
Draft Report

Hydrogeologic Assessment of the Seaside Groundwater Basin

Prepared for
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and
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Privileged and Confidential Settlement Communication (Cal. Evidence Code §§ 1152 and 1154);
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Acronyms/Abbreviations

af	acre-feet
afy	acre-feet per year
AMC	antecedent moisture condition
ASR	aquifer storage and recovery
Cal-Am	California-American Water Company
CIMIS	California Irrigation Management Information System
CN	curve number
FORA	Fort Ord Reuse Authority
ft	feet
ft/d	feet per day
ft bgs	feet below ground surface
ft MSL	feet mean sea level
GDT	Geographic Data Technologies
GIS	geographic information systems
gpd	gallons per day
gpm	gallons per minute
M&I	municipal and industrial
MCWD	Marina Coast Water District
mg/L	milligrams per liter
MPWMD	Monterey Peninsula Water Management District
SCS	Soil Conservation Service
SGD	Staal, Gardner, & Dunne, Inc.
SMB	soil moisture budget
SMD	soil moisture deficit
SVIGSM	Salinas Valley Integrated Ground and Surface Water Model
SWRCB	California State Water Resources Control Board
TDS	total dissolved solids
USCS	Unified Soil Classification System
USGS	U.S. Geological Survey

Executive Summary

In March 2003, CH2M HILL (as part of a cooperative exercise embarked upon by various parties who account for essentially all of the current groundwater production in the Seaside Basin [Basin]) preliminarily concluded that current extractions from the Basin might significantly exceed its perennial yield. In light of this preliminary finding, California American, with the encouragement of other groundwater producers within the Basin, directed CH2M HILL to complete its assessment of the Basin focusing on the following:

- Completion of preliminary work to determine the Perennial Yield of the Basin.
- Assess the probability that unrestricted pumping from the Basin would cause salinity intrusion or other long-term adverse effects to the Seaside Basin.
- Define or better characterize the boundaries of the Seaside Basin.
- Provide recommendations on how the Basin could be managed over the next five to eight years, while additional water supplies which, directly or in lieu, could provide recharge capability for the Basin are developed. Management during this period of time would be for the protection of the Basin while allowing, to the maximum degree possible, continued extraction from the Basin.

The Seaside Basin is a northwest-southeast trending coastal subbasin that occupies an area of approximately 22 square miles and is located within a larger groundwater basin that potentially extends north to Pajaro Valley and east to Corral de Tierra. Previous investigators have divided the Seaside Basin into the inland subbasin, which underlies Fort Ord, and the coastal subbasin, which underlies the majority of the City of Seaside. The subbasins are further divided into subareas. These subdivisions are loosely based on the inferred locations of discontinuous, southwest steeply dipping, northwest trending reverse faults associated with the Monterey fault zone and the presence of an east-west trending anticline in the southern part of Fort Ord, which is considered a barrier to groundwater flow

A physical control does not exist for the northern and eastern boundaries, which were established in previous studies based on limited groundwater level data suggesting the presence of a groundwater divide caused by local pumping. Geologic evidence exists to suggest the water-bearing formations utilized for water supply in the Basin are contiguous with those encountered at depth north of the Basin boundaries. Hydrographs for monitoring wells north of Seaside's boundary exhibit a pronounced response to pumping in the Seaside Basin. This evidence suggests that the northern Basin boundary may be subject to migration depending on the relationship of pumping in Seaside to the wells supplying water for the Marina area.

Available driller's logs for wells in the study area were compiled and used to construct hydrogeologic cross-sections in the study area. The principal formations were identified and interpretation of formation surfaces were superposed on the hydrogeologic cross-sections and used to depict basinwide hydrostratigraphic units. The principle water-bearing

formations in the study area from oldest to youngest are: (1) the Miocene/Pliocene Santa Margarita Formation; (2) the Miocene/Pliocene Purisima Formation; (3) the Plio-Pleistocene Paso Robles Formation; and (4) the Pleistocene Aromas Formation. Wells in the Seaside Basin primarily are screened in the Paso Robles and Santa Margarita Formations. North of the Seaside Basin, municipal wells are completed in the Paso Robles and Purisima Formations.

Aquifer test data for the study area are limited. Therefore, the majority of the available transmissivity values were estimated using specific capacity data. Mean values of transmissivity for the Paso Robles Formation range from 20,000 gallons per day per foot (gpd/ft) in the Fort Ord subarea to 21,500 gpd/ft in the Northern subarea and 8,500 gpd/ft in the Southern subarea. Only two wells, City No. 1 and 2 located in the Northern subarea, are completed exclusively in the Santa Margarita Formation. Mean transmissivity for these wells is 38,500 gpd/ft. Well yields in the Basin typically range from 20 to 1,900 gpm. The lowest yields occur in the Southern subarea, and the greatest in the Northern and Fort Ord subareas. Increasing yields to the north can likely be attributed to a thickening of water-bearing sediments in this direction.

Groundwater in the Seaside Basin typically flows from areas of higher elevation in the east to lower elevations along the coast. Prior to any significant groundwater development in the Basin, water levels ranged from over 300 feet mean sea level (ft MSL) in the foothills of the North Inland subarea to about 10 ft MSL near the coast. After about 1965, groundwater production in the Basin substantially increased and pumping became the primary influence on water levels in the study area. Long-term pumping of municipal supply wells has created a large cone of depression, causing the gradient to be steep in the Fort Ord and Northern coastal subareas. The most dramatic declines are observed in the Fort Ord subarea, where water level elevations in production wells such as Luzern and Ord Grove have declined to -30 ft MSL.

Groundwater in the Paso Robles formation is generally of good quality and can be characterized by relatively low concentrations of total dissolved solids (TDS) (190 to 650 mg/L with a mean of about 265 mg/L), chloride (40 to 230 mg/L), sulfate (15 to 290 mg/L), and nitrate (2 to 12 mg/L). Groundwater in the Santa Margarita Formation can be characterized by moderate concentrations of TDS (225 to 680 mg/L with a mean of about 510 mg/L) and chloride (70 to 190 mg/L), and elevated concentrations of iron (0.03 to 1.25 mg/L). North of the Basin, water quality data for the Purisima Formation is available from water supply wells in the vicinity of Marina and a deep monitoring well cluster installed by the U.S. Geological Survey (USGS). Water quality in the Purisima Formation is of good quality, with some localized zones of high salinity due the presence of fine-grained marine sediments. Where continuous data were available, long-term trends in water quality for coastal wells were reviewed. TDS and chloride for coastal wells suggest that ionic concentrations are increasing with depth. Previous investigators have concluded that the marine depositional environment of the Santa Margarita sandstone, longer residence times, and less flushing of residual waters by recharging meteoric water are the potential reasons for this vertical trend (MPWMD 1997). Additional chemical data for inland monitoring wells suggest the vertical variation in TDS and chloride diminishes inland and to the north.

Geologic maps used as part of this study indicate that the Aromas Sand and Paso Robles units outcrop in the Monterey Bay immediately offshore of the Northern and Fort Ord

subareas and pose a threat to fresh water supply wells in the Basin. Seawater intrusion has locally impacted the shallow "180-Foot" and "400-Foot" aquifers (the Aromas Sand equivalent) in the Salinas Valley and Marina Coast Water District (MCWD). Salt water has intruded about 6 miles in the 180-Foot aquifer and about 3 miles in the 400-Foot aquifer in the Salinas Valley (Harding ESE 2001a). Farther south in the vicinity of Marina and the former Fort Ord area, seawater has intruded about 2 miles in the 180-Foot aquifer and about 3 miles in the 400-Foot aquifer (Harding ESE 2001a). In the Seaside Basin, periodic occurrences of seawater intrusion associated with heavy pumping have been reported in Cal-Am's Orange well (15S/1E-21J1) in 1966, 1974, and 1976 (USGS 1982).

A water budget was compiled for the Seaside Basin in order to quantify the primary sources of recharge to and discharge from the Basin. This analysis, coupled with information about the physical characteristics of the Seaside Basin, was utilized to develop an estimate of the perennial yield of the Basin for existing conditions. The perennial yield calculation is based on a "base period," typically defined by climate trends. Criteria for selection of a base period must include at least one period each of overall wet conditions and overall dry conditions (relative to average annual conditions). The base period selected for the Seaside Basin (1962 through 1989) satisfies most of these criteria. Perennial yield was also assessed using a long-term period which accounts for all the available data for the period of record (1949 to 2002). An alternative perennial yield was estimated, which represents the potential yield of the Basin should subsurface flow from the North Inland subarea be captured instead of migrating northward out of the Basin. Results of the perennial yield assessments indicate that a net groundwater extraction of 2,913 acre-feet per year (afy) over a climatic period similar to that of the base period could be sustained in the Basin without triggering an adverse impact (e.g., wells going dry or inducing seawater intrusion). This perennial yield estimate may potentially increase to 3,472 afy if pumping operations are optimized to capture subsurface flow exiting the northern boundary of the Basin. Perennial yield based on the long-term period, which incorporates all the data for the period of record, is 2,581 afy for existing conditions and 3,481 afy if production wells are positioned to capture subsurface flow exiting the northern boundary of the Basin.

Due to uncertainties in the soil moisture model, perennial yield was also estimated using an additional 20 percent deep percolation of precipitation for the same periods and scenarios described above. Results of this assessment suggest that there is no net benefit of an additional 20 percent of recharge from deep percolation for the base period. Because the North Inland area accounts for a large portion of the total recharge from deep percolation of precipitation, the groundwater gradient in the vicinity of the north boundary significantly increases under this scenario, which facilitates additional subsurface flow across the north boundary before reaching the coastal subareas and becoming recharge to wells. However, the perennial yield may potentially increase to 3,754 afy for this scenario if the subsurface flow exiting the northern boundary of the Basin is captured. Table ES-1 provides a range of possible perennial yields for the Basin depending on the scenario.

TABLE ES-1
Summary of Perennial Yield Estimates for the Seaside Groundwater Basin

Scenario	Perennial Yield, No Capture ¹ (afy)	Perennial Yield, w/Capture ¹ (afy)
Base Period (1962-1989)	2,913	3,472
Long-Term (1949-2002)	2,581	3,481
Base Period plus 20% more deep percolation of precipitation (1962-1989)	2,625	3,754
Long-Term plus 20% more deep percolation of precipitation (1949-2002)	2,673	4,051

Note:

¹ "Capture" signifies capture of subsurface flow from North Inland subarea, as opposed to this flow migrating northward out of the Seaside Basin.

Current net groundwater extraction in the Seaside Basin is estimated to total approximately 4,800 afy, and was about 5,600 afy as recently as 1995. This indicates that current extraction may exceed the perennial yield estimate of 2,913 afy by as much as 40 percent for the base period. Net groundwater extraction in excess of this perennial yield is expected to continue until an alternate source of water can be used in lieu of groundwater and/or pumping is reduced and additional flows in the North Inland subarea are captured before exiting through the northern boundary of the Basin.

Development of a supplemental supply to relieve over-production is estimated by Cal-Am to range from five to eight years. To protect and manage Seaside Basin's groundwater assets on a sustainable basis, while supplemental supplies are pursued, it is recommended that groundwater production from the Basin remain at the current rates and/or be reduced where appropriate. Currently, the Basin has excess groundwater available due to a recent period of relatively wet climatic conditions as evidenced by precipitation and groundwater level data. Therefore, current levels of groundwater production may be temporarily sustained in excess of the long-term perennial yield which will result in borrowing against future production. During this period, groundwater levels in the Basin should be closely monitored to assess storage conditions in the Basin and an annual determination should be made as to the status of the Basin. Eventually net groundwater extraction from the Basin should be reduced to within its perennial yield. Additional recommendations include the following:

- Develop a numerical groundwater flow model of the Seaside Basin and adjacent areas. A calibrated flow model of the Basin can be used as a groundwater management tool to evaluate and optimize future operational scenarios.
- Evaluate the potential for redistributing pumpage to capture subsurface flow from the North Inland subarea that would otherwise exit the Basin across the northern boundary.
- Perform additional studies to assess the lateral and vertical extent of the Santa Margarita Formation underlying the Seaside Basin. If results of these studies indicate

that conditions are favorable (i.e., reasonable aquifer properties and little or no potential for seawater intrusion), temporarily mining the Santa Margarita Formation may be considered as a short-term management option to sustain production while other supplies are being developed.

- The lateral extent of stratigraphic subunits within the Paso Robles formation within the Fort Ord and Northern subareas should be investigated to evaluate the feasibility of installing production wells in only the lower confined portion of this unit. Production from the lower water-bearing subunit will temporarily reduce the risk of seawater intrusion to the Paso Robles Formation.
- Develop and implement a detailed water level and water quality monitoring program.
- Suitable wells in the Seaside Basin should be identified and retrofitted for aquifer storage and recovery operations in order to replenish the Seaside Basin from any surplus flows that might occur in the Carmel River system during the next 5 to 8 years
- A review of all water level and water quality data collected should be assessed on an annual basis to re-evaluate the Basin's status and update the groundwater model for use in making management decisions

1.0 Introduction

1.1 Purpose

In March 2003, CH2M HILL (as part of a cooperative exercise embarked upon by various parties who account for essentially all of the current groundwater production in the Seaside Basin [Basin]) preliminarily concluded that current extractions from the Basin might significantly exceed its perennial yield. In light of this preliminary finding, California American, with the encouragement of other groundwater producers within the Basin, directed CH2M HILL to complete its assessment of the Basin focusing on the following:

- Completion of preliminary work to determine the Perennial Yield of the Basin.
- Assess the probability that unrestricted pumping from the Basin would cause salinity intrusion or other long-term adverse effects to the Seaside Basin.
- Define or better characterize the boundaries of the Seaside Basin.
- Provide recommendations on how the Basin could be managed over the next five to eight years, while additional water supplies which, directly or in lieu, could provide recharge capability for the Basin are developed. Management during this period of time would be for the protection of the Basin while allowing, to the maximum degree possible, continued extraction from the Basin.

1.2 Background

Water supply in the Monterey Peninsula area is comprised of surface water from the Carmel River, groundwater from the Carmel Valley alluvial aquifer, and groundwater from the coastal subareas of the Seaside Basin. In 1995, the California State Water Resources Control Board (SWRCB) issued Board Order No. 95-10, which stated that the Carmel River was over-appropriated during summer months and required Cal-Am to reduce its annual diversions from the river, including pumpage from the Carmel River aquifer system, by more than 10,000 acre-feet (af). Restricted supply from the Carmel River has increased reliance on groundwater in the Seaside Basin to meet the current water supply demand of the communities. Plans for supplemental water supplies for the region are being evaluated by various government agencies and Cal-Am, and include desalinization, aquifer storage and recovery (ASR) using surplus winter flows from the Carmel River, and reclaimed water. Development of a supplemental supply to relieve over-production from the Carmel River is estimated by Cal-Am to take five to eight years. In the interim, groundwater production from the Seaside Basin will provide a substantial share of the water supply for the communities on the Monterey Peninsula. While a supplemental supply is pursued, increased reliance on groundwater production from Seaside Basin will require proper Basin management to protect local groundwater assets from adverse consequences. This study provides the results of an assessment of Seaside Basin's hydrogeologic condition, an

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evaluation of the Basin's perennial yield, and recommendations for Basin management until a supplemental water supply can be secured.

1.3 Methods and Limitations

This study was prepared in accordance with CH2M HILL's scope of work provided in December 2002. The intent of this evaluation was to synthesize existing data on the Seaside Basin, and to provide an assessment within the context of the objectives of the overall study. It is important to note that no new fieldwork has been conducted, and all analyses and information summarized herein are based on existing data and reports. Many reports associated with the Basin were reviewed, and those that yielded significant information or analyses are summarized in the next section.

Existing work was evaluated as the basis for this study. Previous studies were completed with existing data, and limited analysis of data gaps. In this study, data gaps have been identified where existing data led to uncertainties in the assessment.

1.4 Previous Work

The Seaside Basin has been studied extensively in order to evaluate the hydrogeologic condition of the Basin and develop a physical solution for groundwater management within the Basin. These reports are primarily focused on regional geology (including offshore), local hydrogeology, existing and potential for seawater intrusion, and quantification of a Basin perennial yield. Documents pertinent to this study are summarized in Table 1-1 below. (A complete listing of sources referred to in the preparation of this report is presented in Section 7.0, References.)

TABLE 1-1
Pertinent Documents Referenced in This Study

Document	Description
California Geological Survey, California Department of Conservation 2002. <i>Geologic Map of Monterey 30' x 60' Quadrangle and Adjacent Areas, California: A Digital Database</i> . CGS CD 2002-04 (CD-ROM).	This digital database provided a geo-referenced geologic map accompanied by an explanation of the geology and of the electronic files delivered with the database.
Clark, J.C., W.R. Dupre, and L.I. Rosenberg 1997. <i>Geologic Map of the Monterey and Seaside 7.5-minute Quadrangles, Monterey County, California: A Digital Database</i> . U.S. Geological Survey Open-File Report 97-0030.	This digital database provided a geo-referenced geologic map accompanied by an explanation of the geology and of the electronic files delivered with the database. The map is an updated version of previous maps constructed for the quadrangles. In addition, descriptions of the local stratigraphy, fault geometry, and quaternary deformation are presented by the authors.

TABLE 1-1
Pertinent Documents Referenced in This Study

Document	Description
Feeney, Martin, and Lewis Rosenberg 2002. <i>Deep Aquifer Investigation—Hydrogeologic Data Inventory, Review, Interpretation and Implications.</i> Technical Memorandum—Technical Review Draft. Prepared for WRIME, Inc. September 2002.	The purpose of this investigation was to refine the conceptual model of the deep coastal aquifer system underlying the "180-Foot" and "400-Foot" aquifers of the Salinas Valley and Marina area to update the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM). To accomplish this, the authors integrated all available data on the deep coastal aquifer systems from Monterey to Moss Landing. The data were used to construct hydrogeologic cross-sections of the study area, present a description of the geology, and assess the response to local water levels in the deep aquifers from pumping of the Marina Coast Water District's wells. Results of this investigation were considered preliminary.
Fugro West, Inc. (Fugro) 1997a. <i>Reconnaissance-Level Feasibility Study for Seaside Basin Injection/Recovery Project.</i> Prepared for Monterey Peninsula Water Management District. February 1997.	This study focuses on the qualitative aspects of a conjunctive use program that would utilize available excess Carmel River flows for subsurface storage and recovery within the Seaside Basin. Specifically, the study evaluates the technical, regulatory, and economic issues associated with implementation of a conjunctive use program. Work conducted as part of this study included review of existing hydrogeologic data, quantifying the availability of excess flows, identifying favorable areas for injection/extraction in the Seaside Basin, identifying potential constraints for program implementation, developing preliminary cost estimates for pilot testing and full-scale program implementation, and evaluating existing facilities.
Fugro 1997b. <i>Hydrogeologic Assessment: Seaside Coastal Groundwater Subareas Phase III Update, Monterey County, California.</i> Prepared for Monterey Peninsula Water Management District. September 1997.	Fugro conducted a study to assess the hydrogeologic conditions and groundwater resources of the coastal portion of the Seaside Groundwater Basin. Work conducted during this study included compiling and reviewing existing hydrogeologic data, constructing a base map using a Geographic Information System (GIS) format, updating existing cross-sections and hydrographs with new information, updating groundwater production data, assessing the boundary between the Northern Coastal and Fort Ord subareas, estimating the capture zone of the Paralta well, revising estimates of hydraulic parameters and storage, reassessing the potential for seawater intrusion, updating an assessment of long-term yield under natural conditions, and developing recommendations for Basin management.
Greene, Herbert G. 1990. "Regional Tectonics and Structural Evolution of the Monterey Bay Region, Central California." In <i>Geology and Tectonics of the Central California Coast Region, San Francisco to Monterey—Volume and Guidebook</i> , edited by Garrison, R.E., H.G. Greene, K.R. Hicks, G.E. Weber, and T.L. Wright. Bakersfield, California: American Association of Petroleum Geologists, Pacific Section. June 1990.	This is one of a number of articles included in a guidebook arranged by the American Association of Petroleum Geologists, which includes papers on the regional tectonics, structural evolution, and quaternary geology of the Monterey Bay region.

TABLE 1-1
Pertinent Documents Referenced in This Study

Document	Description
Harding ESE 2001a. Final Report: Hydrogeologic Investigation of the Salinas Valley Basin in the Vicinity of Fort Ord and Marina, Salinas Valley, California. Prepared for Monterey County Water Resources Agency. Prepared by M. Taraszki and D.J. Craig. April 2001.	This report examines the hydrostratigraphic continuity of water – bearing sediments underlying the Salinas Valley, Marina, and former Fort Ord areas to assess the potential for seawater intrusion. Hydrogeologic data from the Salinas Valley and Marina area were collected and used to construct cross-sections and assess existing water quality data. The study concludes that the “180-Foot” and “400-Foot” aquifers are continuous throughout the study area and have been affected by seawater intrusion in response to excessive groundwater production. Deeper water-bearing units, the Paso Robles and Purisima Formations, were not examined in detail for this investigation.
Logan, John 1982. Hydrogeology of the Seaside Area. Prepared for Monterey Peninsula Water Management District. June 1982.	Logan's study represents the second comprehensive study of the Seaside Basin after Muir (USGS 1982). In this study, Logan assessed the onshore and offshore geology of the study area, local hydrogeology including water levels and hydraulic properties, water quality, perennial yield, and recommendations for management.
Monterey Peninsula Water Management District (MPWMD) 1991. Technical Memorandum 91-05: Summary of Paralta Well Aquifer Test. Prepared by Oliver, Joseph W. October 1991.	This memorandum summarizes aquifer testing activities at the Paralta well in the Fort Ord coastal subarea. Hydraulic properties were assessed and water quality data collected during aquifer testing were evaluated.
MPWMD 1994. Summary of 1994 Fort Ord Monitor Well Installations. Technical Memorandum 94-07. Prepared by Oliver, Joseph W. December 1994.	As part of the MPWMD's expanded groundwater monitoring program in the Seaside Basin, three monitoring well clusters (FO #7, #8, and #9) were installed in the Fort Ord subarea. Information included in the report includes well constructions details, water level data, and results of water quality sampling.
MPWMD 1996a. Summary of Seaside Basin Monitor Well Data, with Focus on Local Response to Production from the Paralta Well, April to December 1995. Technical Memorandum 96-01. Prepared by Oliver, Joseph W. February 1996.	This memorandum presents water level data from monitoring wells in the vicinity of Cal-Am's Paralta well up to December 1995. Water level data for monitoring wells FO-#7, FO-#8, FO-#10, PCA-East, PCA-West, MSC, and Ord Grove are presented in the report. The report discusses the response of the local groundwater system to pumping from the Paralta well.
MPWMD 1996b. Summary of Seaside Basin Monitor Well Data, with Focus on Paralta Well Pumping and Recovery Period, December 1995 to June 1996. Technical Memorandum 96-02. Prepared by Oliver, Joseph W. August 1996.	This memorandum presents water level data from monitoring wells in the vicinity of Cal-Am's Paralta well from 1995 to 1996. Water level data for monitoring wells FO-#7, FO-#8, FO-#10, Playa 4 Well, and the Paralta test well are presented in the report. The report discusses the response of the local groundwater system to the period of recovery when the Paralta well is not in operation.
MPWMD 1997a. Seaside Basin Coastal Monitor Wells: Ground Water Quality Monitoring Results, 1990-1996. Technical Memorandum 97-02. Prepared by Oliver, Joseph W. February 1997.	This memorandum presents water quality data collected in monitoring well clusters FO-#7, FO-#8, FO-#9, PCA-East, PCA-West, MSC, and Ord Grove well from 1990-1996. The purpose of the report was to provide information on the water quality conditions in the coastal portion of the Basin, and document background water quality for comparison in future studies. The memorandum also addressed seawater intrusion potential in the Seaside Basin.

TABLE 1-1
Pertinent Documents Referenced in This Study

Document	Description
MPWMD 1997b. <i>Summary of 1996 Seaside Basin Monitor Well Installations.</i> Technical Memorandum 97-04. Prepared by Oliver, Joseph W. July 1997.	In 1996, two additional monitoring well clusters (FO-#10, and FO-#11) were installed in the former Fort Ord Military Reservation, north of the Seaside Basin boundary, for the purpose of providing hydrogeologic information in this area and to monitor the local groundwater response to Cal-Am's Paralta well. This memorandum summarizes construction and completion of the monitoring wells, including water level and water quality data.
Staal, Gardner, & Dunne, Inc. (SGD) 1987. <i>Hydrogeologic Investigation: Seaside Coastal Ground Water Basin, Monterey County, California.</i> Prepared for Monterey Peninsula Water Management District. May 1987.	The objective of this study was to assess the feasibility of additional groundwater development in the coastal portion of the Seaside Basin. Work performed as part of this study included development of a water budget, evaluation for the potential for seawater intrusion under future operational scenarios, review of water levels including hydrographs, review of groundwater extraction in the Basin, an estimate of the long-term perennial yield, and identifying locations for increased extractions.
SGD 1990a. <i>Hydrogeologic Investigation: PCA Well Aquifer Test, San City, California.</i> Prepared for Monterey Peninsula Water Management District. July 1990.	The MPWMD developed an "Interim Water Supply Program" to identify and develop sources of water to augment the existing supply for the Monterey area until a long-term supply could be obtained. As part of the MPWMD's Interim Water Supply Program, SGD conducted an investigation which included the installation of two monitoring well clusters (PCA-East and PCA-West) to monitor aquifer response during a five-day aquifer test on the PCA production well. The purpose of the test was to assess the feasibility of increased production from the PCA production well. The study summarizes the construction of the two monitoring well clusters and aquifer testing.
SGD 1990b. <i>Summary of Operations: Paralta Test Well, Seaside, California.</i> Prepared for Monterey Peninsula Water Management District. July 1990.	As part of the MPWMD's Interim Water Supply Program, water supply projects were identified that could provide additional water to the area. Groundwater production from the Fort Ord subarea was identified as a feasible option. To pursue this option, the MPWMD and Cal-Am provided joint funding for the installation of the Paralta test well. This report summarizes drilling operations, well completion, water quality, and aquifer testing of the Paralta test well.
SGD 1990c. <i>Hydrogeologic Update: Seaside Coastal Ground Water Basins, Monterey County, California.</i> Prepared for Monterey Peninsula Water Management District. August 1990.	To assess the impacts and feasibility of additional groundwater development from the Seaside Basin, SGD developed a field exploration program with the MPWMD to help fill in additional data gaps. The field exploration program included installation of monitoring wells and a five-day pumping test on the PCA production well. Data collected from the field exploration program were used to update and refine the hydrogeologic framework of the Seaside Basin. This report documents the field exploration program and provides an updated hydrogeologic analysis of the Seaside Basin using the new information. Included in the analysis is an updated estimate of the Basin's perennial yield.
U.S. Geological Survey (USGS) 1970. <i>Geology of Southern Monterey Bay and its Relationship to the Ground Water Basin and Salt Water Intrusion.</i> Open-file Report 1970. Preliminary report. Prepared by H. G. Greene in cooperation with the California State Department of Water Resources.	The U.S. Geological Survey, in cooperation with the State of California, performed an investigation of Monterey Bay to delineate the offshore groundwater basins and determine where aquifers may outcrop and pose a threat of seawater intrusion. The study concluded that the water-bearing sediments of the Paso Robles Formation and parts of the "180 Foot" aquifer outcrop offshore in Monterey Bay and may provide an entrance for seawater.

TABLE 1-1
Pertinent Documents Referenced in This Study

Document	Description
USGS 1977a. <i>Geology of the Monterey Bay Region.</i> Open-file Report 77-718. Preliminary report. Prepared by H. G. Greene.	This study provides a comprehensive look at the regional geology surrounding the Seaside Groundwater Basin. Detailed maps developed as part of this study illustrate the onshore and offshore geology of the Monterey Bay. Offshore geology was interpreted from seismic refraction surveys and ocean floor rock samples.
USGS 1977b. <i>Initial Assessment of the Ground-water Resources in the Monterey Bay Region, California.</i> Prepared in cooperation with the Association of Monterey Bay Area Governments. Water-Resources Investigations 77-46. Prepared by K.S. Muir.	This report summarizes an initial assessment of groundwater in the Monterey area to assist in the development of local and regional plans. The study area includes the entire area adjacent to the Monterey Bay from Santa Cruz south to Carmel. Muir divided the region into six groundwater subbasins based on the drainage areas of various coastal streams. The study is primarily qualitative and does not provide any detail regarding perennial yield analyses of the subbasins.
USGS 1982. <i>Ground Water in the Seaside Area, Monterey County, California.</i> Prepared in cooperation with the Monterey Peninsula Water Management District. Water-Resources Investigations 82-10. Prepared by K.S. Muir, September 1982.	This investigation represents the first detailed hydrogeologic assessment of the Seaside Groundwater Basin. In this report the boundaries of the Basin are established and the Basin is divided into five subareas. Muir discusses the local hydrogeology, including water levels and water quality. In addition, a water budget and perennial yield are developed during this investigation to be used by the MPWMD in planning long-term utilization of groundwater within the Basin.
USGS 2002. <i>Geohydrology of a Deep-Aquifer System Monitoring-Well Site at Marina, Monterey County, California.</i> Prepared in cooperation with the Monterey County Water Resources Agency. Water-Resources Investigations Report 02-4003. Prepared by Hanson, R.T., R.R. Everett, M.W. Newhouse, S.M. Crawford, M.I. Pimentel, and G.A. Smith.	The USGS completed a deep-aquifer system monitoring well cluster at Marina, California to provide basic geologic and hydrologic information about the deep-aquifer system of the coastal region along Monterey Bay. Four monitoring wells were constructed at the site and completed in the Paso Robles and Purisima Formations to a total depth of 1,860 feet below ground surface. The study provides a detailed description of lithology, hydraulic properties, and water quality of the deep-aquifer system in the vicinity of the Seaside Groundwater Basin.
USGS and California Department of Conservation, Division of Mines and Geology 1989. <i>Geology of the Central California Continental Margin, Scale 1:250,000.</i> California Continental Margin Geologic Map Series. Central California Continental Margin—Area 5 of 7. Map Nos. 5A, 5B, 5C, and 5D. Edited by Greene, H.G. and M.P. Kennedy.	These maps are the fifth set in a series of seven that detail the geology of the California continental margin. The maps provided in the set for the central region series (5A – 5D) are geology, fault plane solutions and earthquake epicenters, gravity and magnetic anomaly, and well trackline and data source. The geology map (5A) is a larger-scale, color version of the offshore maps presented by Greene in previous studies.
Yates, G., M. Feeney, and L. Rosenberg 2002. <i>Draft Report: Laguna Seca Subarea Phase III Hydrogeologic Update.</i> Prepared for Monterey Peninsula Water Management District. April 2002.	Yates et. al. evaluated groundwater conditions and water supply demand in the Laguna Seca subarea of the Seaside Basin. Evaluation of the subarea included assessing updated geology with respect to the structural characterization of the subarea, thickness of the water-bearing sediments, analysis of groundwater production records, review of water level elevation data, development of a groundwater budget, and quantification of the perennial yield of the Laguna Seca subarea.

2.0 Basin Description

This section describes the location, setting, physiography, climate, and land use of the Seaside Basin and adjacent areas.

2.1 Location and Setting

The Seaside Basin is located along the central coast portion of Monterey County, California. The Basin is situated on the Monterey Bay, directly northeast of the Monterey Peninsula and south of Marina and Salinas Valley (Figure 2-1). Population centers overlying the Basin include the City of Seaside, Sand City, and parts of Del Rey Oaks, as well as the former Fort Ord Military Reservation.

