectangle and Neighborhood interpolants (such as TIN), do not assume a form of the underlying surface. Instead, they assume that the data are true representations of the surface (with no superimposed noise). Noise in the data can be a real problem with interpolant analysis. [See Watson (1992) and North (1996, p. 460) for an excellent description of the analysis of spatial data. For more rigorous descriptions, scan the last ten years of the Journal of Mathematical Geology.]

May and Schmitz (1996) and Schmitz and May (1996) used a multi-staged process to evaluate well data. They were primarily interested in locating sand bodies. Well samples were collected and the depositional environment was estimated based on grain size, grain content, sedimentary structure, electric logs, geophysics, etc. This information was used to estimate the size and distribution of the sand body. That data were then statistically analyzed using Kriging and variograms to estimate the possible extent and location of the sand body away from the borehole.

Barrash and Morin (1997) and Barrash et al. (1997) found that drilling logs (or even samples) were not adequate by themselves in identifying hydrologically significant lithologic units/variations in gravel and sand aquifers. Combining a full suite of borehole electric logs with principal component analysis (multivariate analysis of the percentage of sand, gravel, and clay from borehole samples) provided a reasonable method to identify hydrologically significant sedimentary units. Hydrologic characteristics were evaluated from the electric logs (cross-plots, and porosity) and boreholes testing (slug tests and heat-pulse flowmeter measurements). Mackey and Bridge (1995) evaluated the three-dimensional nature of alluvial fans. This was a theoretical forward analysis, but it provided a good analysis of the details of the depositional nature and environment of alluvial fans over time.

A combination of techniques is necessary to geologically/hydrogeologically evaluate the sub-subsurface. These techniques include: analysis of surrounding outcrops (such as done by Anderson et al, 1997); adequate description, sampling and testing of boreholes, including a full suite of electric logs; hydrologic testing of various units; and a basin wide geologic integration of the data.

REFERENCES

AGS, Inc, 1993a, Foundation Report Underpass, Overhead, Retaining Walls, and Soundwall Richmond Parkway, Section 1B-North Richmond California; unpublished report for the City of Richmond, Job No. SF0040A, dated July 23, 1993, ≈80 pp. [City of Richmond]

AGS, Inc, 1993b, Foundation Report Castro Street Overhead, Richmond Parkway, Section 1A, Richmond California; unpublished report for the City of Richmond, Job No. SF00405, dated April 1993, ≈80 pp [City of Richmond]

Anderman Jr., W.H., 1980, The Effect of Size and Maintenance on Life Expectancy of Septic Tank Systems; unpublished doctoral dissertation, University of California at Los Angeles, Department of Public Health, (unnumbered, but approximately 200 pages)

Anderson, S., Link, P.K., and Ore, H.T., 1997, Sedimentology and Hydrogeology of the Pleistocene Bear River Delta, Cache Valley, Idaho; in Proceedings of the 32nd symposium on Engineering Geology and Geotechnical Engineering, p. 325-340

Anonymous, 1886?, Quality of the Water Furnished by Contra Costa Water Company; unpublished report for the Oakland City Council, 4 pp. [WRCA]

Anonymous, 1917, A Brief History of the Water Companies which have Supplied With Water the Cities and Towns of the East Shore of San Francisco Bay for the Years 1866-1917, unpublished report, 11 pp. [WRCA G4421-D7]

Anonymous, 1989, Alameda County Water District, A Brief History; unpublished pamphlet by the Alameda County Water District, dated May 1, 1989, 23 pp.

Arden, D.D., 1961, Sediments from Borings Along the East Side of San Francisco Bay; unpublished doctoral dissertation, University of California at Berkeley, Department of Paleontology, 202 pp.

Army Corps of Engineers, 1963, Comprehensive Survey of San Francisco Bay and Tributaries, California, Appendix E, Geology, Soils, and Construction Materials; unpublished report part of the Technical Report on San Francisco Bay Barriers, dated March 1963, 144 pp. and 107 plates [at Corps of Engineers library, San Francisco]

Note: Where listed, the information in brackets is the library and call number of the report.

WRCA is the Water Resources Center Archives at UC Berkeley.
BAN is the Bancroft Library at UC Berkeley
MAIN is the main library at UC Berkeley
EERC is the Earthquake Engineering Resource Center at the Richmond Field Station
TRAN is the Transportation Library at UC Berkeley
STATE is the State Library in Sacramento
BART is the BART library in Oakland
CDMG is the Division of Mines and Geology Library in Sacramento
USGS is the United States Geological Survey Libray in Menlo Park
SFSU San Francisco State University

Some of the references are not referred to in the text. They are obscure reports that have hard data, but the data was too site specific for this report. Those references were listed so future researchers are able to find them.

Atwater, B.F., 1979, Ancient Processes at the Site of Southern San Francisco Bay: Movement of the Crust and Changes in Sea Level; in: San Francisco Bay: the Urbanized Estuary, 58th meeting of the Pacific Division/American Association for the Advancement of Science on June 12-16, 1977, edited by Conomos, T. J., Leviton, A.E., and Berson, M., p 31-45

Atwater, B.F., Hedel, C.E., and Helley, E.J., 1977, Late Quaternary Depositional History, Holocene Sea Level Changes, and Vertical Crustal Movement, Southern San Francisco Bay, California; U. S. Geological Survey, Professional Paper 1014, 15 pp.

Atwater, B.F., Ross, B.E., and Wehmiller, J.F., 1981, Stratigraphy of Late Quaternary Estuarine Deposits and Amino Acid Stereochemistry of Oyster Shells Beneath San Francisco Bay California; Quaternary Research, v. 16, p. 181-200

Aydin, A, and Page, B., 1984, Diverse Pliocene-Quaternary Tectonics in a Transform Environment, San Francisco Bay Region, California; Geol. Soc. America, v.95, p. 1303-1317

Bailey, P., 1920a, Engineers' Report on Investigations on the Niles Cone, 1916-1920; unpublished report to the State Water Commission of 1916, dated May 1920, 175 pp.[WRCA Harding 26-1] - Note: a summary of this report was published in the third Biennial Report of the State Water Commission, Appendix E, 1921

Bailey, P., 1920b, The Precise Determination of Replenishment and Draught from the Niles Cone Aquifer, unpublished masters thesis, Stanford University.

Bardossy, A., Bogardi, I., and Kelly, W.E., 1990, Kriging with Imprecise (Fuzzy) Variograms; Jour. of Mathematical Geology, v. 22, p. 63-81

Barrash, W., and Morin, R., 1997, Recognition of Units in Coarse, Unconsolidated Braided-stream Deposits from Geophysical Log Data with Principal Components Analysis; Geology, v. 25, p. 687-690

Barrash, W., Morin, R.H., and Gallegos, D.M., 1997, Lithologic, Hydrologic and Petrophysical characterization of an Unconsolidated Cobble-and-sand Aquifer Capital Station Site, Boise, Idaho, in Proceedings of the 32nd symposium on Engineering Geology and Geotechnical Engineering, p. 307-321

Bechtel, 1965a, Soil Investigation Segment A704, Segment A001, Southern Alameda County Line BART: unpublished report for BART, dated December 1965, ≈150pp. [BART]

Bechtel, 1965b, Soil Investigation Segment A704, Segment A002, Southern Alameda County Line BART: unpublished report for BART, dated December 1965, ≈150pp. [BART]

Bechtel, 1965c, Soil Investigation Segment A704, Segment A003, Southern Alameda County Line BART: unpublished report for BART, dated December 1965, ≈150pp. [BART]

Bechtel, 1965d, Soil Investigation Segment A704, Segment A004, Southern Alameda County Line BART: unpublished report for BART, dated December 1965, ≈150pp. [BART]

Bechtel, 1966a, Soil Investigation Segment K702, Segment K002, West Oakland Line BART: unpublished report for BART, dated March 1966, ≈100pp. [BART]

Bechtel, 1966b, West Oakland Line- Segment K002, Appendix B Laboratory Test Results, unpublished report for BART, ≈120pp. [BART]

Bell, H.H., 1947, George C. Pardee and the Oakland Water Supply, 1889-1890; unpublished masters thesis, University of California at Berkeley, History Department, 124 pp.

Bennett, M.J., 1979, Depositional Environments and Geotechnical Properties of Quaternary Sediments From South San Francisco Bay, San Mateo County, California, unpublished masters thesis, San Jose State University, Department of Geology, 133 pp.

Berg, R.R., 1970, Identification of Sedimentary Environments of Reservoir Sandstones; Gulf Coast Assoc. Geol. Soc. Trans., v. 20, p. 137-143

Binkley, T.C. and Dunn, W.G., 1955, Water Suppy Investigation, Part I - Water Works Investigation; unpublished report for the Alameda County Water District, dated October, 1955, ≈30 pp.

Blair, T.C. and McPherson, J.G., 1994, Alluvial Fans and their Natural Distinction from Rivers Based on Morphology, Hydraulic Processes, Sedimentary Processes, and Facies Assemblages; Jour. of Sedimentary Research, v. 64, p. 45-489 also: Discussion, 1995, Jour. Sedimentary Research, v. 65, p. 408-415

Blake, R.G., Noyes, C.M., and Maley, M.P., 1995, Hydrostratigraphic Analysis- The Key to Cost-Effective GroundWater Cleanup at Lawrence Livermore National Laboratory; Lawrence Livermore National Laboratory paper # UCRL-JC-120614 (also published in Proceedings, Environmental Remediation '95, Denver Co., August 13-18, 1995)

Bliven, B., 1959, The Boodling Boss and the Musical Mayor; American Heritage, v. 11, no. 1, p. 8-11

Blow, B., 1920, California Highways, a Descriptive Record of Road Development by the State and by such Counties as have Paved Highways; H.S. Crocker Co., San Francisco, 308 pp. [TRANS TE 24 C2B6]

Bolin, W.W., 1913, A Report Upon the Water Distribution System of Berkeley, California; unpublished Senior thesis, University of California at Berkeley, Civil Engineering Department, 41 pp.

Bowhill, T., 1895, The Alvarado Artesian Water of the Oakland Water Company Compared with the Surface Waters of Lake Temescal and Lake Chabot; unpublished report for the Oakland Water Company, dated December 17, 1895 [BAN F869.02 B64]

Brabb, E.E. and Pampeyan, E.H., 1983, Geologic Map of San Mateo County, California; United States Geological Survey, Miscellaneous Investigation I-1257-A

Brewer, R.C., Bolton, J.C., and Driese, S.G., 1990, A New Classification of Sandstone; Jour. of Geological Education, v. 38, p. 343-347

Brown, V.M., Harrell, J.A., 1991, Megascopic Classification of Rocks; Jour. Geological Education, v. 39, p. 379-387

Bull, W.B., 1964, Geomorphology of Segmented Alluvial Fans in Western Frenso County, California, U.S. Geological Survey, Professional Paper 352-E, 129 pp.

Burgess, S.D., 1948, Early History of the Oakland Water Supply, 1880-1876; unpublished masters thesis, University of California at Berkeley, History Department, 143 pp.

Burgess, S.D., 1992, The Water King, Anthony Chabot, His Life and Times; Panorama West Publishing, Davis, California, 197 pp.

Burns, B.A., Heller, P.L., Marzo, M., and Paola, C., 1977, Fluvial Response in a Sequence Stratigraphic Framework: Example from the Montserrat Fan Delta, Spain; Jour. of Sedimentary Research, v. 67, p. 311-321

Burow, K.R, Weissmann, G.S., Miller, R.D., and Placzek, G., 1997, Hydrogeologic Facies Charactgerization of an Alluvial Fan Near Fresno, California, Using Geophysical Techniques; USGS Open File Report 97-46

Buwalda, J.P., 1929, Nature of the Late Movements on the Hayward Rift, Central California; Bull. Seisomol. Soc. of America, v. 19, p. 186-199

Carle, S.F., 1996, A Transition Probability-Based Approach to Geostatistical Characterization of Hydrostratigraphic Architecture; unpublished Doctoral Dissertation, University of California at Davis, Department of Land, Air, and Water Resources, 182 pp.

California Department of Public Works, 1930, San Francisco Bay Bridge; unpublished report to the Hoover-Young San Francisco Bay Bridge Commission, dated July, 1930, 257 pp.[TRAN TG25 S22A2 D1]

California Department of Public Works, 1947, Preliminary Studies for an Additional Bridge Between San Francisco and the East Bay Metropolitan Area; unpublished report to the California Toll Bridge Authority, dated January 31, 1947, ≈200pp [TRAN TG25 S223C3]

California Division of Bay Toll Crossing, 1948, A Report to Department of Public Works on Additional Toll Crossings of San Francisco Bay; unpublished report to the Department of Public Works, dated November, 1948, 144 pp. [TRAN TG25.S223 C35 1948]

California Division of Bay Toll Crossing, 1949, Log of Borings, 1948-1949, San Francisco Bay Bridge; unpublished report to the Department of Public Works, no date, 45 pp. [TRAN TG25.S223 C68 1949]

California Division of Bay Toll Crossing, 1950, Final Report on Preliminary Foundation Explorations for the Richmond-San Rafael Bridge Project, Contract 1002; unpublished report to the Department of Public Works, dated November 28, 1950, ≈50 pp. [TRAN TG25 R5 C64]

California Division of Bay Toll Crossing, 1951, On Proposed Highway Toll Crossing - Richmond San Rafael Bridge; unpublished report to the Department of Public Works, dated January 2, 1951, 233 pp. [TRAN TG25 S23 C37 1951]

California Division of Bay Toll Crossing, 1955a, Final Report on Foundation Explorations for the Southern Crossing of San Francisco Bay, Contract No. 2001; unpublished report to the Department of Public Works, dated September 1, 1955, 115 pp. [TRAN TG25 S223--]

California Division of Bay Toll Crossing, 1955b, The Southern Crossing of San Francisco Bay, unpublished report to the California Department of Public Works, dated December, 1955, [TRAN TG25 S223 C68 1955]

California Division of Bay Toll Crossing, 1957, Richmond-San Rafael Bridge; Fourth Annual Report, dated March 1, 1957 [TRAN TG25 S223 R88 1956]

Caltrans, 1978, Ground Water Investigation for the Richmond Semi-Depressed Section, report 04-CC-17, dated September, 1978, 158 pp

City Club of Berkeley, 1923, Report of Committee on Municipal Ownership of Water; The Berkeley Civic Bulletin, Vol. 10, no. 1, [WRCA Galloway-81(2)]

Clark, W.O., 1915, Ground-water Resources of the Niles Cone and Adjacent Areas, California; United States Geological Survey Water Supply Paper 345-H, 168 pp.

Commonwealth Club, 1904, Swamp Land Reclamation; Trans. of the Commonwealth Club, San Francisco, California, vol. 1, no. 4, dated October 15, 1904, p. 3-47

Commonwealth Club, 1914, The Water Commission Act, the Blue Sky Law and other Measures; Trans. Commonwealth Club, San Francisco, California, vol. 9, no. 11, dated October 1914, p. 581-587

Commonwealth Club, 1926, Drought in California; The Commonwealth, the Journal of the Commonwealth Club, San Francisco, California, vol. 2, no. 52, dated December 28, 1926, p. 474-523

Commonwealth Club, 1929, The Salt Water Barrier; The Commonwealth, the Journal of the Commonwealth Club, San Francisco, California, vol. 5, no. 53, dated December 31, 1929, p. 419-479

Contra Costa Water Company vs. City of Oakland, 1913-14, transcript of court case in District Court, Northern California, second Division, No. 13599 and 13765, ≈7,000 pages [in locked cage, Oakland Historical Room, Oakland Public Library; ground water information is in vols. 11 and 13]

Robert S. Cooper and Associates, 1964, Soil Investigation R708 El Cerrito: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated July 31, 1964, ≈100pp. [BART]

Robert S. Cooper and Associates, 1965a, Soil Investigation R709 Richmond: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated 1965, ≈100pp. [BART]

Robert S. Cooper and Associates, 1965b, Soil Investigation R710 Richmond: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated 1965, ≈100pp. [BART]

Robert S. Cooper and Associates, 1965c, Soil Investigation portion of Southern Alameda Line Segment A006: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated August 31, 1966, ≈150pp. [BART]

Robert S. Cooper and Associates, 1966, Foundation Investigation R709 Richmond: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated May 14, 1965, ≈100pp. [BART]

Robert S. Cooper and Associates, 1967, Foundation Investigation and Testing for Pavement Design, Proposed Maintenance of Way and Structure Facility, Oakland, California: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated September 20, 1967, ≈75 pp. [BART]

Cory, H.T., 1914, Water Supply of the San Franciscan-Oakland Metropolitan District; American Society of Civil Engineers, vol. 40, no. 7, p. 2101-2187 also see discussion, p. 3175-3185

Cressie, N., 1990, The Origins of Kriging; Mathematical Geology, v. 22, p. 239-252

Dalrymple, R.W., Zaitlin, B.A., and Boyd, R., 1992, Estuarine Facies Models: Conceptual Basis and Stratigraphic Implications; Jour of Sedimentary Petrology, v. 62, p. 1130-1146 also: Discussion, 1994, v. 64, p. 74-75

Dames & Moore, 1963, Soil Investigation K705 Oakland- 8th and 9th Streets: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated December 9, 1963, ≈150pp. [BART]

Dames & Moore, 1964, Report on Soils Investigation Segment R-005 Berkeley California BART: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated January 3, 1964, ≈100pp. [BART]

Dames & Moore, 1965a, Report on Soils Investigation Segment B-002 Oakland California BART: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated May 28, 1965, ≈100pp. [BART]

Dames & Moore, 1965b, Report on Soils Investigation Segment B7042 Maritime Street-West Oak. Sta.: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated June 16, 1965, ≈100pp. [BART]

Dames and Moore, Inc., 1980, Report, Confidential Ground Water and Subsurface Conditions Investigation Richmond, California, unpublished report for Chevron Chemical Company, Job No. 03818-058-03, dated October 29, 1980, ≈200 pp. [RWQCB]

Dames and Moore, Inc., 1981, Report Groundwater Investigation Richmond, California Refinery for Chevron USA, Inc., unpublished report for Chevron USA, Job No. 00113-531-03, dated May 18, 1981, ≈200 pp. [RWQCB 810518]

Daniels, P.I., 1921 Collecting and Distributing a Domestic Water Supply; unpublished report East Bay Water Company, 25 pp. [BAN xF869.O2 O23 v:4:4, also WRCA 41-E2]

Darling, I.J., 1935, The East Bay Municipal Utility District; unpublished masters thesis, University of California at Berkeley, Political Science Department, 71pp.

Davis, A.P., 1924, Additional Water Supply of East Bay Municipal Utility District; unpublished report to the Board of Directors, East Bay Municipal District, dated October 1, 1924, 17 pp. [WRCA G4421-E4]

Davis, G.H., Green, J.H., Olmstead, F.H., and Brown, D.W., 1959, Groundwater Conditions and Storage Capacity in the San Joaquin Valley, California; US Geological Survey, Water Supply Paper 1469, 279 pp.

Dawkins, F., 1983, Water and the Settlement of Berkeley; in - Berkeley Water: Issues and Resources, edited by Sloan, D and Stine, S., unpublished Senior Seminar, University of California at Berkeley, Environmental Sciences Group Major, p. 23-32

de Jonge, C.P, and Meyer, J.G., 1928, A Report on a Drainage System for the Oakland Airport; unpublished senior thesis, University of California at Berkeley, Civil Engineering, 31 pp. [WRCA TC7.4 D327cu]

Division of Water Resources, 1931, Economic Aspects of a Salt Water Barrier, Bulletin 28, 450 pp. [STATE P2500 B9 no. 28-28A]

Dockweiler, J.H., 1912, Report on Sources of Water Supply, East Region of San Francisco Bay; unpublished report for the Cities of Oakland and Berkeley, dated April 10, 1912, 509 pp. [BAN mF868.S156D56]

Dockweiler, J.H., 1913, Measurements and Map of Wells in Niles Cone; unpublished report to The City Engineer of San Francisco, dated January 15, 1913, 11 pp [WRCA Bartell-20]

Dockweiler, J.H., 1916, Report on Water Supply; unpublished report for the Richmond Municipal Water District, Richmond, California, Dated February 15, 1916 [WRCA Bartlett-8]

Dornberger, S., 1935, The Struggle for Hetch-Hetchy, 1900-1913; unpublished masters thesis, University of California at Berkeley, History Department, 55 pp. [MAIN]

Dow, G.R., 1973, Bay Fill in San Francisco: A History of Change: unpublised masters thesis, San Francisco State Univ, Dept. of Geography, 249pp.

Dragon, L., 1932, The Reclamation of the Suisun Marshes, unpublished senior thesis, University of California at Berkeley, Civil Engineering, 63 pp. [WRCA TC7.4 O759]

DWR, 1950, Sea-water Intrusion into Ground Water Basins Bordering the California Coast and Inland Bays; Water Pollution Investigations, Report #1, Dated December, 1950, 29 pp. [MAIN]

DWR, 1952, Ground Water Basins in California, Water Quality Investigations, Report 3, dated November, 1952, 45 pp.

DWR, 1955a, Feasibility of Construction by the State of Barriers in the San Francisco Bay System; in: Report to the Water Project Authority of the State of California, dated March, 1955, ≈100 pp. [TRANS TG 25.5 S22C90 1955 D1]

DWR, 1955b, Economic Development of San Francisco Bay Area, Appendix A; in Report to the Water Project Authority of the State of California, dated Octobter 1955, ≈150pp. [TRANS TG 25.5 S22C90 App. A 1955 D1]

DWR, 1955c, Geology, Appendix H; in Report to the Water Project Authority of the State of California, dated June 1955, ≈75 pp. [TRANS TG 25.5 S22C90 App. H 1955 D1]

DWR, 1958, Quality of Ground Waters in California, 1955-1956; Bulletin 66, 230 pp.

DWR, 1960, Intrusion of Salt Water into Ground Water Basins of Southern Alameda County; Bulletin 81, 44 pp.

DWR, 1963a, South Bay Ground Water Basins Investigation; Bay Area Branch, first progress report, dated July 1963, 21 pp, [MAIN]

DWR, 1963b, Alameda County Investigation; Bulletin 13, dated March, 1963 196 pp.

DWR, 1967, Evaluation of Ground Water Resources, South Bay, Appendix A: Geology; Bulletin 118-1, 153 pp.

DWR, 1968, Evaluation of Ground Water Resources: South San Francisco Bay, Volume I, Fremont Study Area; Bulletin 118-1, 117 pp.

DWR, 1973, Evaluation of Ground Water Resources: South San Francisco Bay, Volume II, Additional Fremont Area Study; Bulletin 118-1, 57 pp.

DWR, 1975, Evaluation of Ground Water Resources: South San Francisco Bay, Volume III, Northern Santa Clara County Area; Bulletin 118-1, 153 pp.

DWR, 1985, Reconnaissance Investigation of Ground Water Storage in Santa Clara Valley to Increase Yield of the State Water Project, un-numbered report from the Central District, dated August 1985, 58 pp [MAIN]

DWR, 1994, Groundwater Storage Capacity of a Portion of the East Bay Plain, Alameda County, California; unnumbered report from the Central District, DWR, dated January 1994, 36 pp. [note: this report was authored by E. Senter and is sometimes referenced under his name]

EXLOG, 1981, Field Geologist Training Manual and Formation Evaluation: EXLOG company reports , Sacramento CA [these are training manuals for well site geologists]

Fio, J.L. and Leighton, D.A., 1995, Geohydrologic Framework, Historical Development of the Ground-water System and General Hydrologic and Water-quality conditions in 1990, South San Francisco Bay and Peninsula Area, California; USGS, OFR 94-357, 46 pp.

Fisher, E.B., 1923, Salinity in the Sacrament and San Joaquin Rivers; unpublished senior thesis, U.C. Berkeley, Civil Engineer Department, 45 pp. [WRCA TC7.4 F533]

Foote, A.D, 1910, The Redemption of the Great Valley of California, Transactions of the American Society of American Engineers, v. 66, p. 229-279

Forbes, H., 1914, Report on the Underground Waters of Niles Cone; unpublished report to Stanford University, 60 pp. [WRCA G 4426 D4 c.1]

Forbes, H., 1924, Ground Water Hydrology and Related Hydrography; 450 pp. [WRCA 64.1 E4 C.1]

Forbes, H., 1925, Geology and Ground Water Hydrology of East Bay Region, Alameda County, California, unpublished report, dated May, 1925 to H.L. Hael, Construction Engineers. 67 pp. [WRCA G4421 E5] [note: none of the maps are in the report. The well location code is keyed to a map that is in the EBMUD files]

Forbes, H., 1949, Effect of Niles-Irvington Section of the Hayward Fault, Bull. Seismological Society of America, V. 39, p.243-247

Ford, M.W., 1923, The East Bay Water Supply and Study of Future Requirements; unpublished seniors report, University of California at Berkeley, Civil Engineering Department, 62 pp. [WRCA]

Fox Jr., K.F., 1983, Tectonic Setting of Late Miocene, Pliocene, and Pleistocene Rocks in Part of the Coast Ranges North of San Francisco, California; USGS prof. paper 1239, 33 pp.

Fumal, T.E., 1978, Correlations between Seismic Wave Velocities and Physical Properties of Near-surface Geologic Materials in the Southern San Francisco Bay Region, California; U.S. Geological Survey open file report 78-1067, 114 pp. [note: this was his masters thesis from U.C. Santa Cruz]

Fumal, T.E., 1991, A Compilation of the Geology and Measured and Estimated Shear-wave Velocity Profiles at Strong-Motion Stations that Recorded the Loma Prieta, California Earthquake; U.S. Geological Survey open file report 91-311, 163 pp.

Fumal, T.E., Gibbs, J.F., and Roth, E.F., 1982, In-situ Measurements of Seismic Velocity at 10 Strong Motion Accelerograph Stations in Central California; U.S. Geological Survey open file report 82-407, 75 pp.

Gale, S.J. and Hoare, P.G., 1992, Bulk Sampling of Coarse Clastic Sediments for Particle-size Analysis; Earth Surface Process and Landforms, v. 17, p. 729-733; also see discussion Earth Surface Process and Landforms, v. 19, p. 255-261 and Reply Earth Surface Process and Landforms, v. 19, p. 262-268

Geomatrix Consultants, 1992a, Seismic Response Study for Proposed Benicia-Martinez Bridge; unpublished report for CALTRANS, contract 59K167, dated December 1992, 250 pp. [EERC 262.82 G46]

Geomatrix Consultants, 1992b, Seismic Ground Motion Study for the West San Francisco Bay Bridge; unpublished report for CALTRANS, contract 59N772, dated December 1992, 200 pp. [EERC 262.82 G46]

Geomatrix Consultants, 1993a, Seismic Response Study for Proposed Carquinez Bridge; unpublished report for CALTRANS, contract 59K167, dated February 1993, 250 pp. [EERC 262.82 G46]

Geomatrix Consultants, 1993b, Seismic Ground Motion Study for San Mateo-Hayward Bridge; unpublished report for CALTRANS, contract 2016G, dated February 1993, 325 pp. [EERC 262.82 G46 M27b]

Geomatrix Consultants, 1993c, Seismic Ground Motion Study for Richmond-San Rafael Bridge; unpublished report for CALTRANS, contract 2016G, dated June 1993 , 250 pp. [EERC 262.82 G46]

Geomatrix Consultants, 1993d, Seismic Ground Motion Study for Dumbarton Bridge; unpublished report for CALTRANS, contract 2016G, dated July 1993, 275 pp. [EERC 262.82 G46 D85]

Gibbs, J.F., and Borcherdt, R.D., 1974, Effects of Local Geology on Ground Motion in the San Francisco Bay Region, California, A Continued Study; U.S. Geological Survey open file report 74-222, 132 pp

Gibbs, J.F., and Fumal, T.E., 1994, Seismic Velocities and Geologic Logs from Borehole Measurements at Seven Strong-Motion Stations that Recorded the 1989 Loma Prieta, California, Earthquake, Part IV; U.S. Geological Survey open file report 94-552, 89 pp.

Gibbs, J.F., Fumal, T.E., and Borcherdt, R.D., 1975, In-situ measurements of Seismic Velocities at Twelve Locations in the San Francisco Bay Region; U.S. Geological Survey open file report 75-564, 87 pp.

Gibbs, J.F., Fumal, T.E., and Borcherdt, R.D., 1976, In-situ measurements of Seismic Velocities in the San Francisco Bay Region Part II; U.S. Geological Survey open file report 76-731, 145 pp.

Gibbs, J.F., Fumal, T.E., Borcherdt, R.D., and Roth, E.F., 1977, In-situ measurements of Seismic Velocities in the San Francisco Bay Region Part III; U.S. Geological Survey open file report 77-850, 143 pp.

Gibbs, J.F., Fumal, T.E., Boore, D.M., and Joyner, W.B., 1992, Seismic Velocities and Geologic Logs from Borehole Measurements at Seven Strong-Motion Stations that Recorded the 1989 Loma Prieta Earthquake; U.S. Geological Survey open file report 92-287, 139 pp.

Gibbs, J.F., Fumal, T.E., and Powers, T.J., 1993, Seismic Velocities and Geologic Logs from Borehole Measurements at Eight Strong-Motion Stations that Recorded the 1989 Loma Prieta, California, Earthquake; U.S. Geological Survey open file report 93-376, 119 pp.

Gibbs, J.F., Fumal, T.E., and Powers, T.J., 1994, Seismic Velocities and Geologic Logs from Borehole Measurements at Seven Strong-Motion Stations that Recorded the 1989 Loma Prieta, California, Earthquake; U.S. Geological Survey open file report 94-222, 104 pp

Gillespie, C.G., 1907, A discussion on the Sanitary Aspect of Oakland's Surface Water Supply; unpublished senior thesis, University of California at Berkeley, department of Civil Engineering, 6 pp. [WRCA TC7.4 G478 Cu]

Goldberg, D.S., 1939, The Development and Utilization of Groundwater in California; unpublished masters thesis, University of California at Berkeley, department of Irrigation, 162 pp. [WRCA TC7.4 G618]

Goldman, H.B., 1967, Geology of San Francisco Bay; unpublished report for the San Francisco Bay Conservation and Development Commission, 65 pp. [CDMG QE90 .S156 G65 1967]

Goldman, H.B., 1969, Geology of San Francisco Bay; in Geologic and Engineering Aspects of San Francisco Bay Fill, CDMG Special Report 97, p. 11-29

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming; USGS professional paper 1400-B, 65 pp.

Hansen, A.C., 1903, Rainfall and Runoff of Strawberry Valley; unpublished senior thesis, University of California at Berkeley, department of Civil Engineering, 6 pp. [WRCA TC7.4 H249a]

Harding Associates, 1965, Soil Investigation, Southern Alameda Line, Segment A005, Ashland Avenue to Jackson Street, Hayward California; unpublished report for Tudor/Braccia/Bentley, dated October 26, 1965, ≈ 100 pp.

Harding, Miller, Lawson & Associates, Inc., 1972, Soil Investigation San Francisco Bulk Mail Facility Richmond California; unpublished report for Tudor/Braccia/Bentley, job no. 5836,001.04, dated June 26, 1792, 127 pp.

Harroun, P.E., 1908, The New Water Supplies for the Cities of the East Shore of San Francisco Bay; The Engineering Record, Vol. 57, No. 19, p. 609-611

Harroun, P.E., 1920, Report to the Water Commission of the East Bay Cities on Water Supply; unpublished report, dated April 14, 1920, 45 pp. [WRCA G4421-E, also MAIN TD 225 Q3H3 1920]

Haviland, Dozier & Tibbetts, 1913, Report on Proposed Water Supply for the Richmond Municipal Water District; unpublished report to the Board of Directors of the Richmond Municipal Water District, dated December 1913, 109 pp. [WRCA G4482-D3, also MAIN TD 225 R5 H3]

Hawk Engineers, 1964, Report on Soils Investigation Segment R-703 Oakland, Berkeley California BART: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated March 18, 1964, ≈100pp. [BART]

Hawk Engineers, 1965, Report on Soils Investigation Segment R-702 Oakland California BART: unpublished report for Parsons Brinckerhoff Tudor Bechtel, dated August 30, 1965, ≈50pp. [BART]

Hawley, J.W., and Haase, C.S., 1992, Hydrogeologic Framework of the Northern Albuquerque Basin; New Mexico Bureau of Mines and Mineral Resources, Open File Report 387, 62 pp.

Hawley, J.W., and Lozinsky, R.P., 1992, Hydrogeologic Framework of the Mesilla Basin in New Mexico and Western Texas; New Mexico Bureau of Mines and Mineral Resources, Open File Report 323, 55 pp.

Hawley, R.S., 1903, Rainfall and Runoff of Strawberry Valley 1902-03; unpublished senior thesis, University of California at Berkeley, department of Civil Engineering, 6 pp. [WRCA TC7.4 H396]

Hering, R., 1903, Availability of Subterranean Water at Niles; unpublished report to the Citizens' Committee of Oakland California concerning the Municipal Ownership of Water and Available Sources of Supply for Oakland, California, dated January 10, 1903, p. 18-14 [BAN xF869.02 O23 v.4:4]

Hickenbottom, K., and Muir, K., 1988, Geohydrology and Groundwater-Quality Overview, of the East Bay Plain Area, Alameda County, California; unpublished report to the California Regional Water Quality Control Board, San Francisco Bay Region, dated June 1988, 83 pp.

Hickey, L.T., 1907, The Production of Water from Wells, unpublished senior thesis, University of California at Berkeley, department of Civil Engineering, 37 pp. [WRCA TC7.4 H628]

Hilchie, D.W., 1979, Old Electric Log Interpretation; publ. by D. Hilchie, Golden Colo., 159 pp

Hilchie, D.W., 1982, Applied Openhole Log Interpretation for Geologists and Engineers; publ. by D. Hilchie, Golden Colo., ≈250 pp.

Hogenson, G.M., Wahl, K.D., and Brennan, R., 1960, Effects of Proposed Salinity-Control Barriers in San Francisco Bay, California Upon Ground-Water Resources; United States Geological Survey, Open File Report (no number), revised March 14, 1967, 99 pp.

Hooker, W.H., 1916, A Study of the Sources of the Water Supply for the Region East of San Francisco Bay; unpublished seniors report, University of California at Berkeley, Civil Engineering Department, 49 pp. [WRCA]

Howard, K.A., 1962, Pleistocene Geology of the Berkeley Campus of the University of California, unpublished masters thesis for the department of Geological Engineering, U. C. Berkeley, 48pp.[note: I got a copy from the author, there is no library copy at this time]

Hoover-Young Commission, 1930, San Francisco Bay Bridge; unpublished report of the Hoover-Young San Francisco Bay Bridge Commission, dated August, 1930, 201 pp [EERC 630 H67 1930]

Hudson, J.D., 1996, Use of Geophysical Logs to Estimate the Quality of Ground Water and the Permeability of Aquifers; USGS Water Resources Investigations Report 95-4300

Hutchinson, F.C., 1962, Street Names of the City of Berkeley, unpublished report for the Berkeley Public Library, 20 pp [at reference desk of main Berkeley Public Library]

Iwamura, T.A., 1980, Saltwater Intrusion Investigation in the Santa Clara County Baylands Area, California; unpublished report for the Santa Clara Valley Water District, dated September 1980, 96 pp

Jarvis, C.S., 1921, Control of Flood and Tidal Flow in the Sacramento and San Joaquin Rivers, California; Trans. American Soc. of Civil Engineers, paper 1472, v. 84, p, 455-488

Johnson, N.M., 1994, Analysis of Alluvial Hydrostratigraphy Using Indicator Geostatistics, with Examples from Santa Clara Valley, California; unpublished Doctoral Dissertation, University of California at Santa Cruz, Department of Earth Sciences, 213 pp.

Joint Army-Navy Board, 1947, Report of Joint Army-Navy Board on an Additional Crossing of San Francisco Bay; unpublished report, dated 1947, [TRAN TG25 S223 U5 with 8 appendix]

Kessell, J., 1997, Geologic Framework of the East Bay Plain for Groundwater Use Planning in Hayward, California; Unpublished Senior Thesis, San Francisco State University, Dept. of Geology, 63 pp.

King, Chi-Yu, 1981, Fault-Zone Water and Gas Monitoring; in Summaries of Technical reports, volume XII for the National Earthquake Hazards Reduction Program, USGS, OFR 81-833, p. 375-376 [USGS Menlo Park 240.5 U3 v.12]

Koltermann, C.E.M., 1993, Geologic Modeling of Spatial Variability in Sedimentary Environments for Groundwater Flow Simulation: unpublished Doctoral Dissertation, Stanford University, Department of Applied Earth Sciences, 311 pp

Kondor, R., 1983, Water, Water, Everywhere, or was There?; in - Berkeley Water: Issues and Resources, edited by Sloan, D and Stine, S., unpublished Senior Seminar, University of California at Berkeley, Environmental Sciences Group Major, p. 33-44

Kraus, M.J. and Aslan, A., 1993, Eocene Hydromorphic Paleosols: Significance for Interpreting Ancient Floodplain Processes; Jour. of Sedimentary Petrology, v. 63, p. 453-463

Kuhn, M.W., 1965, Ground Water in the Santa Clara Valley, Santa Clara County, California; unpublished masters thesis, University of California at Los Angeles, Department of Geography, 153 pp.

LeConte, L.J., 1900, Report on the Conditions of the Water Supply of the Cities of Oakland, Alameda and Berkeley; unpublished report to Mr. Quilty, dated August 27, 1900, 5 pp. [WRCA SCHU 77.6]

Lee, C.H., 1905, An Investigation of Water-Supply Possibilities in the Neighborhood of the University Campus; unpublished Senior thesis, University of California at Berkeley, 44 pp.

Lefler, H.A., 1910, The History of Water and Water Companies in the City of Oakland, 1866-1910; unpublished report in the East Bay Municipal Utilities District files, 53 pp.

Leighton, D.A., Fio, J.L., and Metzger, L.F., 1995, Database of Well and Areal Data, South San Francisco Bay and Peninsula Area, California; USGS Water Resources Investigation Report 94-4141, 47 pp.

Leighton, D.A., Fio, J.L., and Metzger, L.F., 1994, Data base of well and areal data, south San Francisco Bay and Peninsula area, California; USGS Water-Resources Investigations Report 94-4151, 47 pp.

LeVan, J.D., 1924, The East Bay Water Problems, unpublished senior report, Department of Civil Engineering, University of California at Berkeley, dated November 15, 1924, 51 pp [BAN mF862.25 C59 #7]

Mackey, S.D. and Bridge, J.S., 1995, Three-Dimensional Model of Alluvial Stratigraphy: Theory and Application: Jour. of Sedimentary Research, v. B65, p. 7-31

Maill, A.D., 1984, Principles of Sedimentary Basis Analysis, New York, Springer-Verlag, 480 pp.

Maill, A.D., 1985, Architectural-element Analysis: A new Method of Facies Analysis Applied to Fluvial Deposits: *in* Recognition of Fluvial Depositional Systems and their Resource Potential: SEPM short course notes 19, p. 33-81

Maill, A.D., 1992, Alluvial Deposits, *in* Walker, R.G. and James, N.P., eds., Facies Models: Response to Sea-Level Change, Toronto, Geological Society of Canada, p. 119-142

Maill, A.D., 1994, Reconstructing Fluvial Macroform Architecture from Two-Dimensional Outcrops: Examples from the Castlegate Sandstone, Book Cliffs, Utah; Jour. of Sedimentary Research, v. 64, p. 146-158

Maslonkowski, D. P., 1988, Hydrogeology of the San Leandro and San Lorenzo Alluvial Cones of the Bay Plain Groundwater Basin, Alameda County, California; unpublished masters thesis for San Jose State University, Department of Geology, 143 pp.

May, J.H. and Schmitz, D.W., 1996, Development of a Predictive Model for Defining Subsurface Sand Bodies; Engineering Geology, v. 42, p. 175-186

McCloskey, T.F. and Finnemore, E.J., 1996, Estimating Hydraulic Conductivities in and Alluvial Basin from Sediments Facies Models; GroundWater, v. 34, p. 1024-1032

McFarland Jr., H.J., 1926, The Growth of Municipalized Water Service in California; unpublished masters thesis, University of California at Berkeley, Political Science Department, 147 pp.