2.2 Physiography

The physiographic and topographic features of the Seaside Basin have been described in numerous previous investigations (USGS 1982, Logan 1982, SGD 1987b, SGD 1990c). The area that defines the Seaside Basin, as described by Muir (USGS 1982), is characterized as a northwest-southeast trending coastal alluvial subbasin that occupies an area of approximately 24 square miles and is located within a larger groundwater basin that potentially extends as far north as Pajaro Valley (Feeney and Rosenberg 2002) and as far east as Corral de Tierra (Logan 1982). For the purposes of this study, the Basin is defined as being bound on the west by the Monterey Bay and the south by the Chupines Fault where alluvial sediments are in contact with the Monterey shale formation. The southern and western boundaries represent a hydrogeologic boundary and were established based on physical features. A physical control does not exist for the northern and eastern boundaries, which were established in previous studies based on limited water level data suggesting the presence of a groundwater divide caused by local pumping (USGS 1982). A more detailed discussion of these boundaries and their impact on this study are addressed in Section 3.1, Basin Boundary.

Previous investigators have divided the Seaside Basin into the inland subbasin, which underlies Fort Ord, and the coastal subbasin, which underlies the majority of the City of Seaside (USGS 1982). The coastal subbasin generally comprises the area east of Monterey Bay and west of North-South Road paralleling the Fort Ord Military Reservation boundary. The inland subbasin lies entirely within the former Fort Ord Military Reservation. The coastal subbasin is further subdivided into the Fort Ord, Northern, and Southern subareas located from north to south, respectively (Figure 2-1). These subdivisions are loosely based on the inferred locations of discontinuous, steeply southwest-dipping, northwest-trending reverse faults associated with the Monterey fault zone. The Ord Terrace fault separates the Fort Ord subarea and the Northern subareas, and the Seaside fault separates alluvial deposits between the Northern and Southern Subareas. The inland subbasin can be further divided into the Northern Inland and Laguna Seca subareas. The division between the Northern Inland and Laguna Seca subareas is based on the presence of an east-west

trending anticline in the southern part of Fort Ord, which is considered a barrier to groundwater flow (Figure 2-1). Table 2-1 summarizes the approximate area each subarea occupies within the Basin.

TABLE 2-1
Approximate Size of Seaside Groundwater Basin Subareas (in Acres)

Coastal Subbasin			Inland Subbasin	
Fort Ord	Northern	Southern	North Inland	Laguna Seca
1,462	824	1,021	7,725	2,977

Topography consists primarily of currently active coastal sand dunes, followed by a coastal plain and older stabilized sand dunes (SGD 1987b). Coastal sand dunes are present along a narrow quarter-mile-wide stretch of land where the Basin meets the bay. These coastal dunes rise approximately 100 feet in elevation and grade eastward into a narrow coastal plain varying in width from one to two miles (Logan 1982). Older sand dunes dominate the topography in the eastern portion of Seaside and the majority of Fort Ord Military Reservation. Topography generally slopes downward to the Monterey Bay, ranging in elevation from about 800 feet mean sea level (ft MSL) in the east to 0 ft MSL in the west, where the active sand dunes meet the Monterey Bay (Figure 2-2).

2.3 Climate

The area has a Mediterranean-type climate, with warm dry summers and mild winters. Rain gauge stations are not present within the Seaside Basin. Precipitation in the Seaside Basin was therefore estimated for the period 1949 through 2002 using monthly data available from nearby NOAA Stations (Station #045795 [Monterey] and, to a much lesser degree, NOAA Station #047669 [Salinas Municipal Airport.]) Yates et al. (2002) estimate that long-term average annual precipitation in the Seaside Basin is approximately 15 inches per year. Using this estimate of long-term average annual precipitation, monthly rainfall values in the Seaside Basin were estimated by scaling the average annual precipitation at the Monterey NOAA station (19.72 inches per year) by 15/19.72 and applying this scaling factor to the monthly NOAA data. Using this method, average annual rainfall in the Seaside Basin is estimated at 14.62 inches, most of which occurs between the months of November and April. Figure 2-3 provides a graphical summary of water-year annual precipitation in the vicinity of the Seaside Basin, as estimated by this method. Historically, precipitation has ranged from 5.45 inches (low – 1951) to 36.02 inches (high – 1998). Figure 2-3 also provides a plot of cumulative departure from mean annual precipitation for the same period and illustrates longer-term climate trends. Drier or drought conditions occurred for the periods 1958 through 1966 and 1983 through 1992, and wetter-than-average conditions occurred during the periods 1977 through 1983 and 1992 through 1998.

2.4 Land Use

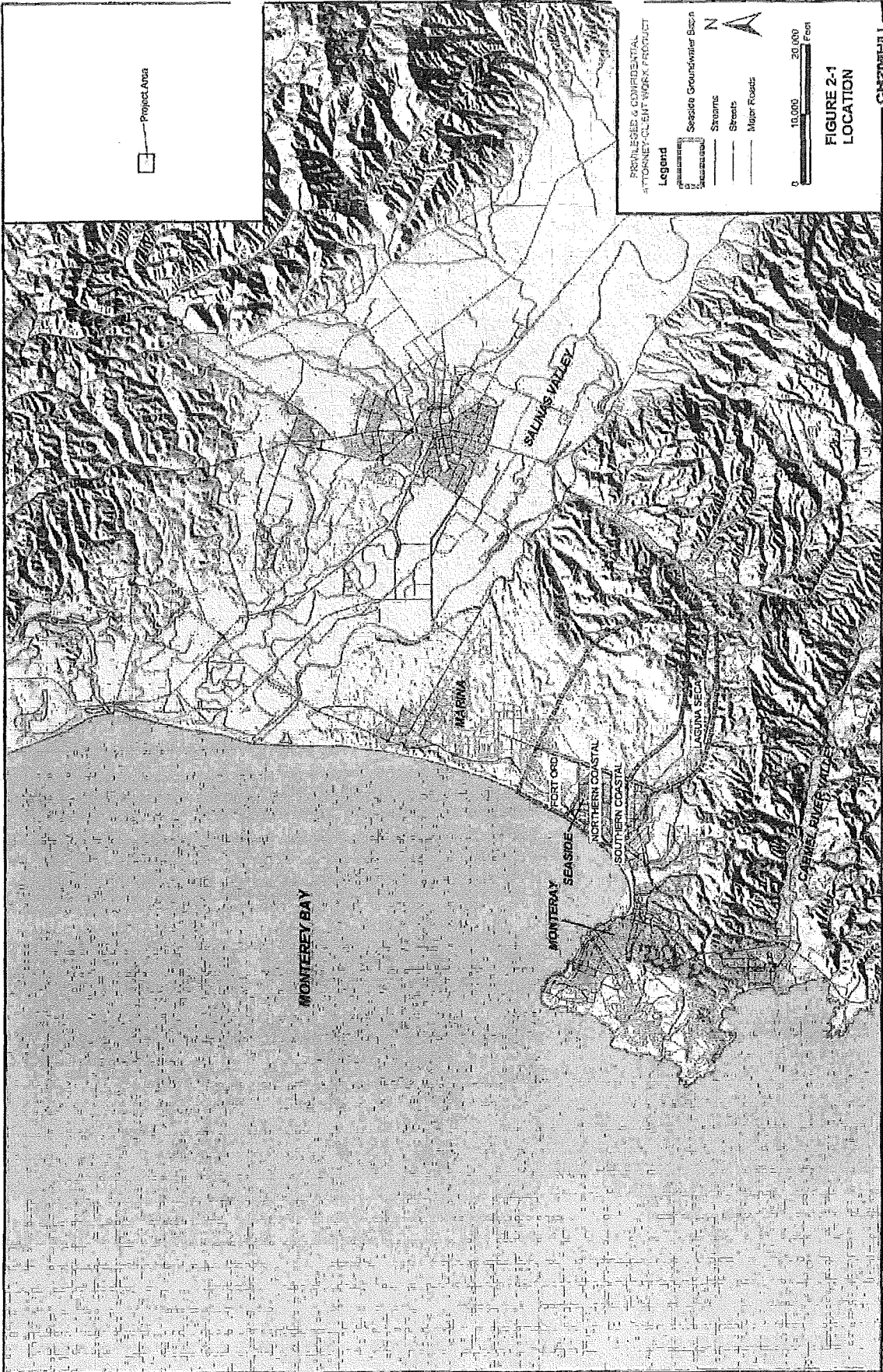
Current land use in Seaside Basin varies greatly due to the location of the former Fort Ord Military Reservation with respect to the communities of Seaside, Del Rey Oaks, and Marina. A large portion of the Basin is occupied by the former Fort Ord Military Reservation and has

historically remained undeveloped. Figure 2-4 summarizes the current land use within the Basin.

The Fort Ord Reuse Authority (FORA) was established in 1994 to adopt, finance, and implement a plan for the area formerly occupied by Fort Ord. FORA published a plan in 1997 that outlined the future development of the former Fort Ord within the context of current regional land use. The North Inland subarea, which comprises about 55 percent of the total Basin area, lies entirely within the former Fort Ord Military Reservation and was historically used by the U.S. Army as a practice range. Currently, the land remains undeveloped and the upland portions of the subarea are subject to ordnance removal (Figure 2-4). In the plan presented by FORA, the North Inland Subarea will be designated primarily for habitat management, with smaller areas reserved for open space recreation. In the western portion of the North Inland subarea, some land is zoned for a military enclave, a medium-density residential area, business parks, a golf course and hotels (Figure 2-5). The majority of the Fort Ord Subarea is within the boundaries of the former Fort Ord Military Reservation. Land use in this area is currently a military enclave but has been designated for construction of a golf course with hotels and a medium-density residential area (Figure 2-5).

The Northern and Southern subareas are within the cities of Seaside and Del Rey Oaks. Land use in these subareas is dominated by residential, commercial, and industrial uses (Figure 2-4). Land use in the western portion of the Laguna Seca subarea is predominantly business parks and industrial, whereas the eastern half is characterized by residential areas interspersed with open areas for parks and recreation (Figure 2-4).

The closing of the former Fort Ord Military Reservation may have contributed to the overall population decline of the Basin in the last decade (USGS 2002). The main population center of Seaside has declined approximately 27 percent during the last decade, from 38,921 in 1990 to 28,404 in 1999 (U.S. Census Bureau 2000). The former Fort Ord Military Reservation historically maintained a military presence of approximately 14,500 personnel. In addition, family members of active-duty personnel totaled about 17,000 and Fort Ord employed 3,800 civilians. The resident population of Fort Ord totaled 31,270 in 1991.



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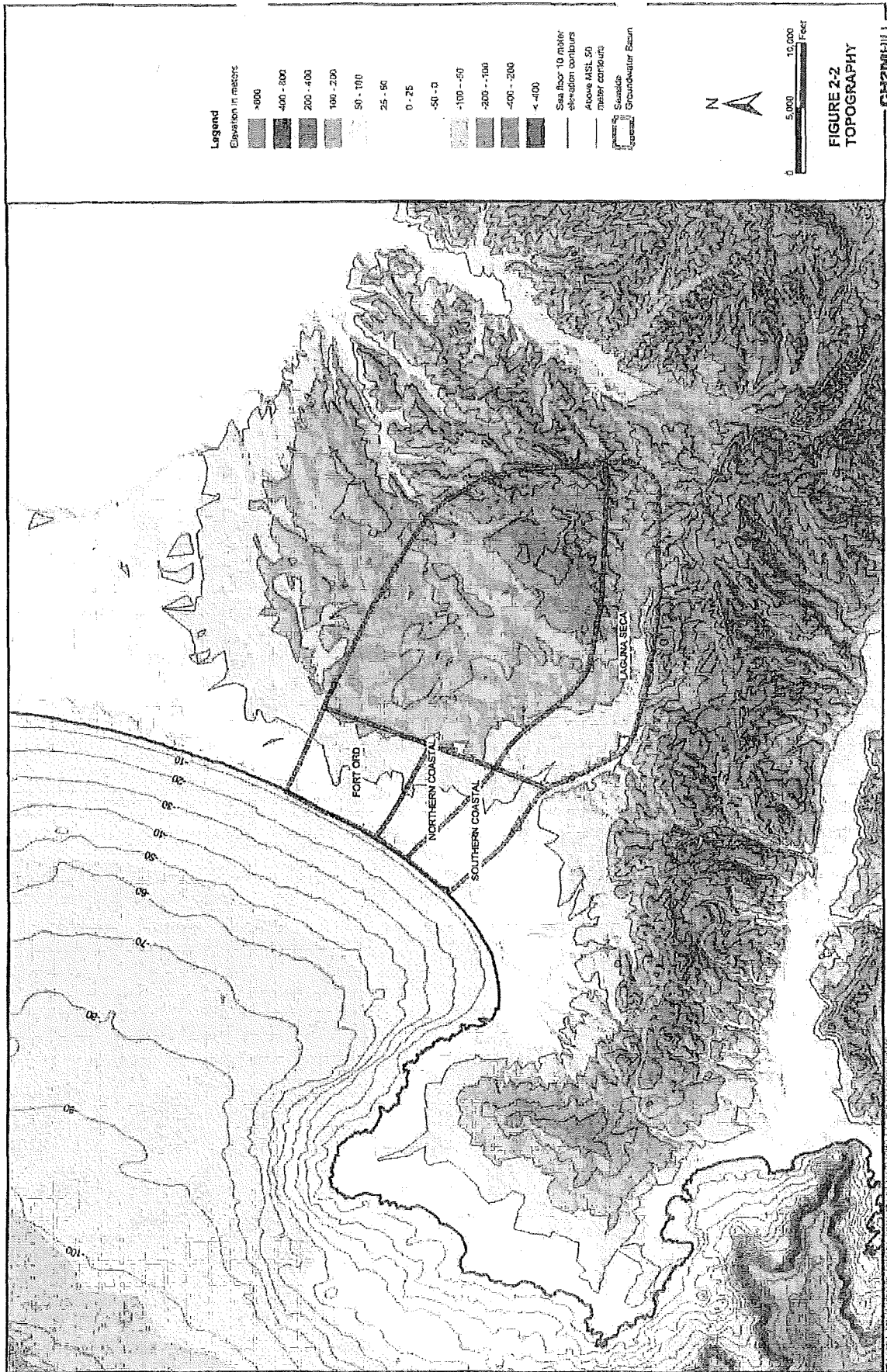


FIGURE 2-2
TOPOGRAPHY

CH2MHILL

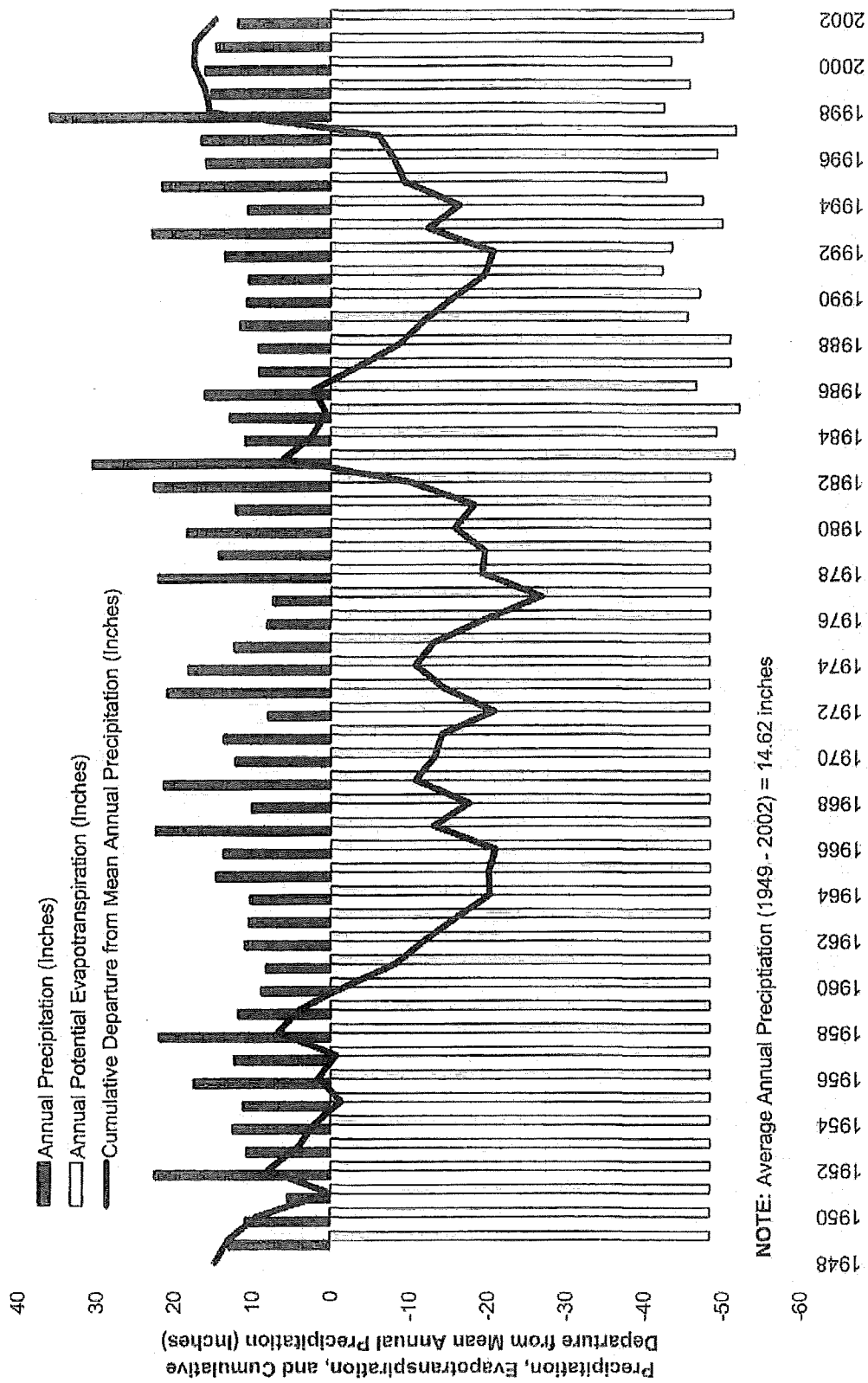
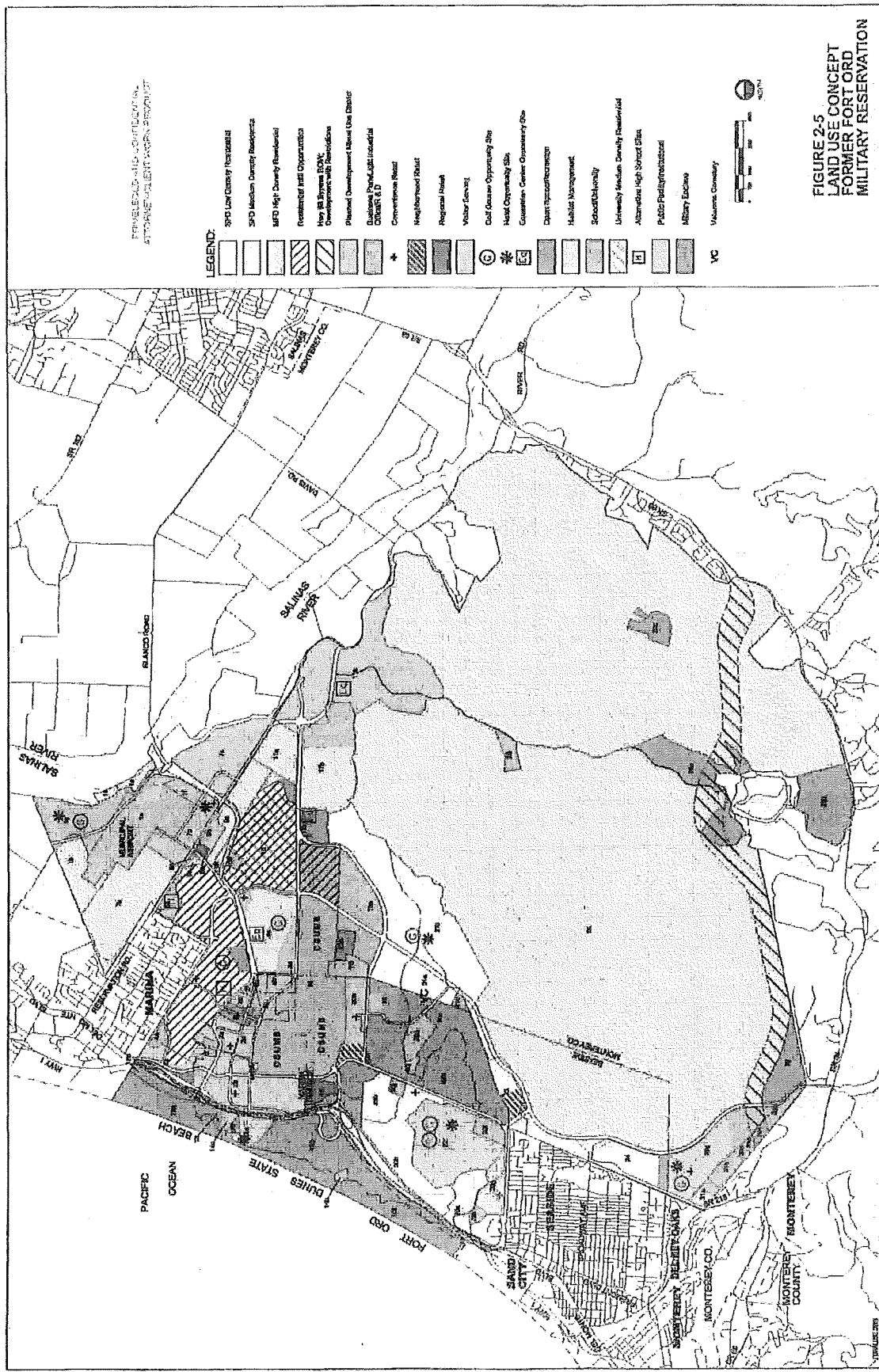


FIGURE 2-3
 SEASIDE AREA CLIMATIC
 DATA AND TRENDS

Privileged and Confidential

CH2MHILL





Source: Fort Ord Reuse Plan (Fort Ord Reuse Authority 2001)
Map of the Fort Ord Reuse Plan

3.0 Hydrogeologic Setting

This section presents a description of the hydrogeology of the Seaside Groundwater Basin and water-bearing strata contiguous with the Basin boundary. The description is based largely on a compilation of information from sources listed in Table 1-1. In addition, a project GIS database was developed as part of this study that compiled electronic information from Geographic Data Technologies (GDT) and the USGS. The GIS includes digital information files generated from tables and figures developed by the MPWMD, Cal-Am Water, City of Seaside, Marina Coast Water District (MCWD), and other consultants that have performed work in the Monterey coastal region.

The Seaside Groundwater Basin lies in a tectonic depression between two structural highs, the Gabilan Range to the northeast and the Santa Lucia Range to the southwest (Dupre 1990). This region is a geologically complex and diverse portion of the continental margin within the California Coast Ranges Province and represents a deformed part of the active tectonic boundary between the Pacific and North American plates known as the Salinian block. The San Andreas and San Gregorio fault zones define the northeastern and southwestern boundaries of the Salinian block, respectively. As a result of compressional tectonics related to these fault systems, numerous high angle faults trend northwest across the study area. These less-understood subsidiary faults displace bedrock, locally offset water-bearing Quaternary deposits, and help define the physical boundaries of the groundwater systems in the study area and vicinity.

3.1 Basin Boundary

The northern and eastern boundary of the Seaside Groundwater Basin has been somewhat tentative since it was defined by Muir (USGS 1982). More recent information developed by the MPWMD and investigations of the Fort Ord subarea indicate that the northern boundary requires further analysis.

Previous investigations of the Seaside Groundwater Basin have used the Basin boundaries advanced by Muir (USGS 1982) as the basis for study. Muir's brief description of the study area states that the north and east boundaries are in the vicinity of groundwater divides but provides no additional evidence for establishing these boundaries. Cross-sections provided by Muir suggest that the primary water-bearing formations in the Basin extend beyond the defined boundary, especially in the north. Subsequent investigations acknowledge the lack of hydrogeologic control on the northern and eastern boundaries but do not attempt any additional investigation (Logan 1982; SGD 1987b). Recent hydrogeologic investigations conducted north of the study area in the vicinity of Marina and the Salinas Valley (see Figure 2-1) present data that indicate deep water-bearing formations as far north as the Salinas River are contiguous with those of the Seaside Basin (Harding ESE 2001a; USGS 2002; Feeney and Rosenberg 2002). The USGS, in cooperation with the Monterey County Water Resources Agency, conducted a study (USGS 2002) to characterize the hydrogeology of the deep coastal aquifer system underneath Marina. Work conducted as part of the study led to an increased understanding of the continuity of the water-bearing sediments that

compose the coastal deep aquifer system and the relationship of water pressures in the deep-aquifer system to pressures in the submarine outcrops in the Monterey Bay, which are the source of local seawater intrusion. A deep monitoring well installed during the study penetrated the same principal water-bearing formations underlying the Seaside Groundwater Basin. Building on information collected by the USGS (2002), Feeney and Rosenberg (2002) compiled all available information on deep wells in an area encompassing the Seaside Basin, Marina, and Salinas Valley north to the Monterey County line. Their study represents the first documented attempt to integrate all available geologic data to assess the continuity of the major water-producing sediments in the Seaside area. Cross-sections produced from the study show that the hydrostratigraphic units of the Seaside Basin continue north at least 13 miles to Moss Landing.

Since recent studies show that the principal water-bearing strata underlying the Seaside Basin extend northward, groundwater pumping from those formations may potentially impact water levels in the vicinity of the boundary established by Muir (USGS 1982). Water level fluctuations caused by pumping could influence the position and shape of the groundwater divide currently used to delineate Seaside's northern boundary. During the mid-90s the MPWMD installed a monitoring well network in the northern portion of the Basin to more effectively monitor the response of the local groundwater system to production from the Paralta well. The Paralta well is owned and operated by Cal-Am and was completed in 1991 in the Fort Ord subarea. The Paralta well was screened in multiple aquifer zones, and historical production has averaged about 40 percent of Cal-Am's total production. Monitoring wells FO #8, FO #10, and FO #11 were installed in Fort Ord, north of the Seaside Basin boundary (Figure 3-1). Figures 3-2 to 3-4 show water levels collected from these wells for the period 1994 to 2002 with relation to pumping by Cal-Am in Seaside and from MCWD's deep production wells. Water levels for the period appear to be strongly influenced by pumping in the area. Because Cal-Am's production is significantly greater than MCWD's for the period of record, and the monitoring wells were completed at depths aimed at measuring drawdown from Seaside, it is inferred that the observed water levels are primarily influenced by Cal-Am's pumping in the Seaside Basin.

Hydrostratigraphic and groundwater-level evidence suggests that the northern Basin boundary may be subject to migration depending on the relationship of pumping in Seaside and of wells supplying water for MCWD. For the purposes of assessing the perennial yield and quantifying Seaside Basin's water budget components, the present investigation primarily focuses on the area within the original Basin boundaries advanced by Muir (USGS 1982) and accounts for fluxes into and out of the Basin across the north boundary. However, the investigation of local hydrogeology, including hydrostratigraphy, aquifer properties and yield, groundwater movement, and water quality, includes the area within the historically established Basin boundary as well as adjoining areas considered important to the current evaluation and future management of local groundwater assets. These include the Monterey Bay, Marina, and the western extent of the Salinas Valley; all of these areas are collectively referred to in this report as the "study area" (Figure 2-1).

3.2 Hydrostratigraphic Units

As part of this study, available driller's logs for wells in the study area were compiled and entered in an electronic database. The majority of the logs were obtained from previous

investigations and Cal-Am. Within the study area, there were 53 driller's logs with geologic information. Each log entry was reviewed and placed into one of the Unified Soil Classification System (USCS) categories. The x-y coordinates for some wells were available from tables or the log itself and the remainder were assigned approximate values based on digital map files. The driller's logs were used to construct six hydrogeologic cross-sections in the study area (Figures 3-5 through 3-11).

The hydrostratigraphy of the coastal Monterey Bay area has been characterized and mapped in detail (Clark et al. 1997; Feeney and Rosenberg 2002; Greene 1977; Logan 1982, USGS 1970; USGS 1977a) and has resulted in identification of the principal formations within the study area. Interpretations of the formation surfaces were superposed on the hydrogeologic cross-sections and used as a guide to Basin-wide stratigraphic analysis (Figures 3-5 through 3-11). Some investigators have assigned subdivisions to layers within these units (USGS 1982; Logan 1982); however, the lateral continuity of the layers is uncertain (MPWMD 1997). An attempt to correlate these subdivisions in cross-section was not made during this investigation.

From oldest to youngest, the subsurface geology of the Seaside Groundwater Basin and surrounding area, as described in available well logs and reports, consists of the following:

- Miocene Monterey Formation
- Miocene/Pliocene Santa Margarita Formation
- Miocene/Pliocene Purisima Formation
- Plio-Pleistocene Paso Robles Formation
- Pleistocene Aromas Formation
- Surficial Quaternary Sediments

Figures 3-12a and 3-12b present the geology of the Monterey Bay region. A more detailed map illustrating local onshore and offshore surficial geology of the Seaside Basin (as described by the California Geological Survey 2002; USGS 1977a; and USGS and Ca. Dept. of Conservation 1989) is presented in Figure 3-13. The following subsections briefly describe each of the geologic units identified above.

3.2.1 Monterey Formation

The Monterey Formation is a sequence of marine shale and mudstone that consists of siliceous and diatomaceous beds that may be as much as 3,000 feet thick in the Monterey Peninsula area (California Geological Survey 2002). Three mappable subdivisions of the Monterey Formation have been identified within the vicinity of the study area. The lower unit is a thinly bedded, yellowish-brown mudstone containing siltstone interbeds. This subdivision is about 100 feet thick. The middle unit is as much as 2,000 feet thick predominantly consisting of thin, laminated porcellanite with waxy-yellow brown chert interbeds. The upper unit is characterized as a thick bedded, pale orange to white diatomite containing thin interbeds of dark brown chert and light gray tuff (Clark et al. 1997). This unit is approximately 800 feet thick. Recognition of the white diatomite is commonly used in driller's logs to distinguish between the Monterey and overlying Santa Margarita Formations. The Monterey Formation outcrops south of the Chupines fault and in parts of the Laguna Seca subarea. Within the Seaside Basin, the Monterey Formation is vertically offset by the Chupines and Seaside Faults (see Figure 3-13). As a result, alluvial sediments in

the Southern subarea are less than 200 feet thick. The Monterey Formation was encountered at a depth of 820 feet while drilling the Paralta test well in the Fort Ord subarea (SGD 1990b). Offshore geologic mapping shows the Monterey Formation outcropping immediately offshore from the Northern and Southern subareas (USGS 1977a; USGS and Ca. Dept. of Conservation 1989) (Figure 3-13). Logan (1982) characterizes the Monterey Formation as having almost no porosity and only providing water to a few domestic wells. The Monterey Formation defines the base of water-bearing alluvial sediments in the Seaside Basin.