McLean, W.R., 1933, Repairs to Levee and Flood Gates, Fitchburg Property: unpublished internal EBMUD report (feature report no. 14), dated December 21, 1933, 6 pp.[WRCA MS 76/7 40]

McLean, W R., 1938, Repairs to Berryman Tunnel: unpublished internal EBMUD report (feature report no. 26), dated November 1, 1938, 5 pp.[WRCA MS 76/7 6]

Mehta, C.H., Radhakrishnan, S., and Srikanth, G., 1990, Segmentation of Well Logs by Maximum-Likelihood Estimation; Jour. of Mathematical Geology, v. 22, p. 853-869

Merritt, F.C., 1928, History of Alameda County California; S.J. Clarke Publishing Company, Volume I, 694 pp.

Metzger, L.F. and Fio, J.L., 1997, Ground-Water Development and the Effects of Ground-Water Levels and Water Quality in the Town of Atherton, San Mateo County, California; USGS Water Resources Investigations Report 97-4033

Miller, M.K., 1903, Groundwater sources in Oakland; unpublished report to the Citizens' Committee of Oakland California concerning the Municipal Ownership of Water and Available Sources of Supply for Oakland, California, dated January 10, 1903, p. 41-50 [BAN xF869.02 O23 v.4:4]

Muir, K., 1993, Geologic Framework of the East Bay Plain Groundwater Basin, Alameda County California, unpublished report to the Alameda County Flood Control and Water Conservation District, Dated August, 1993, 37 pp. [WRCA G4421 N3-2]

Mukhopadhyay, A.K., 1981, Politics of Water Supply, the Case of Victorian London; pub. by World Press Private, Ltd, Calcutta, India, 235 pp. [MAIN]

Myrow, P.M., 1990, A New Graph for Understanding Colors of Mudrocks and Shales; Jour. of Geological Education, v. 38, p. 16-20

Nadon, G.C., 1994, The Genesis and Recognition of Anastomosed Fluvial Deposits: Data from the St. Mary River Formation, Southwestern Alberta, Canada; Jour. Sedimentary Research, v. 64, p. 451-463

Neton, M.J., Dorsch, J., Olson, C.D., and Young, S.C., 1994, Architecture and Directional Scales of Heterogeneity in Alluvial-Fan Aquifers; Jour of Sedimentary Research, v. 2, p. 245-257

Noble, J.W., 1970, Its Name was M.U.D.; published by the East Bay Municipal Utility District, 178 pp.

North, C.P., 1996, The Prediction and Modeling of Subsurface Fluvial Stratigraphy; *in*: Advances in Fluvial Dynamics and Stratigraphy, P.A. Carling and M.R. Dawson eds., p. 395-508

Oakland Chamber of Commerce, 1923, Report on the East Bay Water Problem; unpublished report, dated March 3, 1923, 25 pp. [WRCA G4421-E3]

Oakland Free Library, 1930, An Oakland Chronology; unpublished pamphlet, dated May 4, 1930, 9 pp. [BAN xF869.O2 O23 v:4:4]

Patterson, W.D., 1955, The Alameda County Water District; as told to John E. Caswell [BAN C-D-405]

Phillips, S.P. and Belitz, K., 1992, Calibration of a Texture-Based Model of a Ground-Water Flow System, Western San Joaquin Valley, California; GroundWater, v. 29, p. 702-715

Pierce, J.W, 1948, Salt Water Infiltration into the Alameda County Water District; unpublished Dissertation, Stanford Univ (Dept of Geol.) [Brand Lib. 3781 S78 P]

P B Q & D, 1965, Soil Investigation Segment B7200, Trans-Bay Tube, unpublished report for BART by Parsons Brinckerhoff Tudor and Bechtel, dated August 1965, ≈ 80 pp. [BART]

Posey, G.A., and Tibbetts, F.H., 1924, Bay Farm Island, Alameda County; unpublished report to Alameda Investment Company Oakland, California, dated November 20, 1924, 60 pp. [WRCA MS-76/8] there is also a copy in the state library (the topographic map is missing from both copies)

Powers, T.J. and Fumal, T.E., 1993, Geologic Logs from 25 Boreholes Near Strong Motion Accelographs that Recorded the 1989 Loma Prieta, California Earthquake, U.S. Geological Survey open file report 93-502, 176 pp.

Prims, J. and Furlong, K.P., 1995, Subsidence of San Francisco Bay: Blame it on Salinia; Geology, v. 23, p. 559-562

Provenzano & Associates, Inc., 1993, Materials Report Richmond Parkway Project Section 4B; unpublished report for the City of Richmond, dated July 1993, ≈70 pp. [City of Richmond]

Provenzano & Associates, Inc., 1994, Foundation Report Richmond Parkway Project Section 4B; unpublished report for the City of Richmond, dated May 9, 1994, ≈60 pp. [City of Richmond]

Purcell, M.F., 1940, History of Contra Costa County; the Gillick Press, Berkeley California, 742 pp.

Quilty, E.G. and Roeloffs, E.A., 1994, Water Level Observations in the East San Francisco Bay Area, California; USGS open file report 94-418, 17 pp.

Radbruch, D.H., 1957, Aeral and Engineering Geology of the Oakland West Quadrangle; U. S. Geological Survey, Map I-239

Radbruch, D.H., 1969, Aeral and Engineering Geology of the Oakland East Quadrangle; U. S. Geological Survey, Map GQ-769

Reed, W.G. and Loy, H.M., 1915, Water Resources of Strawberry Creek, Berkeley California; The Monthly Weather Review, vol. 43, p. 35-39

Rogers, J.D. and Figuers, S.H., 1991, Engineering Geologic Site Characterization of the Greater Oakland-Alameda Area, Alameda and San Francisco Counties, California; unpublished report for the National Science Foundation (grant #BCS-9003785), 52 pp [EERC]

Romanucci, J., 1983, Groundwater in Berkeley; in - Berkeley Water: Issues and Resources, edited by Sloan, D and Stine, S., unpublished Senior Seminar, University of California at Berkeley, Environmental Sciences Group Major, p. 13-22 [MAIN]

Ross, B.E., 1977, The Pleistocene History of San Francisco Bay Along the Southern Crossing; unpublished masters thesis, San Jose State University, Department of Geology, 121 pp.

Rozell, A.B. and Wigglesworth, D.C., 1953, Springs of Water; unpublished masters thesis, Occidental College, Department of History, 246 pp.

Rowe, 1971, Representative Sampling in Location, Quality, and Size; in: Sampling of Soil and Rock, ASTM STP 483, American Society for Testing and Materials, p. 77-108

Sanborn Map Company, 1870 to 1930, Fire Insurance Maps of Various Cities in the East Bay area, [microfilm copies of some of the maps are located in the Map Library at U. C. Berkeley, an almost complete set is located in the Bancroft Library]

San Francisco Bay Marine Piling Committee, 1921, Report on the San Francisco Bay Marine Piling Survey; unpublished report for the American Wood-preservers' Association, 104 pp. [TRANS TA780 S255 D1 1921]

San Francisco Bay Marine Piling Committee, 1922, The San Francisco Bay Marine Piling Survey, Second Annual Report; unpublished report for the American Wood-preservers' Association, 95 pp. [TRANS TA780 S255 D1 1922]

San Francisco Bay Marine Piling Committee, 1923, The San Francisco Bay Marine Piling Survey, Third Annual Report; unpublished report for the American Wood-preservers' Association, 398 pp. [TRANS TA780 S255 D1 1923]

Sander, C.P., 1924, The East Bay Water Situation, unpublished Senior Report, Department of Civil Engineering, University of California at Berkeley, dated December 8, 1924, 15 pp [BAN mF862.25 C59 #12]

Sanders, W.H., 1903, Water supply of the Niles Cone and Vicinity; unpublished report to the Citizens' Committee of Oakland California concerning the Municipal Ownership of Water and Available Sources of Supply for Oakland, California, dated January 10, 1903, p. 25-28 [BAN xF869.02 O23 v.4:4]

Schmitz, D.W., and May, J.H., 1996, Test Applications of a Predictive Model for Delineation of Fluvial Sand Bodies using Geologically Based Calculations; Engineering Geology, v. 42, p. 187-203

Schuyler, J.D., 1886, Contra Costa Water Works; an unpublished report to the Contra Costa Water Company, 10 pp. [WRCA SCHU 1.1] (this was also published by the Contra Costa Water Company as a pamphlet)

Schuyler, J.D., 1900a, Report on the Project of the Mr. Hamilton Water and Power Company in Santa Clara County, California; unpublished report to the Light and Power Company San Jose CA, 30 pp. [WRCA SCHU 77.6]

Schuyler, J.D., 1900b, Report on Artesian Well Tests at San Lorenzo; unpublished report to Capt. Roberts, 6 pp. [WRCA SCHU 3]

Sloan, D., 1981, Ecostratigraphic Study of Sangamon Sediments Beneath Central San Francisco Bay; unpublished doctoral dissertation, University of California at Berkeley, Department of Paleontology, 315 pp

Sloan, D., 1992, The Yerba Buena Mud: Record of the Last-Interglacial Predecessor of San Francisco Bay, California: Geol. Soc. Amer., vol. 104, p. 716-727

Sloan, D. and Stine, S. (editors), 1983, Berkely Water: Issues and Resources; unpublished collection of senior seminar reports, dated June 1983, Univ. Calif. Berkeley, Environmental Sciences, 305 pp.

Sminchak, J.R., Dominic, D.F., and Ritzi Jr., R.W., 1996, Indicator Geostatistical Analysis of Sand Interconnections within a Till; Groundwater, v. 34, p. 1125-1131

Society of Professional Well Log Analysts (SPWLA), 1979, The Art of Ancient Log Analysis, Houston, Tx., ≈250 pp.

State Water Resources Board, 1955a, Santa Clara Valley Investigation, Bulletin 7, dated June, 1955, ≈150 pp.

State Water Resources Board, 1955b, Alameda County Investigation, Bulletin 13, dated July, 1955, ≈250 pp.

Stocks, A.J., 1932, Final Report Foundation Investigaions San Francisco-Oakland Bay Bridge (Boring Contracts 1, 1a and 1b); unpublished report to the California Department of Public Works, dated May 25, 1932, 88 pp. [TRANS TG25 S223 S73 1932 D1]

Sturgeon, G.B., 1913, Review of the Water Situation of the East Region of San Francisco Bay; The Report of the Committee on Water Supply to the City Club of Berkeley, in: Berkeley Civic Bulletin, Vol. 1, No. 12, p 118-130 [WRCA G4422-D3]

Suttner, L.J., 1989, Recent Advances in Study of Detrital Mineralogy of Sand and Sandstone: Implications for teaching; Jour. of Geological Education, v. 37, p. 235-240

Swanson, R.G., 1981, Sample Examination Manual; Amer. Assoc. Petrol. Geol., Methods in Exploration Series, 124 pp.

Teese, E., 1933, Waterfront Development in the San Pablo and Richmond, California Region to 1917; unpublished masters thesis, University of California at Berkeley, Department of History, 154 pp.

Taylor, S.G., 1956, Gravity investigations of the Southern San Francisco Bay Area; unpublished PhD dissertation, Stanford Univ, Depart of Geology,

Taylor, C.L. and Conwell, F.R., 1981, BART-Influence of Geology on Construction Conditions and Cost; Bulletin of Association of Engineering Geologists, v. 18, p. 195-205

Thiel Jr., S.C., and Schneider, J.F., 1993, Investigations of Thirty-Three Loma Prieta Earthquake Strong Motion Recording Sites; unpublished report by CURE (California Universities for Research in Earthquake Engineering), dated July, 1993, ≈500 pp. [EERC 330.326 1989L I584]

Tolman, C.F., 1931, Geology of the Upper San Francisco Bay Region with Special Reference to a Salt Water Barrier: California Division of Water Resources Bull 28, Appendix D, p. 309-359 [STATE] note: DWR has 5 rolls of microfilm that contain copies of the supporting documents for this Bulletin. You need to go to Sacramento to view them. The location of the originals of the supporting documents is unknown.

Trask, P.D., 1950, Investigation of Proposed Crossings of San Francisco Bay, 1948-1950; Geologic Report of Investigations; unpublished report of the Division of San Francisco Bay Toll Crossing, 4 vols. [TRAN TG25 S223 T7 v. 1, 2, 3, and 4]

Trask, P.D., and Rolston, J.W., 1951, Engineering Geology of San Francisco Bay, Geological Society of America, v. 62, p. 1079-1105

Travis, M.A., 1995, A Hisorical and Environmental Geographic Analysis of Lake Merritt, Oakland California; unpublished masters thesis, San Francisco State, dept of Geography, 163 pp. [AS 36 1995 GEOG .T72 SFSU]

Todd Engineers, 1986, Reconnaissance of Groundwater Resources for the EBMUD Service Area, unpublished report for East Bay Municipal Utility District, dated March 1986, 62 pp.

Vickery, F.P, 1959, Geomorphology of the San Francisco Bay Region, unpublished open file report for the California Division of Mines and Geology, dated June 28, 1959, 59 pp [in CDMG library in Sacramento, open file section]

Wakabayashi, J., 1992, Nappes, Tectonics of Oblique Plate Convergence, and Metamorphic Evolution Related to 140 Million Years of Continuous Subduction, Franciscian Complex, California, Jour of Geology, v.100, p. 19-40

Wakabayashi, J., 1996, Cool Under Pressure: an Exploration of High P/T Metamorphism, the Francisican Complex of the San Francisco Bay Area; 1996 AEG - SF section Field trip, ≈150 pp.

Wakabayashi, J. and Hengesh, J.V., 1995, Distribution of Late Cenozoic Displacment on the San Andres Fault System, Northern California; California; in Recent Geologic Studies in the San Francisco Bay Area: Pacific section S.E.P.M, vol. 76, p. 19-30

Watson, D.F., 1992, Contouring a Guide to the Analysis and Display of Spatial Data; Pergamon Press, 321 pp.

Watts, W.L., 1893, Alameda County; in the Eleventh Report of the State Mineralogist, California State Mining Bureau, p. 129-194

Weaver, M.W, and Radbruch, D.H, 1960, Selected Logs of Borings on the East Side of San Francisco Bay, California; USGS open file report 60-151, 213 pp [the only copy of the report that has a readable map is in the USGS library, Menlo Park]

Webb, E.K., 1994, Simulating the Three-Dimensional Distribution of Sediment Units in Braided-Stream Deposits; Jour. of Sedimentary Research, v. 64, p. 219-231

Webster, D.A., 1972, Map Showing ranges in Probable Maximum Well Yield from Water-Bearing rocks in the San Francisco Bay region, California; USGS, Miscellaneous Field Studies Map MF-431

Weeks, H. G., 1909, A Report Upon A Water Supply for the California Institution for the Education of the Deaf Dumb and Blind at Berkeley, California; unpublished senior thesis, University of California at Berkeley, civil engineering department, 40 pp.

Weeks, J.B., Gutentag, E.D., and Kolm, K.E., 1993, Evaluating Vertical Variability of Aquifer Parameters; Hydrological Science and Technology, v. 8, n. 14, p 131-135

West, C.H., 1937, Ground Water Resources of the Niles Cone at Alameda County, California and Probable Salt-water Intrusion Into Ground Water Supplies of Land Adjacent to Tidal Areas; unpublished report for the Federal Land Bank? (in the mid-1950's a copy of this report was reportedly available at the federal land bank in Berkeley, I have not been able to locate a copy of this report)

Wilcox, G.A., 1911, The Terraces of the Upper San Francisco Bay Region; unpublished masters thesis, U.C. Berkeley, geology department, 194 pp.

Wilson, R.C., Warrick, R.E., and Bennett, M.J., 1978, Seismic Velocities of San Francisco Bayshore Sediments: *in* Earthquake Engineering and Soil Dynamics, Proceedings of ASCE Specialty Conference, Vol II, June 19-21, 1978 in Pasadena CA., p.1007-1023

Wing, R.L., 1951, Water Supplies in the San Francisco Bay Area; in Geologic Guidebook of the San Francisco Bay Counties, CDMG Bulletin 154, p. 293-299

Wood, M.W., 1883, History of Alameda County, California; 1001 pp. [reprinted 1969 by Holmes Book Company, Oakland California]

Woodward-Clyde-Shepard and Associates, 1963a, Soil Library Study (collection of available soil data in the East Bay area along the proposed alignment of the San Francisco Bay Area Rapid Transit System); unpublished report to BART, contract Z-703, dated November 19, 1963, W-C job no. 6002, ≈100 pages [BART]

Woodward-Clyde-Shepard and Associates, 1963b, Soil Investigation K-704 Oakland -Broadway: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated December 13, 1963, ≈ 150 pp. [BART]

Woodward-Clyde-Shepard and Associates, 1964a, Soil Investigation R-706 Berkeley-Richmond Line, Segments R006 and R007 BART: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated 1964, ≈ 180 pp. [BART]

Woodward-Clyde-Shepard and Associates, 1964b, Soil Investigation K-701 Oakland Wye Intersection BART: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated January 20, 1964, ≈ 150 pp. [BART]

Woodward-Clyde-Shepard and Associates, 1967, Soil Investigation R-7055 Ashby Place Station Berkeley California: unpublished report to Parsons Brinckerhoff Tudor and Bechtel, dated August 24, 1965, ≈ 80 pp. [BART]

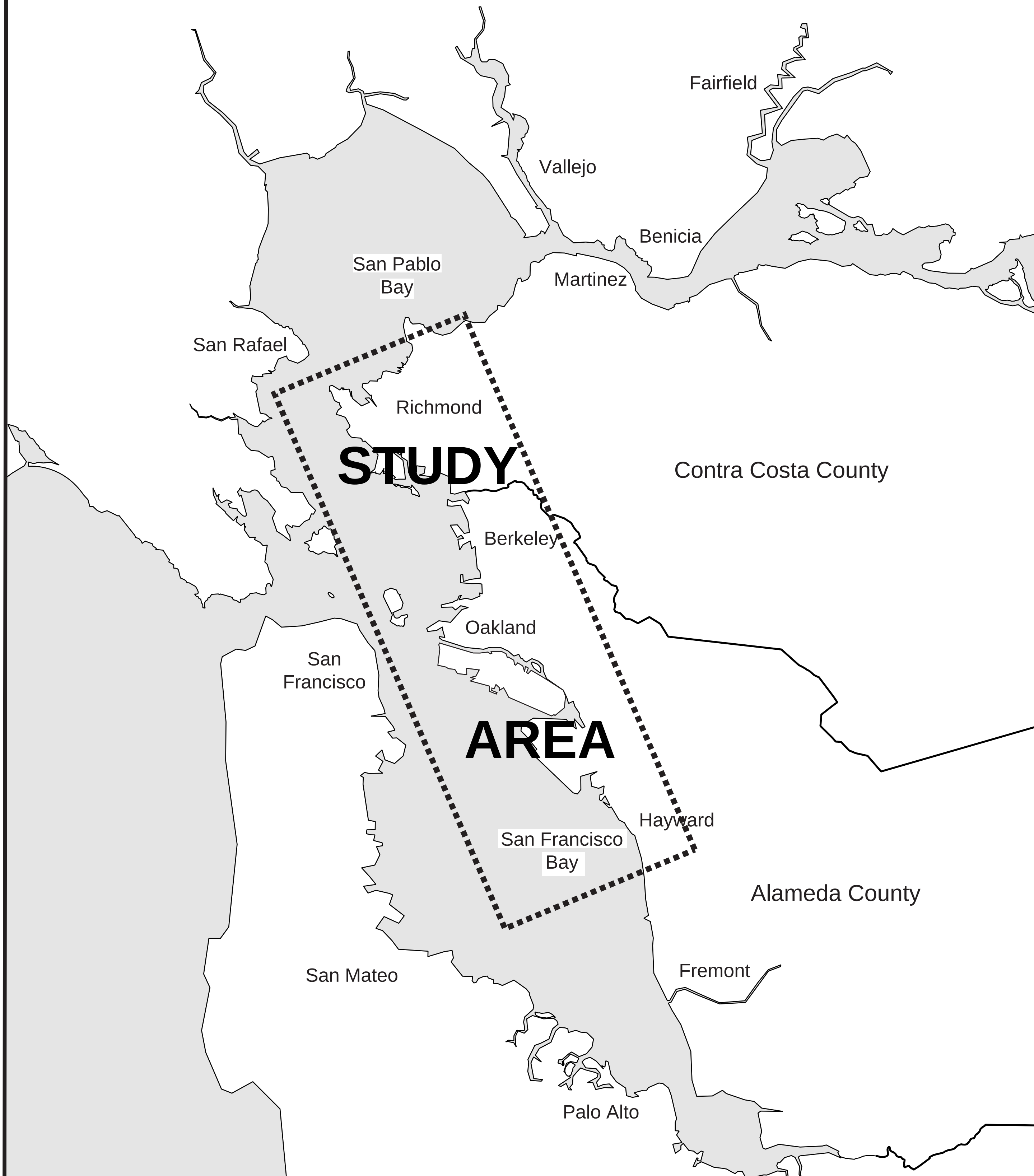
Woodward-Lundgren & Associates, 1972, Soil Investigation for the Proposed Oakland Coliseum Walkway Bart Station and Coliseum Complex; unpublished report for Skidmore, Owings and Merrill, dated December 20, 1972, ≈ 50 pp. [BART]

Woodward-Clyde Consultants, 1993, Hydrogeology of Central San Leandro and Remedial Investigation of Regional Groundwater Contamination San Leandro Plume, San Leandro, California; unpublished report for the California Environmental Protection Agency, 3 volumes, dated December 29, 1993, [RWQCB]

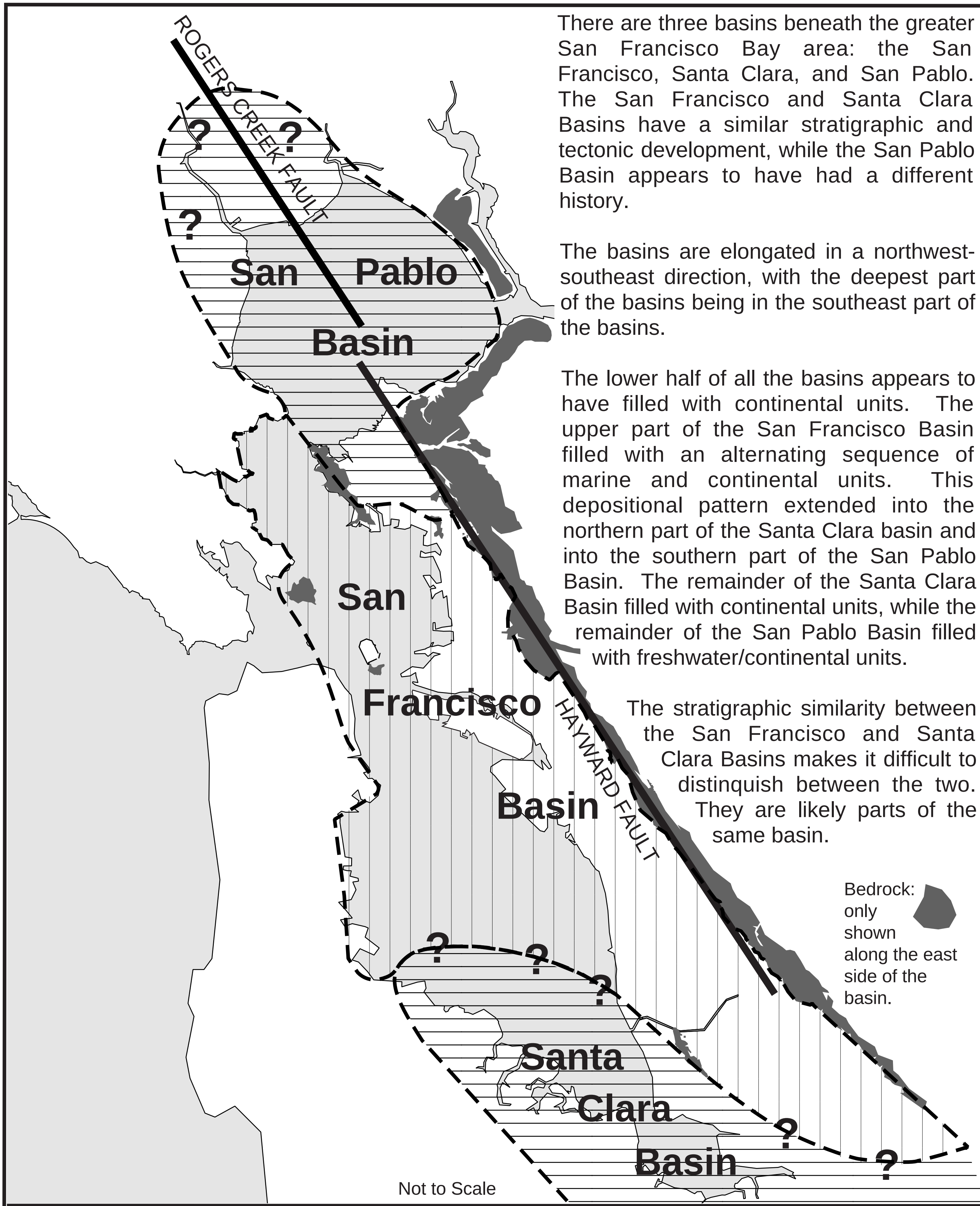
Young, W.R., 1929, Report on the Salt Water Barrier below Confluence of Sacramento and San Joaquin Rivers, California; California Division of Water Resources, Bulletin 22, no. 1, vols. 1 and 2. [STATE P2500 B9 no. 22 vol. 1 and vol. 2]

Zacek, M. and Krivanek, Z., 1991, Reality of the Relation Between Geologic Objects and Mathematical Models, Jour. of Mathematical Geology, v.23, p. 41-46

Zoback, M.L., Olson, J.A., and Jachens, R.C., 1995, Seismicity and Basement Structure Beneath South San Francisco Bay, California; in Recent Geologic Studies in the San Francisco Bay Area: Pacific section S.E.P.M, vol. 76, p. 31-46



Norfleet Consultants	LOCATION OF STUDY AREA				
	EAST BAY PLAIN BENEFICIAL USE STUDY				
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 1		



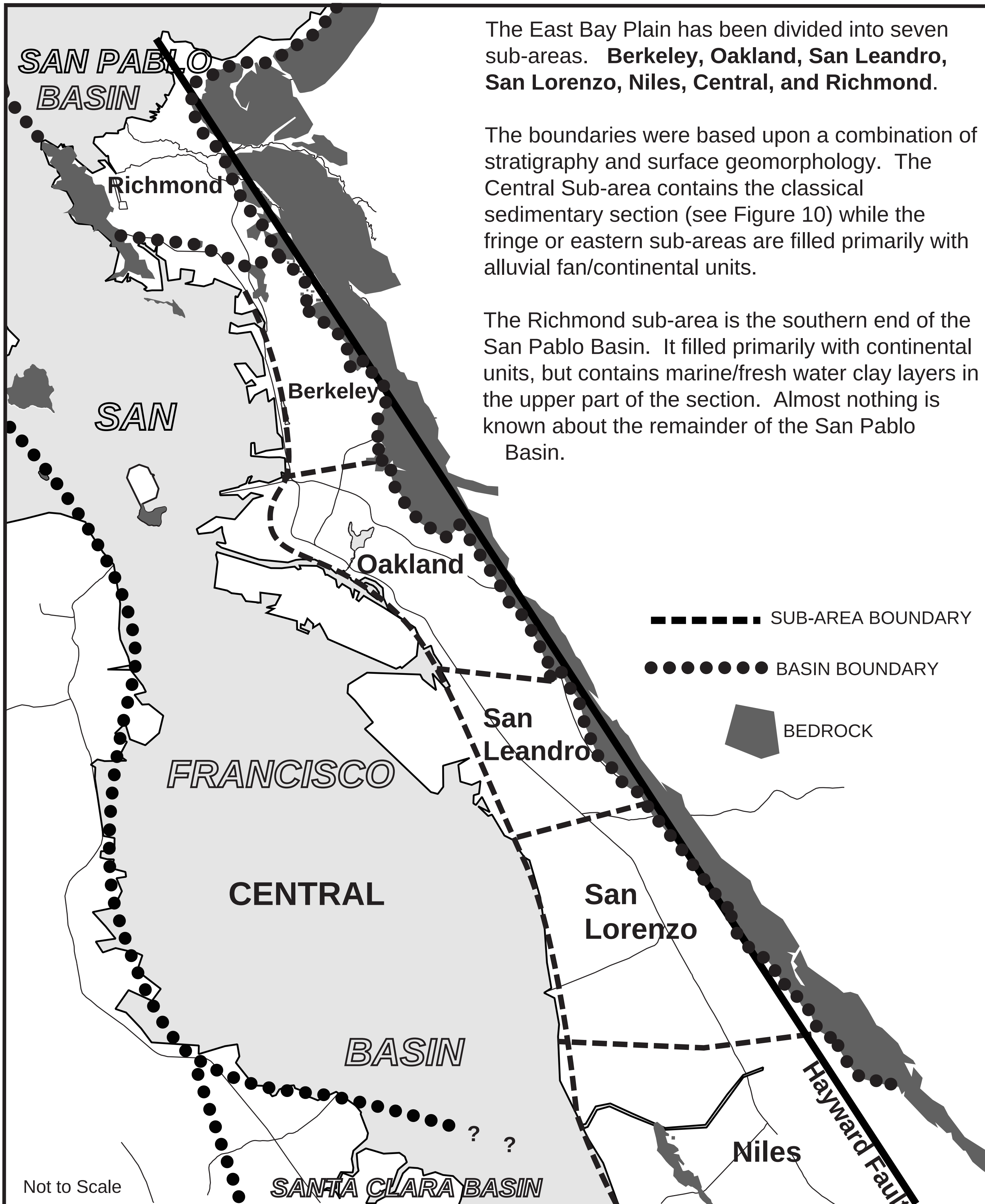
There are three basins beneath the greater San Francisco Bay area: the San Francisco, Santa Clara, and San Pablo. The San Francisco and Santa Clara Basins have a similar stratigraphic and tectonic development, while the San Pablo Basin appears to have had a different history.

The basins are elongated in a northwest-southeast direction, with the deepest part of the basins being in the southeast part of the basins.

The lower half of all the basins appears to have filled with continental units. The upper part of the San Francisco Basin filled with an alternating sequence of marine and continental units. This depositional pattern extended into the northern part of the Santa Clara basin and into the southern part of the San Pablo Basin. The remainder of the Santa Clara Basin filled with continental units, while the remainder of the San Pablo Basin filled with freshwater/continental units.

The stratigraphic similarity between the San Francisco and Santa Clara Basins makes it difficult to distinquish between the two. They are likely parts of the same basin.

Norfleet Consultants	OUTLINE OF MAIN BASINS EAST BAY PLAIN BENEFICIAL USE STUDY
	PROJ NO: 981102 · DATE: 6/15/98 · FIGURE: 2



The East Bay Plain has been divided into seven sub-areas. **Berkeley, Oakland, San Leandro, San Lorenzo, Niles, Central, and Richmond**.

The boundaries were based upon a combination of stratigraphy and surface geomorphology. The Central Sub-area contains the classical sedimentary section (see Figure 10) while the fringe or eastern sub-areas are filled primarily with alluvial fan/continental units.

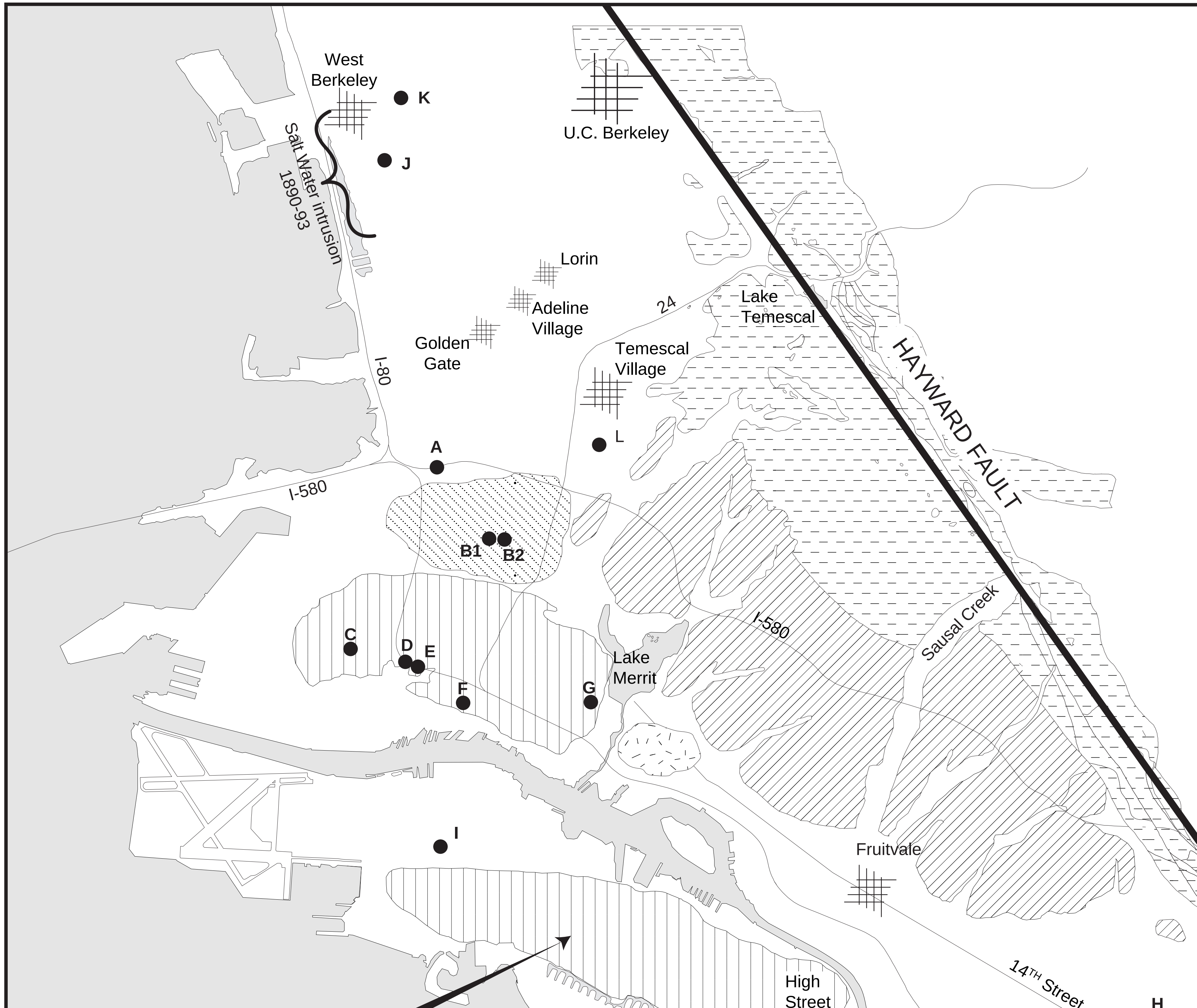
The Richmond sub-area is the southern end of the San Pablo Basin. It filled primarily with continental units, but contains marine/fresh water clay layers in the upper part of the section. Almost nothing is known about the remainder of the San Pablo Basin.

Norfleet Consultants

SUB-AREAS

EAST BAY PLAIN BENEFICIAL USE STUDY

PROJ NO: 981102	DATE: 6/15/98	FIGURE: 3



GROUNDWATER IN OAKLAND, 1890-1900

This map is a graphical representation of geologic and well information described in Watts (1892) and Miller (1903).

BEDROCK - Cretaceous sedimentary units and Franciscan units. San Antonio Formation - Old Alluvial Fans

OLD ALLUVIAL FANS (SANTA CLARA FORMATION?)

MERRITT SANDS - These areas contain 50 to 80 feet of fine grained sand. Water depths were originally 10 to 12 feet below the ground surface. They were lowered to 35 to 40 feet by pumping. Average well production was 600 gph. There was a clay layer below the Merritt, and a water bearing gravel below the clay layer.

NORTH OAKLAND - There were no surface sands in this area. There was a surface clay, 2 to 20 feet thick (sometimes missing). Water bearing gravels were at 20 to 25 feet and 45 to 50 feet. Wells in this area averaged 150 feet deep. There were occasional dry holes.

EAST OAKLAND - There were no surface sands in this area. There was a surface clay, 0 to 50 feet thick (sometimes missing). Water bearing gravels were at 50 to 60 feet and at 90 feet.

HIGH STREET WELL FIELD - By 1893, pumping had lowered the water table from artesian to 8 feet below the ground suface. The best water bearing gravels were 80 to 90 feet and 220 to 240 feet. The field was abandoned in the mid 1890's because of salt water intrusion.

A - Artesian well in the early 1890's.

B - This 3 block area contained the most prolific wells in Oakland. Pumping in these wells reduced ground water levels in wells hundreds of feet away.
B1 - Dingee had 3 deep wells that produced 1,500,000 gpd in 1893.
B2 - Gill nursery had one 281 foot deep well that produced 1,000,000 gpd.

C - This was the largest private water plant in Oakland (1895). It produced from one 12 inch well that was 60 feet deep.

D - Artesian well in the 1890's.

E - Mr. Dingee had four wells here. They were 53 feet deep and each produced 5000 gph.

F - Two 10 inch diameter wells, 554 and 681 feet deep.

G - Well flowing in 1900.

H - In the 1890's there was one 10 inch diameter well, 180 to 190 feet deep. The water depth was 8 feet.

I - Main water bearing gravels were 80 to 90 feet and at 140 feet.

J - Bedrock was encountered at 390 feet in 1893.

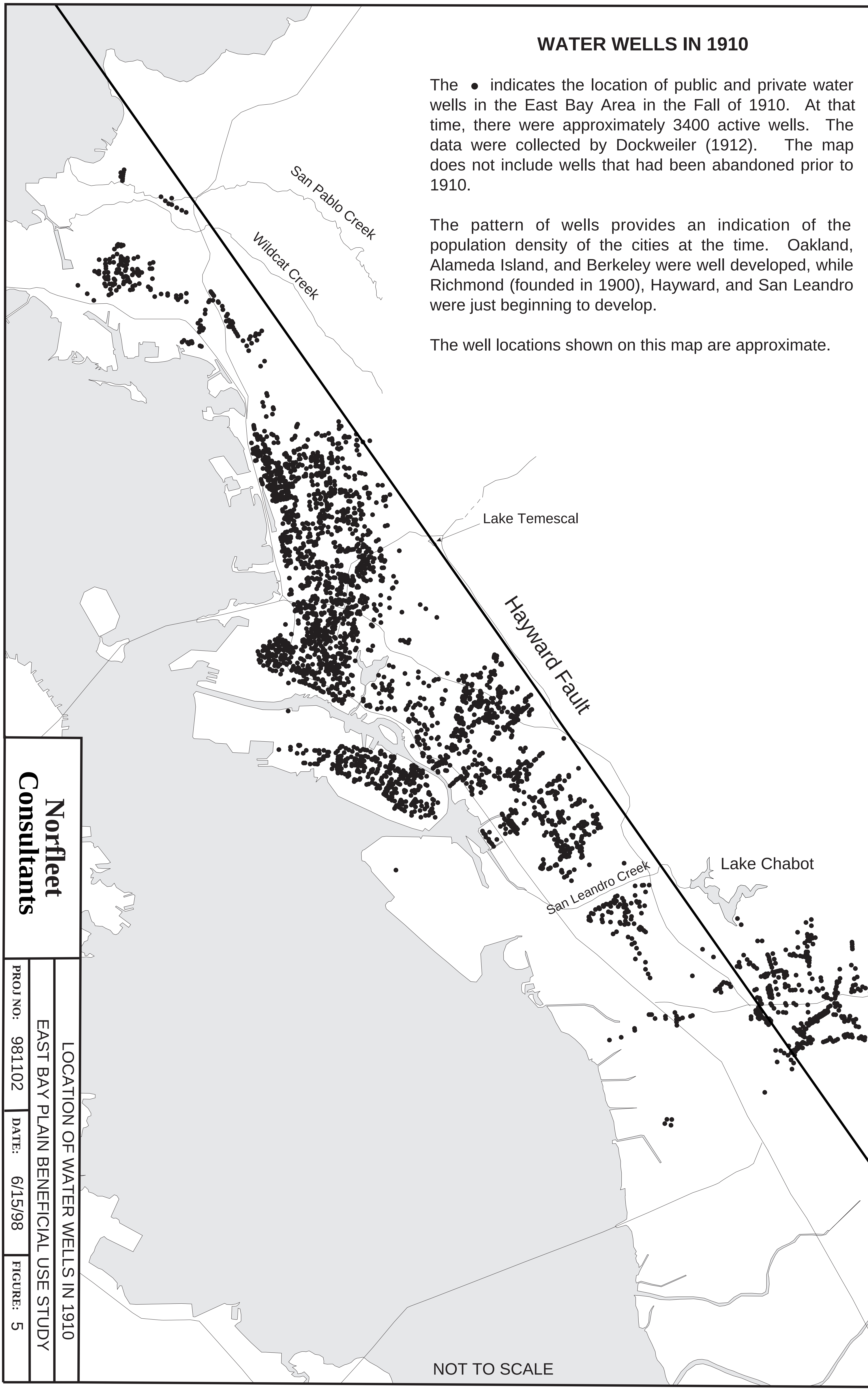
K - Wells in this area averaged 60 to 80 feet deep, and the water table was 20 to 25 feet deep. No bay muds were encountered.