3.2.2 Santa Margarita Formation

The Santa Margarita Formation conformably overlies the white diatomite unit of the Monterey Formation. The Formation is generally characterized as a greenish-white, well sorted, fine to coarse grained arkosic sandstone originating from a transgressive, shallow-water environment (Clark et al. 1997; MPWMD 1997b). The formation outcrops along the steep walls of the El Toro River Canyon immediately east of the Seaside Groundwater Basin (Figures 3-12a, 3-12b and 3-13). Driller's logs show the sandstone ranges in thickness from less than 100 feet near the coast to more than 300 feet inland. Drill cuttings and geophysical logs from the Paralta test well drilled in the Fort Ord subarea indicate the Santa Margarita is 195 feet thick at this location, and was encountered from 625 to 820 feet below ground surface (ft bgs) (Figure 3-7). Monitoring wells located north of the Seaside Basin encounter the Santa Margarita Formation at approximately 1,080 ft bgs (MPWMD 1997b). According to driller's logs, thickness of the formation north of the Basin varies from about 40 feet at FO #11 to 420 feet at FO #10. Based on deflections in the geophysical log for FO #11, the MPWMD (1997b) suggests the Monterey Formation is encountered at or near the borehole bottom. Less than full sections of the Santa Margarita Formation have also been observed at other locations in the Basin and are attributed to either non-deposition or erosion prior to deposition of the overlying units (SGD 1990d; MPWMD 1997b). Alternately, the abnormally thick section observed at FO #10 may represent a transition to the marine sediments of the Purisima formation, which overlies the Santa Margarita north of Seaside.

Logan (1982) reports that the Santa Margarita Formation is only important in the east-central portion of Seaside, where it is used to supply the municipal water systems. Using available borehole and geophysical data, early investigators concluded that the Santa Margarita Formation does not extend west to the coast; it is thought to have pinched out or been eroded in that location (Figure 3-8) (Logan 1982; SGD 1987b). However, drill cuttings and geophysical data collected more recently from a monitoring well cluster located on the coast of the Fort Ord subarea reveal the presence of the Santa Margarita sandstone at depths below 700 ft bgs (SGD 1990d). North of the Seaside Basin, the Santa Margarita is not typically identified by investigators or in driller's logs. It is uncertain if the formation pinches out north of the Basin boundary or is present at depths most boreholes do not encounter. The Santa Margarita is one of the two principal water-bearing formations underlying the Seaside Groundwater Basin and has been the subject of recent investigations (SGD 1990d) aimed at expanding groundwater production in the Seaside Basin.

3.2.3 Purisima Formation

The Purisima Formation consists primarily of poorly indurated gravels, sands, silts, and silty clay, deposited in a shallow marine environment. Regionally, the formation may attain a thickness of up to 10,000 feet (USGS 1970); however, driller's logs indicate the formation thickness ranges from 500 to 1,000 feet in the vicinity of the study area (Feeney and Rosenberg 2002). The formation is not present directly under the Seaside Groundwater Basin but overlies the Santa Margarita Formation north of Seaside and is one of the principal water-bearing formations utilized by the MCWD and the groundwater users in the Salinas Valley. Data collected from driller's logs and cross-sections developed as part of this study and previous investigations shows the Purisima as being relatively thick in the northern Monterey Bay area and thinning toward the southern end of Monterey Bay in the vicinity of the Basin's northern boundary (Figures 3-6 and 3-7). The formation is exposed in the northern portion of Pajaro Valley and offshore along the Monterey Bay submarine canyon (USGS 1970; USGS and Ca. Dept. of Conservation 1989).

3.2.4 Paso Robles Formation

Unconformably overlying the Santa Margarita Sandstone in the Seaside Basin is the Paso Robles Formation. The Paso Robles is a series of continental deposits that can be described as semiconsolidated, fine-grained, oxidized sand and silt beds with gravel interbeds (Clark et. al. 1997). Muir (USGS 1982) reports the Formation to be as much as 700 feet thick in the Seaside Groundwater Basin; however, drill cuttings and geophysical logs from the Paralta test well indicate that the Paso Robles Formation is about 415 feet thick in the Fort Ord subarea (210 to 625 ft bgs). Interpretations of driller's logs north of the Basin indicate that the Paso Robles may be as much as 700 feet thick in the vicinity of the MCWD and Salinas Valley (Figures 3-6 and 3-7). The Paso Robles Formation outcrops in the foothills south of the Chupines fault and Laguna Seca subarea, along the eastern part of the Basin in the El Toro River Valley, and directly offshore of the Fort Ord subarea (Figures 3-12a, 3-12b and 3-13).

Previous investigators have subdivided the Paso Robles Formation into separate components based on lithology and productivity. Muir (USGS 1982) separates the formation into two identifiable units, upper and lower. The upper unit consists of continental clastic sediments typical of alluviated mountain valleys, such as sand, silt, gravel, and clay. These sediments are partly consolidated to indurated and are characterized by abundant fragments of diatomaceous flint and chert. The lower unit is about 150 feet of blue clay and clayey sand containing shells that appear to be of a lagoonal or bay origin. Logan (1982) subdivides the Paso Robles into four units: (1) an upper variable zone; (2) a unit termed the "Seaside Clay"; (3) a lower variable zone; and (4) a zone of whitish sandy clays. Of these units, the two variable zones (units 1 and 3) are the most significant producers of groundwater. The Seaside Clay separating the two water-bearing units ranges in thickness from 40 to 70 feet and is characterized by mixed silty clays and bluish- or greenish-gray clayey sands. The lowest unit is characterized by whitish sandy clays, not to be confused with the white sandstones of the Santa Margarita Formation. Logan points out that this sequence may not be recognizable in every well record and the units he has identified are primarily recognized in the northern Seaside Basin. SGD (May 1987) recognizes the two sand and gravel units separated by the Seaside Clay but gives no mention of the lower-most unit identified by Logan (1982). Water level data collected from piezometers completed

above and below the Seaside Clay indicate that strata below are confined to semiconfined and the portion above the Seaside Clay is unconfined (SGD 1987b). The Paso Robles Formation is an important groundwater source for the Basin and surrounding area, including the MCWD and Salinas Valley, where it locally contains part of the "400-Foot" aquifer. All of the wells in the Basin, with the exception of the City of Seaside Wells No. 1 and 2, produce water from the Paso Robles Formation (SGD 1987b).

3.2.5 Aromas Formation

The Aromas Formation consists of moderately well sorted, friable, quartzose, brown and red sand deposited in a lagoonal or shoreline environment by wind and waves (USGS 1970). This formation lies unconformably over older continental deposits and is up to 300 feet thick in the study area. The Paralta test well encounters the sands from 0 to 210 ft bgs. The sands are extensively exposed in the hilltops of the North Inland and Laguna Seca Subareas (Figures 3-12a, 3-12b and 3-13). Previous investigators have noted that it is often difficult to distinguish between the Aromas Sands and the older Paso Robles Formation in well logs and that the two units may, in part, be facies equivalents (USGS 1982; Clark et al. 1997). Logan (1982) makes no effort to separate the Aromas Formation from the younger alluvial sediments, and Muir (USGS 1982) groups the Aromas Formation with the Paso Robles when illustrating the Basin's hydrostratigraphy in cross-section. Much of the Aromas Formation is unsaturated with the exception of the extreme western edge of the Basin, where it becomes saturated (Logan 1982; SGD 1987b). The Aromas sand is not a significant water-bearing formation with the exception of the near shore environment, where it may also contain parts of the 400-Foot aquifer (USGS 1970).

3.2.6 Surficial Quaternary Deposits

Surficial Quaternary sediments include floodplain deposits, alluvial fans, eolian deposits, fluvial and marine terraces, and basin deposits (Feeney and Rosenberg 2002). With the exception of the valley fill deposits in the Salinas Valley, which may contain the "180-Foot aquifer," these deposits are not a major water supply source for the study area.

3.3 Hydrogeologic Properties and Well Yield

Aquifer test data for the study area are limited. Therefore, the majority of the available transmissivity values were estimated using specific capacity data. For wells where only specific capacity data are available, the methods presented in Driscoll (1995, page 1021) and Logan (1982) for confined aquifers were used to estimate transmissivity. Hydraulic conductivity estimates were calculated by dividing transmissivity by total screen length of the tested well. Available specific capacity and transmissivity data are presented on Figure 3-14 and summarized in Appendix A. Mean values of transmissivity for the Paso Robles Formation range from 20,000 gallons per day per foot (gpd/ft) in the Fort Ord Subarea to 21,500 gpd/ft in the Northern subarea and 8,500 gpd/ft in the Southern subarea. Only two wells, City No. 1 and 2 located in the Northern subarea, are completed exclusively in the Santa Margarita Formation. Mean transmissivity for these wells is 38,500 gpd/ft. Logan (1982) estimated a mean transmissivity for the Basin of 44,000 gpd/ft using estimates of subsurface inflow from the inland subarea to the coastal subareas. The composite value is in general agreement with estimates made from pumping tests and specific capacity data.

Logan believes this value may be too high because leakance from confining layers is not considered in this estimate. A brief description of available aquifer test data for the study area is presented below.

A pumping test of the District's PCA well was conducted as part of an "Interim Water Supply Program" to evaluate the potential for incorporating the well into Cal-Am's system, determine if the Ord Terrace fault acts as a barrier to flow between the Fort Ord and Northern subareas, and assess local aquifer parameters. The PCA well is screened in the Paso Robles Formation from 200 to 632 ft bgs. Work conducted as part of the pumping test program included installation of two monitoring well clusters, PCA East and PCA West, located 750 and 700 feet from the pumping well, respectively. Each cluster included completion of a monitoring well in the Paso Robles and underlying Santa Margarita Formations. Analyses of test data from the pumping well provided a transmissivity estimate of about 9,100 gpd/ft and a specific capacity of 7.7 gallons per minute per foot (gpm/ft) of drawdown at 500 gpm (SGD 1990b). Values of transmissivity estimated from the PCA West shallow monitoring well range from 9,780 gpd/ft for the drawdown data and 21,120 gpd/ft for the recovery data. Analysis of data collected from the PCA East shallow monitoring well provided transmissivity values of 77,650 for the drawdown data and 122,000 gpd/ft for the recovery data. These higher values may suggest that the monitoring well was not in direct hydraulic communication with the producing zones of the pumped well (SGD 1990b). Water level data collected from the deep monitoring wells in the Santa Margarita Formation do not show an aquifer response to pumping in the overlying Paso Robles.

A pumping test of Cal-Am's Paralta well provided a transmissivity estimate of about 130,000 gpd/ft and a specific capacity of 57 gpm/ft at approximately 1,400 gpm (MPWMD 1991). The Paralta well is completed in multiple aquifers below 430 ft bgs that correspond to the Paso Robles and Santa Margarita Formations. Since the Paralta well is completed in multiple aquifers, the transmissivity estimate represents a composite value for both aquifers. Determination of aquifer parameters for the individual units is not possible without the use of specialized tools during testing, such as packers.

Pumping tests of MCWD's supply wells provided estimates of transmissivity and hydraulic conductivity of 30,500 gpd/ft and 25.4 feet per day (ft/d) for MCWD 10, 24,500 gpd/ft and 16.4 ft/d for MCWD 11, and 29,500 gpd/ft and 16.5 ft/d for MCWD 12 (USGS 2002). MCWD's supply wells are screened in sediments below 800 ft bgs that correspond to the Purisima Formation. Slug tests performed on a nearby deep monitoring well cluster also screened in the Purisima Formation yield estimates of transmissivity and hydraulic conductivity that range from 300 gpd/ft and 2 ft/d to 4,300 gpd/ft and 14.5 ft/d (USGS 2002). The relatively lower values of transmissivity and hydraulic conductivity estimated from the monitoring well may be attributable to the method of testing. Slug test results are based on very small changes in water level measured over very short periods and therefore may represent only a small fraction of the aquifer material around the well screen, whereas pumping tests are longer-term and influence a much larger volume of aquifer material adjacent to the well.

Well yields in the Basin range from 20 to 1,900 gpm. The lowest yields occur in the Southern subarea, and the greatest in the Northern and Fort Ord subareas. Increasing yields to the north can likely be attributed to a thickening of alluvial sediments in this direction. Also,

deeper wells tend to be screened across multiple aquifers and therefore do not provide direct information regarding aquifer properties or yield.

3.4 Water Levels

As part of this study, historical water level data were collected and entered into an electronic database. The database holds over 3,000 water level entries for 72 wells from spring 1955 to fall 2002. Groundwater elevations stored in the database were used to produce groundwater elevation maps (Figures 3-15 through 3-20) and hydrographs (Figures 3-2 through 3-4 and 3-21 through 3-32) for select wells in the study area.

Groundwater in the Seaside Groundwater Basin generally flows from areas of higher elevation in the east to lower elevations along the coast. Under natural conditions (pre-groundwater development), water levels generally mimic the topography. Prior to 1965, groundwater production for the Basin was relatively low, less than 1,000 acre-feet per year (afy). During this period water levels ranged from over 300 ft MSL in the foothills of the North Inland subarea to about 10 ft MSL near the coast (Figure 3-15). Water level data were not available for the North Inland subarea. The groundwater elevation contours presented for this subarea are a modified version of the fall 1979 water level map presented by Muir (USGS 1982).

After about 1965, groundwater production in the Basin substantially increased and pumping became the primary influence on water levels in the study area. Recent water level maps illustrate the impact of pumping on groundwater elevations in the coastal subareas (Figures 3-16 through 3-20). Long-term pumping of municipal supply wells has created a large cone of depression causing the gradient to be steep in this portion of the Basin. Groundwater levels that were historically above sea level in the Northern and Fort Ord subareas have dropped below sea level. Long-term hydrographs plotted with production data illustrate the steady decline of water levels since 1985. The most dramatic declines are observed in the Fort Ord subarea where water level elevations in production wells such as Luzern and Ord Grove have declined to -30 ft MSL.

Recent hydrographs for monitoring wells FO #8, #9, #10, and #11 illustrate the effects of pumping near the northern Basin boundary on water levels in the Paso Robles and Santa Margarita Formations. Monitoring wells FO #8 and #9 show a steep decline in water levels in the Paso Robles and Santa Margarita aquifers. Since about 1995, groundwater elevations in the Paso Robles aquifer system declined from 15 ft MSL to about 2 ft MSL and from about 5 ft MSL to -10 ft MSL in the Santa Margarita aquifer (Figures 3-2 and 3-22). Water levels in these wells are heavily influenced by production from Cal-Am's nearby Paralta well, which went on-line in 1995 and is the only well in the subarea screened in the Paso Robles and Santa Margarita aquifers. Monitoring wells FO #10 and #11 show a more subdued response to pumping from Cal-Am's Paralta well (Figures 3-3 and 3-4). FO #10 may be screened in the transitional zone between the Purisima and Santa Margarita Formations and therefore may not be in direct hydraulic communication with the Paralta well's primary zones of production (MPWMD 1997b). FO #11 only encountered a thin section of the Santa Margarita Formation during drilling and therefore may also not be in direct hydraulic communication with the Paralta well's production zones. Water level fluctuations in these wells are also potentially influenced by the MCWD supply wells; however, these wells are screened

exclusively in thin water-bearing zones of the Purisima Formation. Hydrographs for wells in this part of the study area illustrate the fluid nature of the northern Basin boundary and the potential impacts local pumping may have in the vicinity of this boundary.

Two monitoring well clusters, PCA East and PCA West, were constructed near the PCA production well in the western margin of the Fort Ord subarea. Each cluster included completion of a monitoring well in the Paso Robles and underlying Santa Margarita Formations. Hydrographs for these monitoring well clusters exemplify the impact of the Paralta well on the Paso Robles and Santa Margarita formations near the coast (Figures 3-23 and 3-24). Water levels in the Paso Robles aquifer fluctuate seasonally with production. Water levels in the Santa Margarita Formation have declined as much as 20 feet from approximately 5 ft MSL prior to Paralta's production to about -15 ft MSL after Paralta came online (Figures 3-23 and 3-24). Prior to Paralta well operation, water levels in the Santa Margarita Formation were about 5 feet higher on average than in the Paso Robles Formation, indicating a strong vertical upward gradient in this portion of the Basin. These conditions suggest that under non-pumping conditions the Santa Margarita Formation is a source of recharge to the Paso Robles Formation (SGD 1990a).

Hydrographs for some wells in the study area indicate water levels in the Paso Robles formation in some wells stopped declining in about 1998. This response is most pronounced in monitoring wells FO #9, PCA-West, and PCA-East (Figures 3-22 through 3-24, respectively). Though the cyclic effects of pumping are still clearly visible, the overall trend of declining water levels in the Paso Robles formation in these wells ceases and water level response to pumping is more subdued. Water levels in the Santa Margarita formation, however, continue to exhibit a steep decline despite the trend reversal in the Paso Robles formation. The change in water level trend can be explained by the anomalously high precipitation experienced in 1998 and the higher than average precipitation during the 1990s in general (see Figure 2-3). These exceptionally wet years appear to temporarily curb the steep decline in water levels in some wells.

3.5 Water Quality

3.5.1 General Water Quality

Available water quality data for the Basin were compiled from previous reports and are summarized in Figures 3-33 through 3-48, and tabulated in Appendix B. Water quality data presented in Figures 3-34 through 3-43 represent the maximum concentration detected historically at a given location for the shallow and deep aquifer units. For the purposes of this discussion, the Aromas Sands and Paso Robles Formations are categorized on the figures as "Shallow Aquifers" and the Santa Margarita and Purisima Formations are referred to as "Deep Aquifers." Some of the water quality data listed in Appendix A for the FO and PCA monitoring wells were not used for analysis or presented in figures. Initial sampling events at these wells resulted in anomalously high concentrations for total dissolved solids (TDS) and chloride. Elevated concentrations of these constituents were likely due to residual contamination from fluids used during the drilling process.

Groundwater in the Paso Robles Formation is generally of good quality and can be characterized by relatively low concentrations of TDS (190 to 650 milligrams per liter

[mg/L] with a mean of about 265 mg/L), chloride (40 to 230 mg/L), sulfate (15 to 290 mg/L), and nitrate (2 to 12 mg/L) (Figures 3-34 through 3-38). The Calabrese well, located along the coast of the Northern subarea, has elevated concentrations of TDS and chloride. The well is less than 150 feet deep and is likely completed in the Aromas Sands Formation. Elevated concentrations of iron in shallow wells are prevalent, with the highest concentration reported on the coast in the PCA East well. Average concentration of iron in the shallow aquifers of the Basin is about 0.75 mg/L. The California Department of Health recommends that the concentration of iron in domestic wells not exceed 0.3 mg/L. The highest concentrations of ions are observed along the boundary between the Northern and Fort Ord subareas and may be related to the Fort Ord fault.

Groundwater in the Santa Margarita Formation can be characterized by moderate concentrations of TDS (225 to 680 mg/L with a mean of about 510 mg/L), chloride (70 to 190 mg/L) and elevated concentrations of iron (0.03 to 1.25 mg/L) (Figures 3-39 through 3-41). North of the Basin, water quality for the Purisima Formation is available from MCWD's water supply wells and the USGS deep monitoring well cluster, designated DMW (Figure 3-33). Groundwater samples collected from DMW-1-3, which is screened from 1,040 to 1,060 ft MSL, reveal extremely elevated concentrations of TDS (23,000 mg/L), chloride (10,800 mg/L), and sulfate (1,500 mg/L). DMW-1-3 is part of a coastal monitoring well cluster installed during a study by the USGS to gain insight into the deep aquifer system present under the Salinas Valley and Marina areas. By comparing isotope data from the well with seawater, the USGS was able to rule out recent seawater intrusion and cited fine-grained marine sediments as the likely source of high salinity in this well. With the exception of DMW-1-3, groundwater in the Purisima Formation is generally of very good quality, with TDS ranging from 300 to 500 mg/L and chloride ranging from 50 to 150 mg/L.

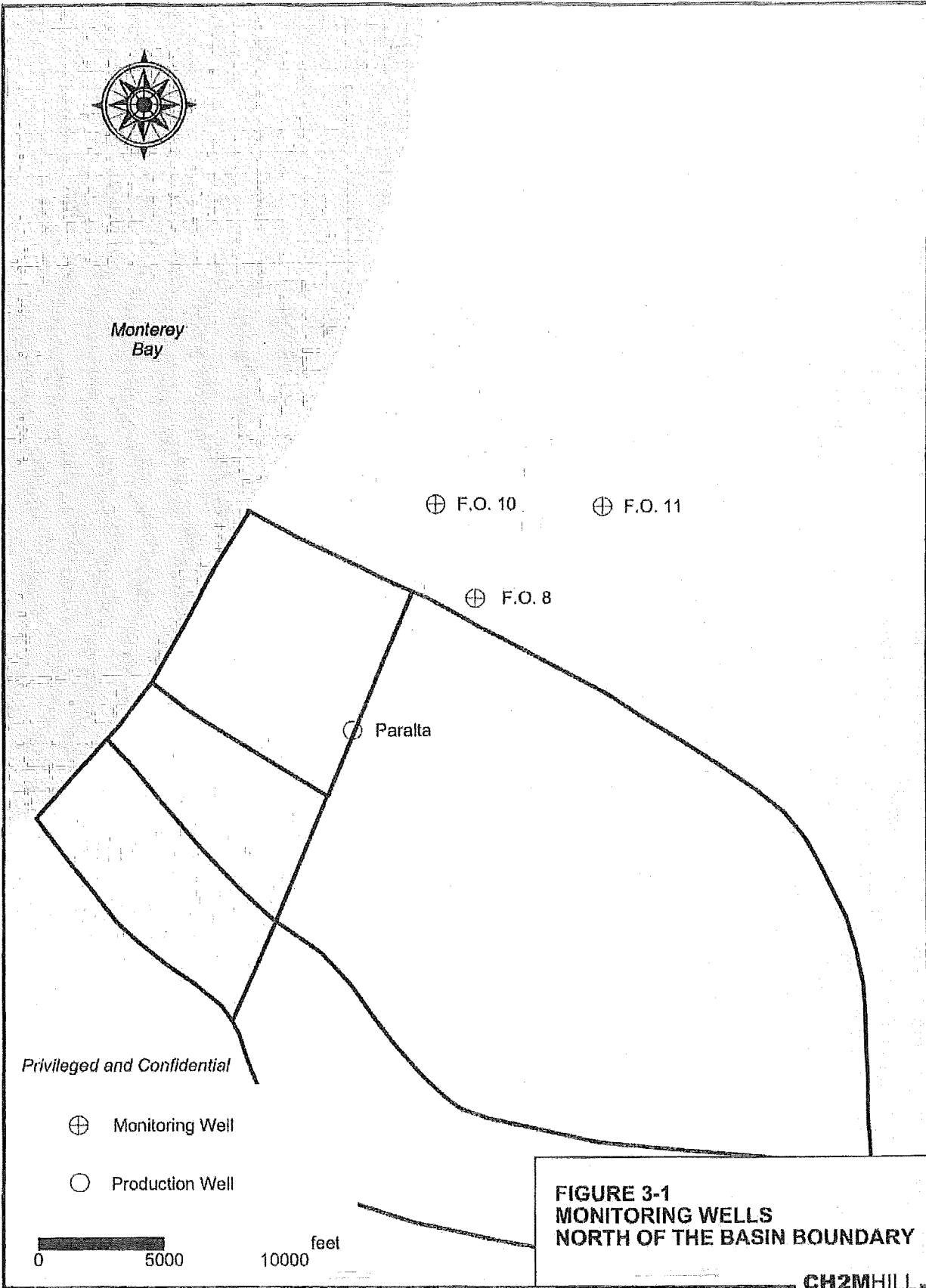
Figures 3-44 through 3-48 illustrate long-term trends in water quality for wells where continuous data were available. Plots of TDS and chloride for coastal wells PCA-East, PCA-West, and MSC suggest that ionic concentrations are increasing with depth. Oliver (MPWMD 1997a) cites the marine depositional environment of the Santa Margarita sandstone, longer residence times, and less flushing of residual waters by recharging meteoric water as the potential reasons for this vertical trend. Plots of chemical data for FO #9 and #10 suggest that the vertical variation in TDS and chloride diminishes inland and to the north.

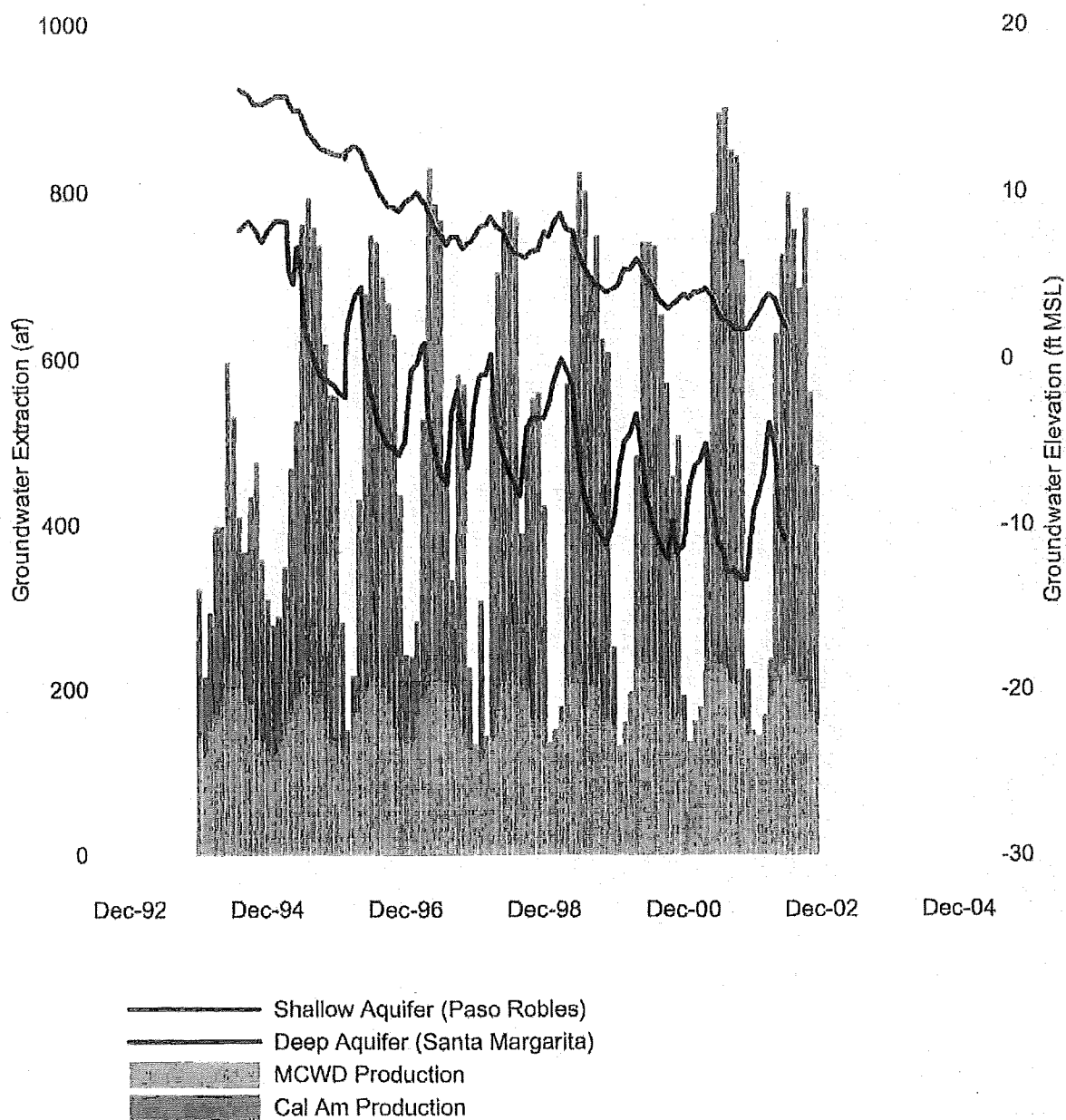
Though water quality of the Santa Margarita formation is generally good, hydrogen sulfide is present in relatively high concentrations. A rotten egg odor, due to hydrogen sulfide in solution, is commonly observed when drilling in the formation. Currently, groundwater from the Paralta well is treated to remove excess hydrogen sulfide. Treatment systems to remove hydrogen sulfide from groundwater will likely be required for new wells completed in the Santa Margarita formation.

3.5.2 Seawater Intrusion

Seawater intrusion is the landward flow of seawater from the ocean through the submarine outcrops of aquifer systems (USGS 2002). Seawater intrusion can occur when coastal freshwater aquifers (unconfined or confined) are in hydraulic connection with the sea and are under the influence of extensive groundwater development, as is the case with the Seaside Basin. Due to complexities in flow derived from differences in density between

freshwater and saltwater, seawater intrusion is difficult to assess and is often discussed in qualitative terms. Previous investigators have assumed that the aquifers in the Seaside Basin outcrop miles offshore, which suggest there is a large freshwater "buffer" protecting the Basin. However, geologic maps used as part of this study indicate that the Aromas Sand and Paso Robles aquifers outcrop in the Monterey Bay immediately offshore of the Northern and Fort Ord subareas and pose a threat to fresh water supply wells in the Basin. Seawater intrusion has locally impacted the shallow 180-Foot and 400-Foot aquifers (the Aromas Sand equivalent) in the Salinas Valley and MCWD. Salt water has intruded about 6 miles in the 180-Foot aquifer and about 3 miles in the 400-Foot aquifer in the Salinas Valley (Harding ESE 2001a). Farther south in the vicinity of Marina and the former Fort Ord area, seawater has intruded about 2 miles in the 180-Foot aquifer and about 3 miles in the 400-Foot aquifer (Harding ESE 2001a). Shallow wells in these areas have been abandoned, and pumping in the lower aquifers, such as the Paso Robles and Purisima Formations, have increased in the last decade as a result. In the Seaside Basin, periodic occurrences of seawater intrusion associated with heavy pumping have been reported in Cal-Am's Orange well (15S/1E-21J1) in 1966, 1974, and 1976 (USGS 1982). This well was abandoned in 1979.

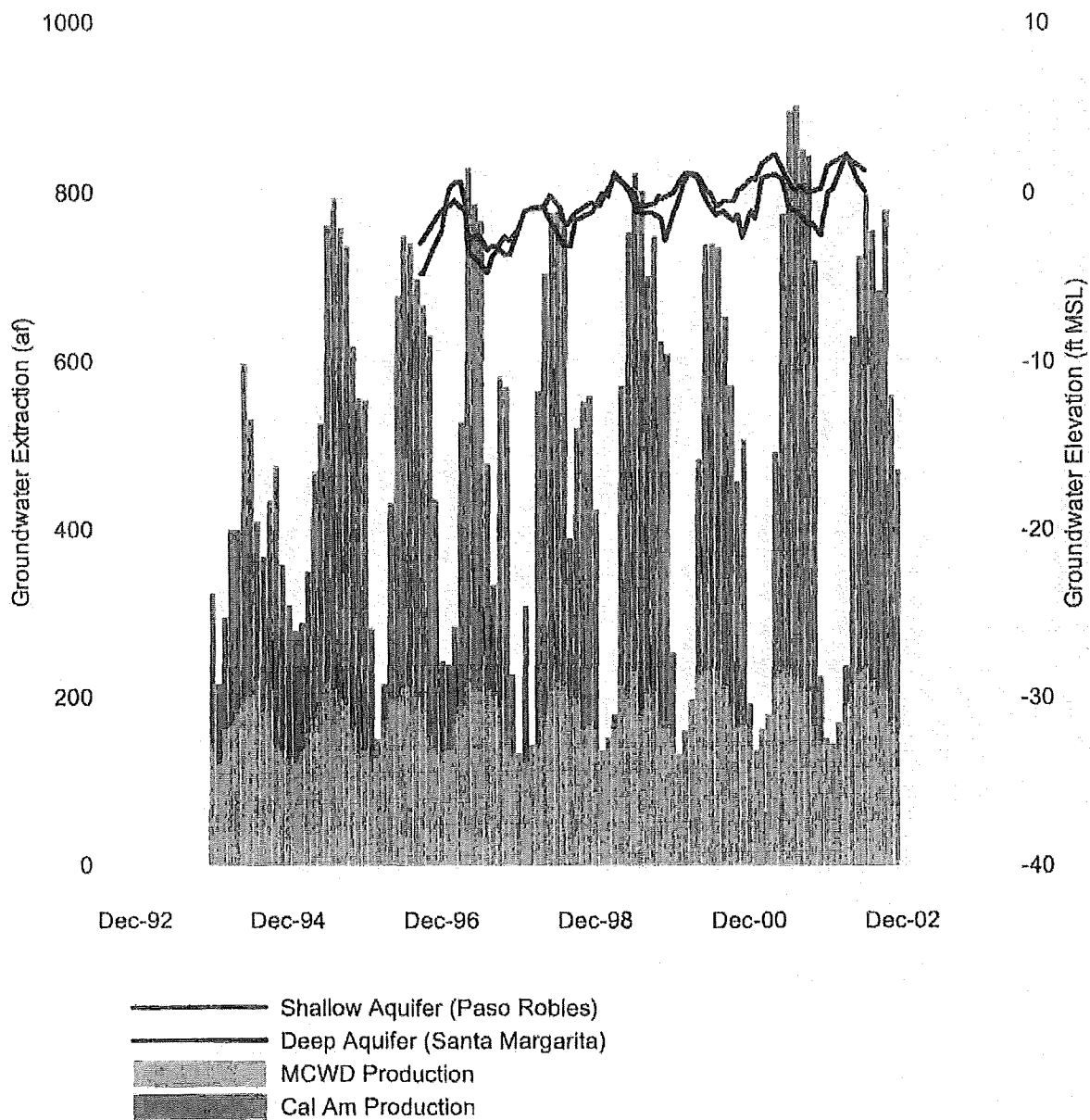




**FIGURE 3-2
FO #8 WATER LEVELS
AND COASTAL PUMPING**

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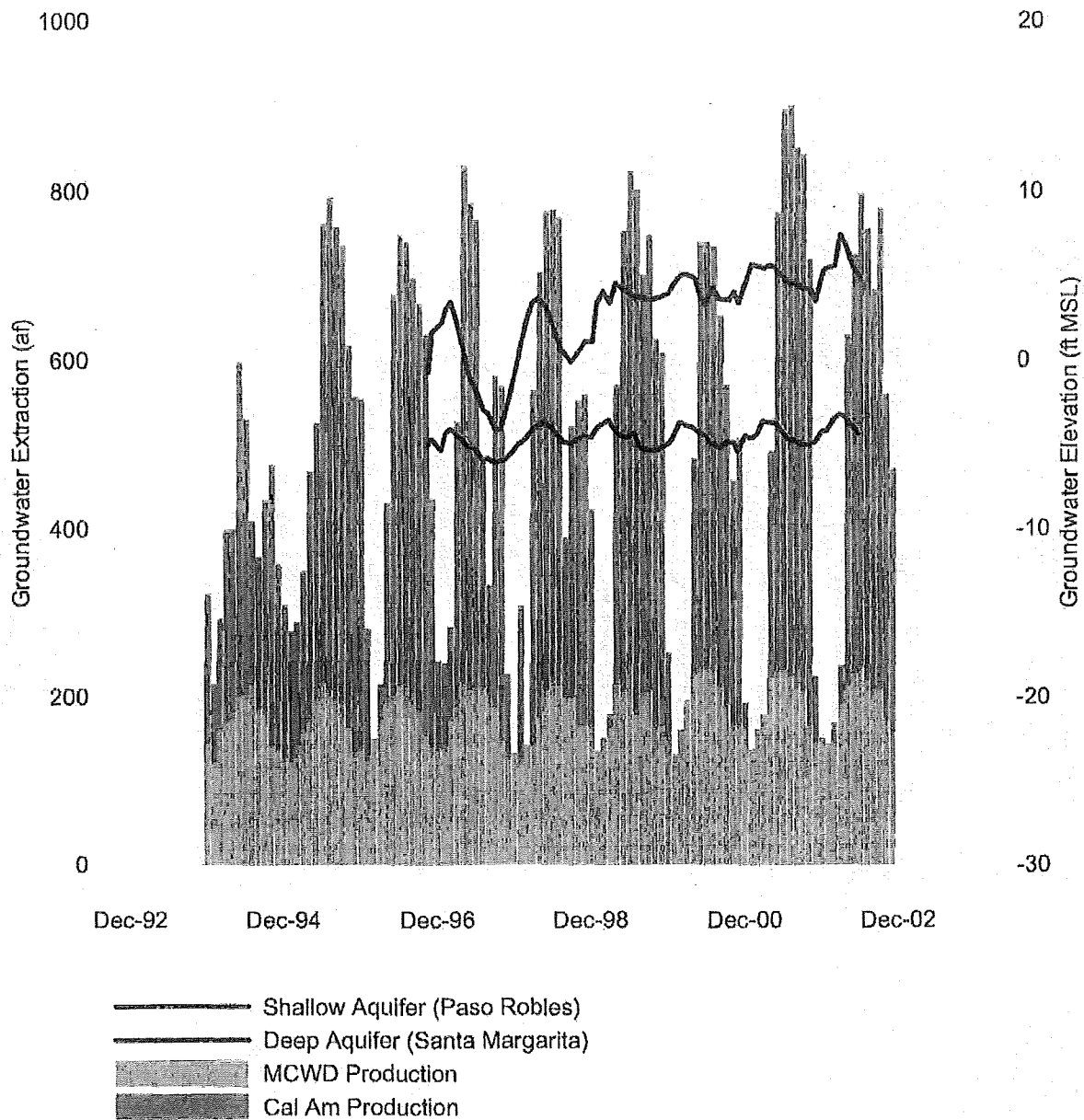
CH2MHILL



**FIGURE 3-3
FO #10 WATER LEVELS
AND COASTAL PUMPING**

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CH2MHILL



**FIGURE 3-4
 FO #11 WATER LEVELS
 AND COASTAL PUMPING**

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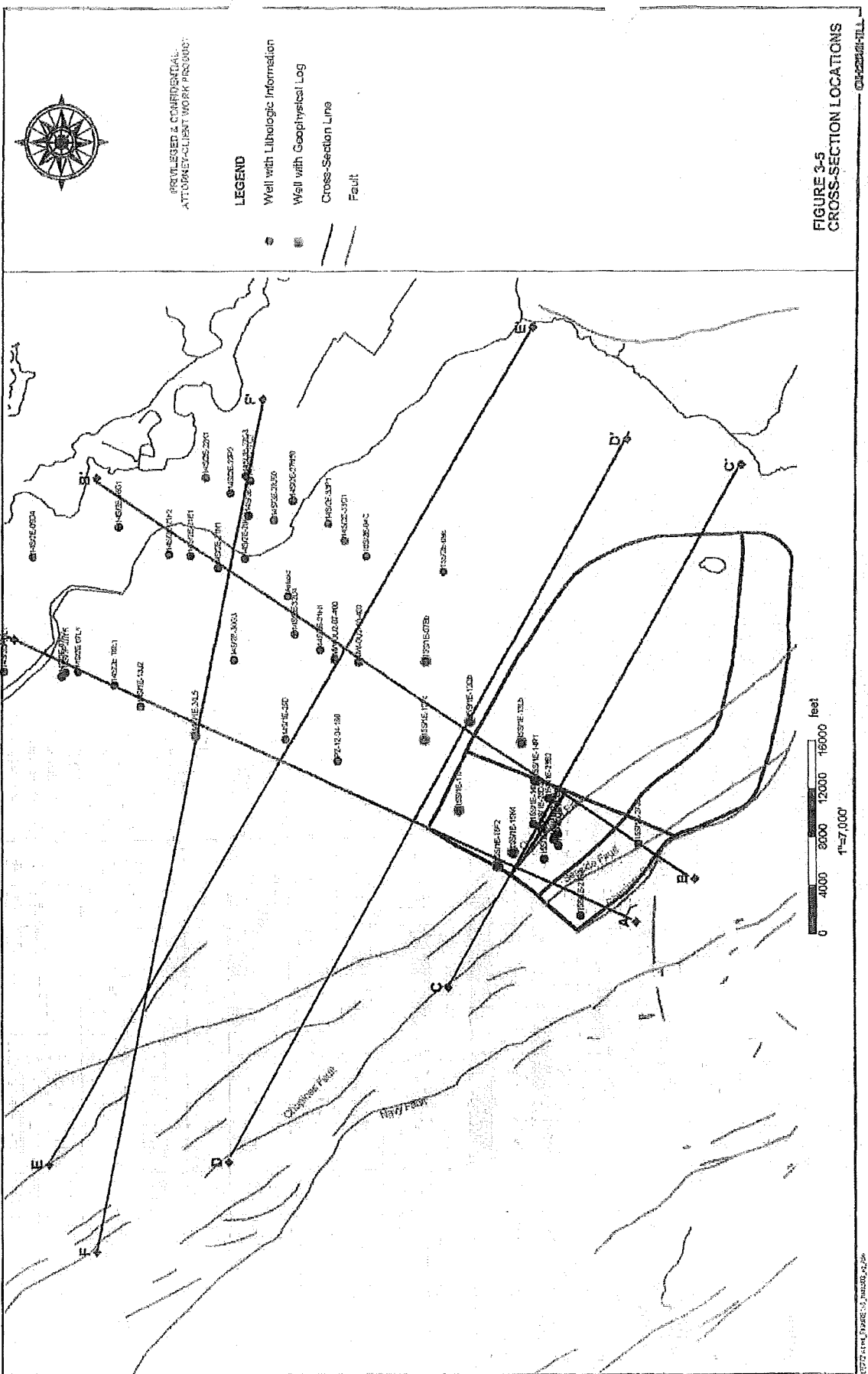
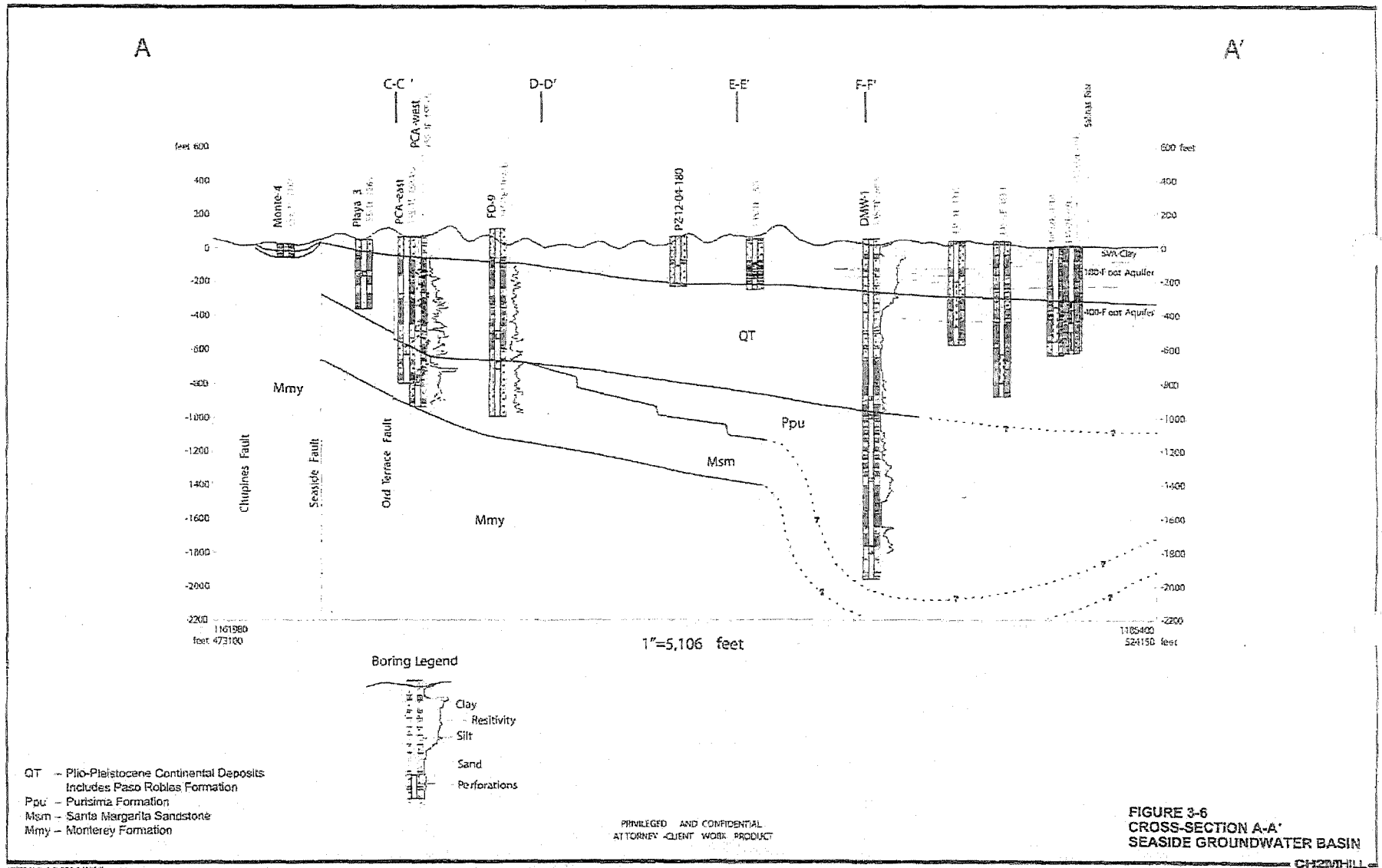
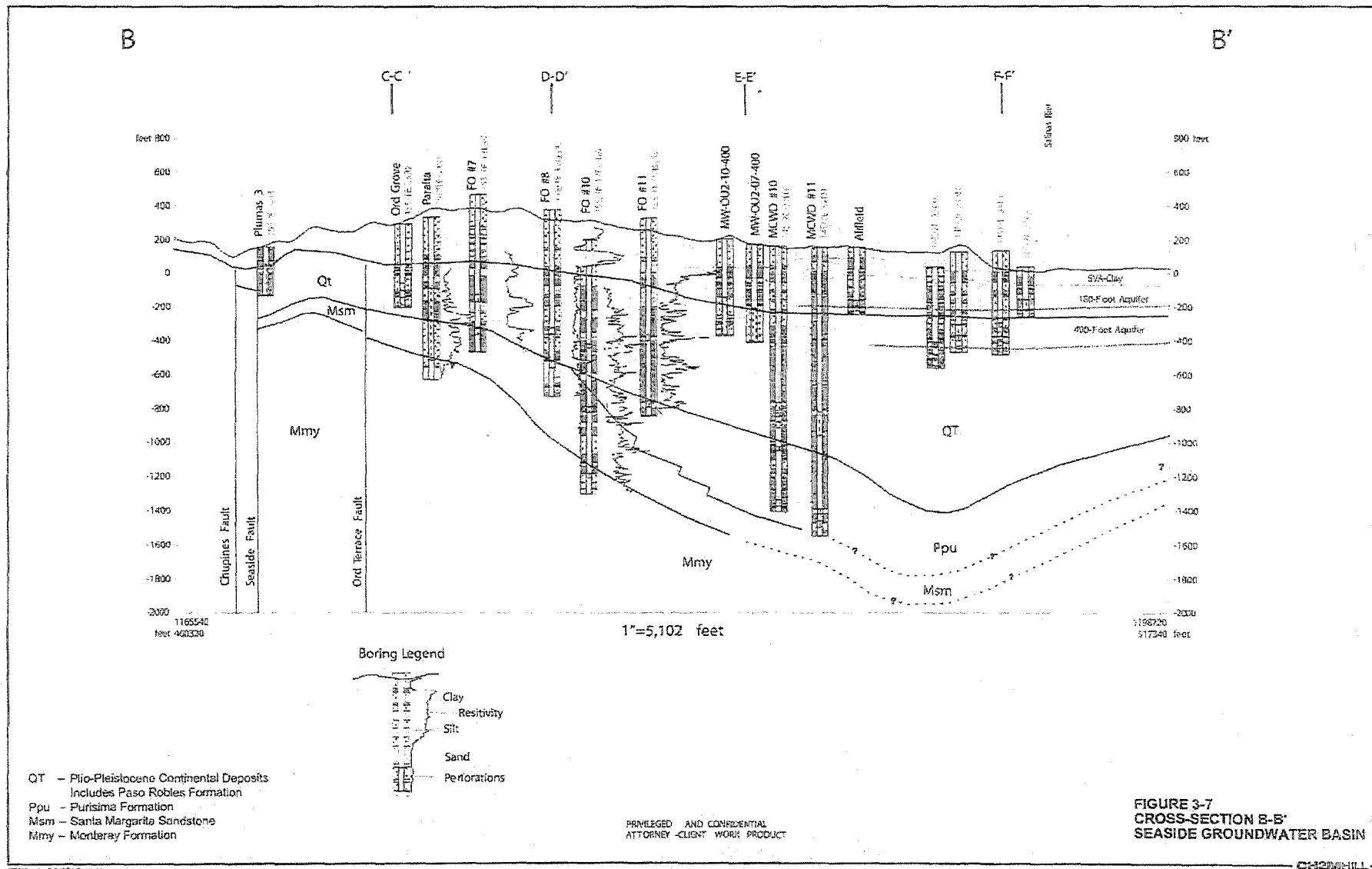
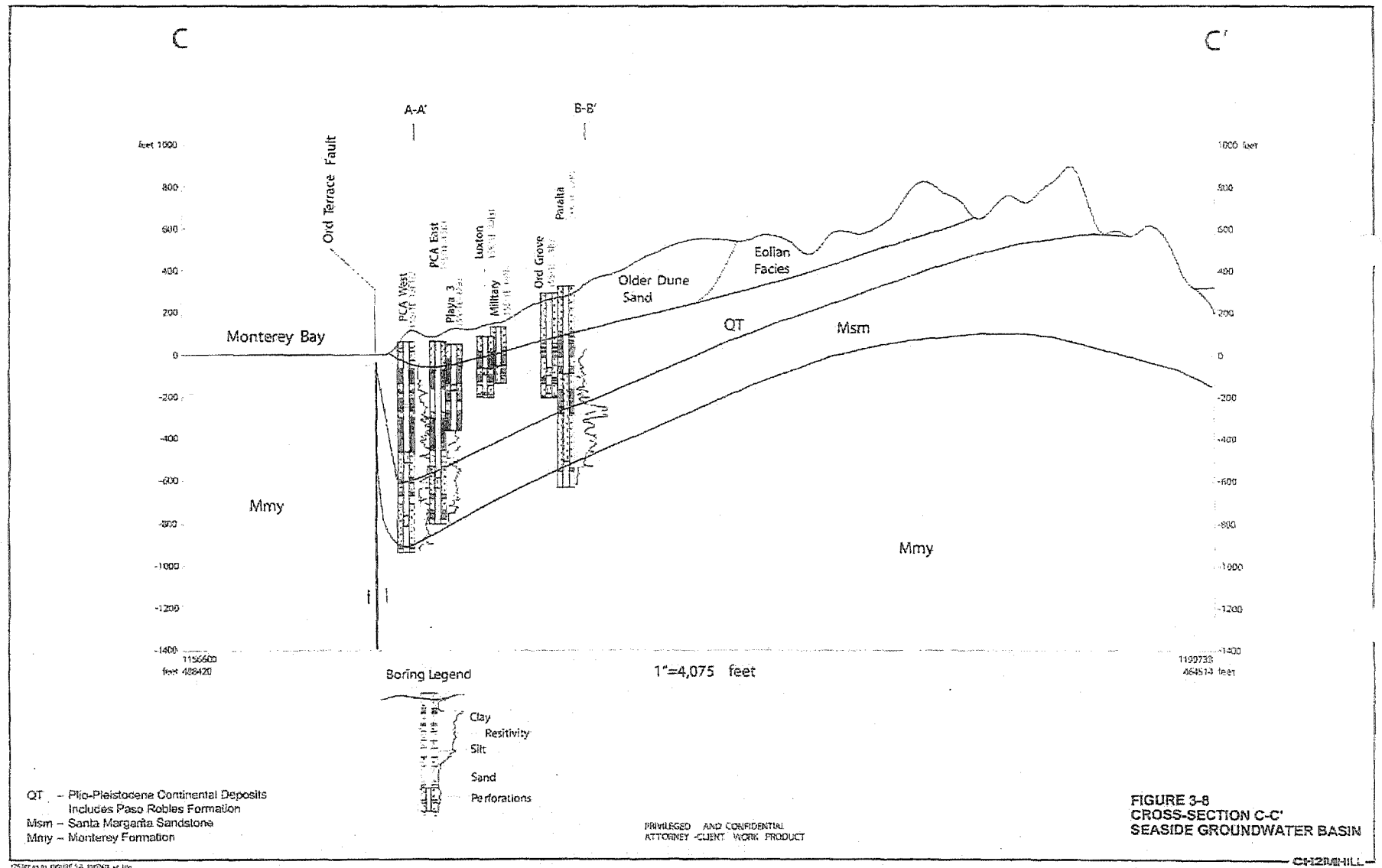