WATER WELLS IN 1910

The ● indicates the location of public and private water wells in the East Bay Area in the Fall of 1910. At that time, there were approximately 3400 active wells. The data were collected by Dockweiler (1912). The map does not include wells that had been abandoned prior to 1910.

The pattern of wells provides an indication of the population density of the cities at the time. Oakland, Alameda Island, and Berkeley were well developed, while Richmond (founded in 1900), Hayward, and San Leandro were just beginning to develop.

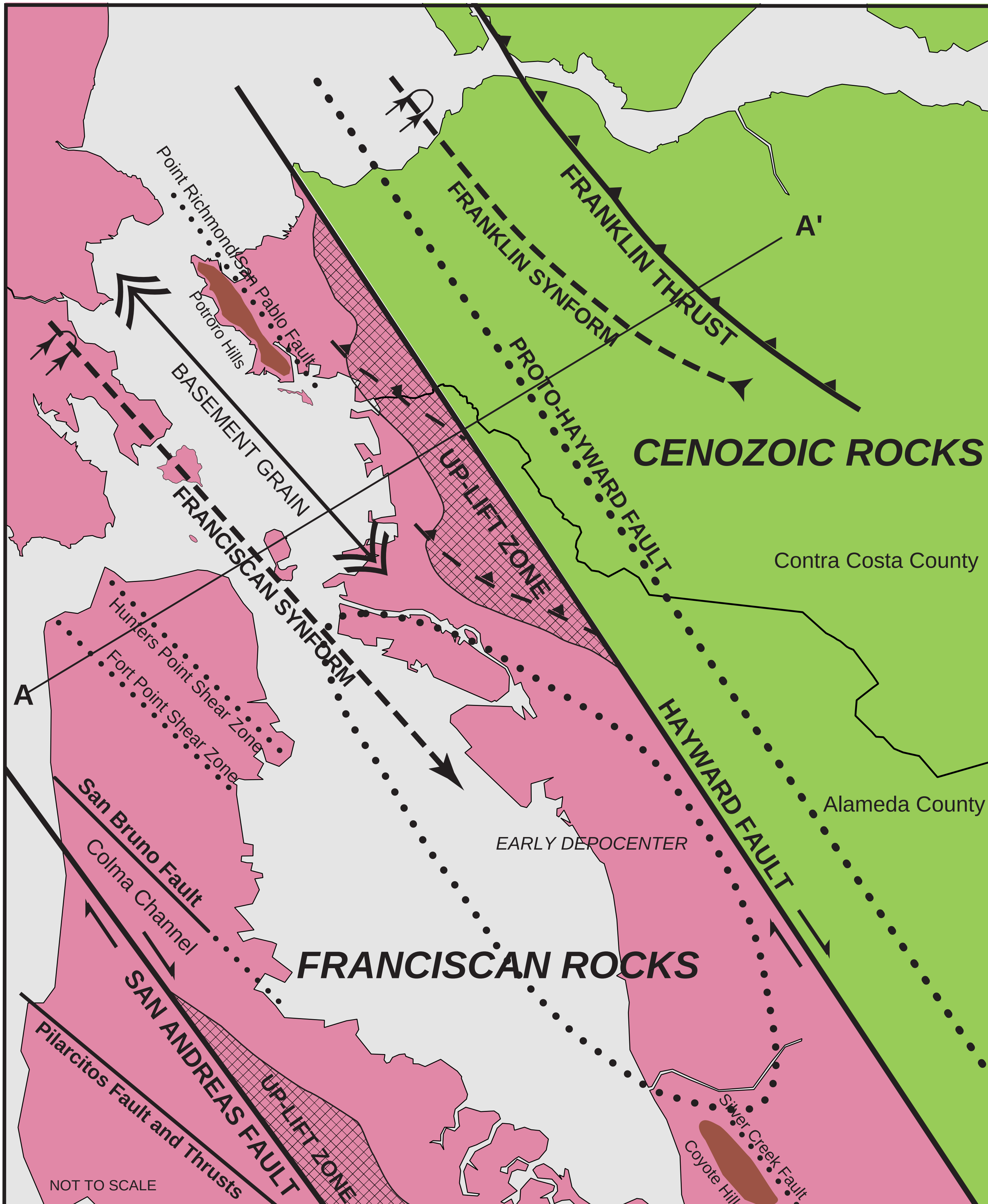
The well locations shown on this map are approximate.



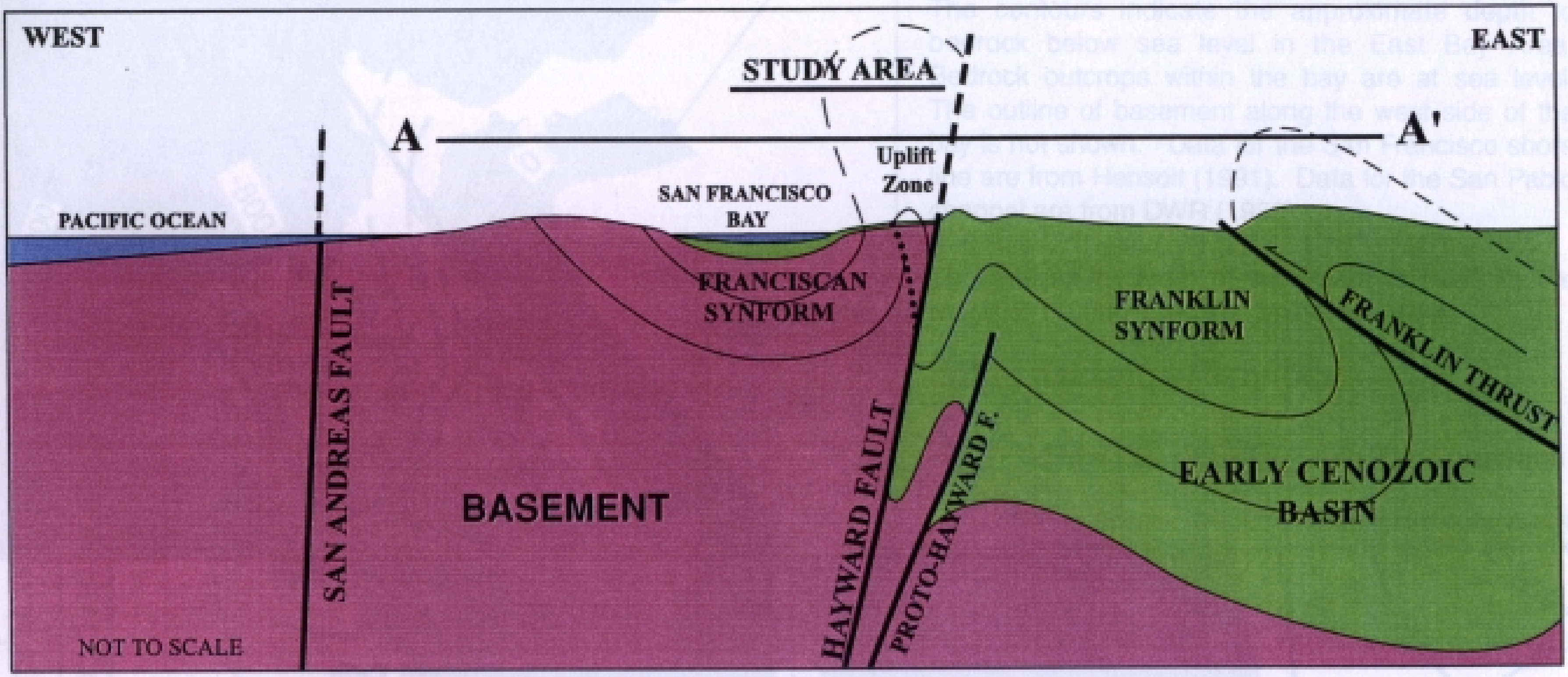
Norfleet Consultants

LOCATION OF WATER WELLS IN 1910
EAST BAY PLAIN BENEFICIAL USE STUDY

PROJ NO: 981102
DATE: 6/15/98
FIGURE: 5



Norfleet Consultants	REGIONAL TECTONIC FEATURES					
	EAST BAY PLAIN BENEFICIAL USE STUDY					
	PROJ NO:	981102	DATE:	6/15/98	FIGURE:	6

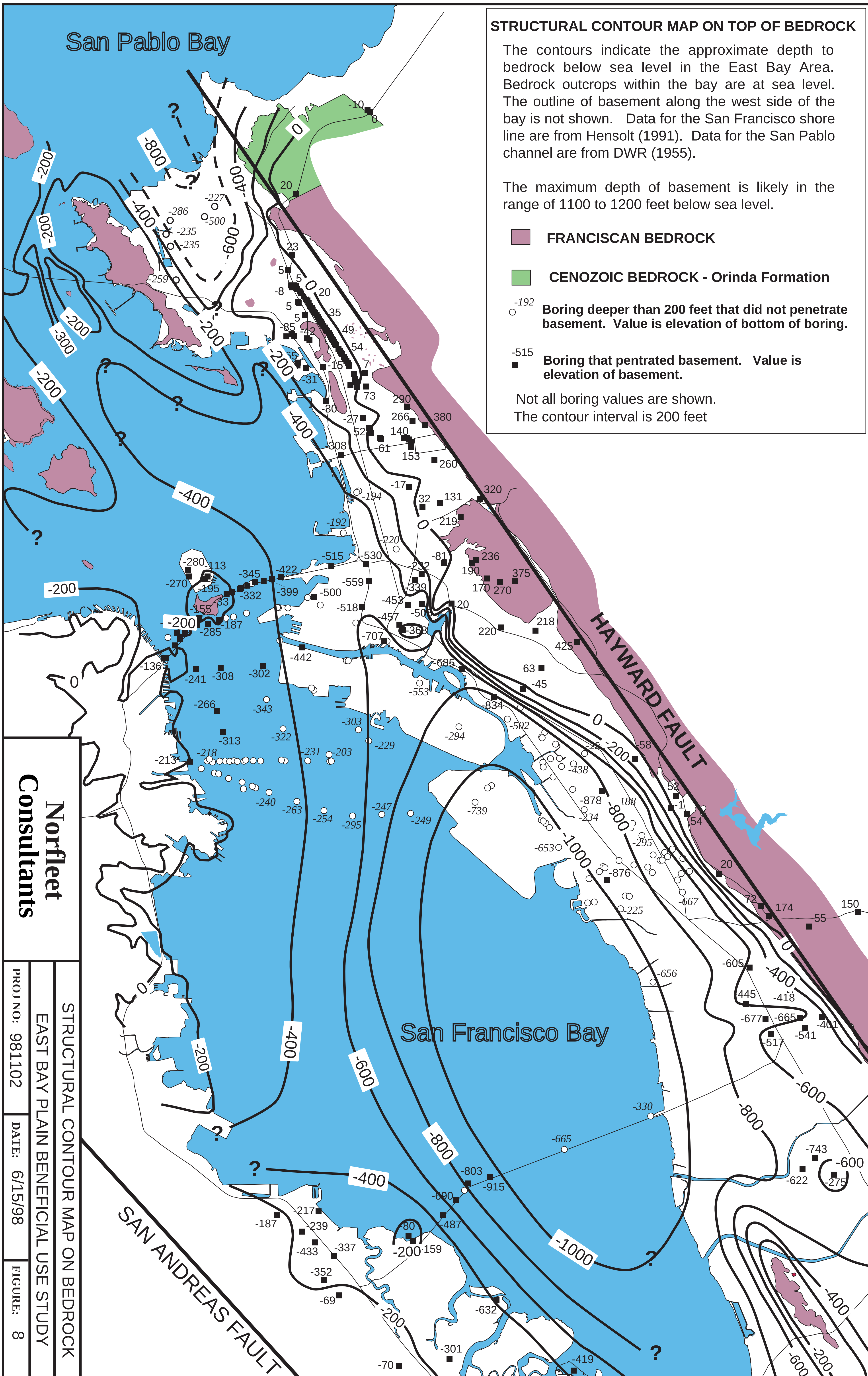


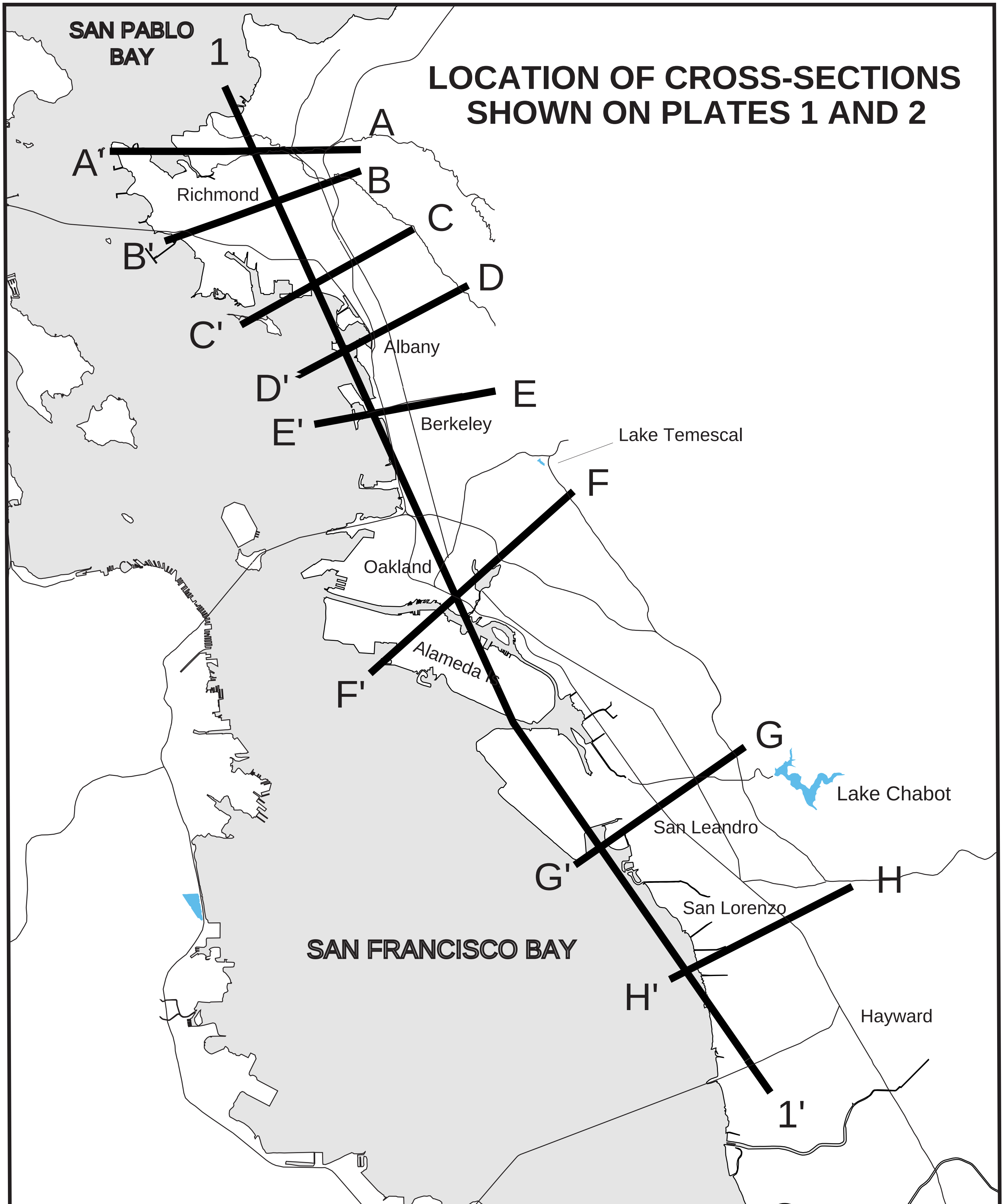
Minimum 3:1 vertical exaggeration

This is a schematic, east-west, regional cross-section through the northern part of the Study Area. It illustrates the upper crustal relationships (down to 50,000 feet) between basement (Franciscan units) and Cenozoic deposits. The San Francisco Bay and Basin are structurally controlled, resting in the core of a basement synform. The uplifted zone (Richmond to Oakland) formed as result of localized compression along the upper Hayward Fault.

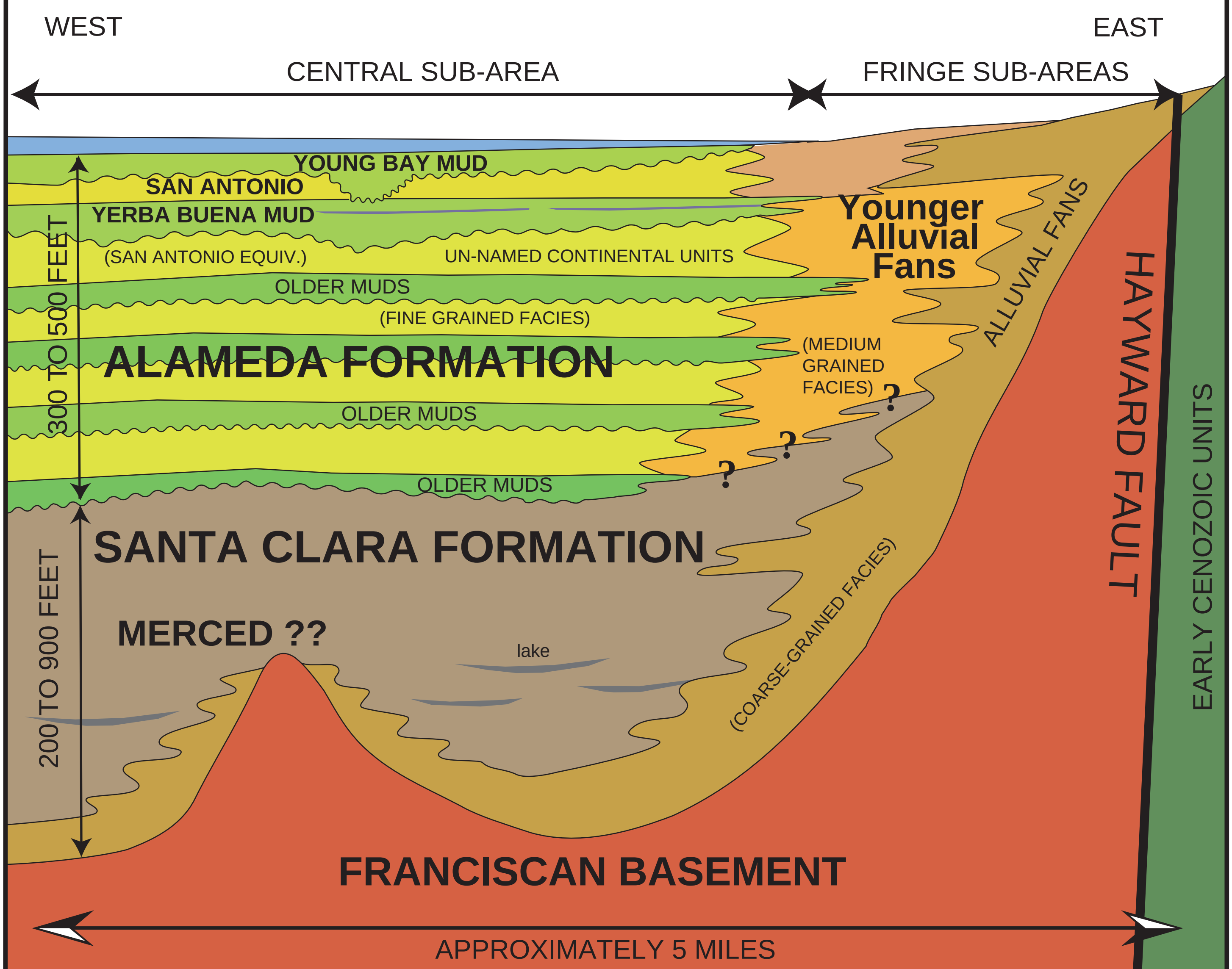
There is an apparent reversal of topography, with the basement rocks forming the lows while basinal units form the ridges. This occurs because the Franciscan units erode as quickly as they are uplifted.