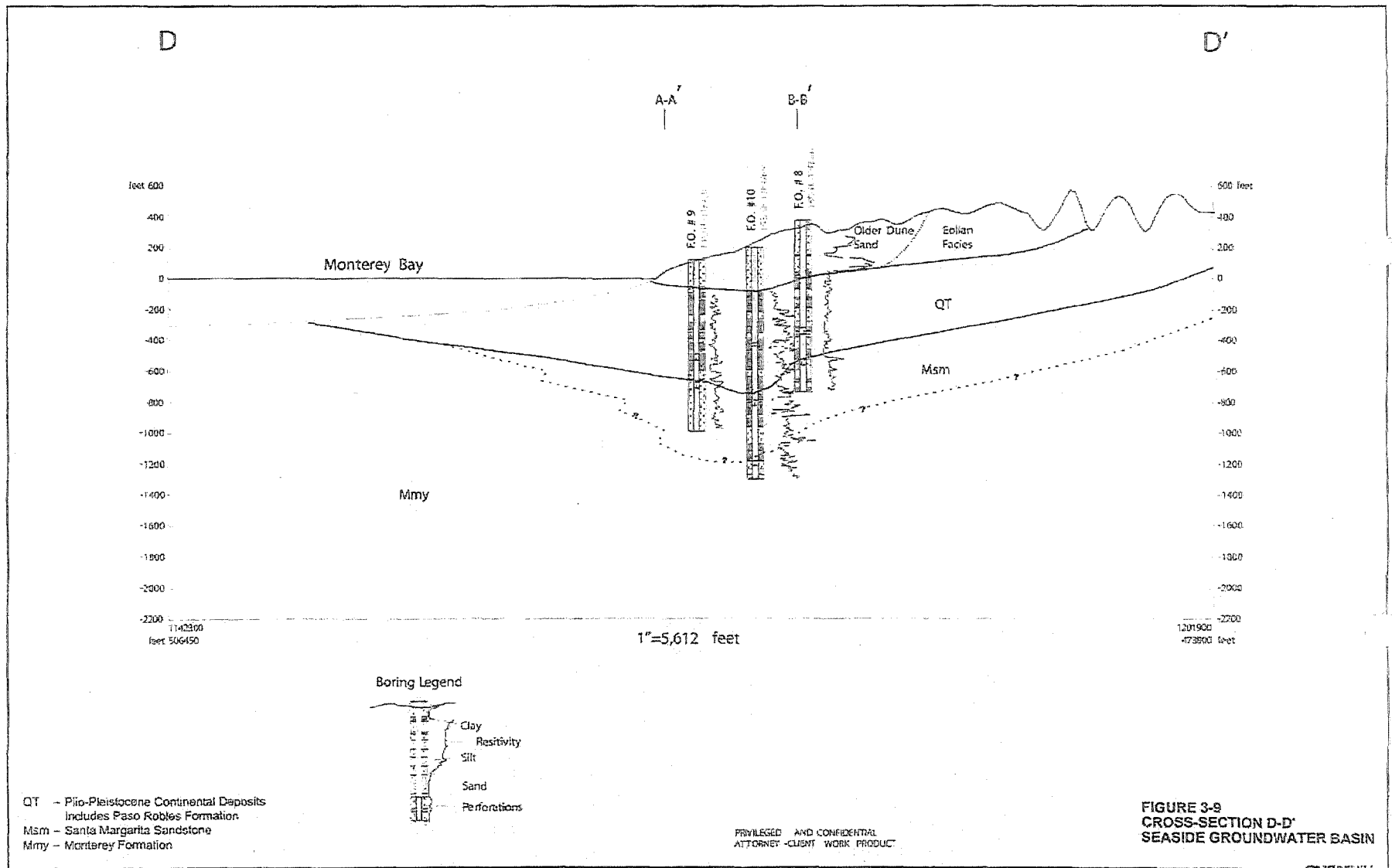
FIGURE 3-5.
CROSS-SECTION LOCATIONS

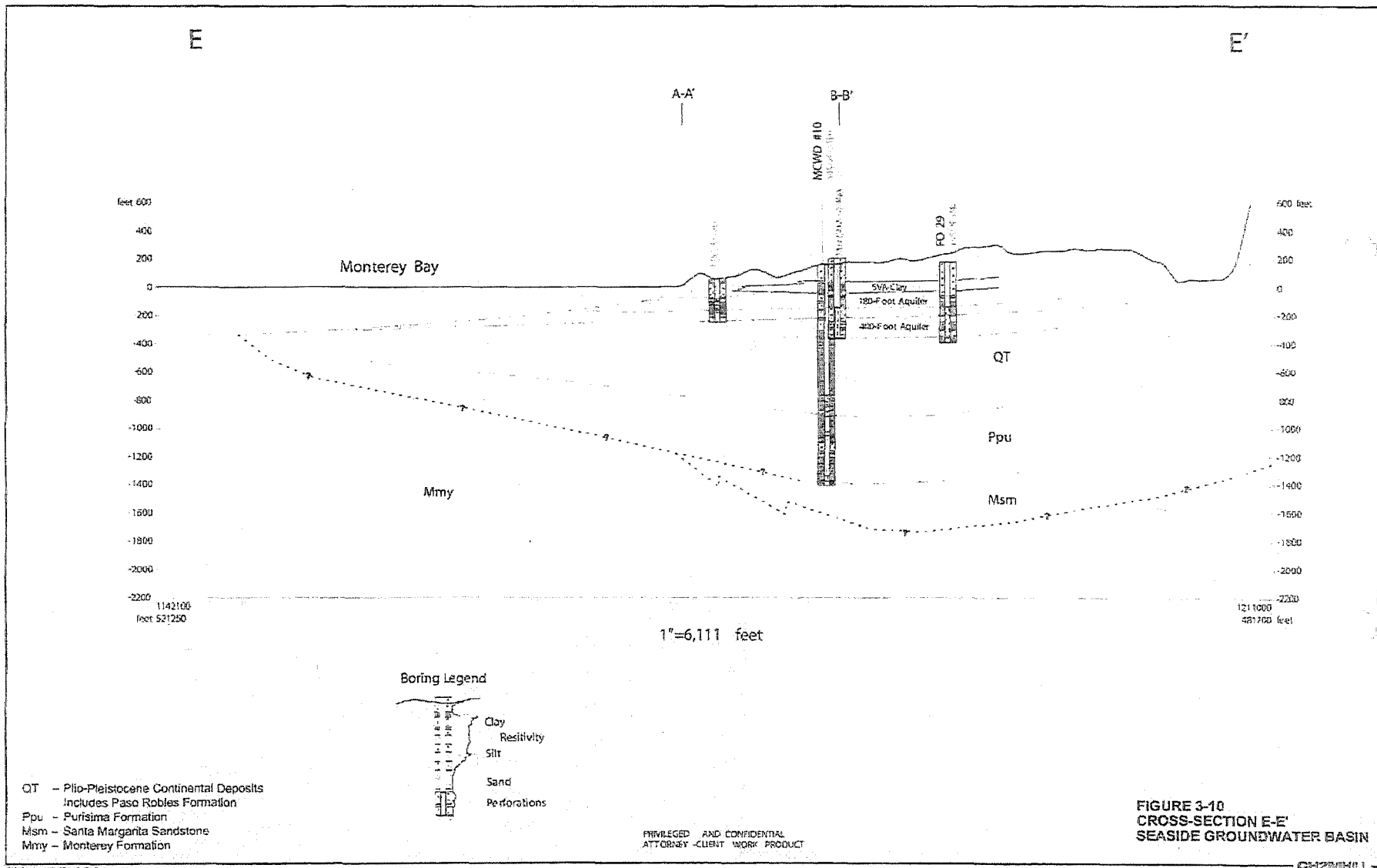
04220-111

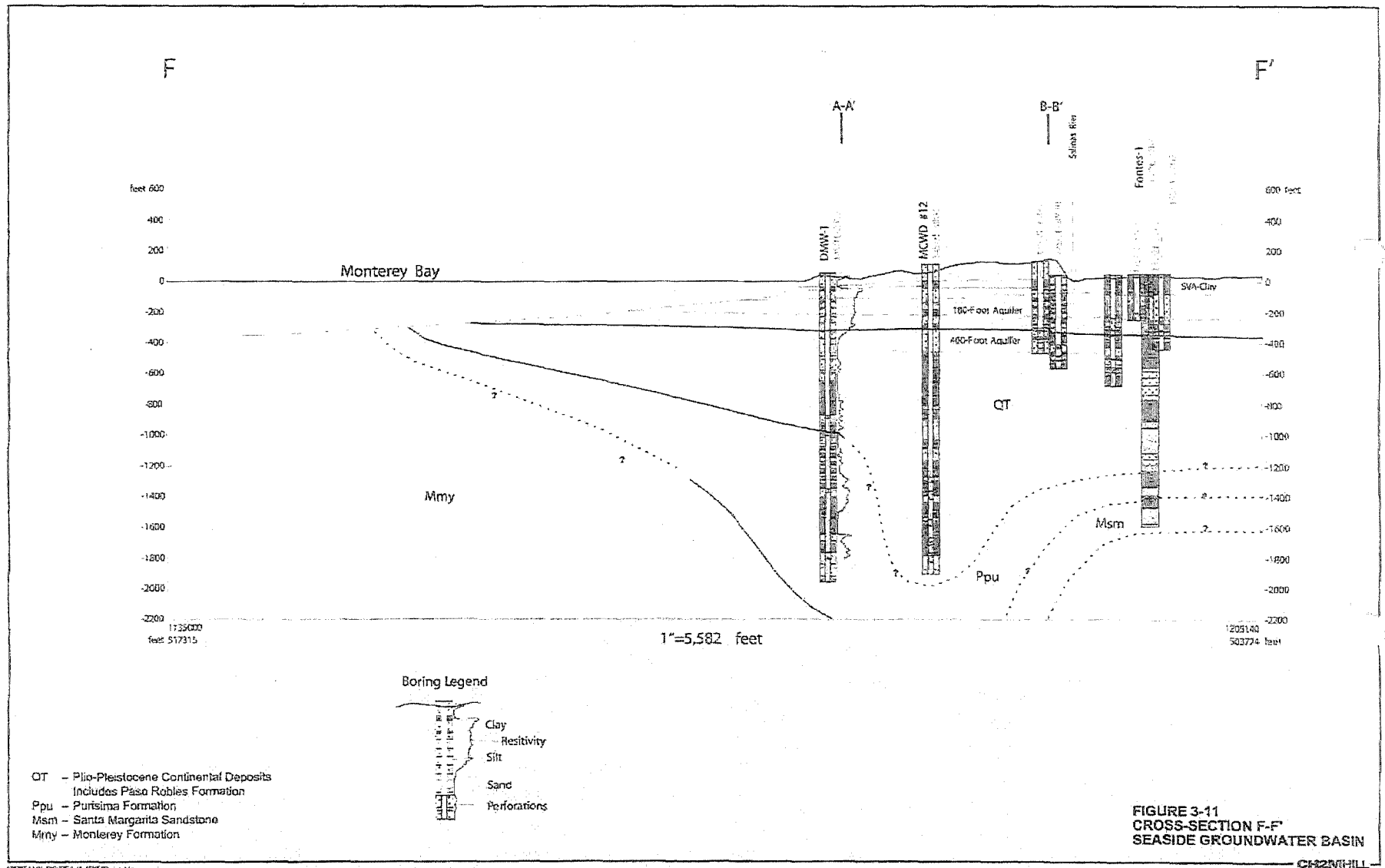


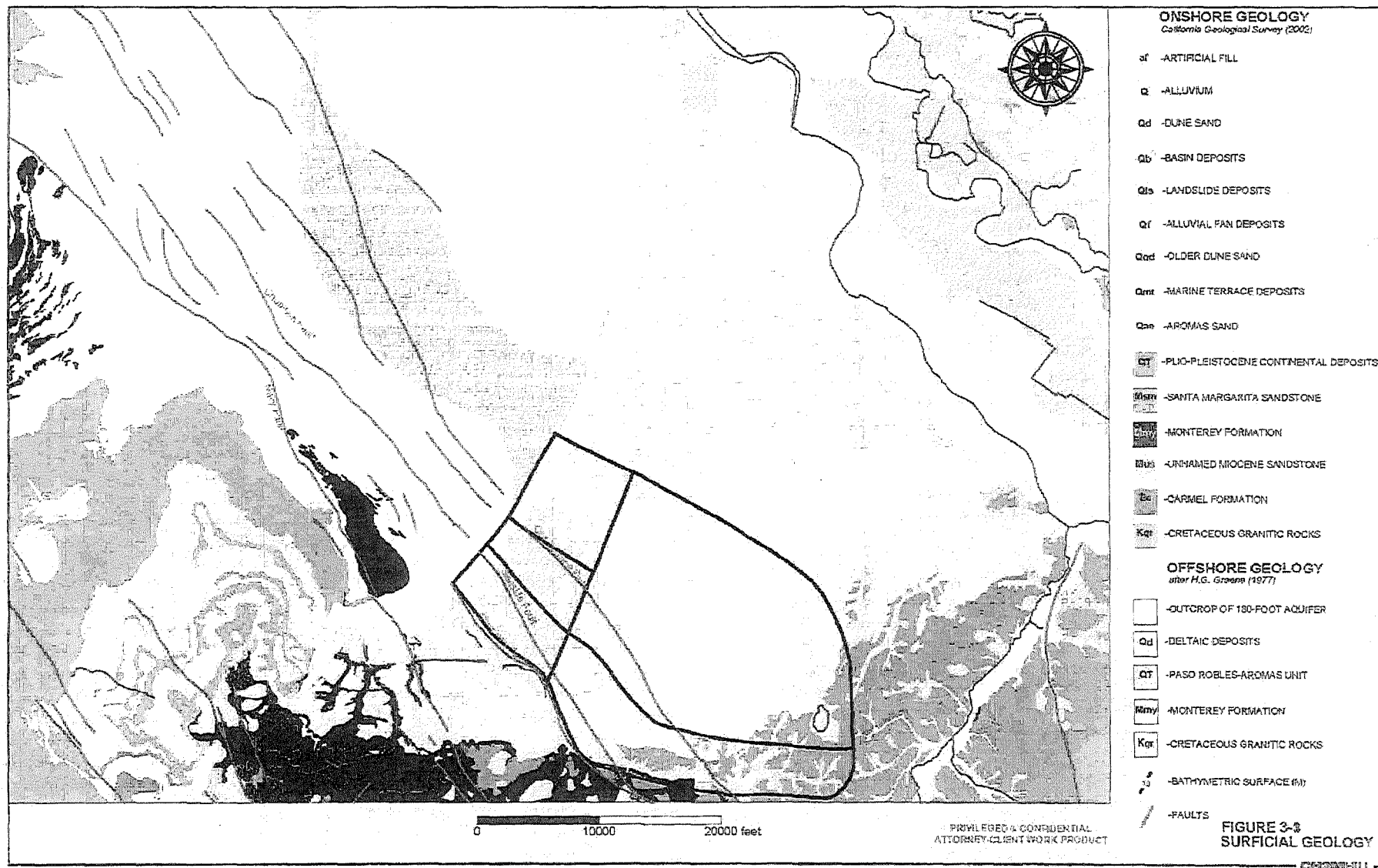


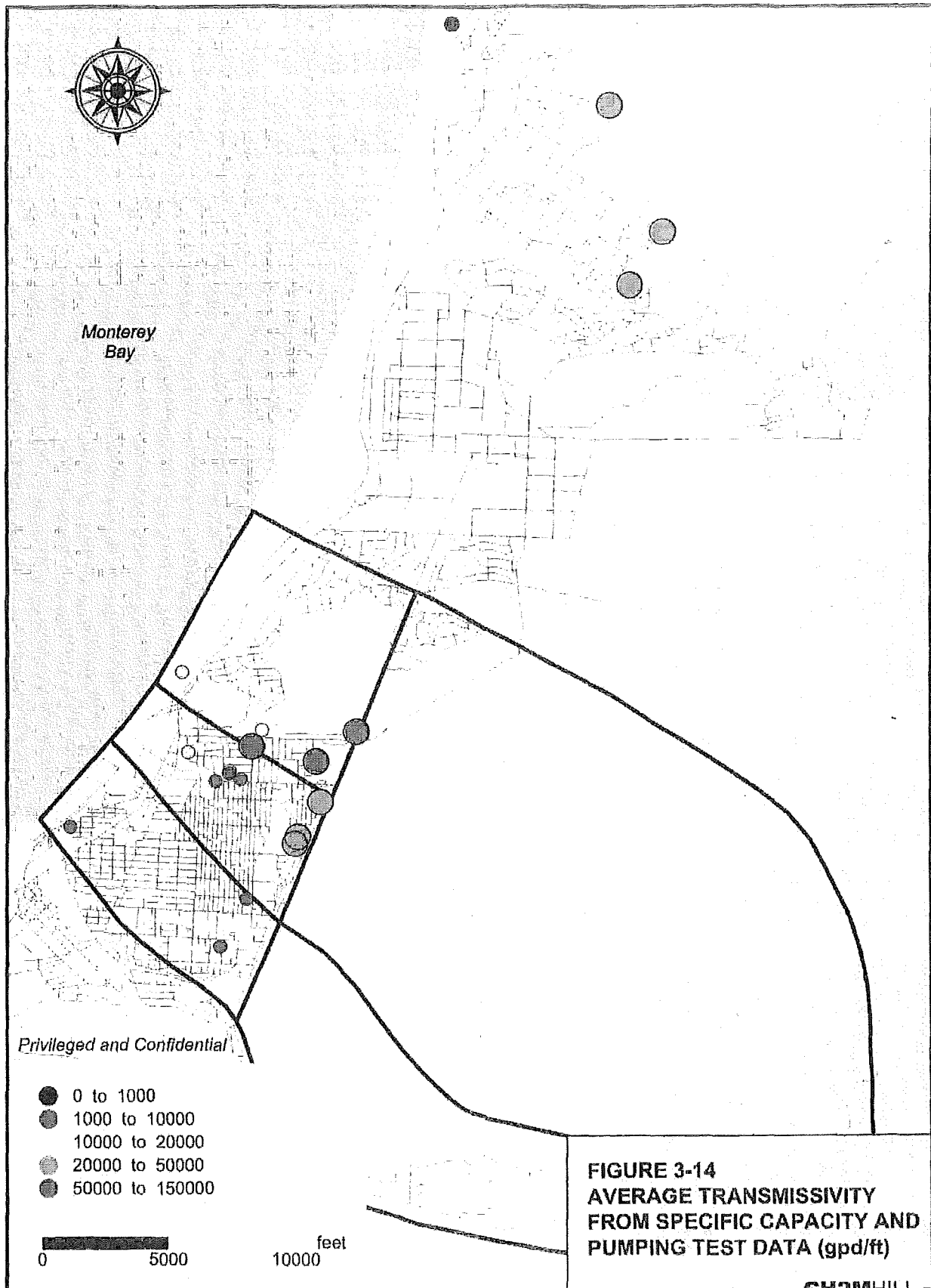


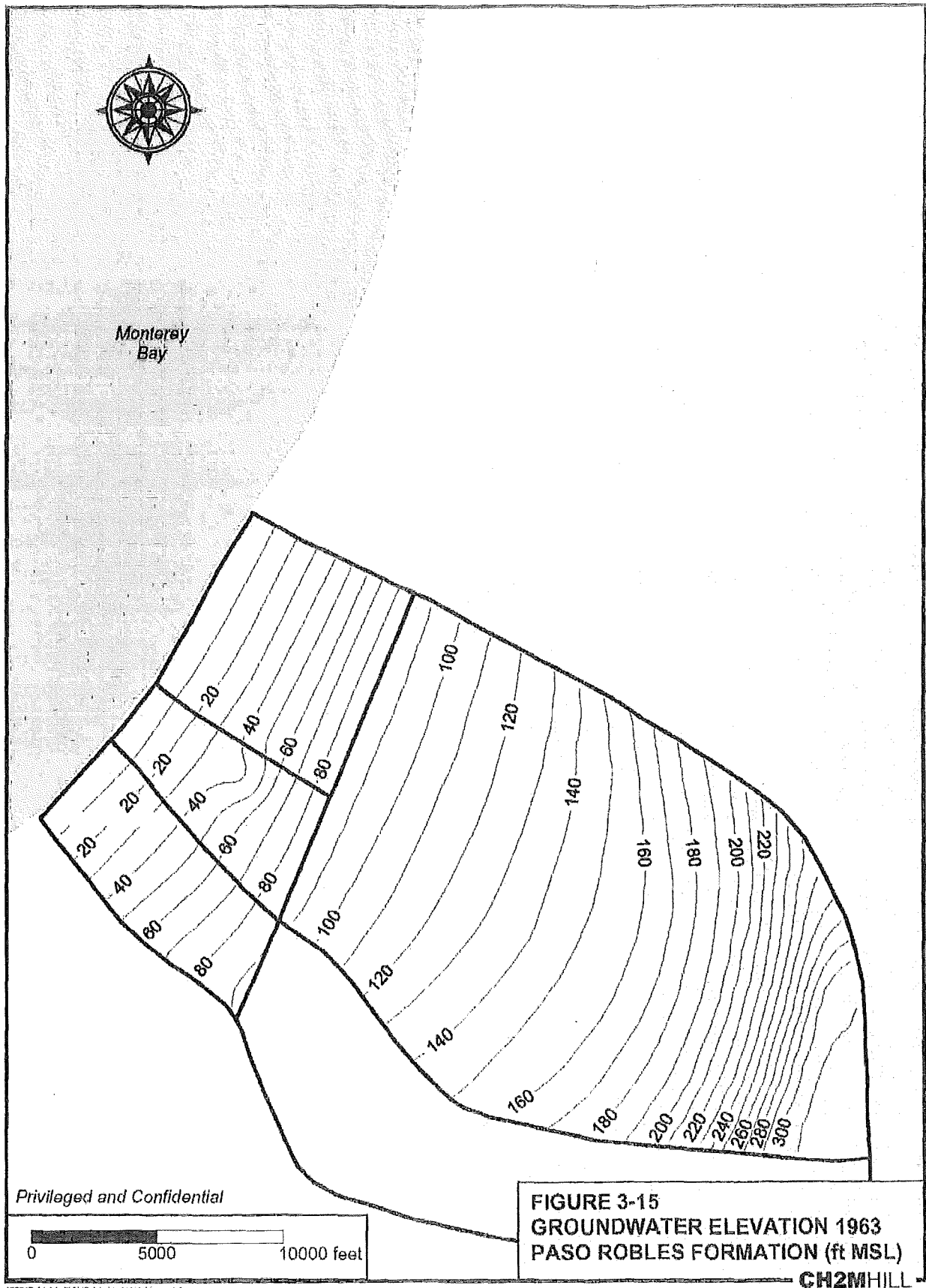


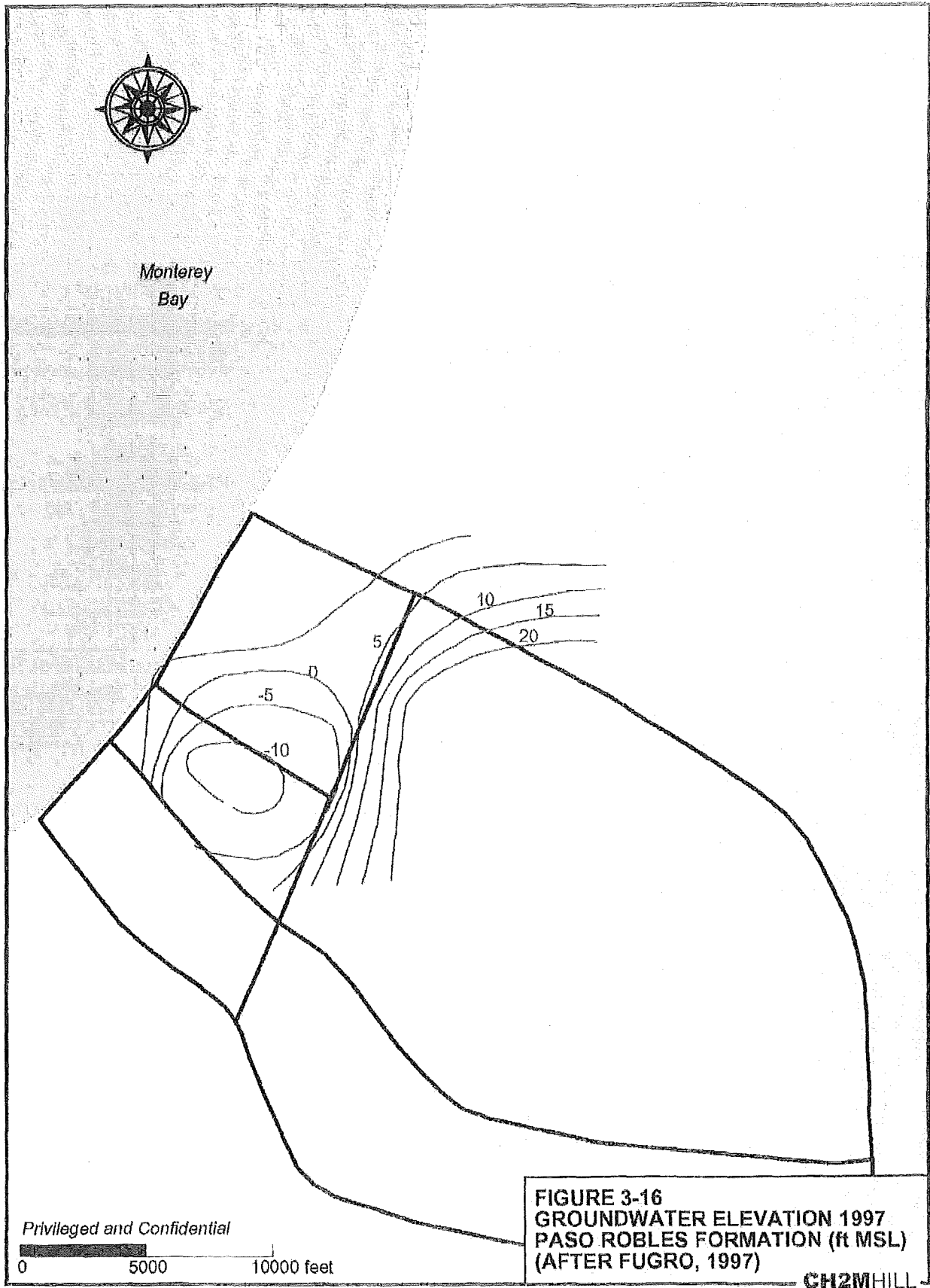


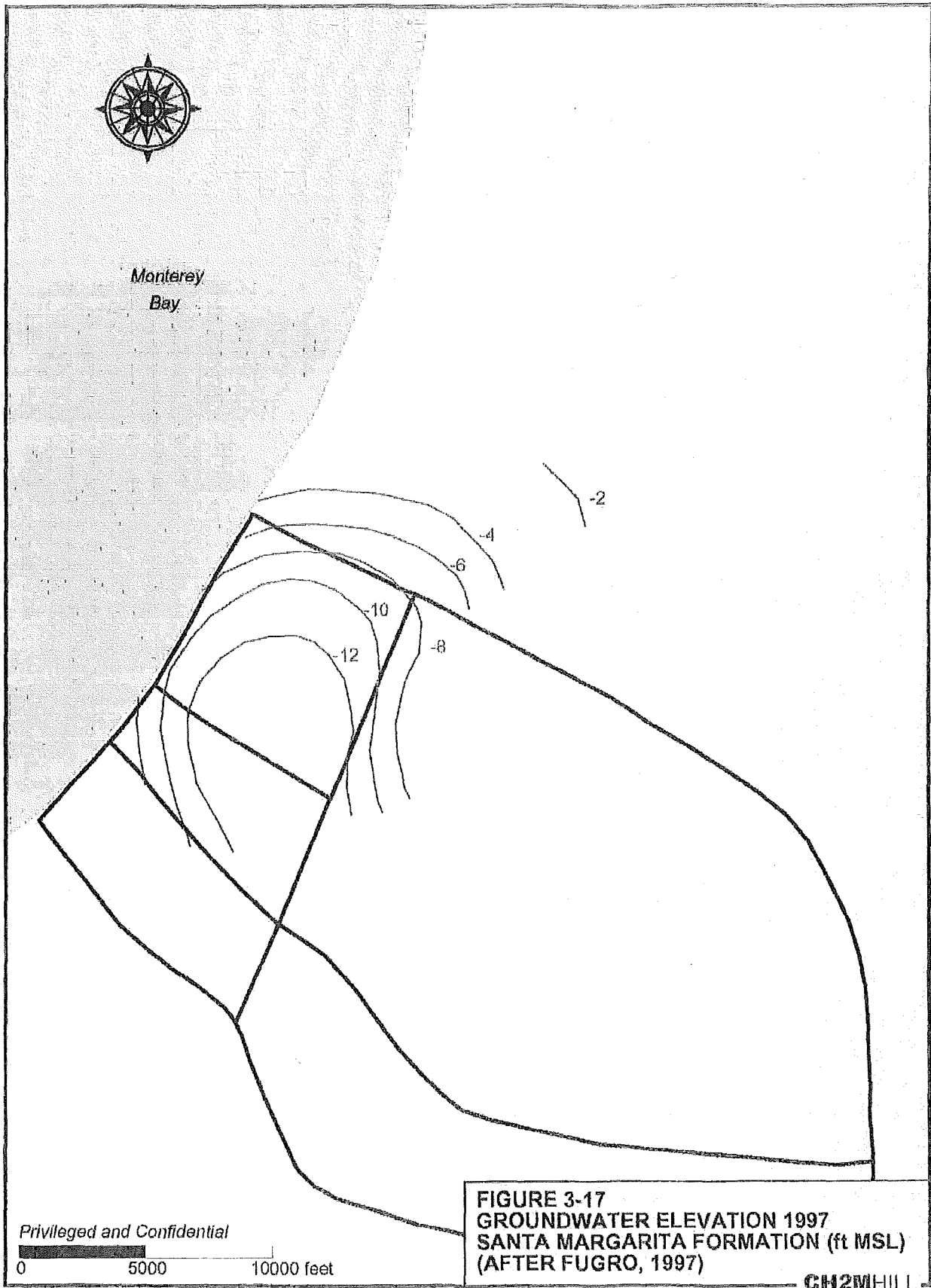


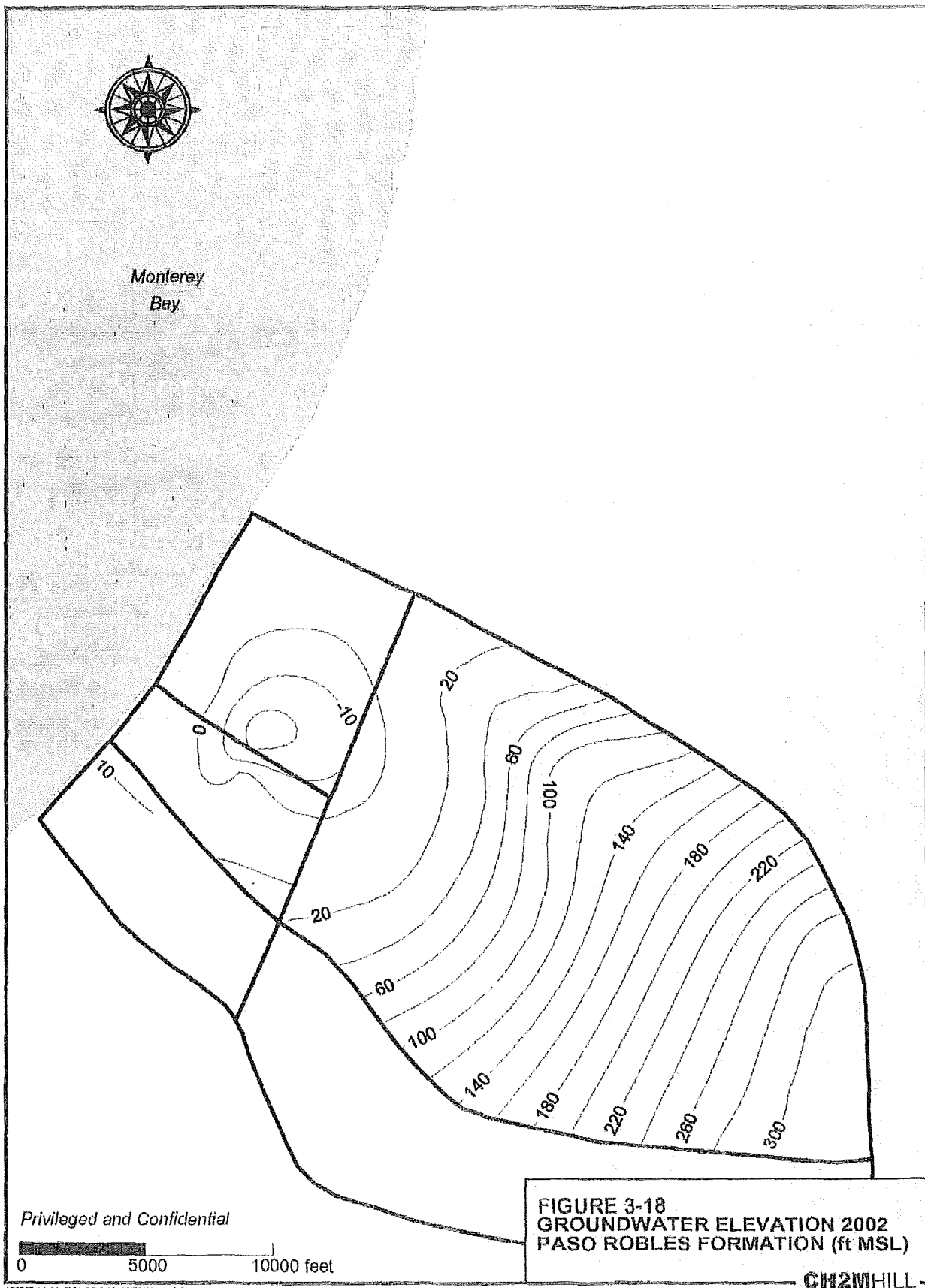


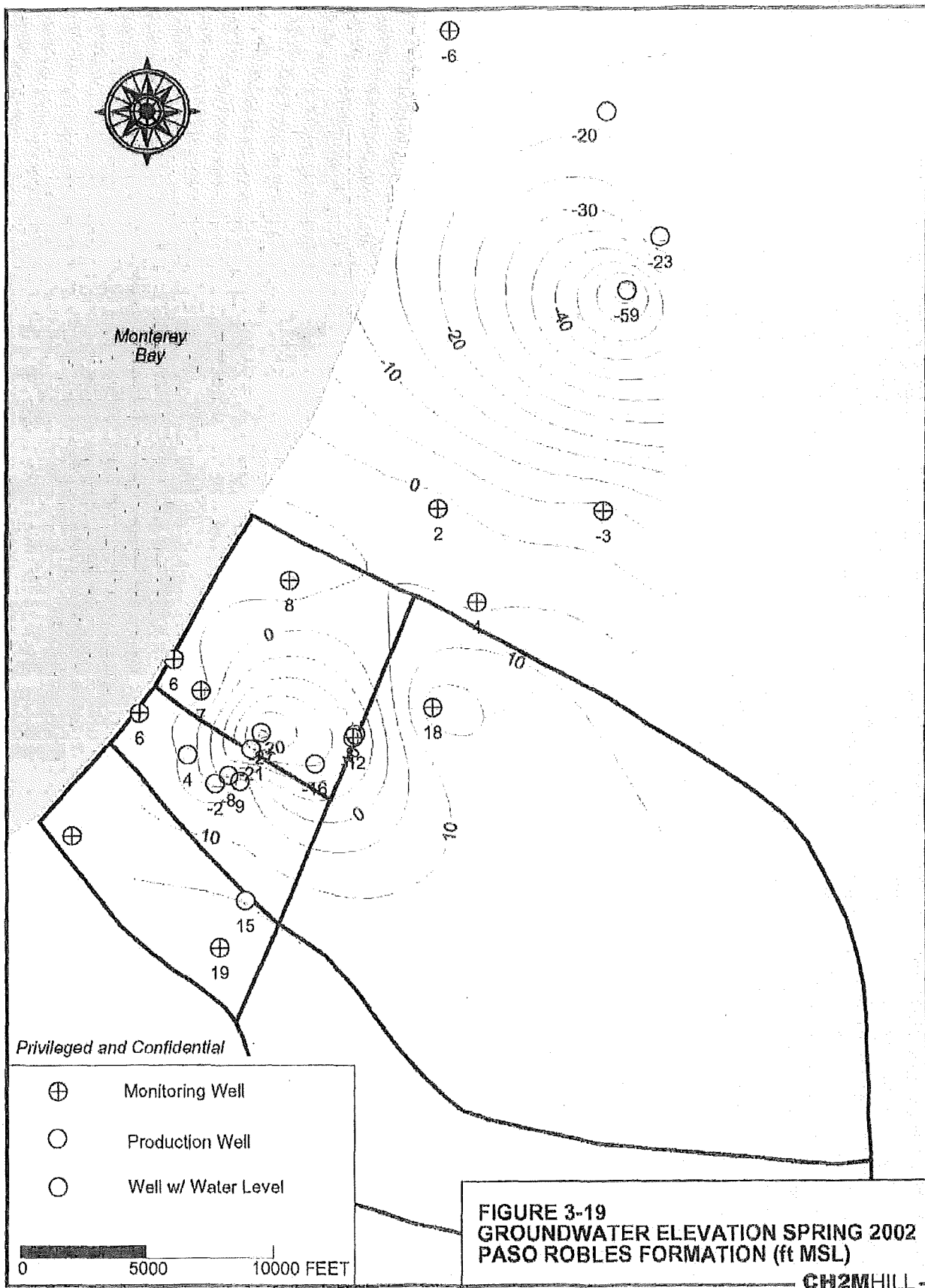


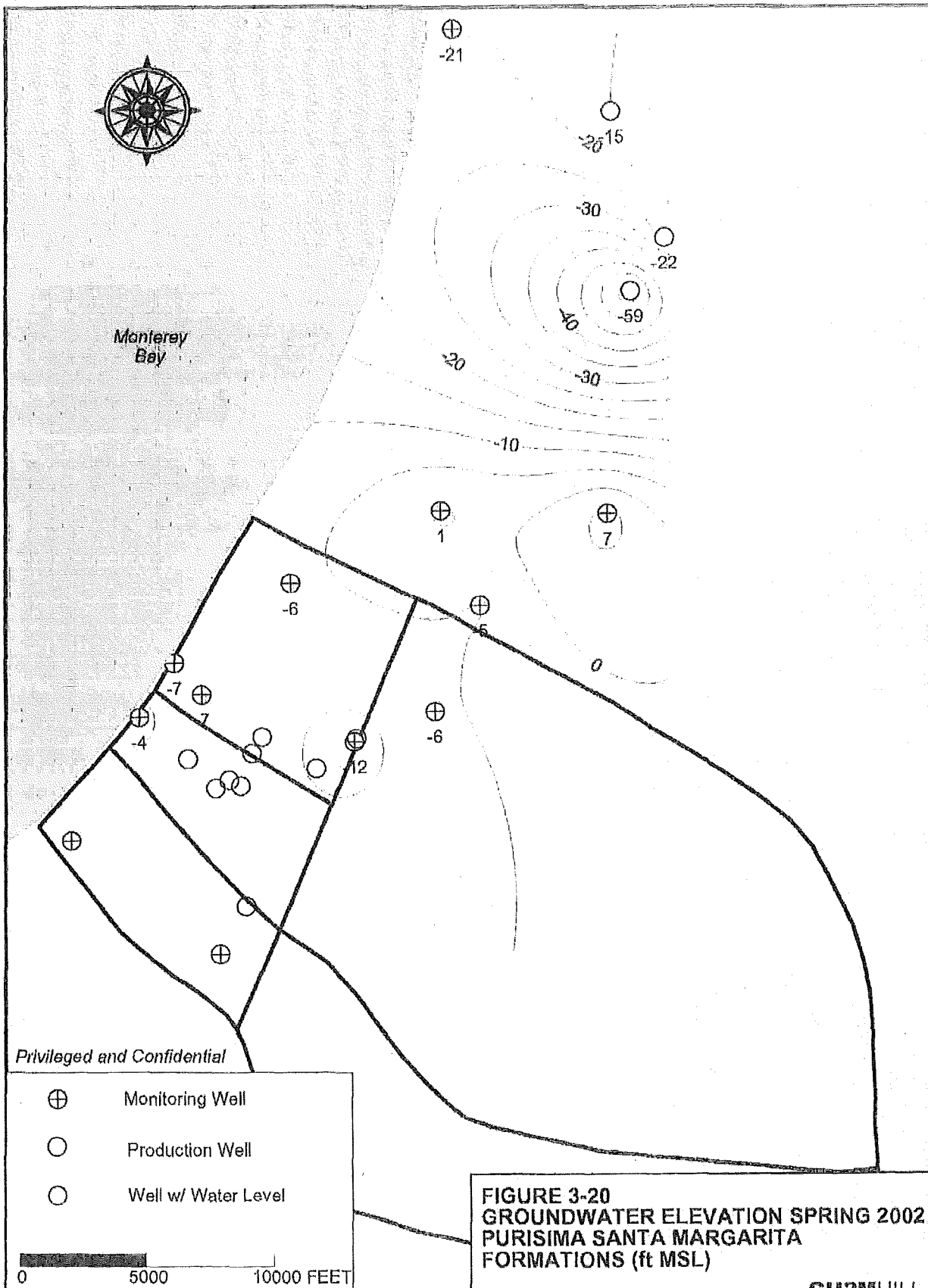


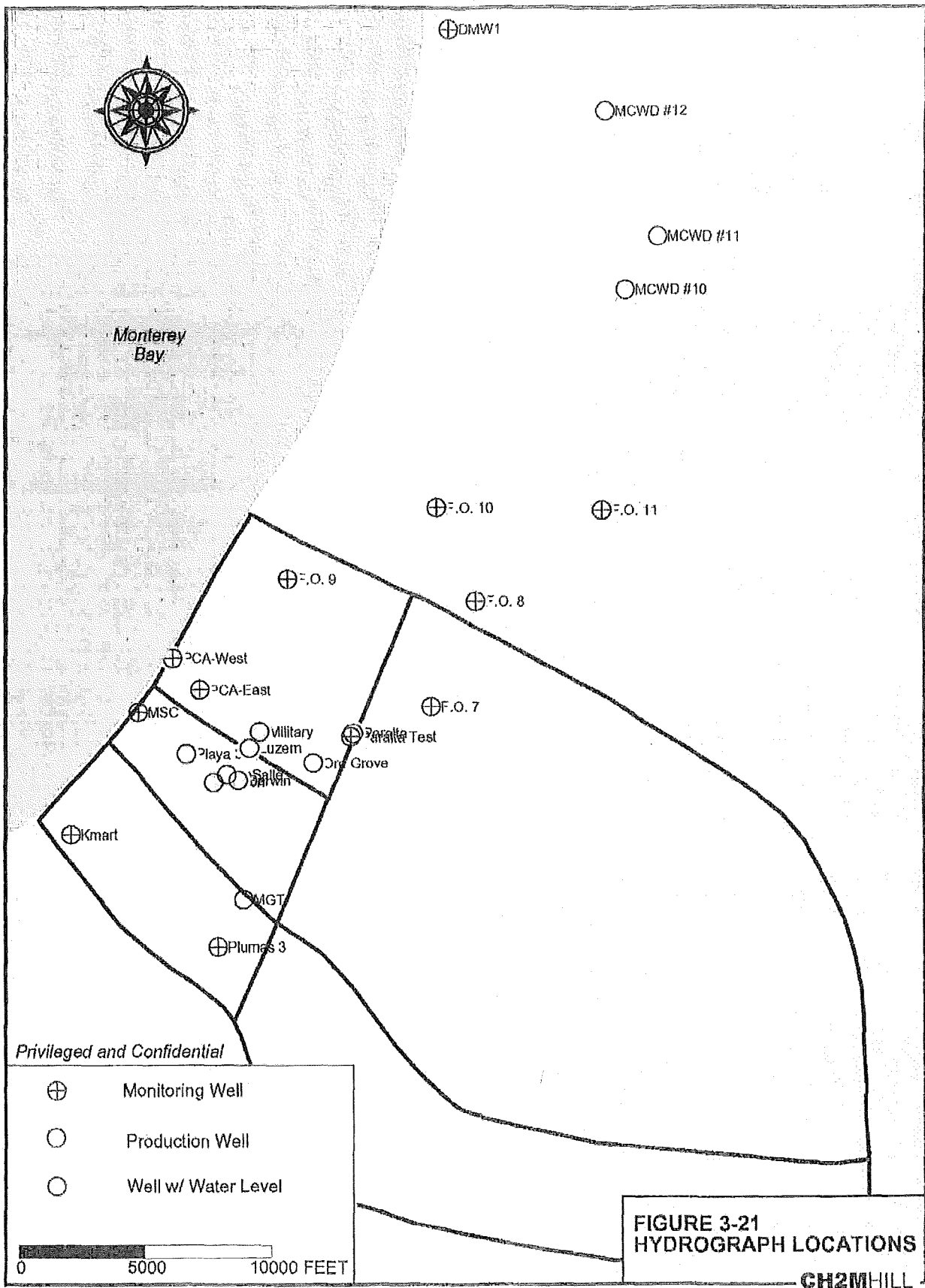


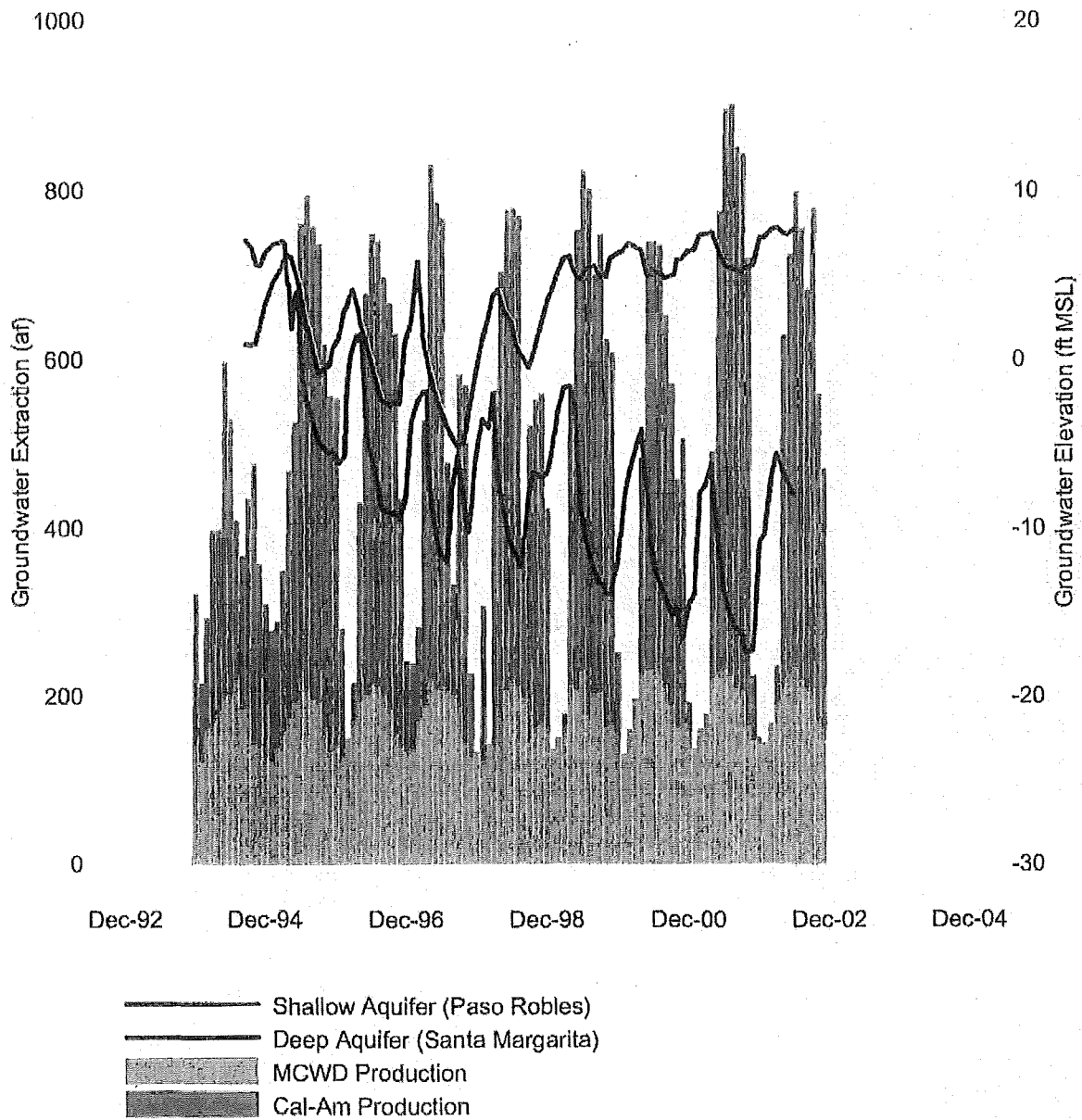








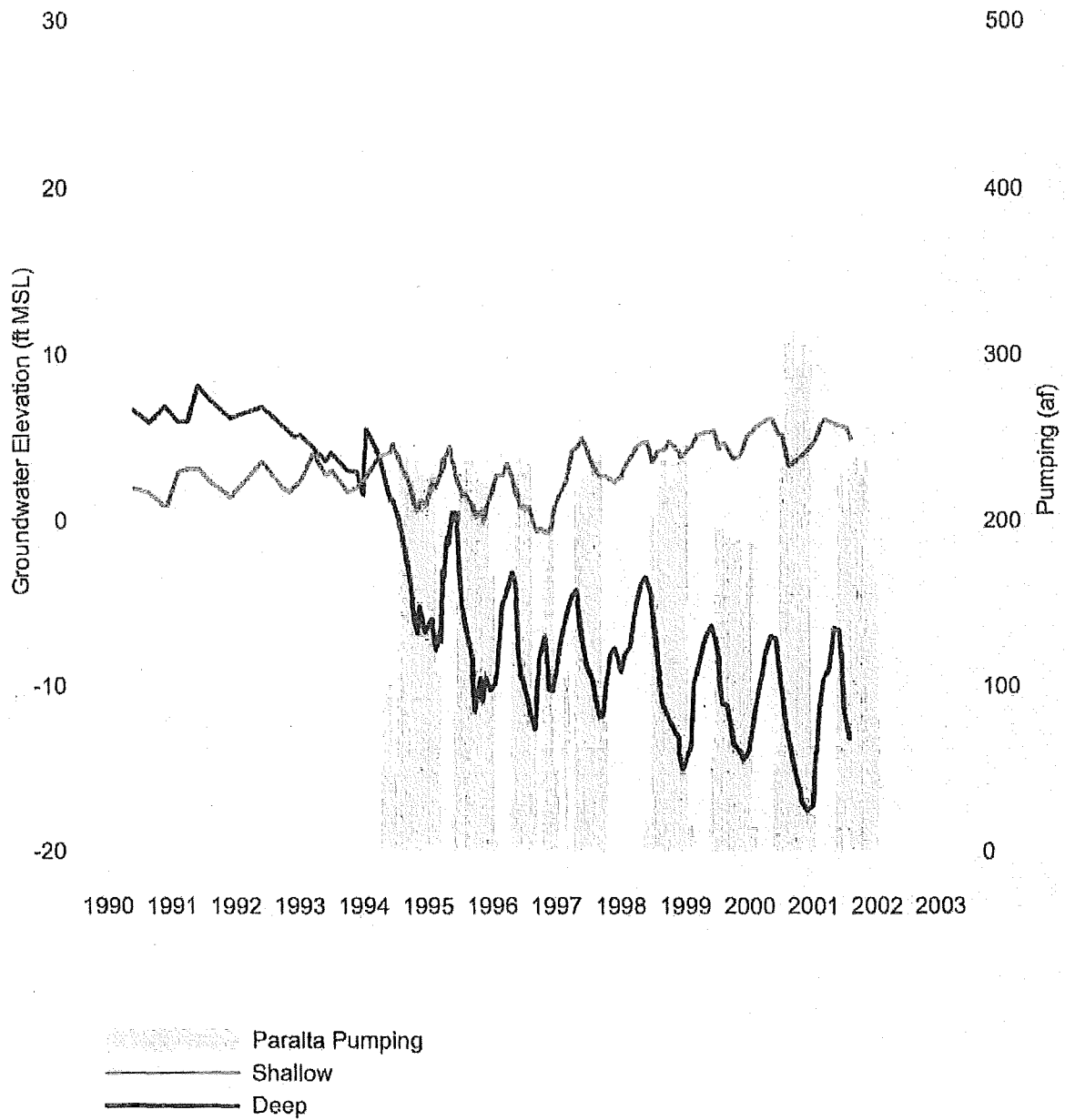




**FIGURE 3-22
FO #9 WATER LEVELS
AND COASTAL PUMPING**

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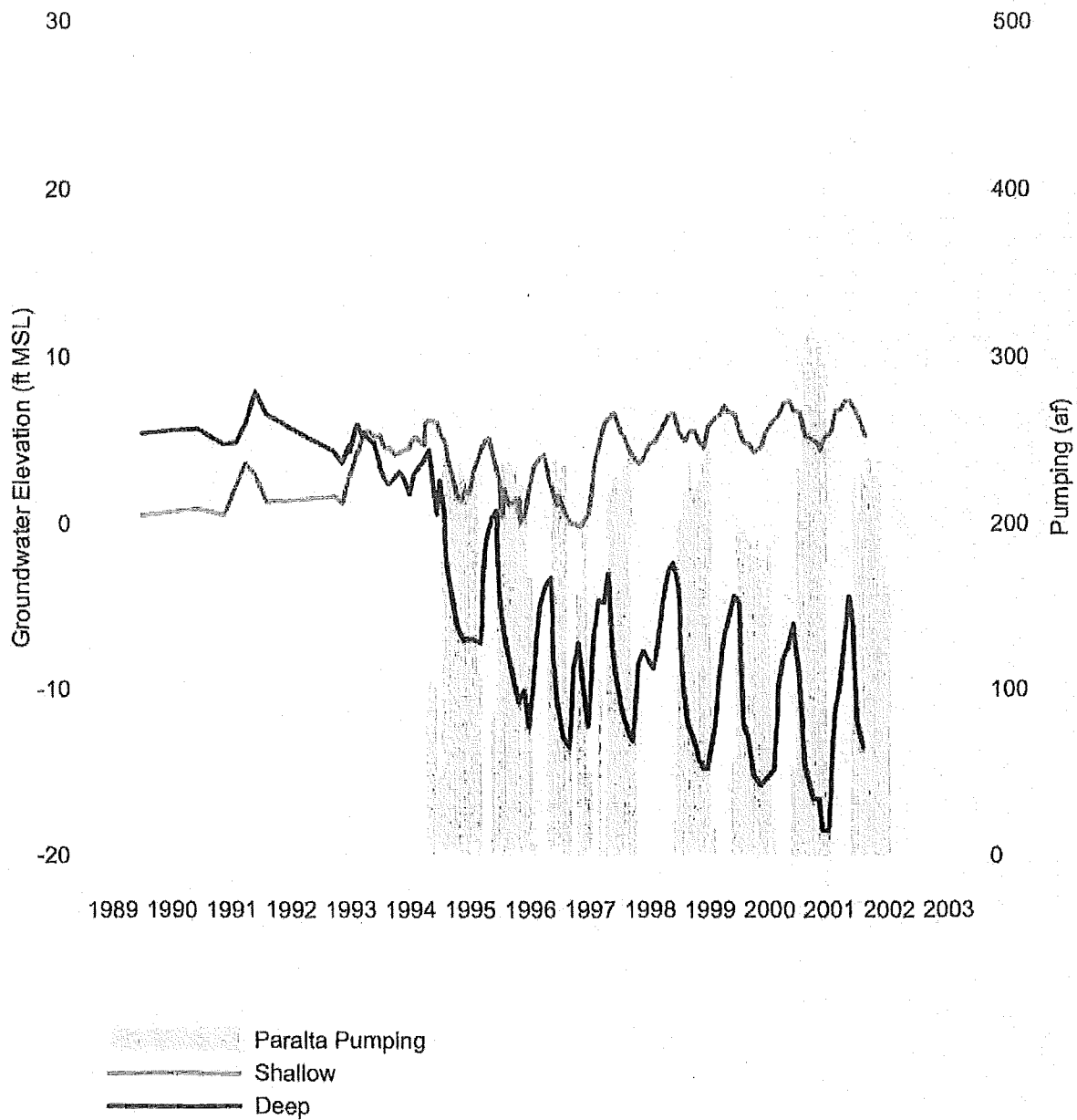
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FIGURE 3-23
PCA WEST

CM2MHILL



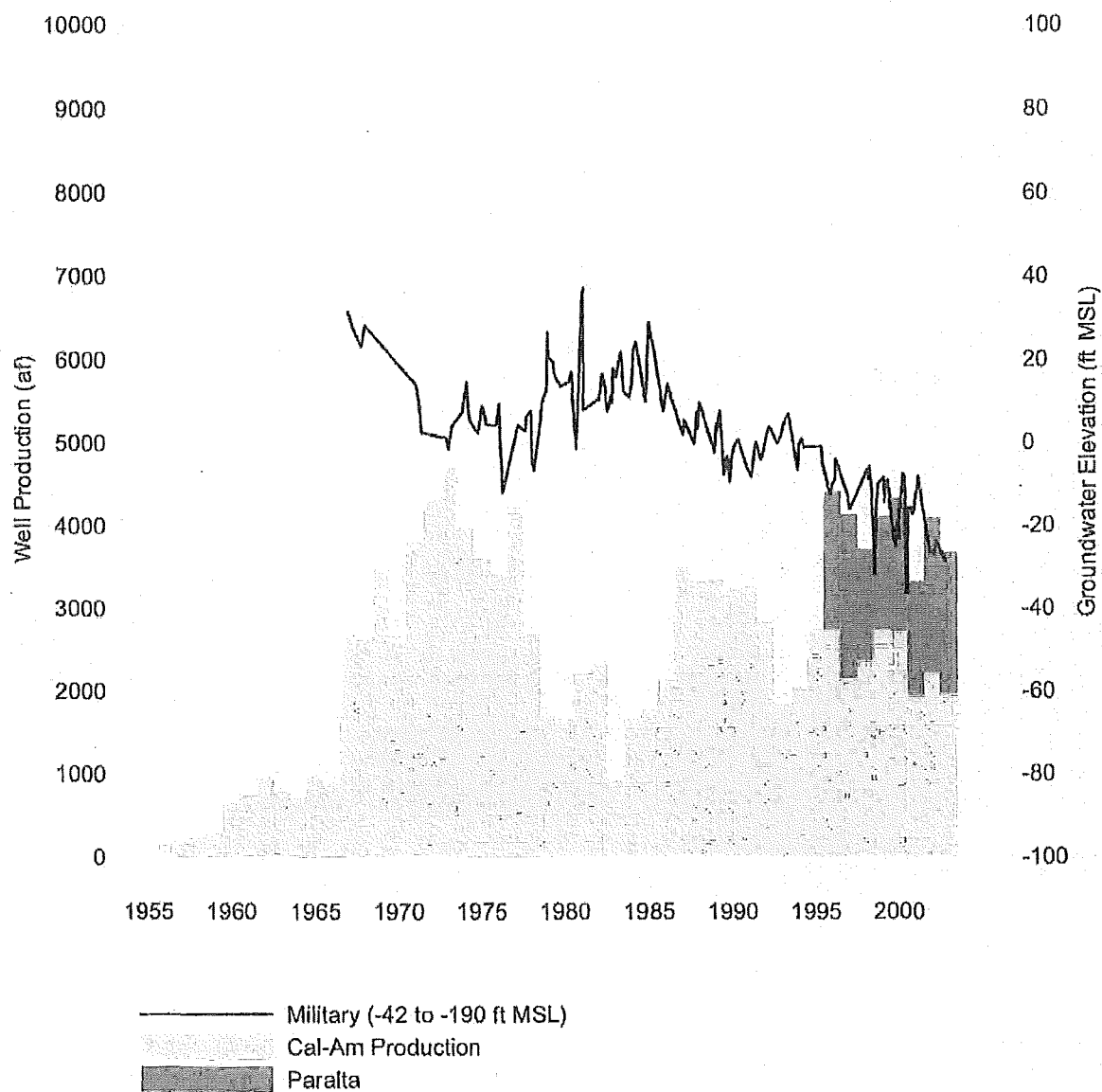
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003

Paralta Pumping
Shallow
Deep

FIGURE 3-24
PCA EAST

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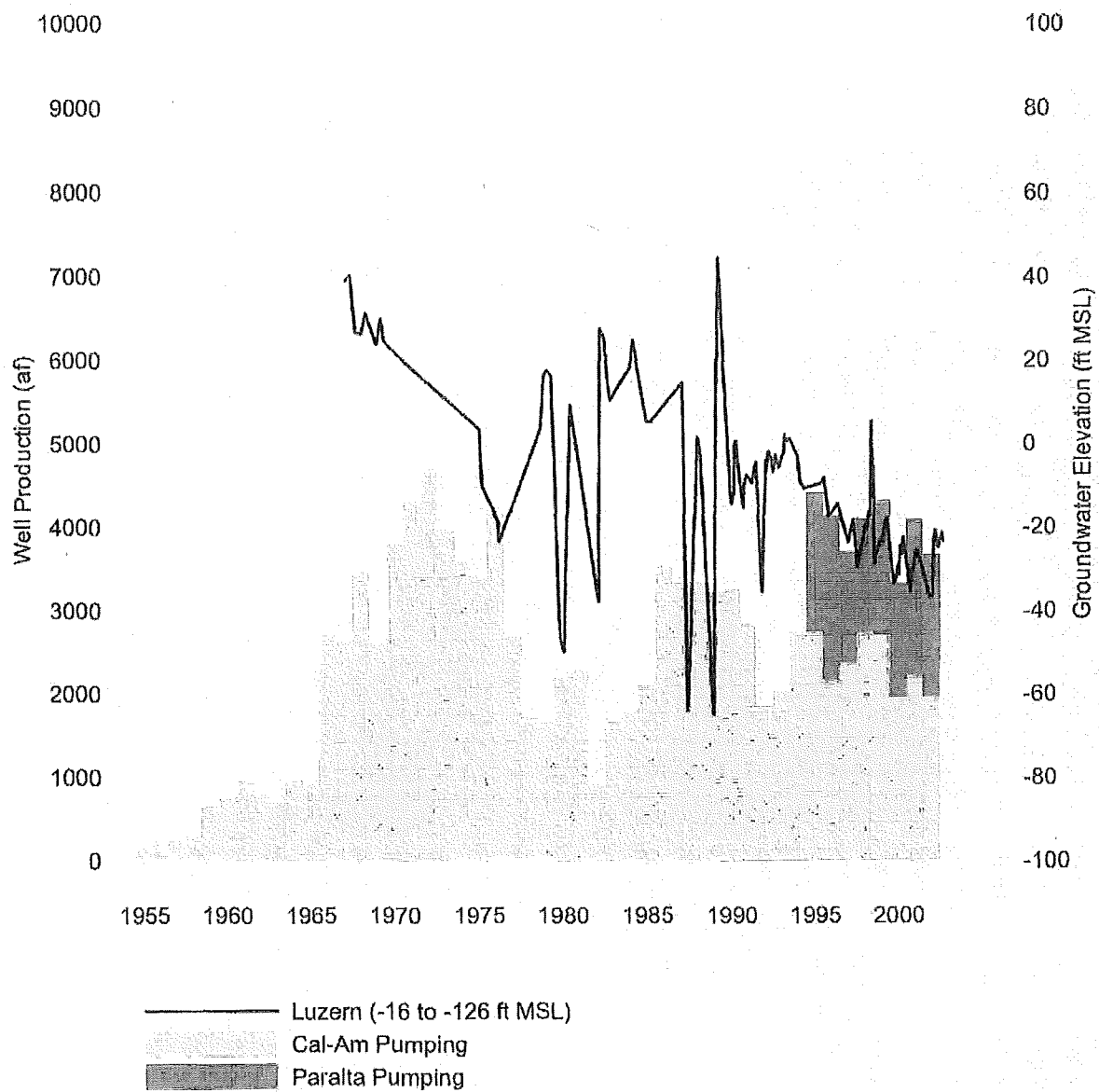
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**FIGURE 3-25
MILITARY**

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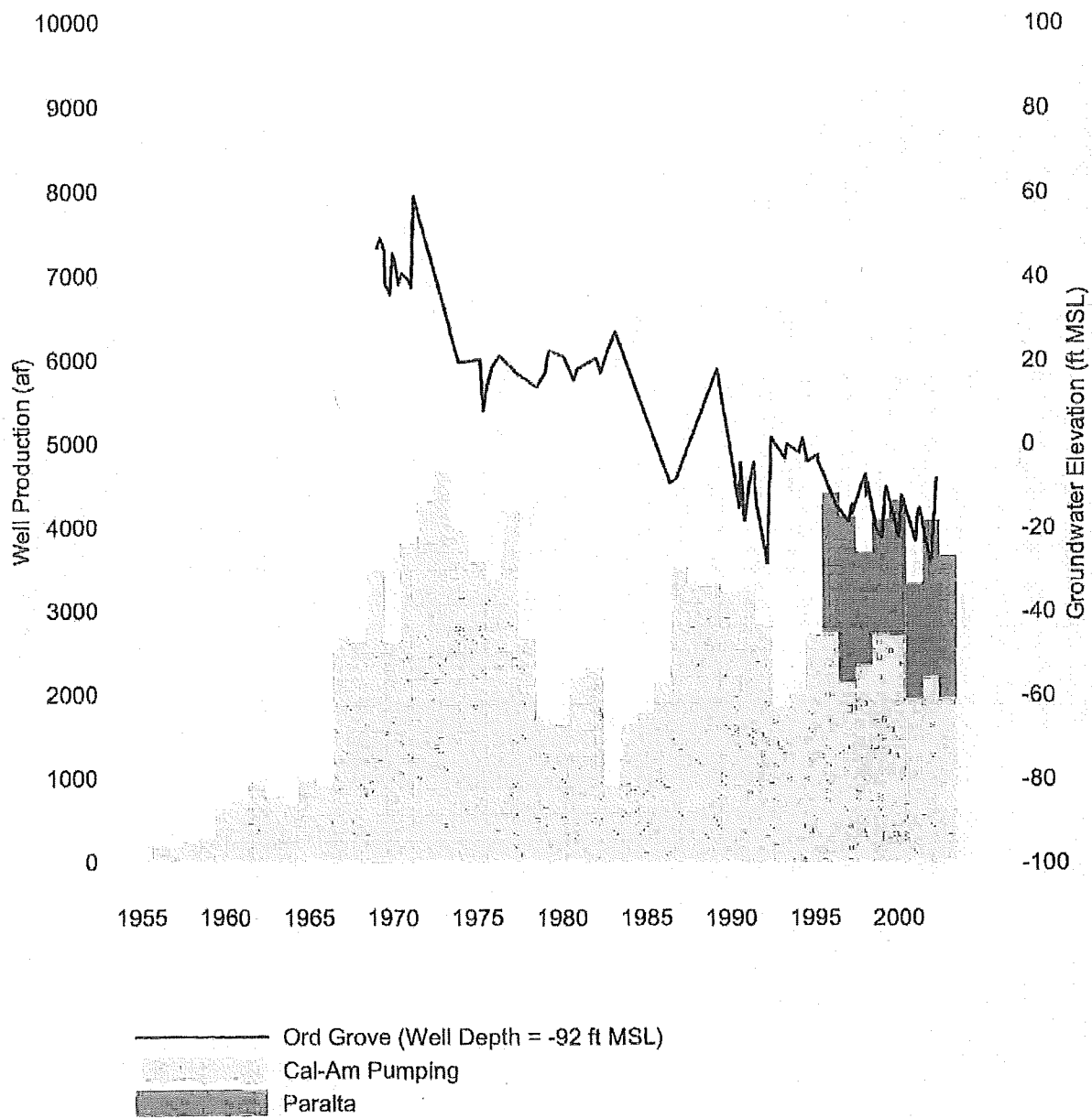
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**FIGURE 3-26
LUZERN**

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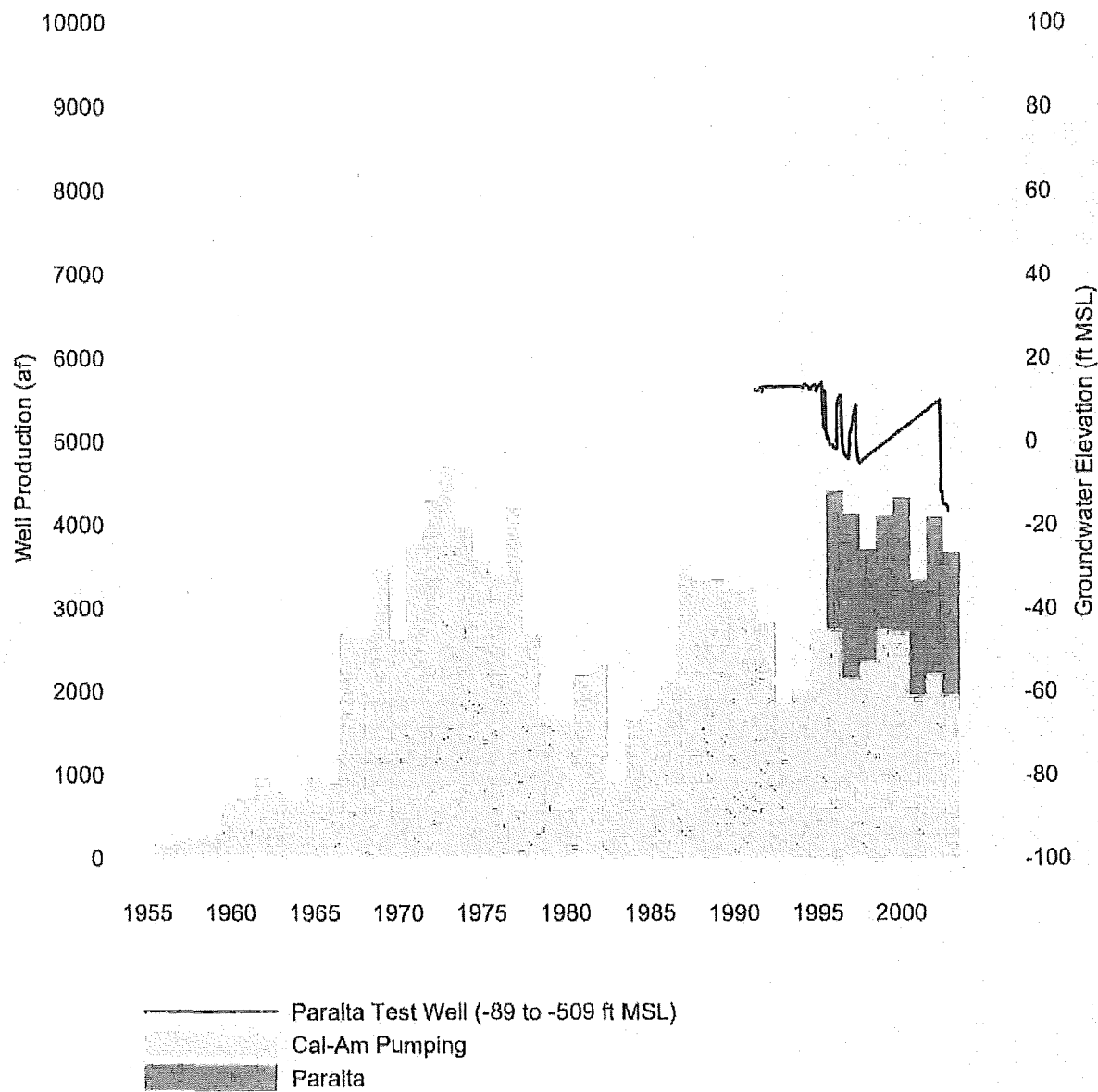
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**FIGURE 3-27
ORD GROVE**