Norfleet Consultants	SCHEMATIC REGIONAL CROSS-SECTION					
	EAST BAY PLAIN BENEFICIAL USE PROJECT					
	PROJ NO:	981102	DATE:	6/15/98	FIGURE:	7


STRUCTURAL CONTOUR MAP ON TOP OF BEDROCK
The contours indicate the approximate depth to bedrock below sea level in the East Bay Area. Bedrock outcrops within the bay are at sea level. The outline of basement along the west side of the bay is not shown. Data for the San Francisco shore line are from Hensolt (1991). Data for the San Pablo channel are from DWR (1955).
The maximum depth of basement is likely in the range of 1100 to 1200 feet below sea level.
FRANCISCAN BEDROCK
CENOZOIC BEDROCK - Orinda Formation
-192
Boring deeper than 200 feet that did not penetrate basement. Value is elevation of bottom of boring.
-515
Boring that pentrated basement. Value is elevation of basement.
Not all boring values are shown.
The contour interval is 200 feet
San Pablo Bay
San Francisco Bay
HAYWARD FAULT
SAN ANDREAS FAULT
Norfleet Consultants
STRUCTURAL CONTOUR MAP ON BEDROCK
EAST BAY PLAIN BENEFICIAL USE STUDY
PROJ NO: 981102
DATE: 6/15/98
FIGURE: 8



Norfleet Consultants	LOCATION OF CROSS-SECTIONS				
	EAST BAY PLAIN BENEFICIAL USE STUDY				
	PROJ NO: 981102	DATE:	6/15/98	FIGURE:	9

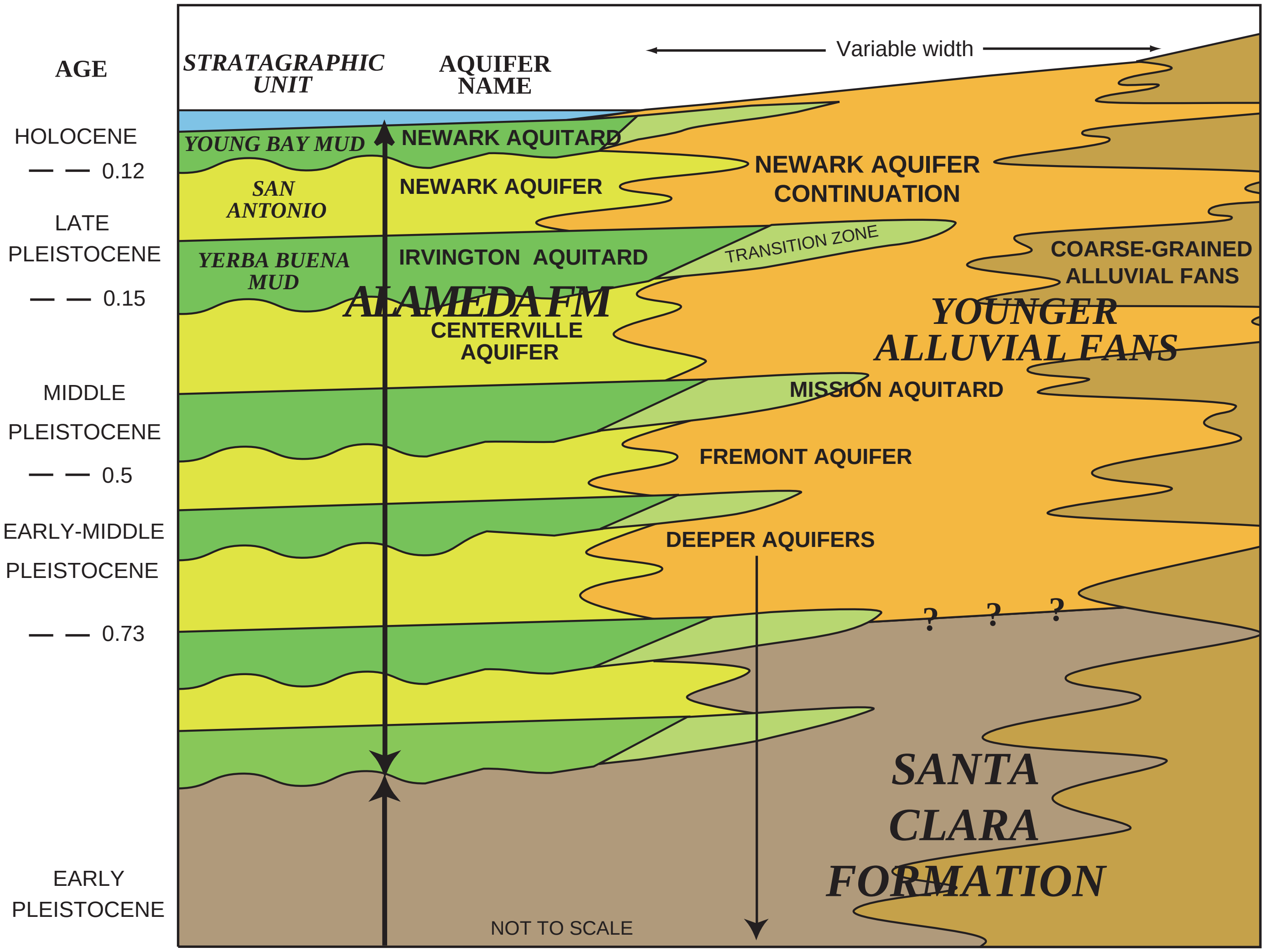


Schematic cross-section of stratigraphic relationships along the east side of the San Francisco Basin (15-20:1 vertical exaggeration). The Alameda Formation is restricted to the marine transgression(s) (including the current transgression), and local names (San Antonio, Yerba Buena Mud, etc.) are members within the Alameda Formation. There were six to eight transgressions of the late Pleistocene seas within the Alameda Formation. The upper two are well defined, but little is known about the earlier transgressions.

The units below the Alameda are likely Santa Clara and possibly Merced formation. The units on the side of the basin are Holocene and late Pleistocene alluvial fans and related deposits. The location of the boundary between the Santa Clara and the Younger fans is unknown.

Basement knobs (hills) are scattered throughout the Basin. Some are exposed (e.g. Yerba Buena Island), but the majority are buried. All basement knobs affected sedimentation patterns laterally and vertically. Basement topography is self replicating through time. The current shape of the bay and the location of the major streams and embayments mimic basement topography.

Norfleet Consultants	SCHEMATIC STRATIGRAPHIC SECTION		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 10



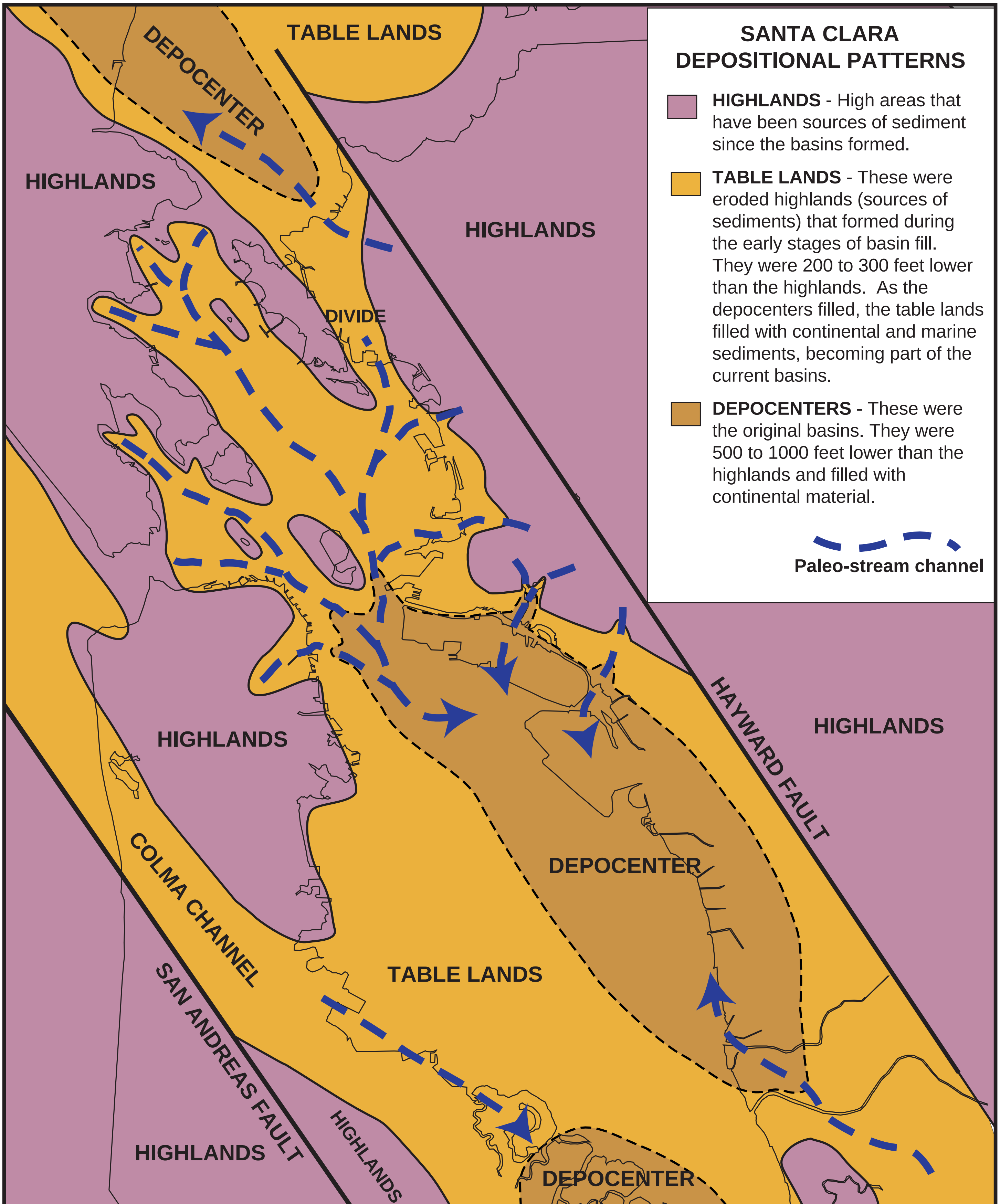
AQUIFER CORRELATIONS

The aquifers/aquitards were formally identified and named in the western part of the Niles Cone in the early 1950's, but were informally described in the early 1910's. Stratigraphically, the aquitards correlate with the estuarine muds (Young Bay Mud and Yerba Buena Mud), while the aquifers correlate with continental/alluvial fan material deposited between the bay muds.

The aquifers extend east towards the Hayward fault where they merge into a vertically continuous coarse-grained alluvial fan sequence. The aquifers are not homogenous. They have an overall fining trend from the hills to the bay but contain significant variations both laterally and vertically. These zones reflect natural depositional environmental variations. The location and style of the stratigraphic boundaries shown on this diagram are illustrative only, and are not suitable for site specific evaluation.

The edge of the aquitards marks the limits of the bay, and it varies with each unit. In Berkeley, the deeper bay muds terminate at approximately the same location as does the current bay, while in the San Leandro-Hayward area the deeper bay muds extend several miles further east (almost to I-880). Fine-grained transition zones extend east from the ends of the aquitards. In the Berkeley area these zones are narrow (50 to 100 feet) while they can extend a thousand feet or more in the San Leandro-Hayward area. The extent of these transition zones varies with location and depth and is poorly known.

Norfleet Consultants	STRATIGRAPHIC UNITS-AQUIFER CORRELATIONS		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 11