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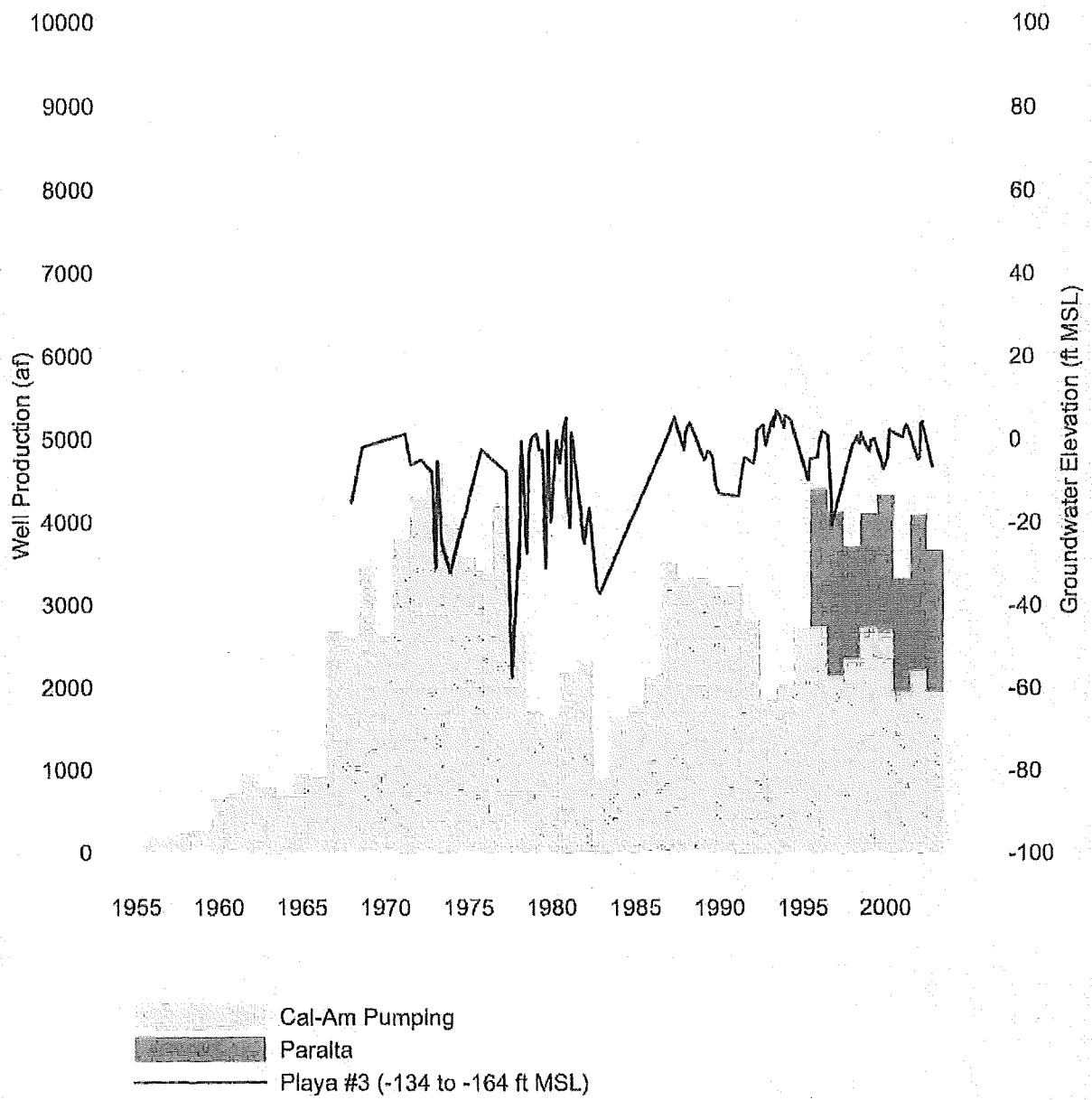
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**FIGURE 3-28
PARALTA TEST WELL**

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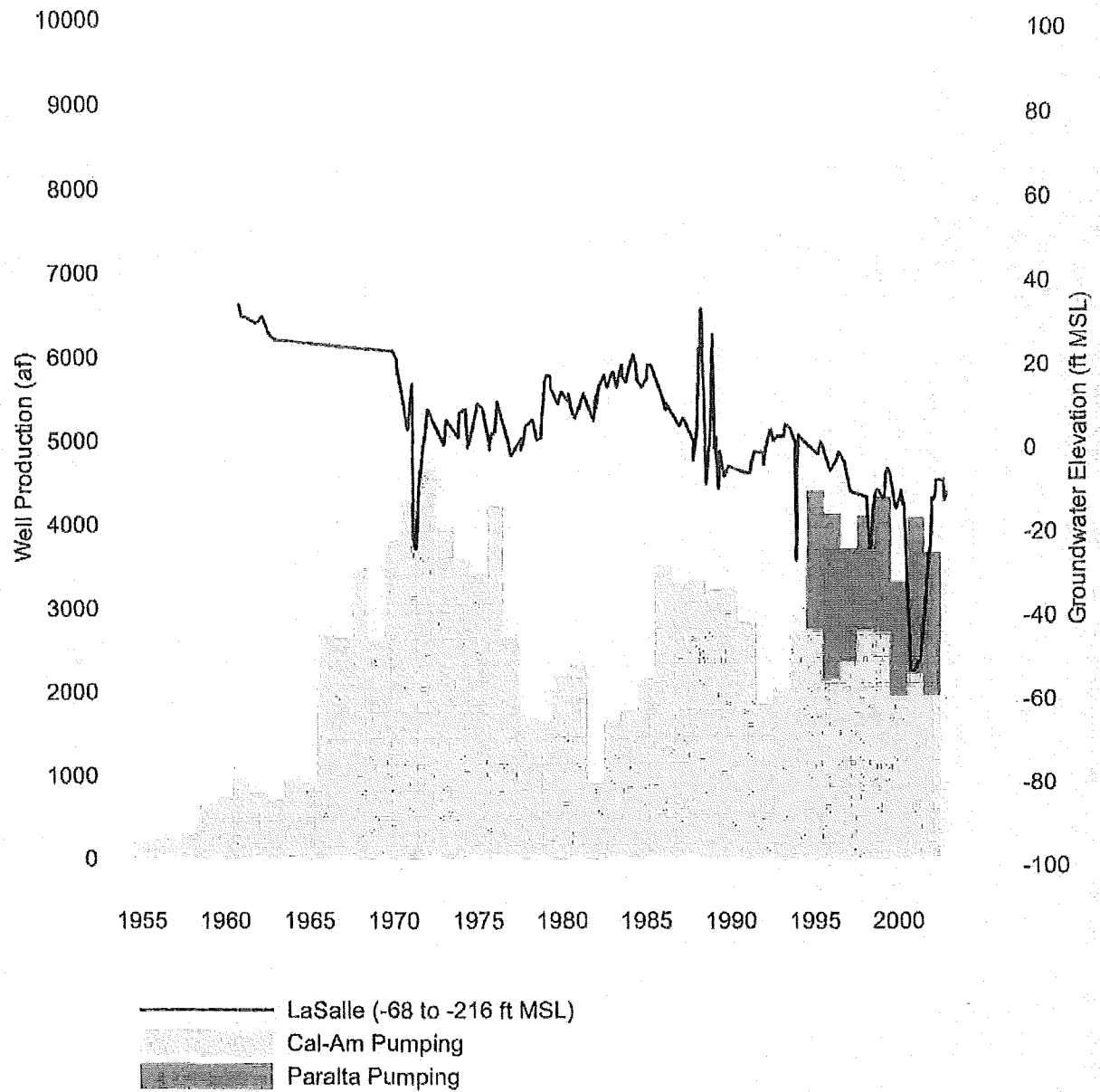
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**FIGURE 3-29
PLAYA #3**

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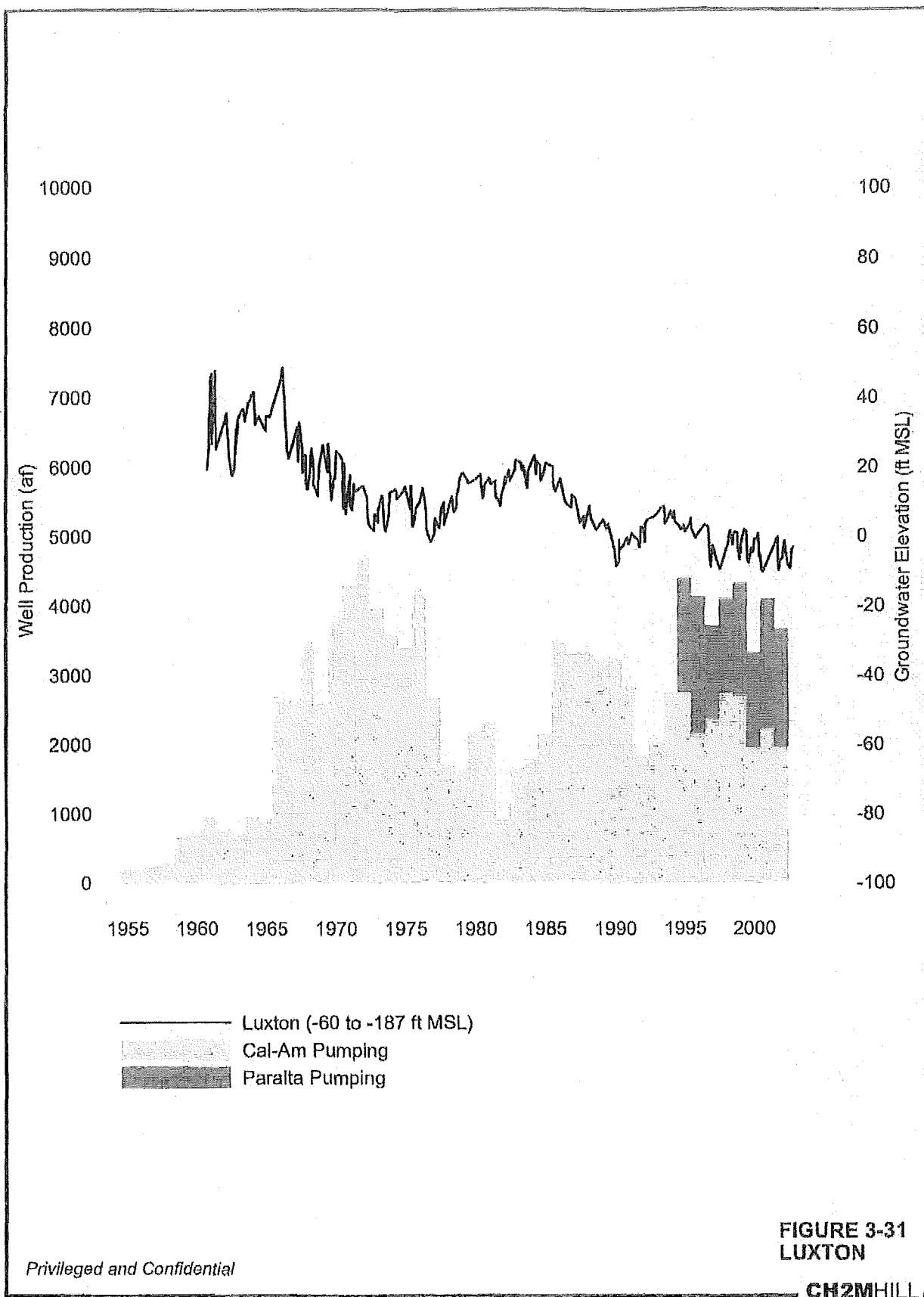
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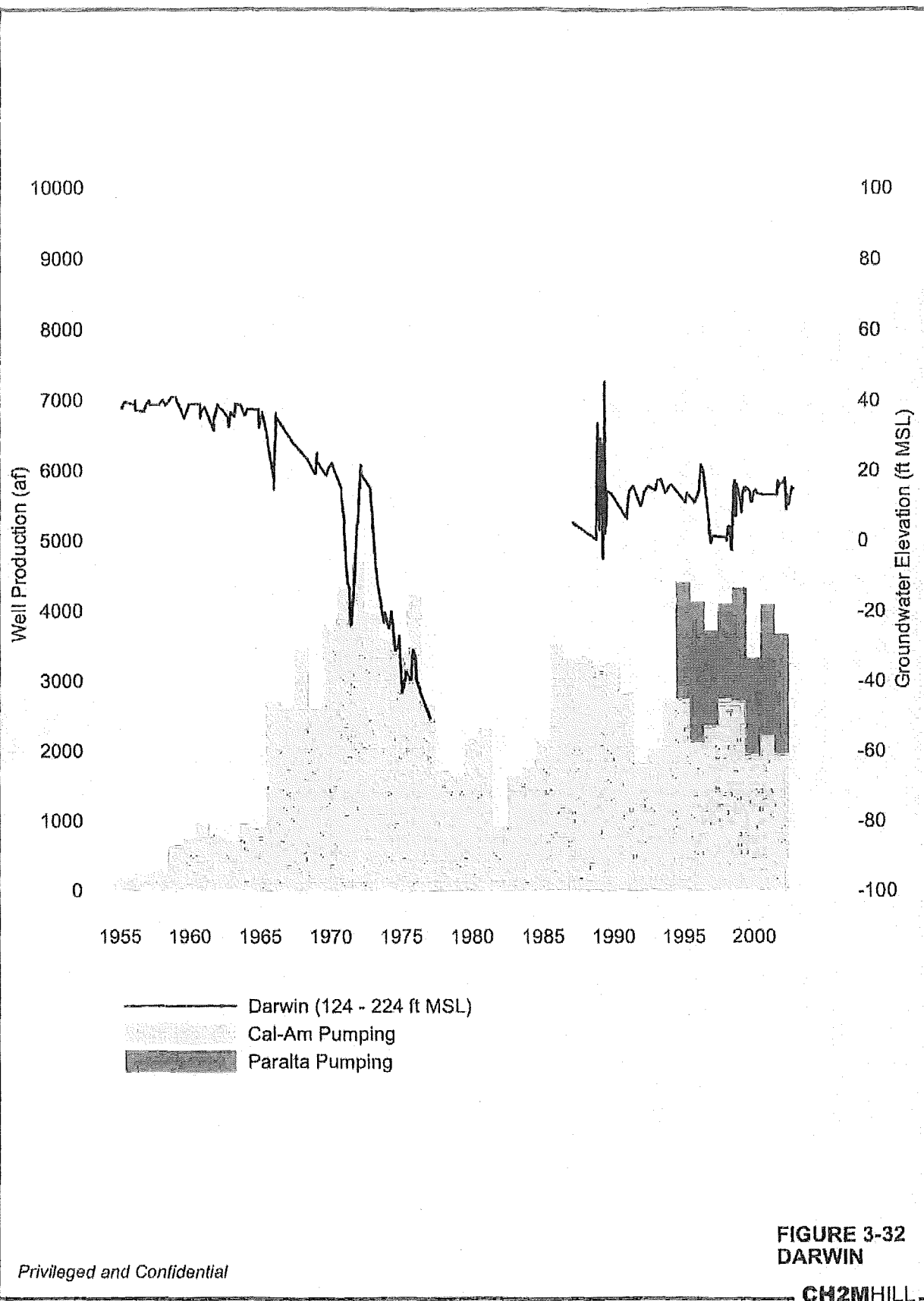


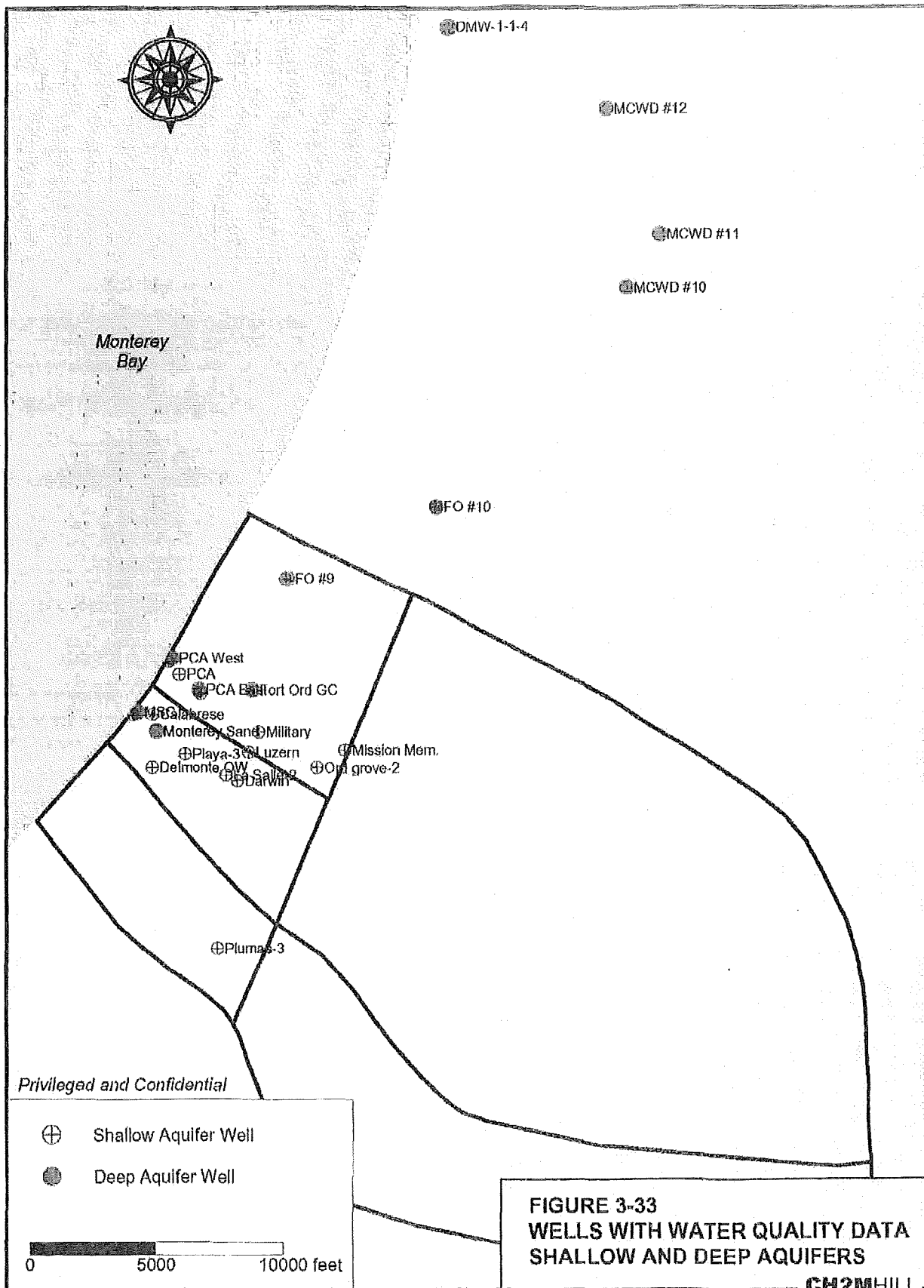
**FIGURE 3-30
LASALLE**

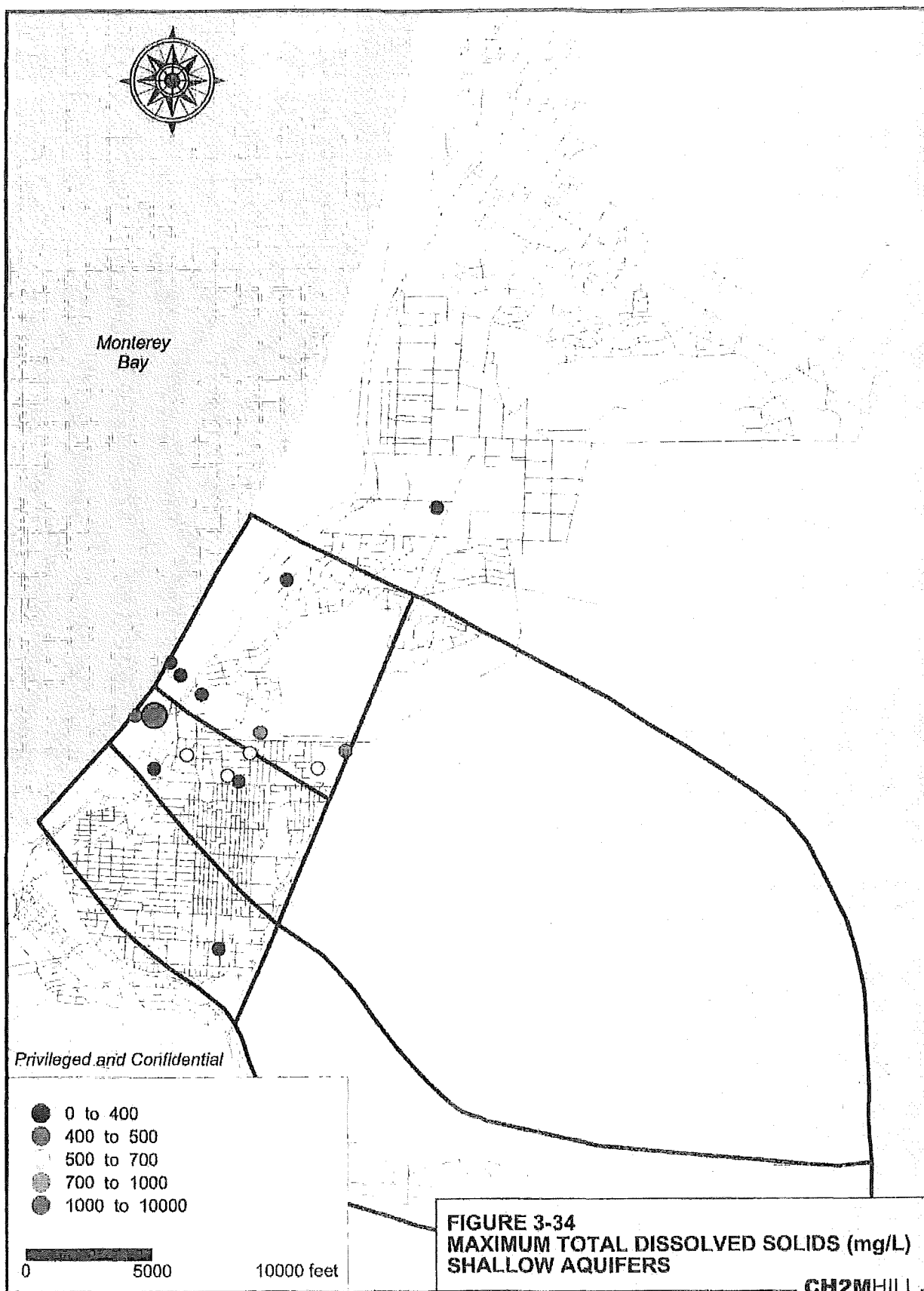
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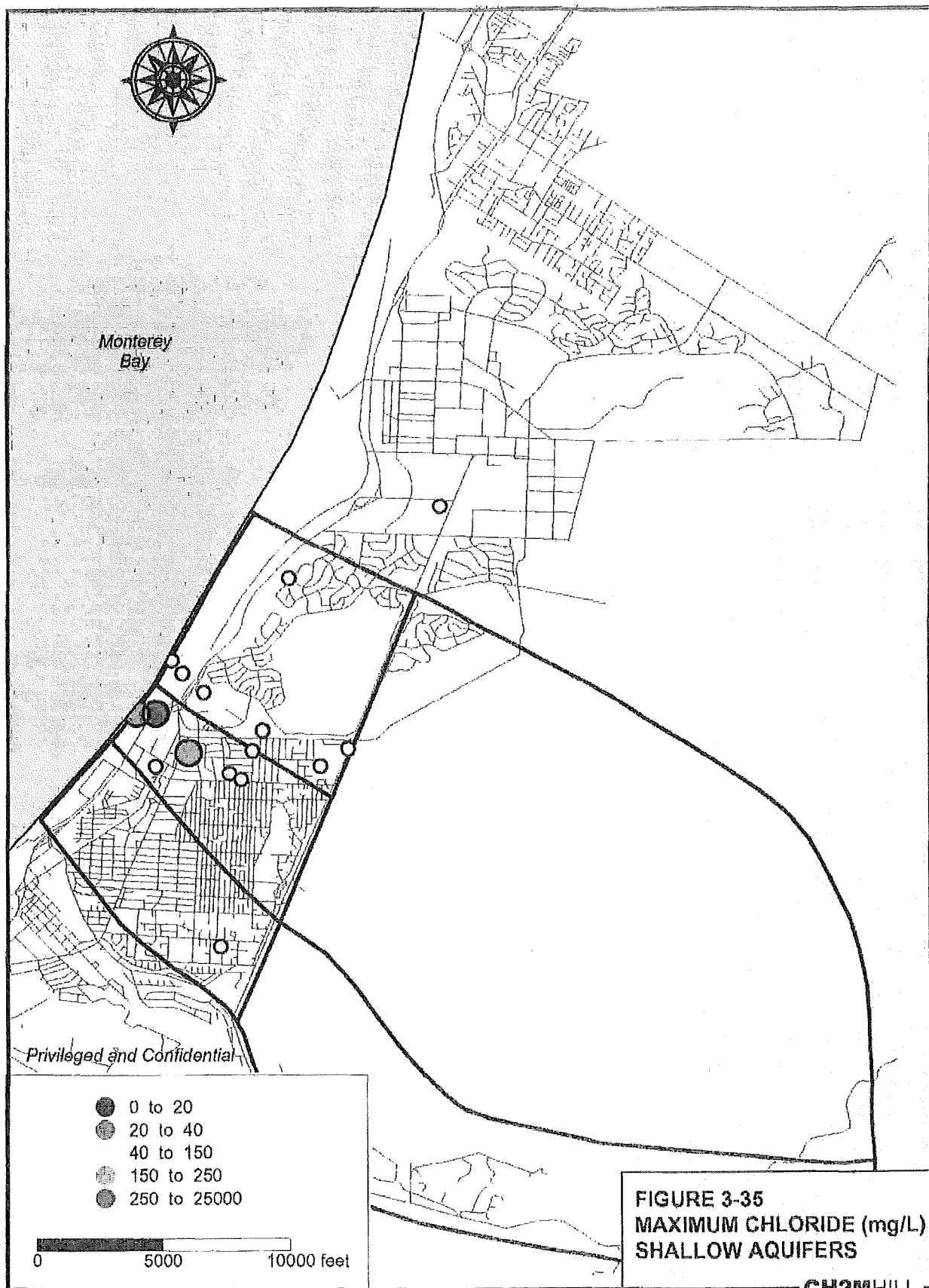
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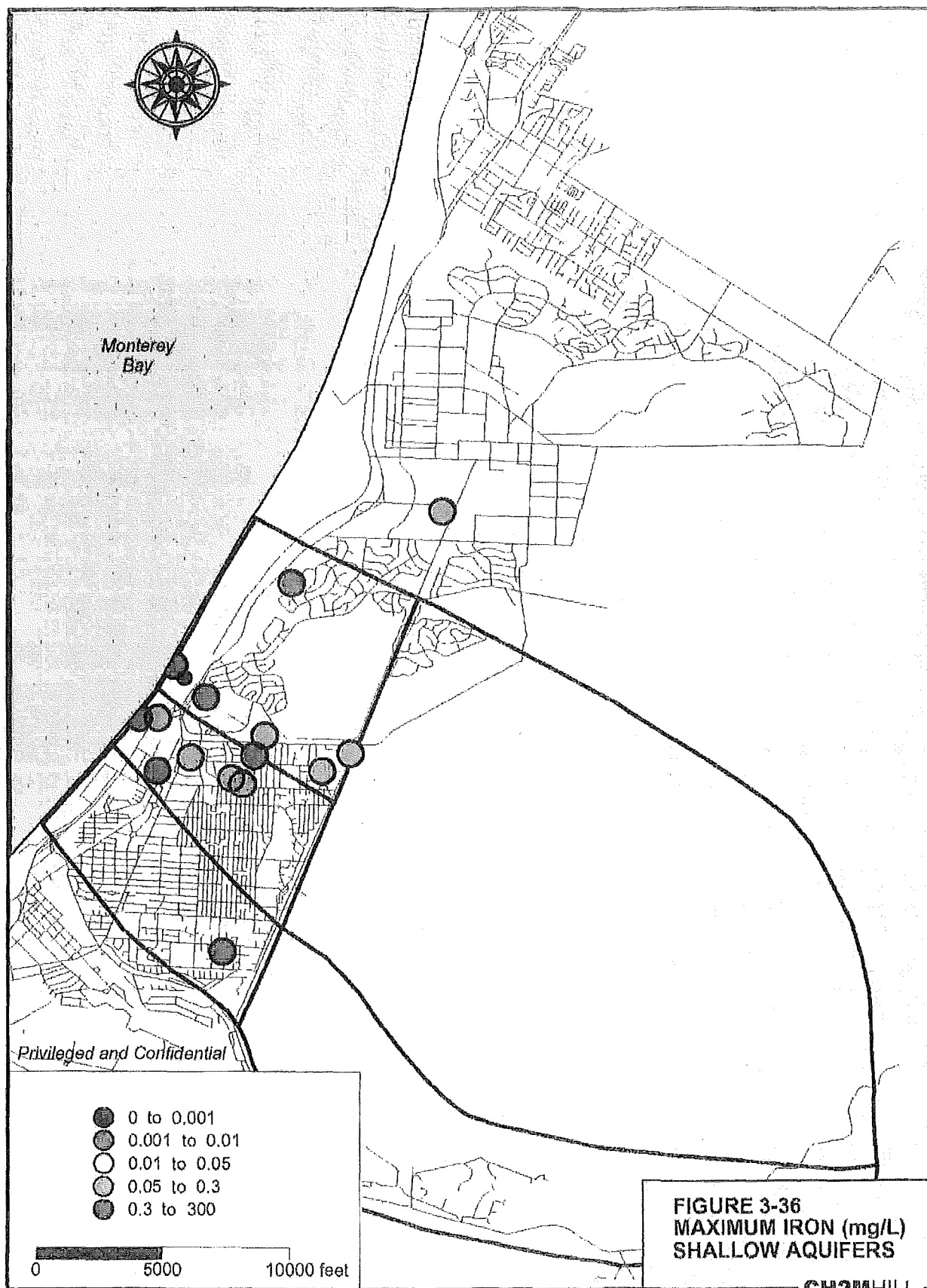