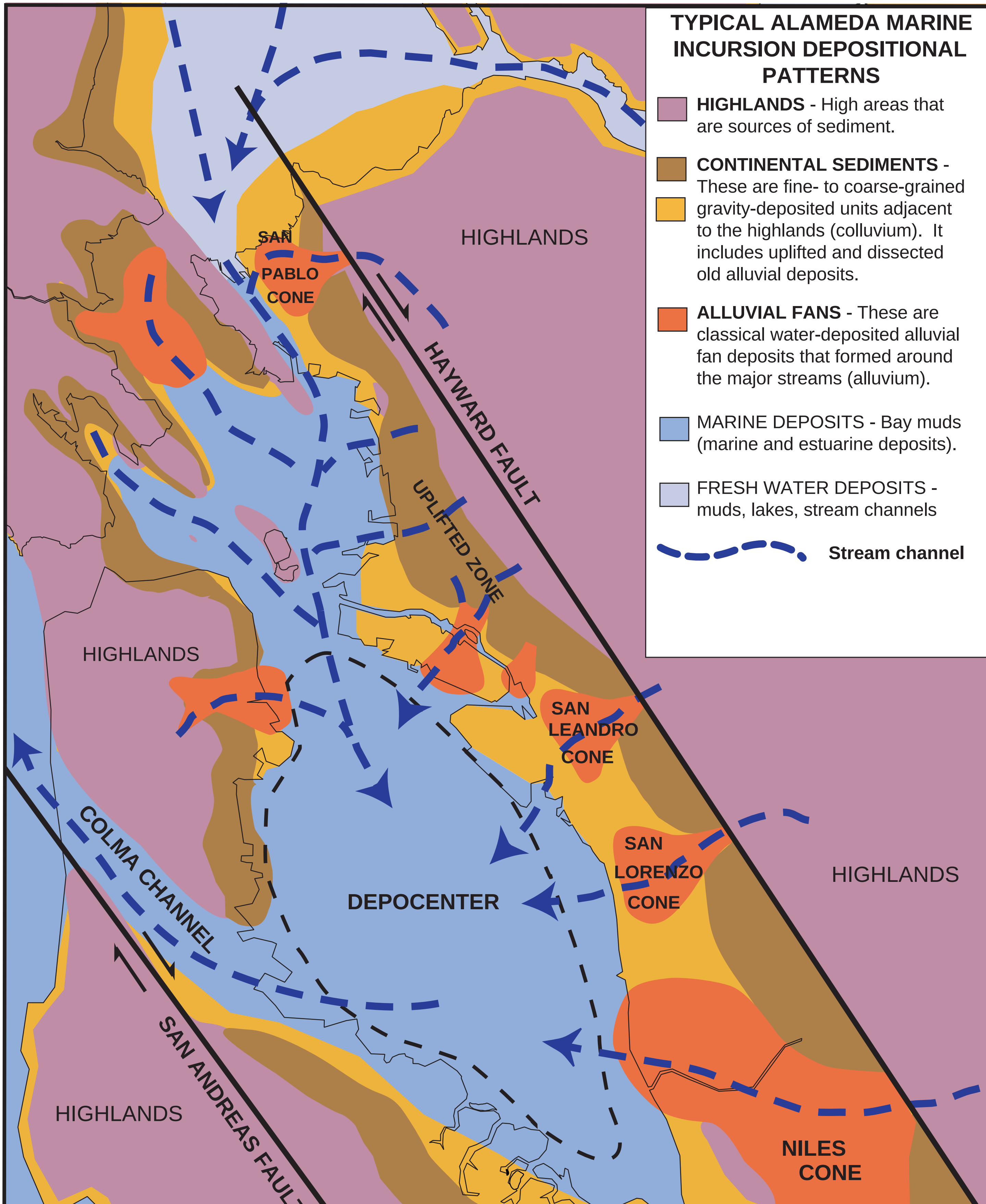


Norfleet Consultants

DEPOSITIONAL PATTERNS - SANTA CLARA TIME

EAST BAY PLAIN BENEFICIAL USE STUDY

PROJ NO: 981102	DATE: 6/15/98	FIGURE: 12

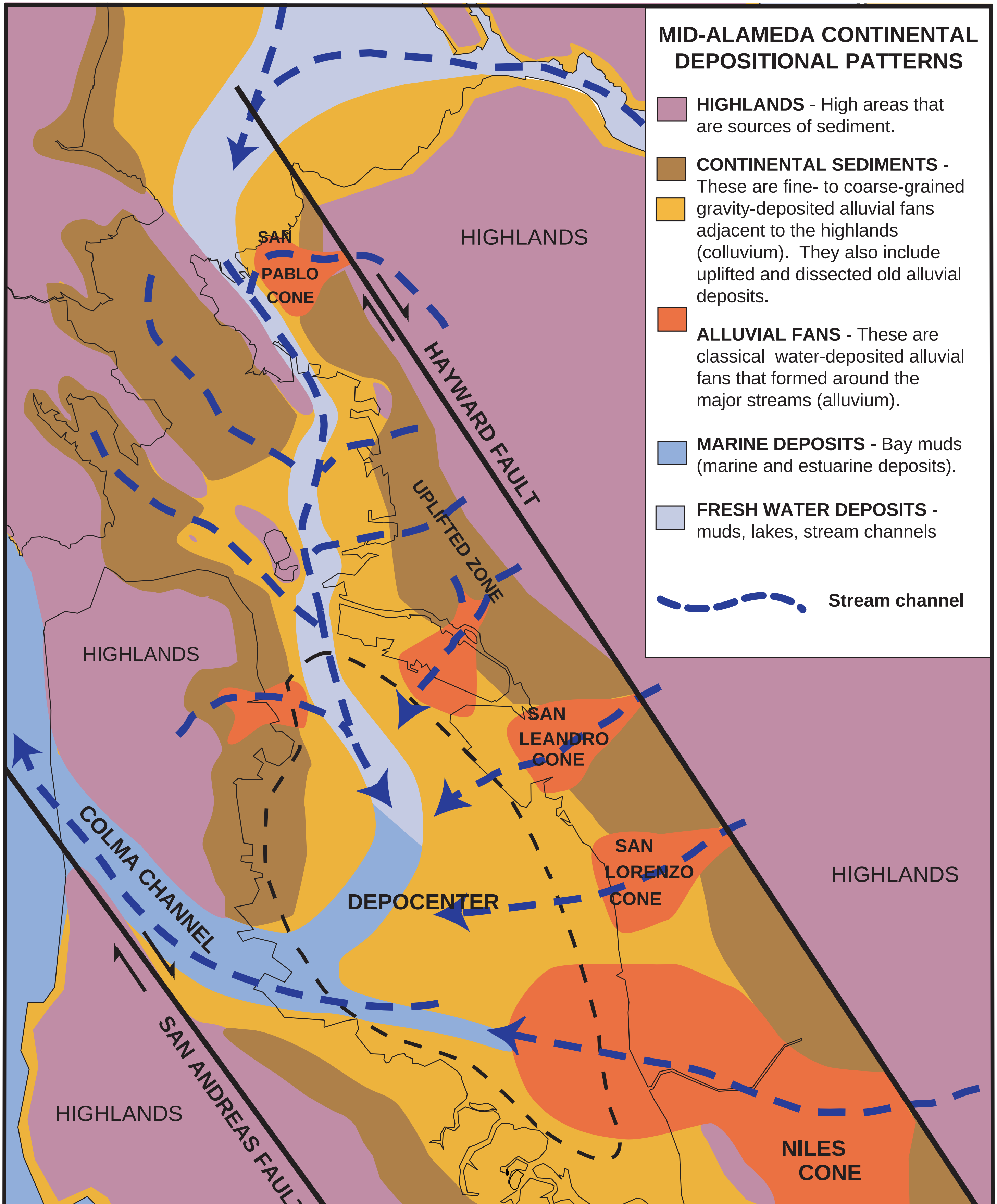


Norfleet Consultants

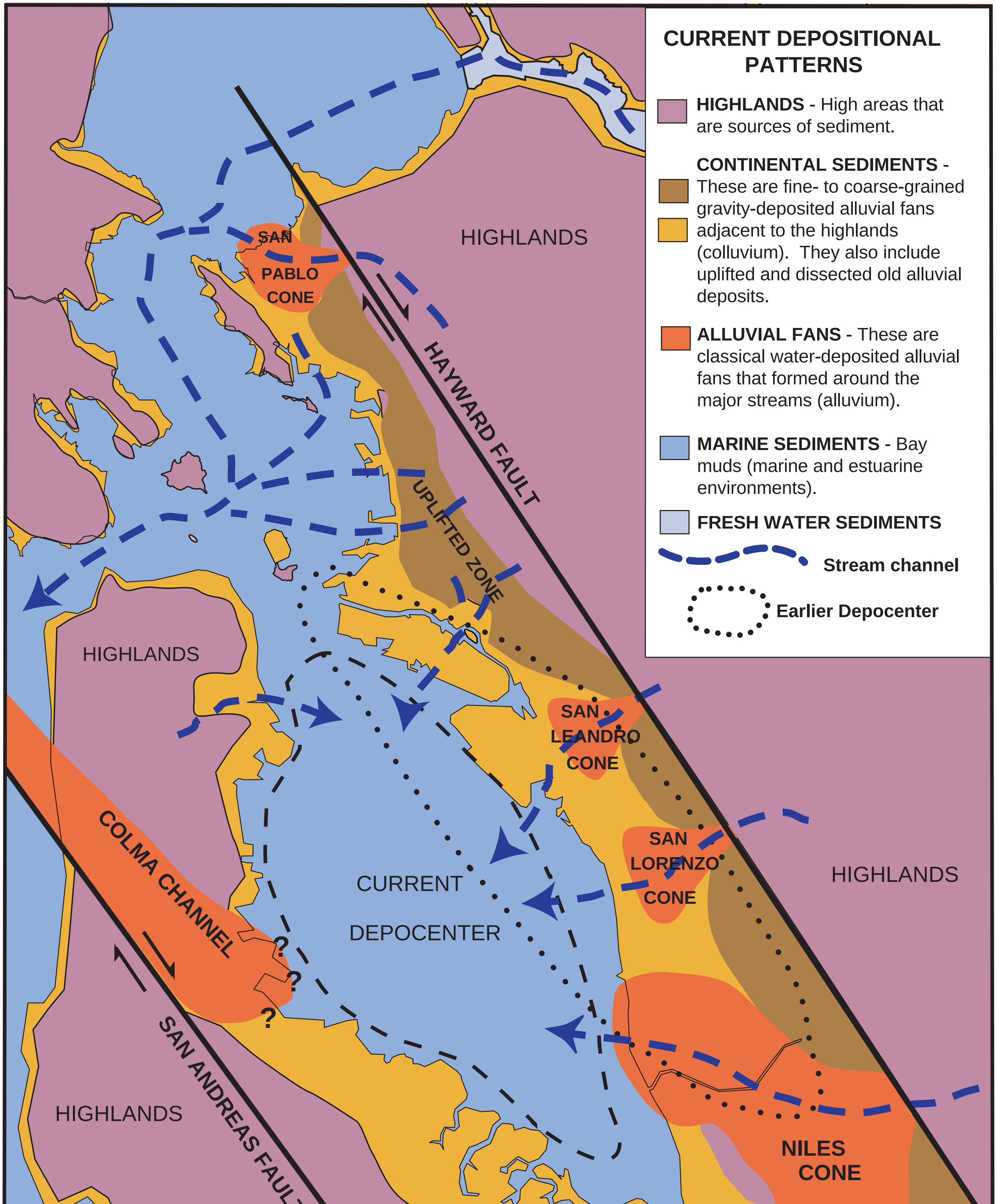
MARINE DEPOSITIONAL PATTERNS - ALAMEDA

EAST BAY PLAIN BENEFICIAL USE STUDY

PROJ NO: 981102	DATE: 6/15/98	FIGURE: 13

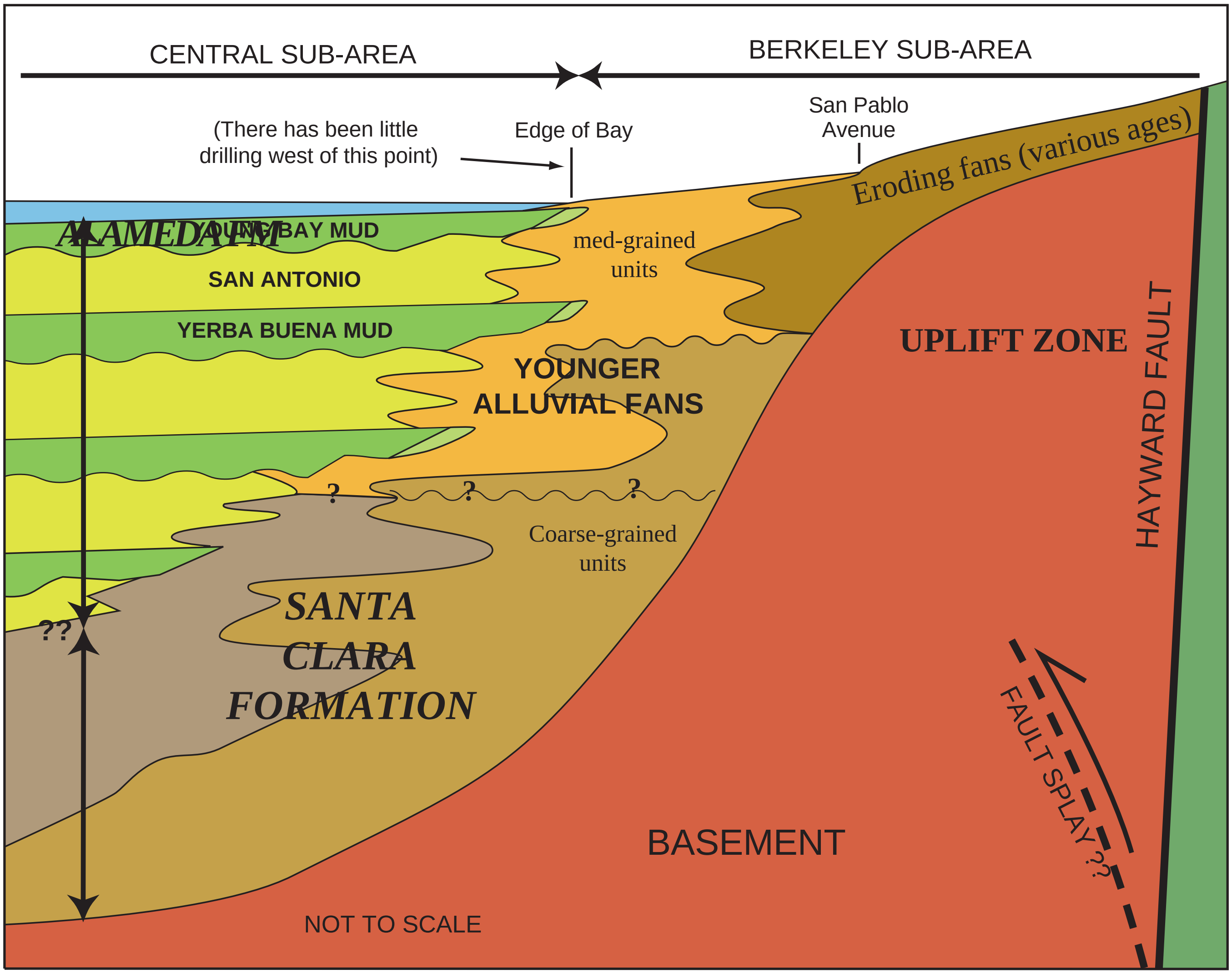


Norfleet Consultants	DEPOSITIONAL PATTERNS - ALAMEDA TIME				
	EAST BAY PLAIN BENEFICIAL USE STUDY				
	PROJ NO: 981102	DATE:	6/15/98	FIGURE:	14



Norfleet Consultants

DEPOSITIONAL PATTERNS - CURRENT		
EAST BAY PLAIN BENEFICIAL USE STUDY		
PROJ NO: 981102	DATE: 6/15/98	FIGURE: 15



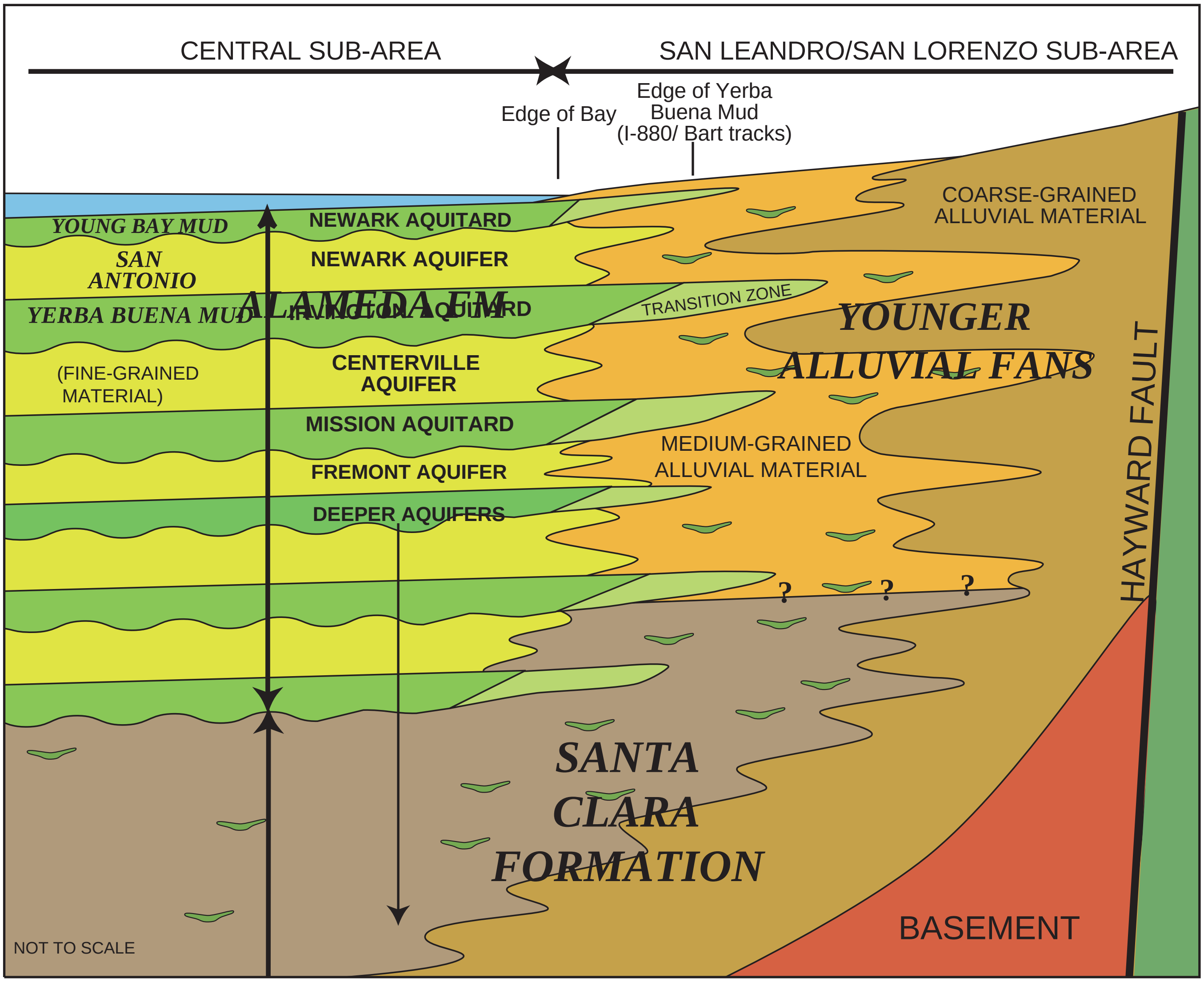
SCHEMATIC STRATIGRAPHIC RELATIONSHIPS IN BERKELEY

This is a schematic cross-section of the eastern part of the San Francisco basin in the vicinity of Berkeley. Beneath the bay, basement is not as deep (only 400 to 500 feet) as it is in the San Leandro area (1000 to 1300 feet). Holocene-Pleistocene blind-thrusting has differentially lifted the area. This movement raised bay muds 50 to 70 feet and exposed basement, stripping earlier alluvial deposits and cutting stream valleys into basement. Since then, alluvial fans have covered basement, but they, in turn, are being incised. The unconformity between the two alluvial fan units is shown at the base of the Yerba Buena Mud, but this is conjecture.

It is unknown if the lower Alameda marine units were deposited. The transition zones at the edges of the bay muds are narrow (50 to 100 feet wide) and the eastern edges of the bay muds appear to end at approximately the same location.

Vertical exaggeration is approximately 30:1.

Norfleet Consultants	SCHEMATIC STRATIGRAPHIC SECTION IN BERKELEY	
	EAST BAY PLAIN BENEFICIAL USE STUDY	
PROJ NO: 981102	DATE: 6/15/98	FIGURE: 16



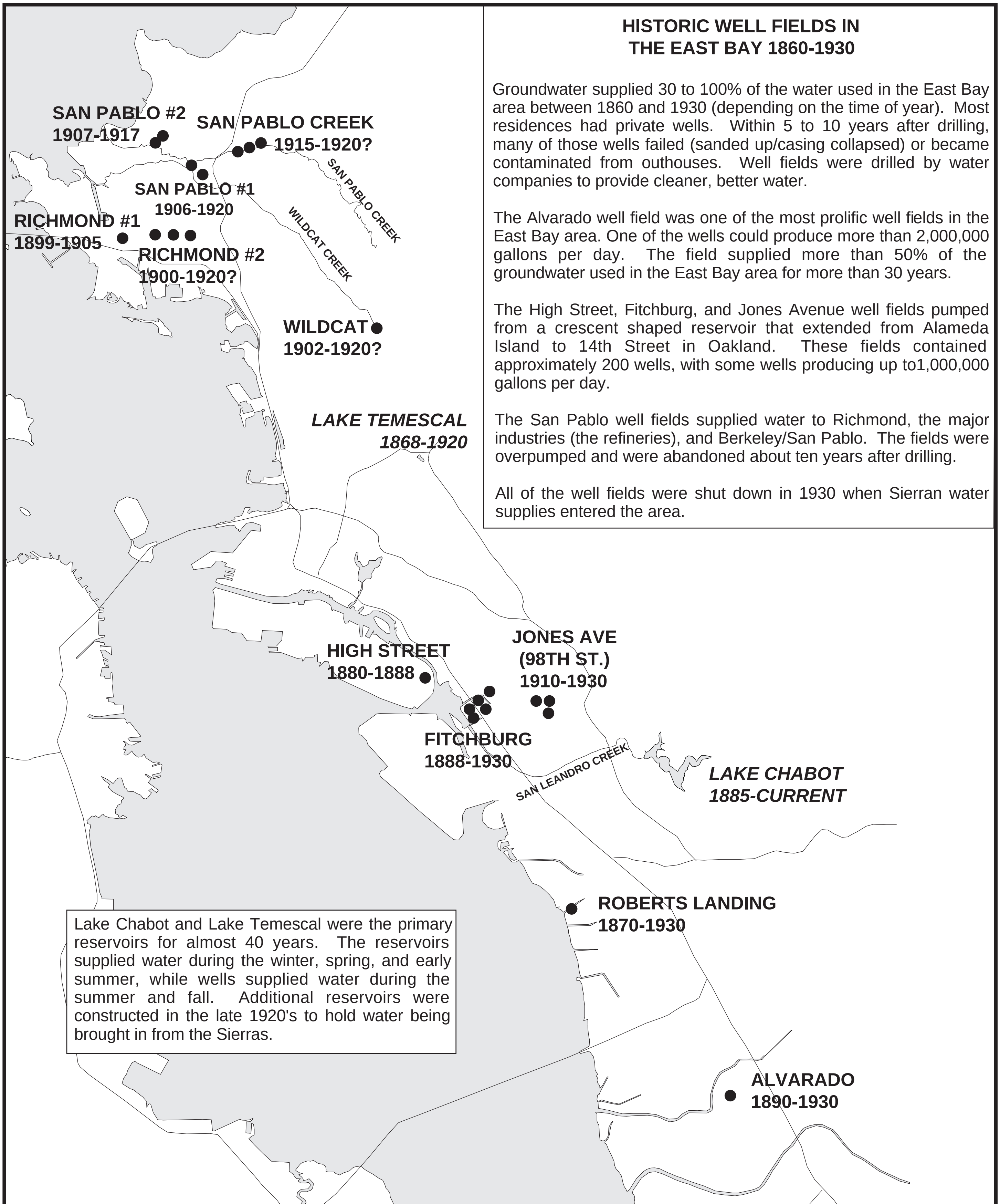
**SCHEMATIC STRATIGRAPHIC RELATIONSHIPS
IN THE SAN LEANDRO-SAN LORENZO AREA**

This is a schematic cross-section of the eastern part of the San Francisco basin in the vicinity of San Leandro-Hayward. This part of the basin contains the classical stratigraphic section: a well developed Alameda formation (marine units) adjacent to a thick, alluvial fan section. The bay muds appear to have a laterally extensive transition zone (tidal flats, lakes, etc) that effectively extends the aquitards to the east. Except for regional climatic influences, the two depositional environments (marine and alluvial) are independent of each other. The existence of an aquitard in the Alameda does not imply a lateral extension of that unit in the alluvial material.

The coarse-grained alluvial deposits adjacent to the Hayward fault form a relatively homogeneous hydrogeologic unit. The finer-grained materials are more hetrogeneous, containing stream channels and other preferential flow paths, ponds, soil horizons, over bank deposits, etc. The Yerba Buena Mud extends east of I-880 and sometimes east of the Bart tracks. Basement extends to the ground surface in various locations. Vertical exaggeration is a minimun of 30:1.

Most of our concepts concerning the hydrogeologic nature of this section are derived from the Niles cone which contains thick, porous gravels. Drilling in the San Leandro and San Lorenzo areas indicates that the finer-grained units are tighter (less porous). There has been virtually no drilling in the bay to evaluate the hydrogeologic properties of the continental units between the aquitards, but it has been known for more than 50 years that pumping in the Niles Cone affects wells on the west side of the bay.

Norfleet Consultants	SCHEMATIC STRATIGRAPHIC SECTION IN THE SAN LEANDRO AREA		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	**DATE:** 6/15/98	**FIGURE:** 17



HISTORIC WELL FIELDS IN THE EAST BAY 1860-1930

Groundwater supplied 30 to 100% of the water used in the East Bay area between 1860 and 1930 (depending on the time of year). Most residences had private wells. Within 5 to 10 years after drilling, many of those wells failed (sanded up/casing collapsed) or became contaminated from outhouses. Well fields were drilled by water companies to provide cleaner, better water.

The Alvarado well field was one of the most prolific well fields in the East Bay area. One of the wells could produce more than 2,000,000 gallons per day. The field supplied more than 50% of the groundwater used in the East Bay area for more than 30 years.

The High Street, Fitchburg, and Jones Avenue well fields pumped from a crescent shaped reservoir that extended from Alameda Island to 14th Street in Oakland. These fields contained approximately 200 wells, with some wells producing up to1,000,000 gallons per day.

The San Pablo well fields supplied water to Richmond, the major industries (the refineries), and Berkeley/San Pablo. The fields were overpumped and were abandoned about ten years after drilling.

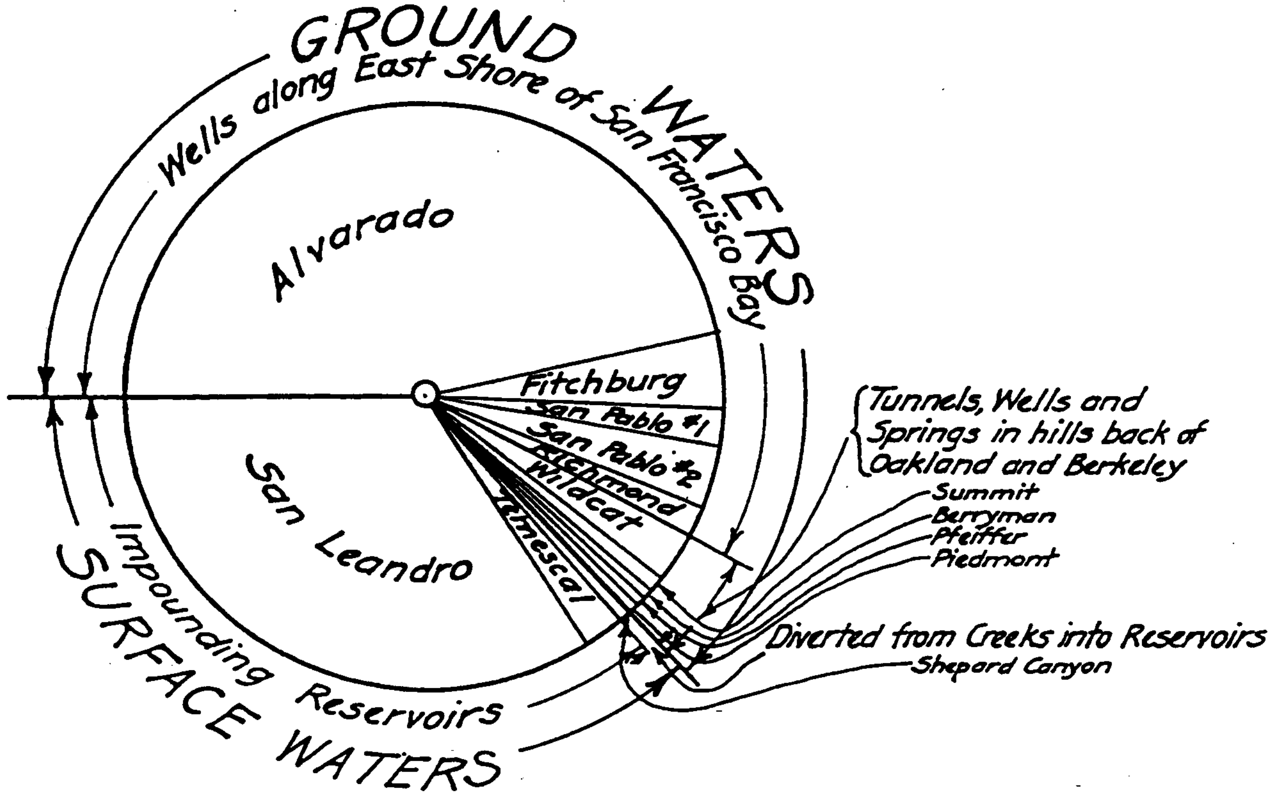
All of the well fields were shut down in 1930 when Sierran water supplies entered the area.

Lake Chabot and Lake Temescal were the primary reservoirs for almost 40 years. The reservoirs supplied water during the winter, spring, and early summer, while wells supplied water during the summer and fall. Additional reservoirs were constructed in the late 1920's to hold water being brought in from the Sierras.

Norfleet Consultants	HISTORIC WELL FIELDS - 1880 TO 1930		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 18

WATER SOURCES - 1911

The pie chart shows the daily average (in gallons per day) of water supplied by surface and groundwaters for the East Bay Area during 1911.



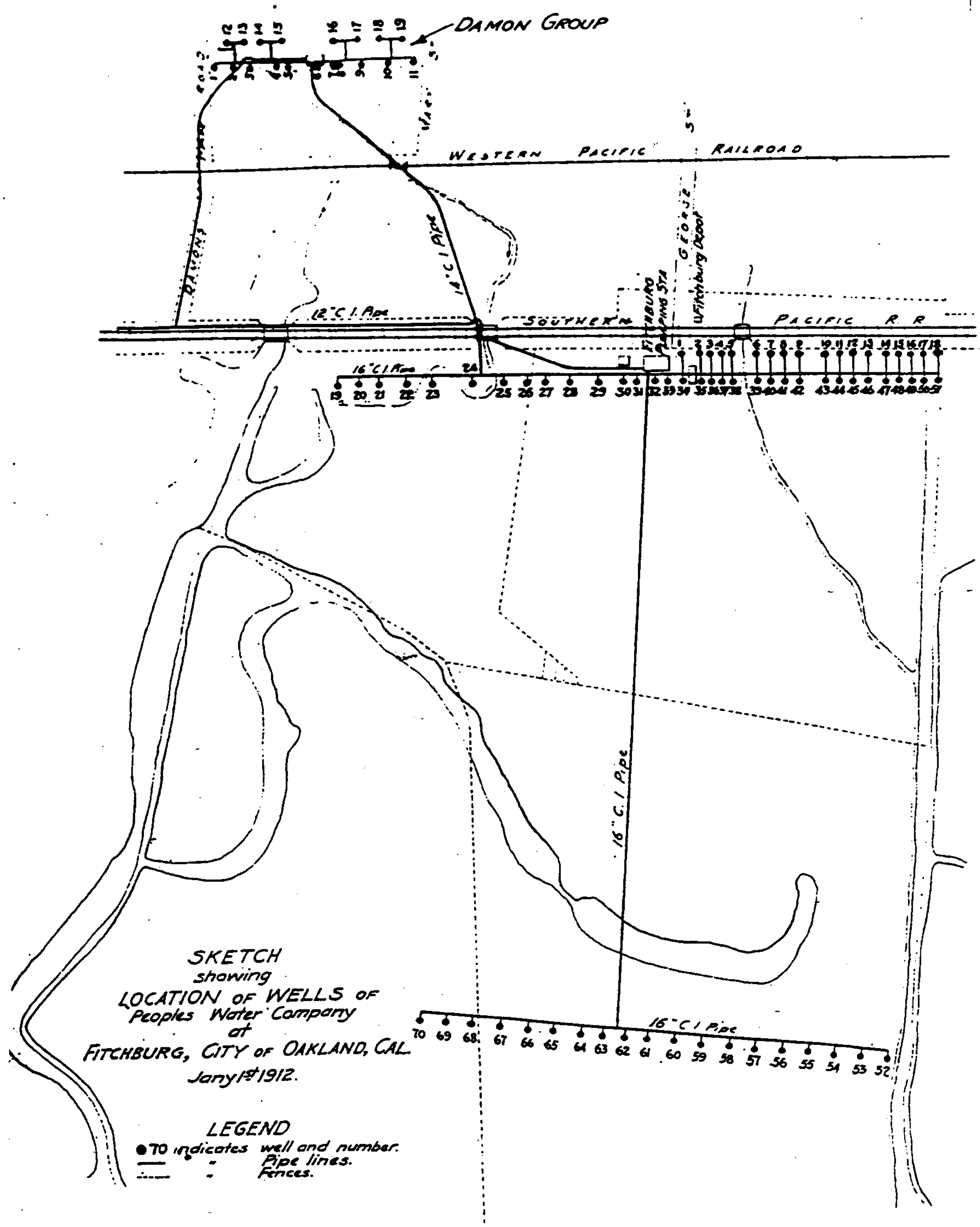
Total water supply was 17,306,834 gallons per day (yearly average).

Surface waters		**6,381,626 (gpd)**
San Leandro Reservior	5,896,567	
Temescal	405,917	
Sheperd Canyon Diversion	79,142	
Ground Water		**10,021,353 (gpd)**
Alvarado	8,051,416	
Fitchburg	746,429	
San Pablo #1	318,331	
San Pablo #2	590,006	
Richmond	315,171	
Tunnels-Springs		**903,855 (gpd)**
Wildcat	471,373	
Summit	145,506	
Berryman	101,870	

Norfleet Consultants	WATER SUPPLY - 1911		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 19

THE FITCHBURG WELL FIELD, OAKLAND - 1912

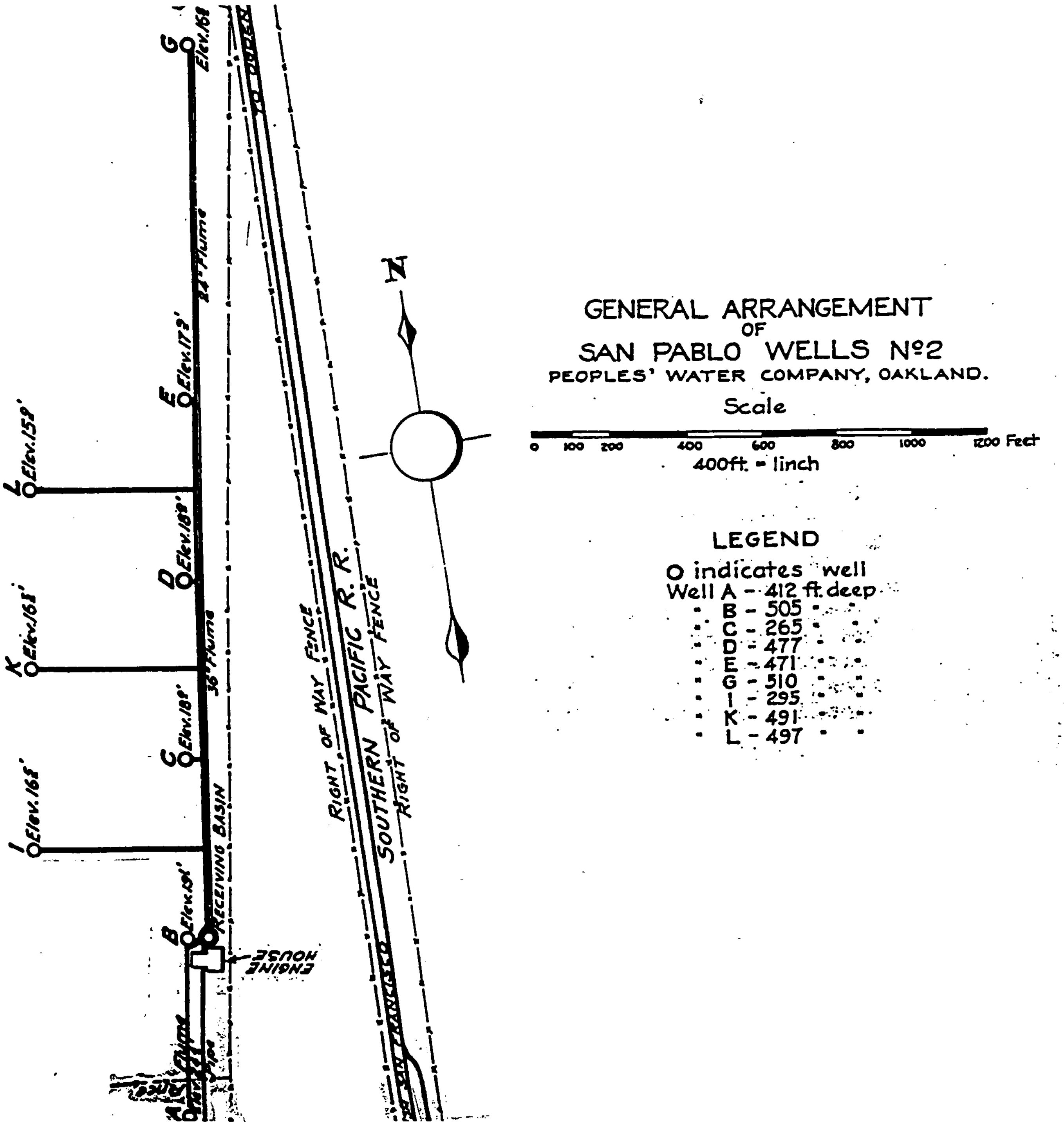
This map shows the approximate location of the wells in the Fitchburg and Damon Well Fields circa 1912. The Damon wells were shut down soon after this map was made, and is now a city park. The Fitchburg Field was active for another 20 years, and about another 30 wells were drilled. The Fitchburg Field is now the site of the Oakland Coliseum.



Norfleet Consultants	FITCHBURG WELL FIELD - 1912		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 20

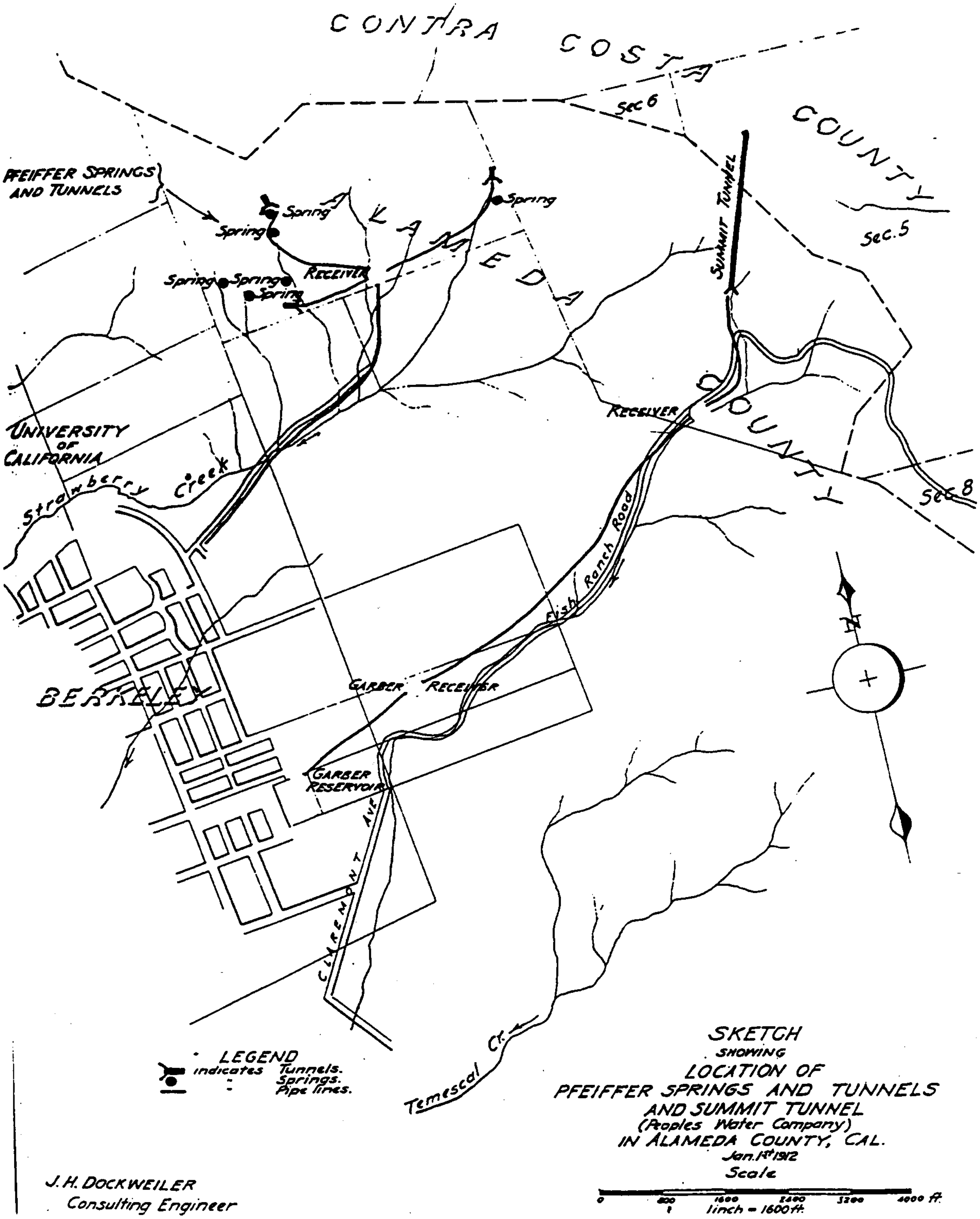
THE SAN PABLO WELL FIELD #2 - 1908

This map shows the approximate location of the wells in the San Pablo Well Field #2. The field was located in Richmond at the northwest corner of the intersection of the Southern Pacific Railroad tracks and Parr Boulevard (the old Crown Cork property). This is a map of the original wells (1907). Two additional wells were drilled in 1910. The field was over pumped and was abandoned in1919 because of water quality problems.



THE BERKELEY SPRINGS AND TUNNELS - 1912

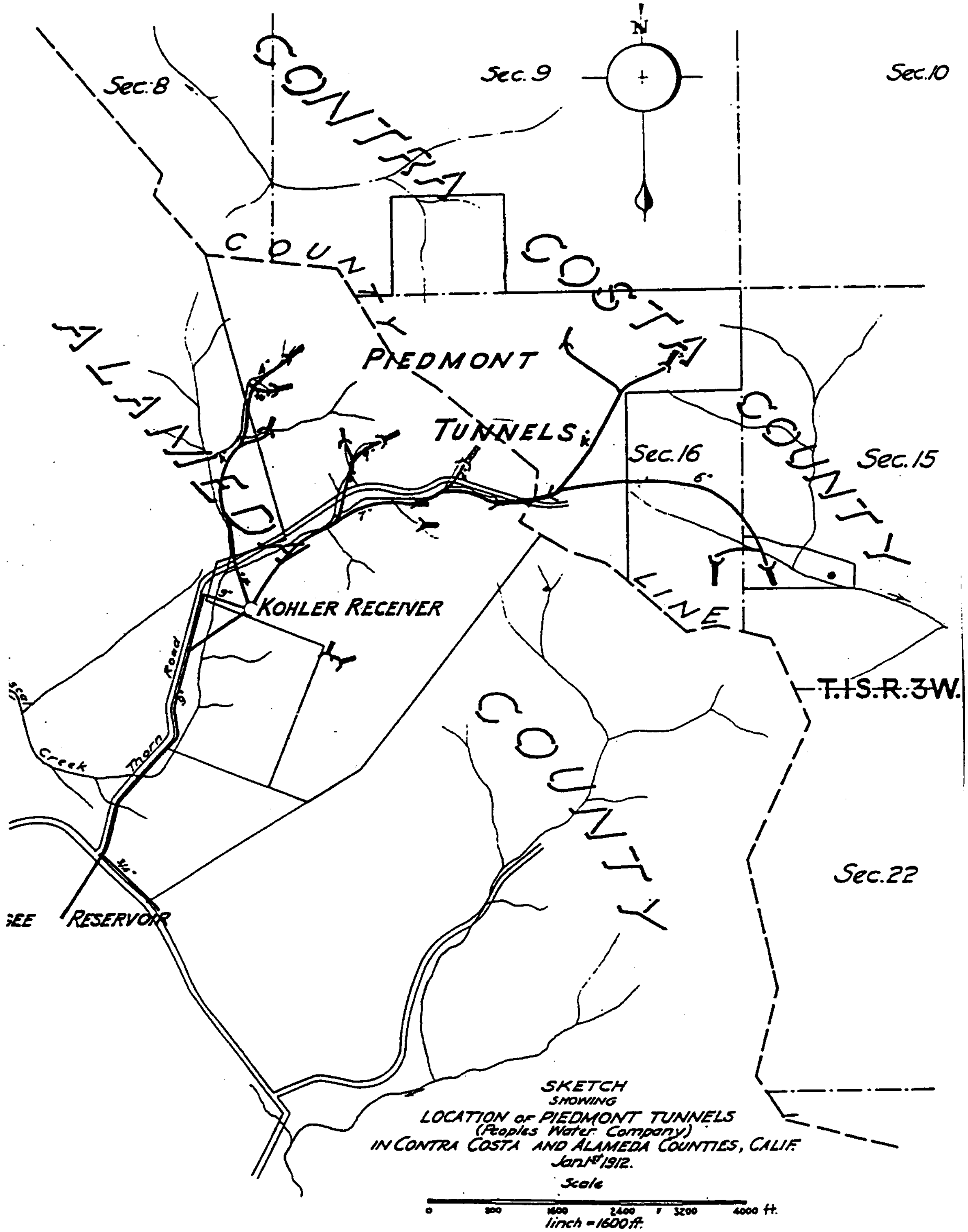
This map shows the approximate location of the springs and tunnels that supplied water to the University of California and the City of Berkeley in 1912. The exact date that the tunnels were abandoned is unknown, but it is likely that it occurred in 1930.



Norfleet Consultants	BERKELEY SPRINGS AND TUNNELS - 1912					
	EAST BAY PLAIN BENEFICIAL USE STUDY					
	PROJ NO:	981102	DATE:	6/15/98	FIGURE:	22

THE PIEDMONT TUNNELS, PIEDMONT 1912

This map shows the approximate location of the water supply tunnels in the Piedmont area that were dug by Mr. Dingee in the early 1890's. There were originally seventeen tunnels, but by 1912, seven to eight of them had gone dry or had been abandoned. Thorn Road is now called Thornhill Drive.



Norfleet Consultants	PIEDMONT TUNNELS - 1912		
	EAST BAY PLAIN BENEFICIAL USE STUDY		
	PROJ NO: 981102	DATE: 6/15/98	FIGURE: 23

DEVELOPMENT OF WATER COMPANIES IN THE EAST BAY 1865-1930