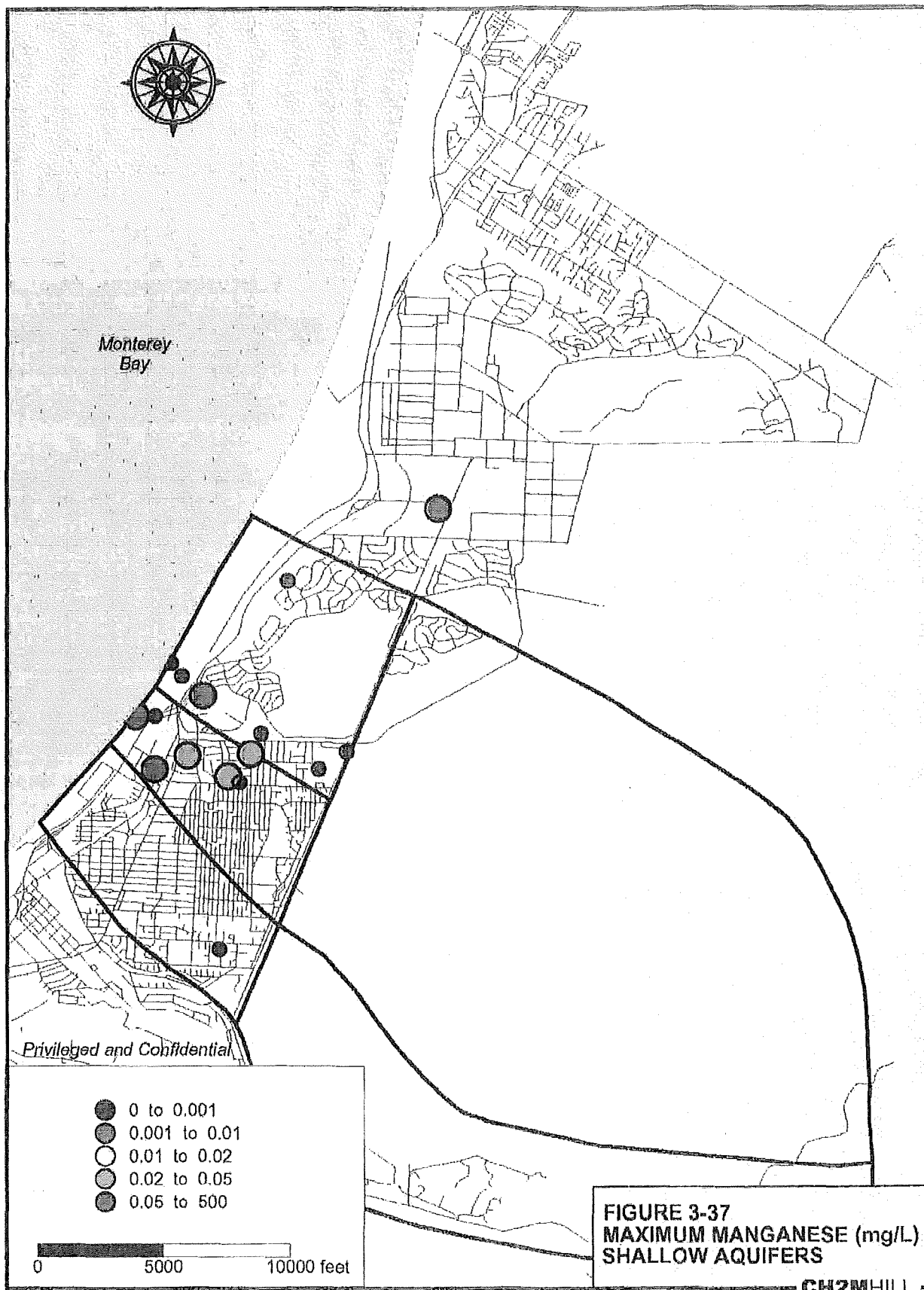


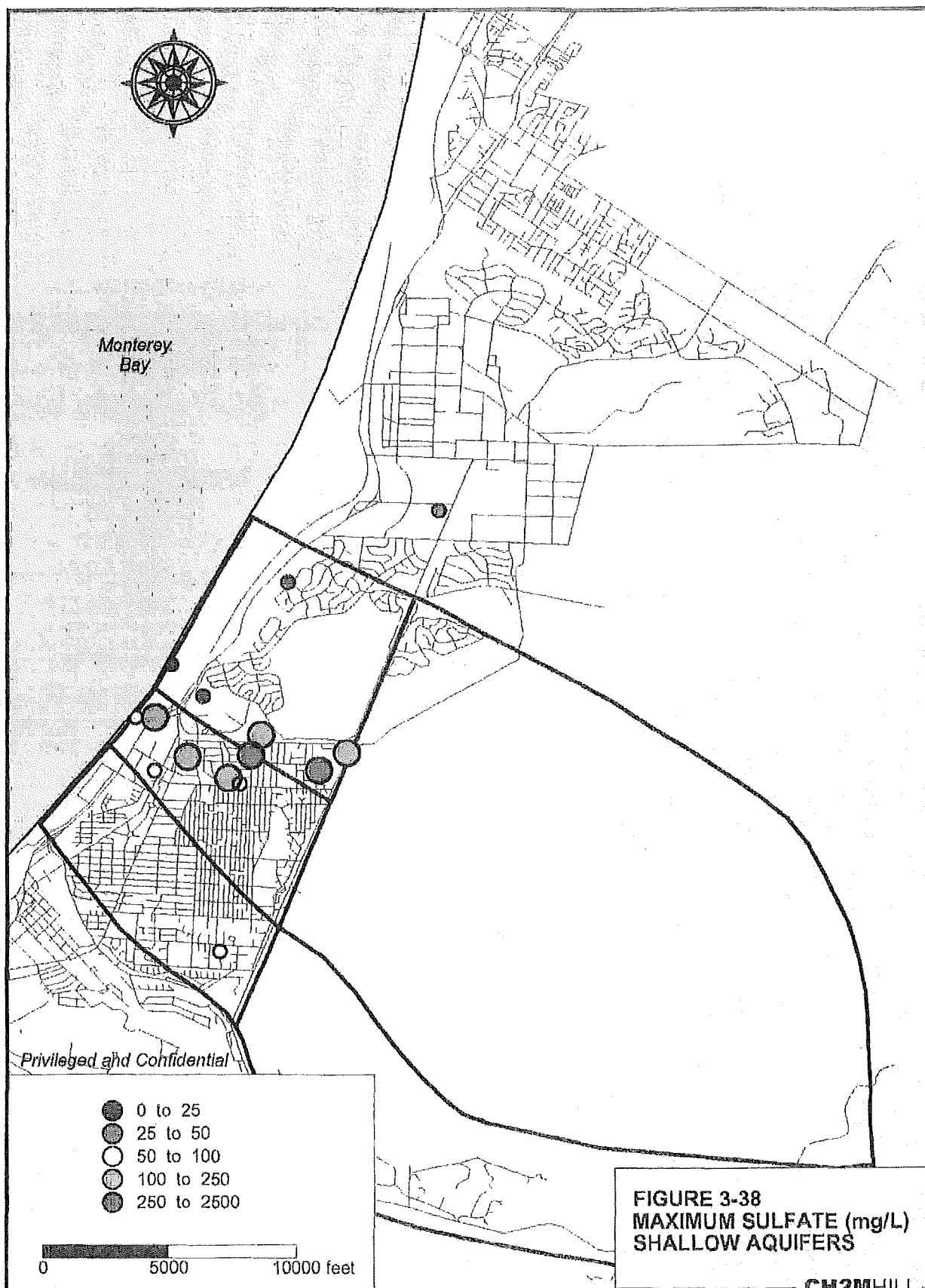


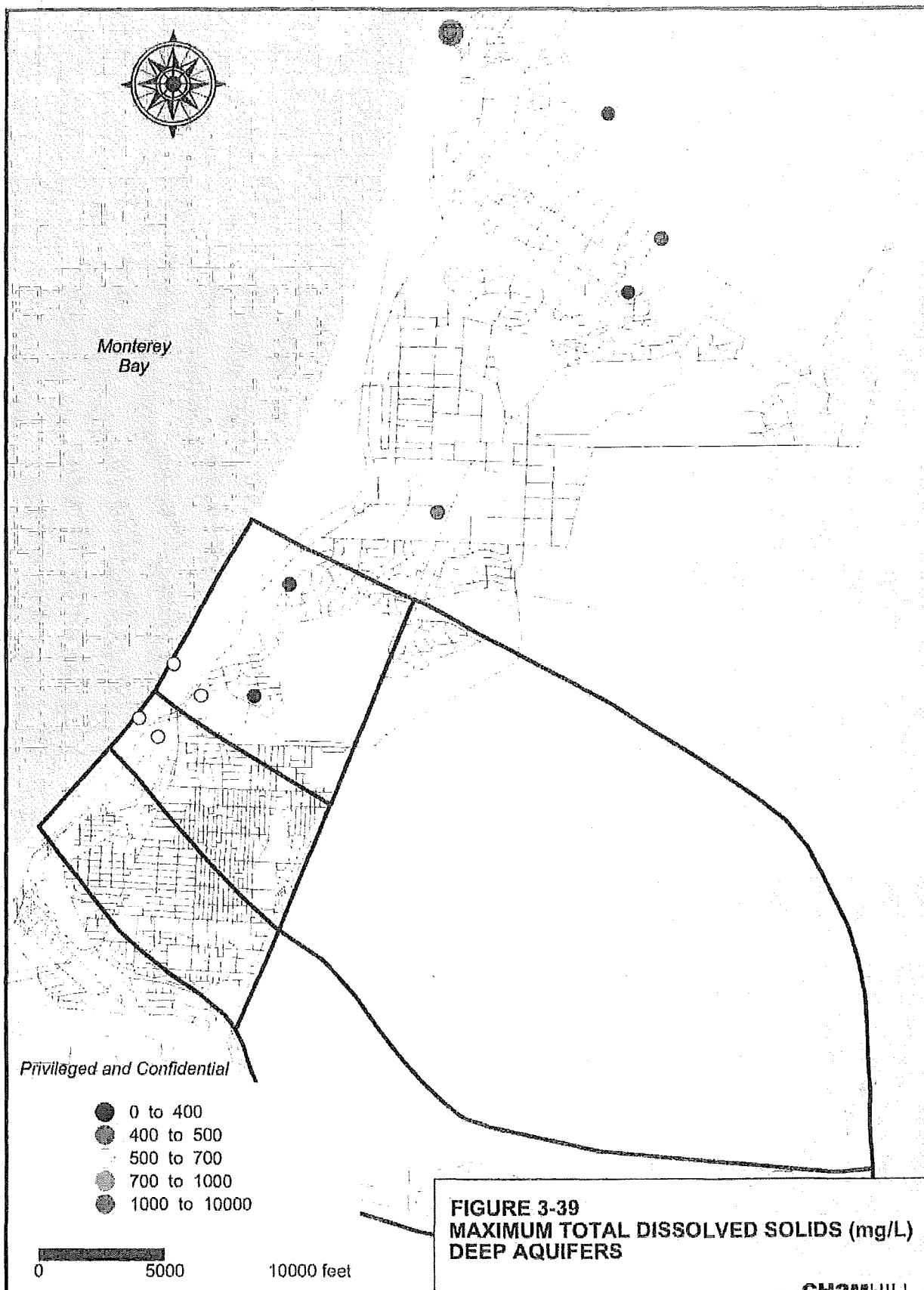


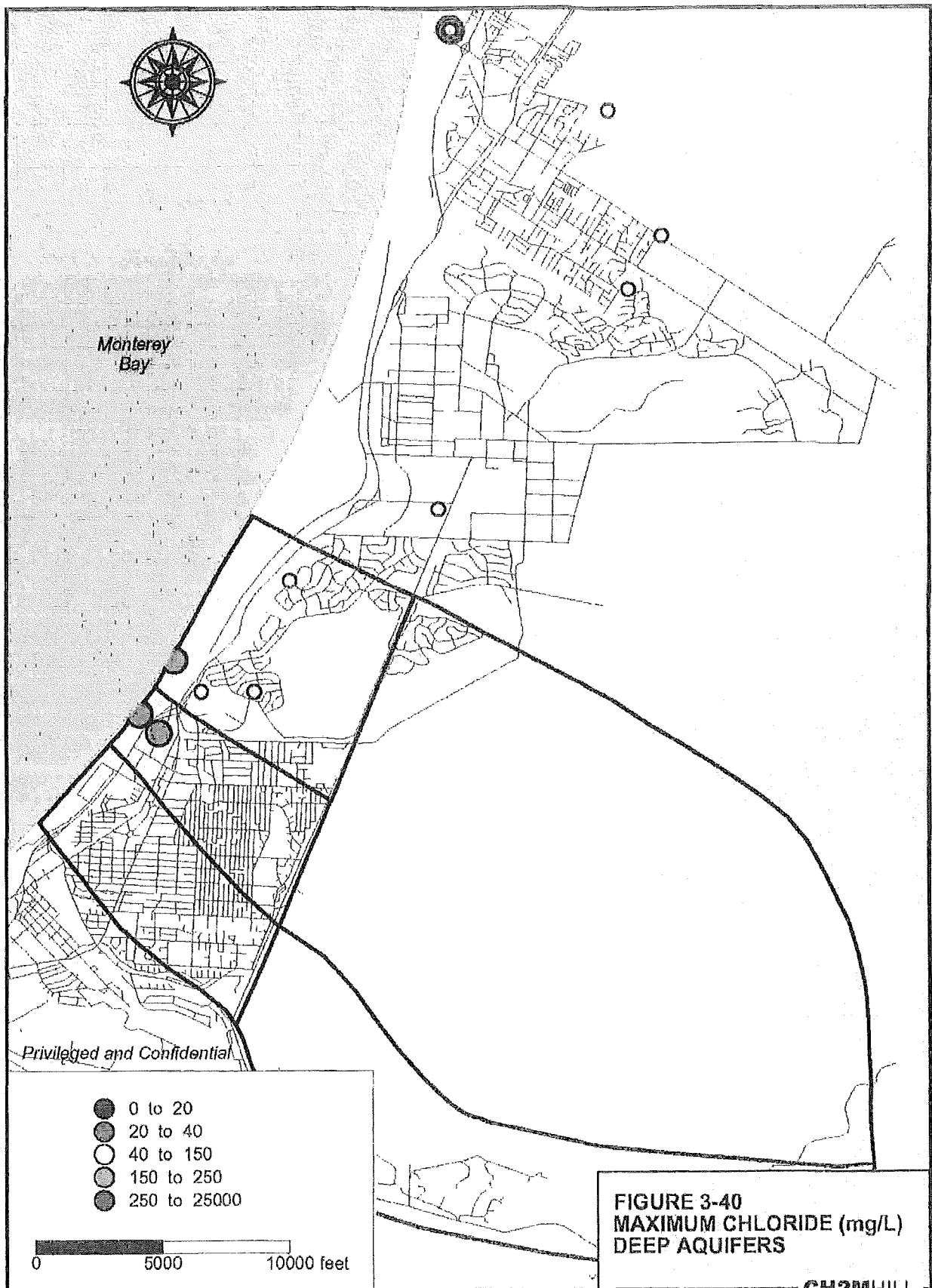


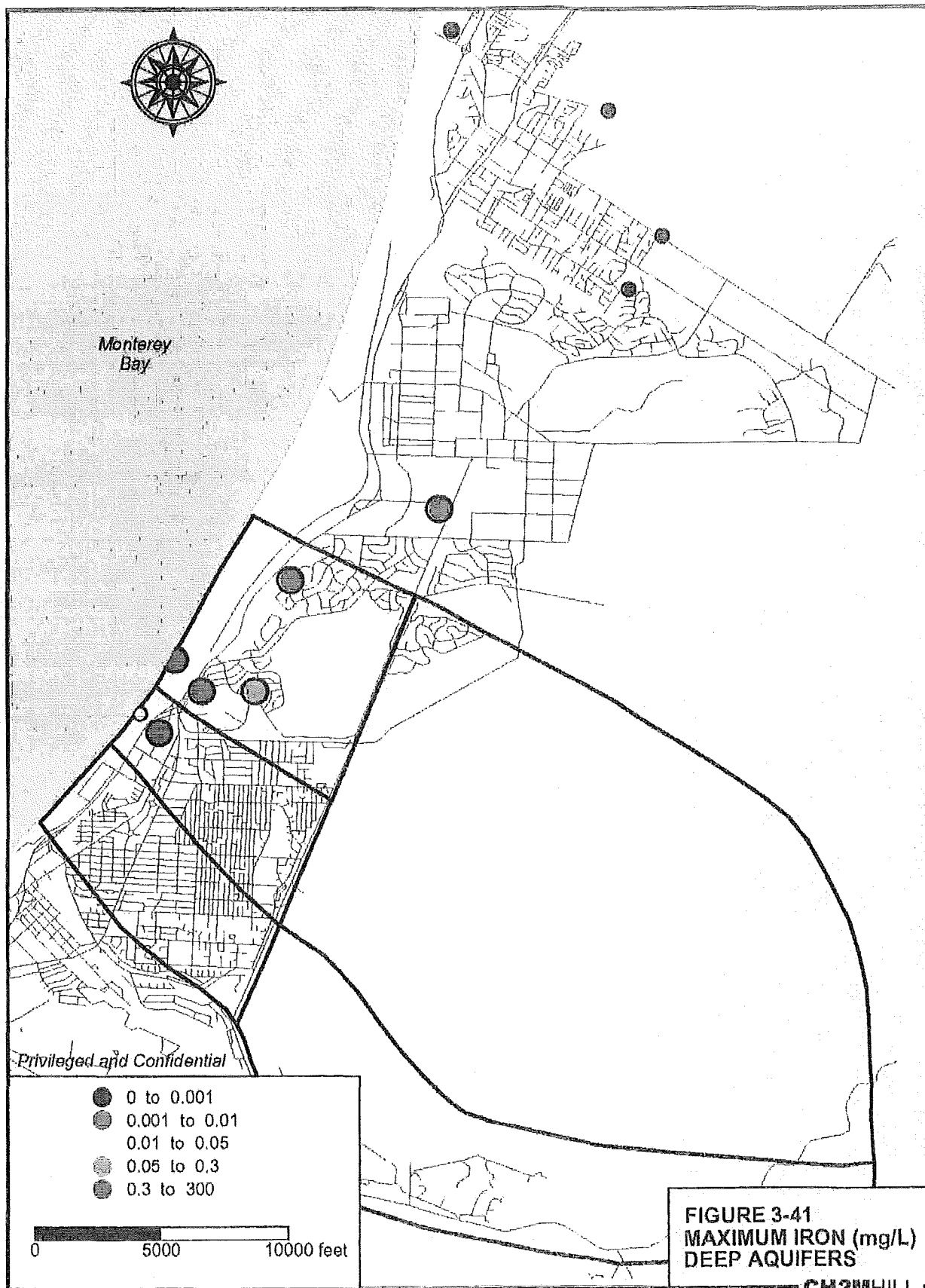


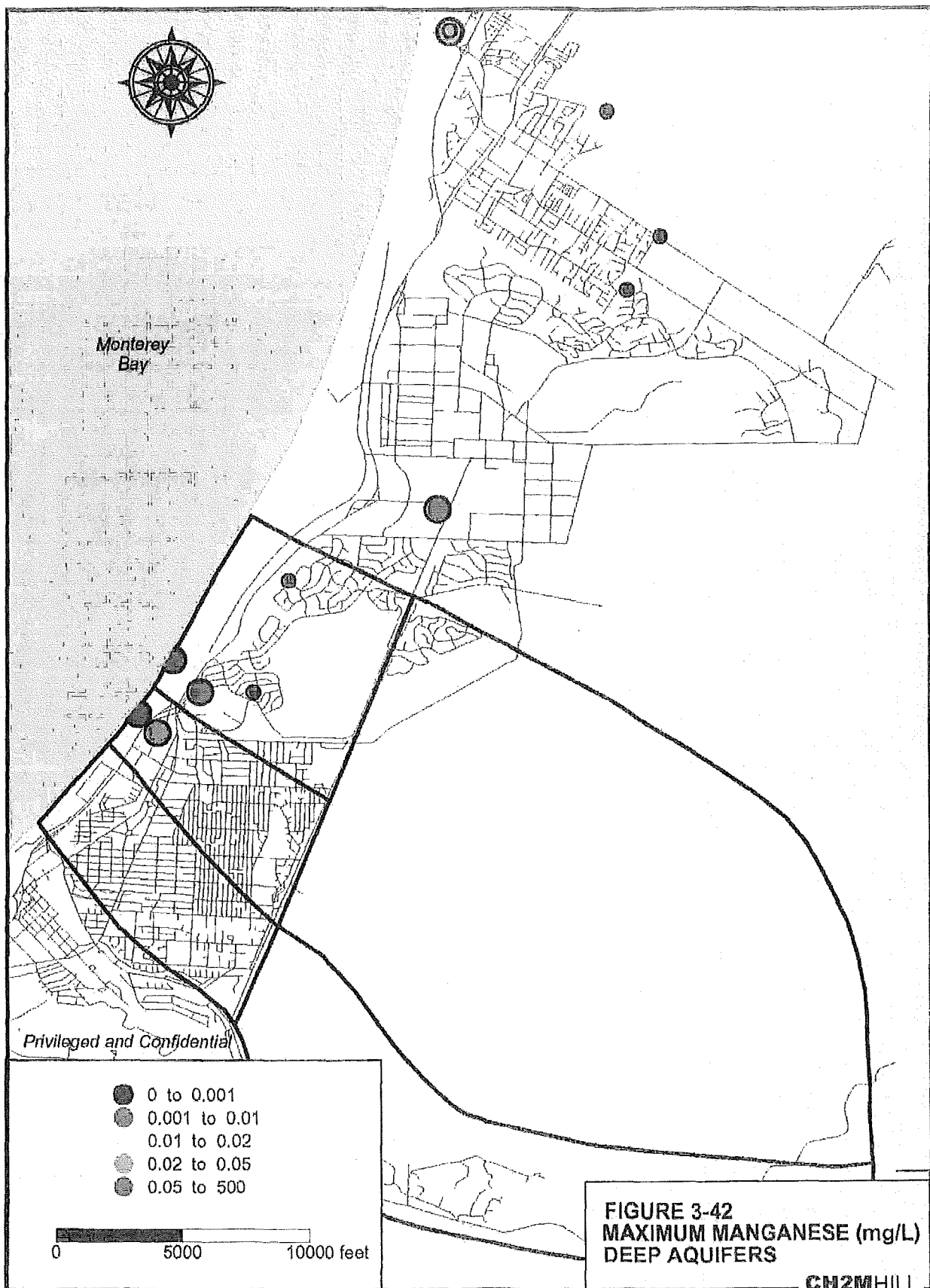


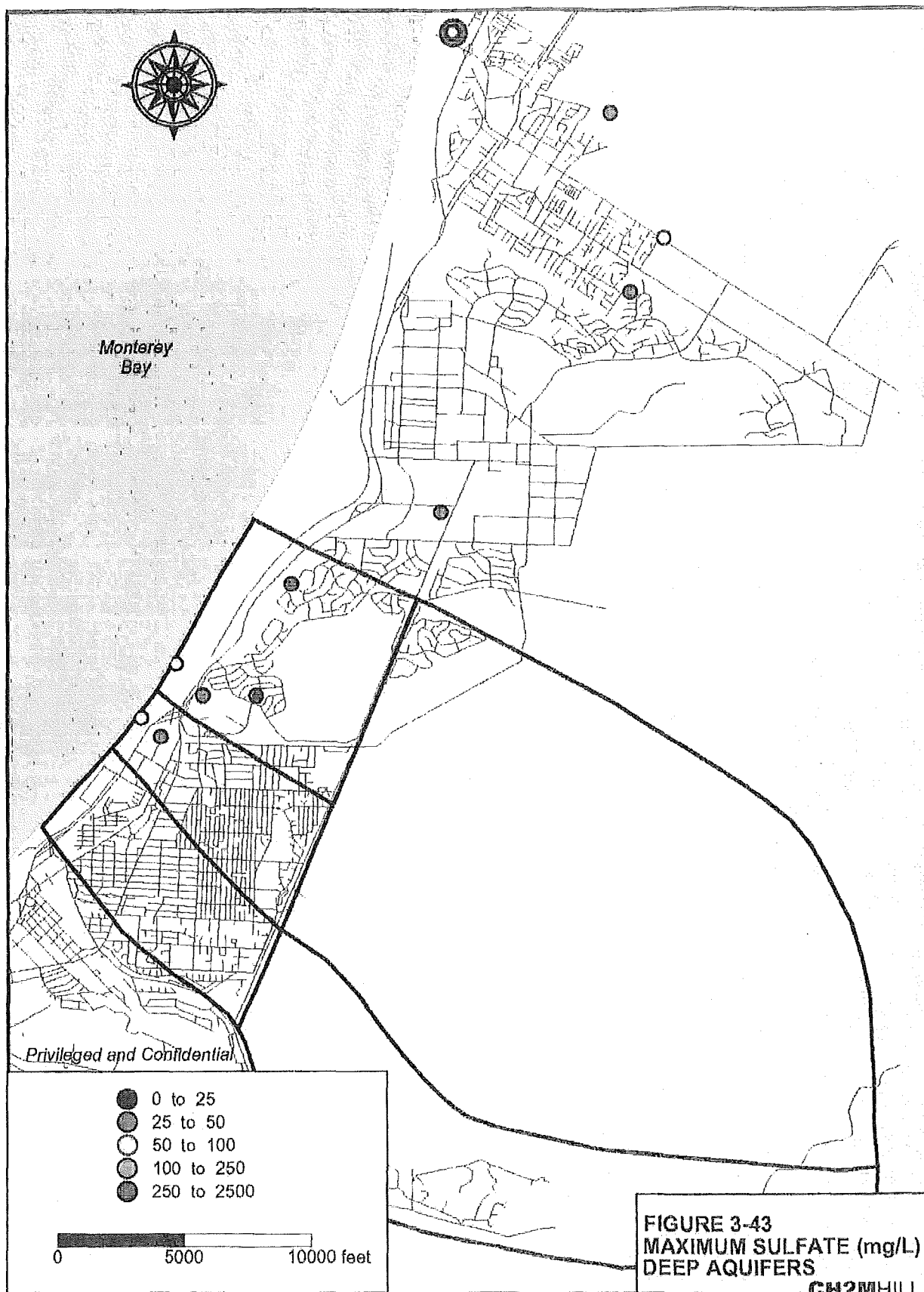


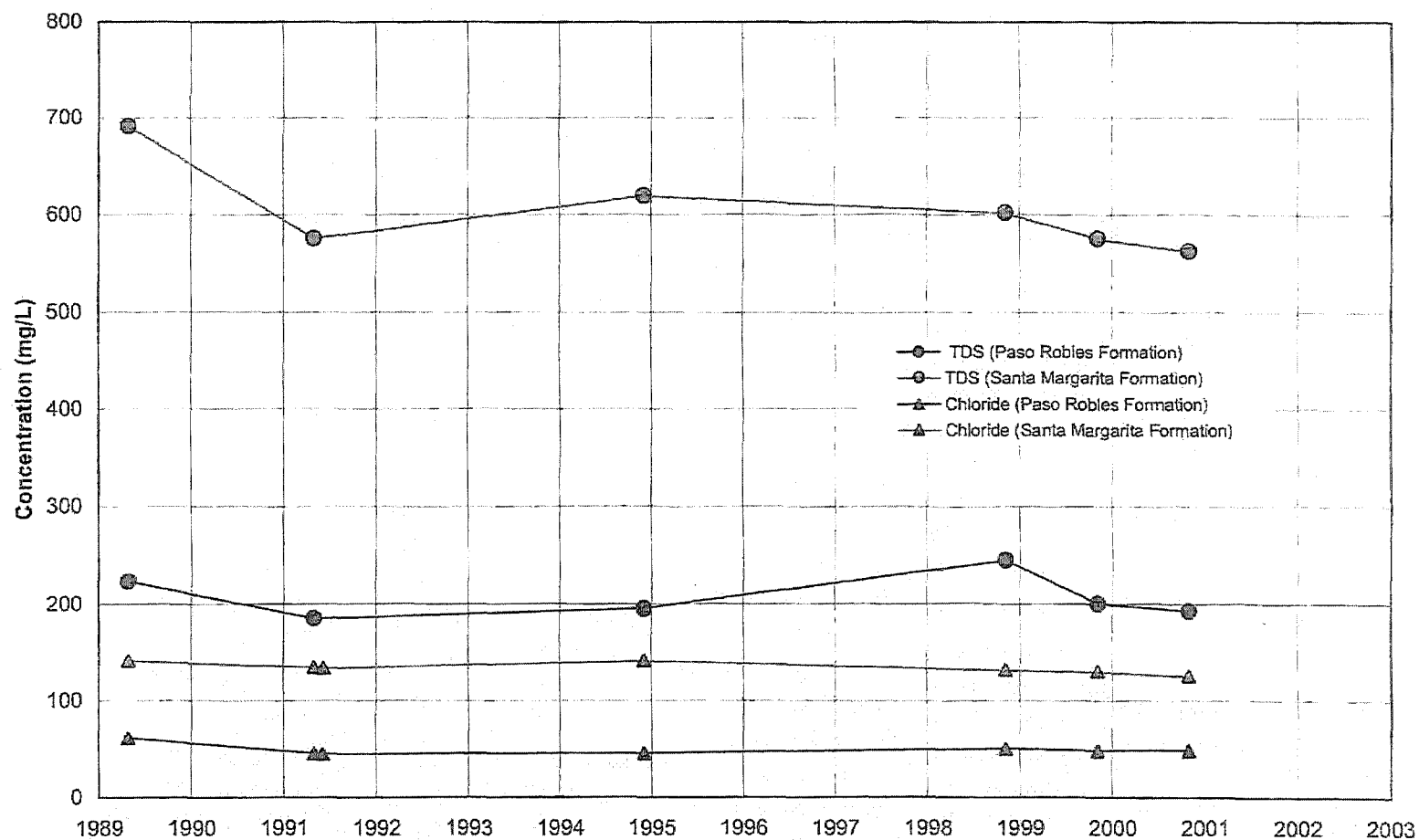








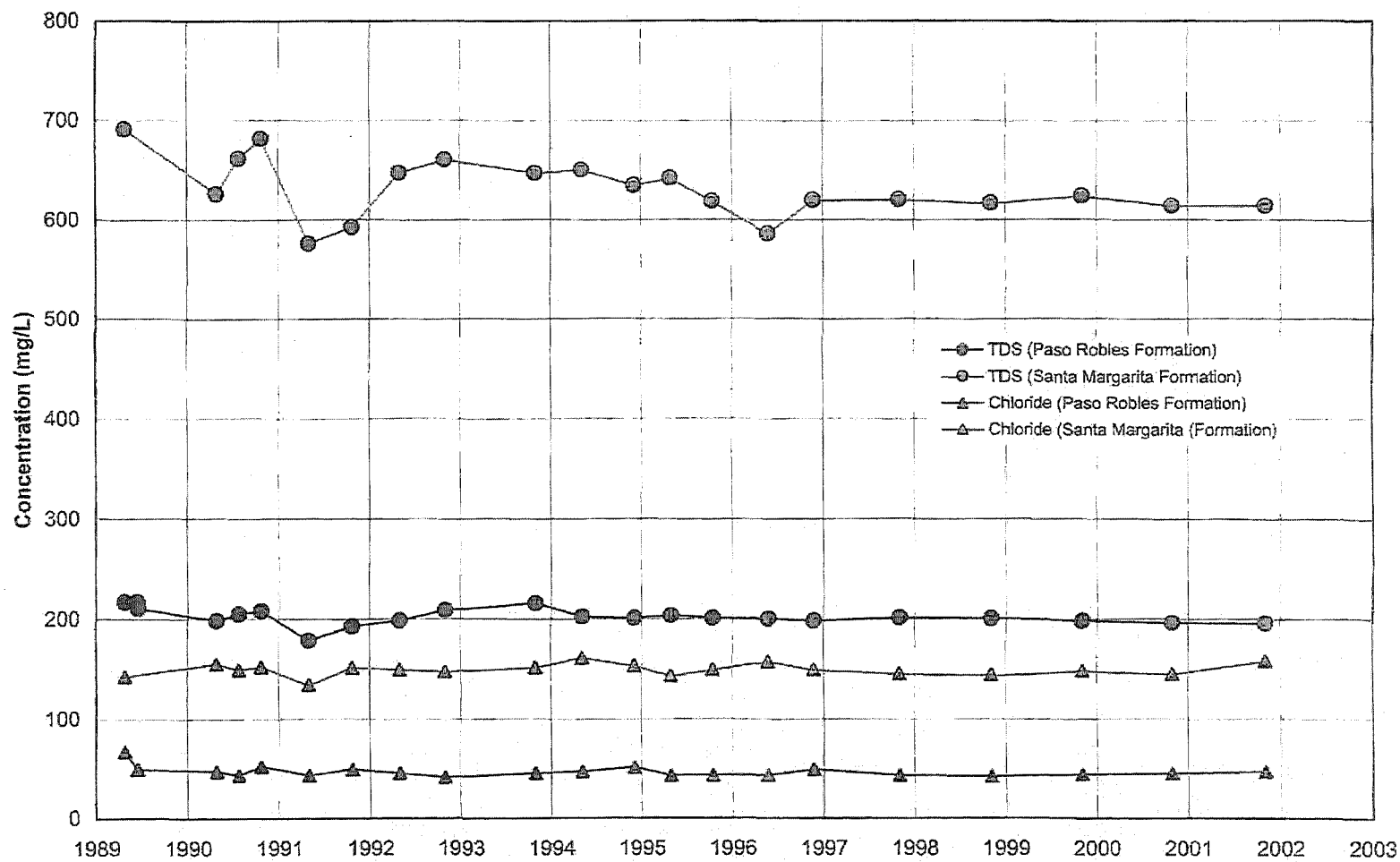




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FIGURE 3-44
PCA EAST MONITORING WELL
TOTAL DISSOLVED SOLIDS
AND CHLORIDE

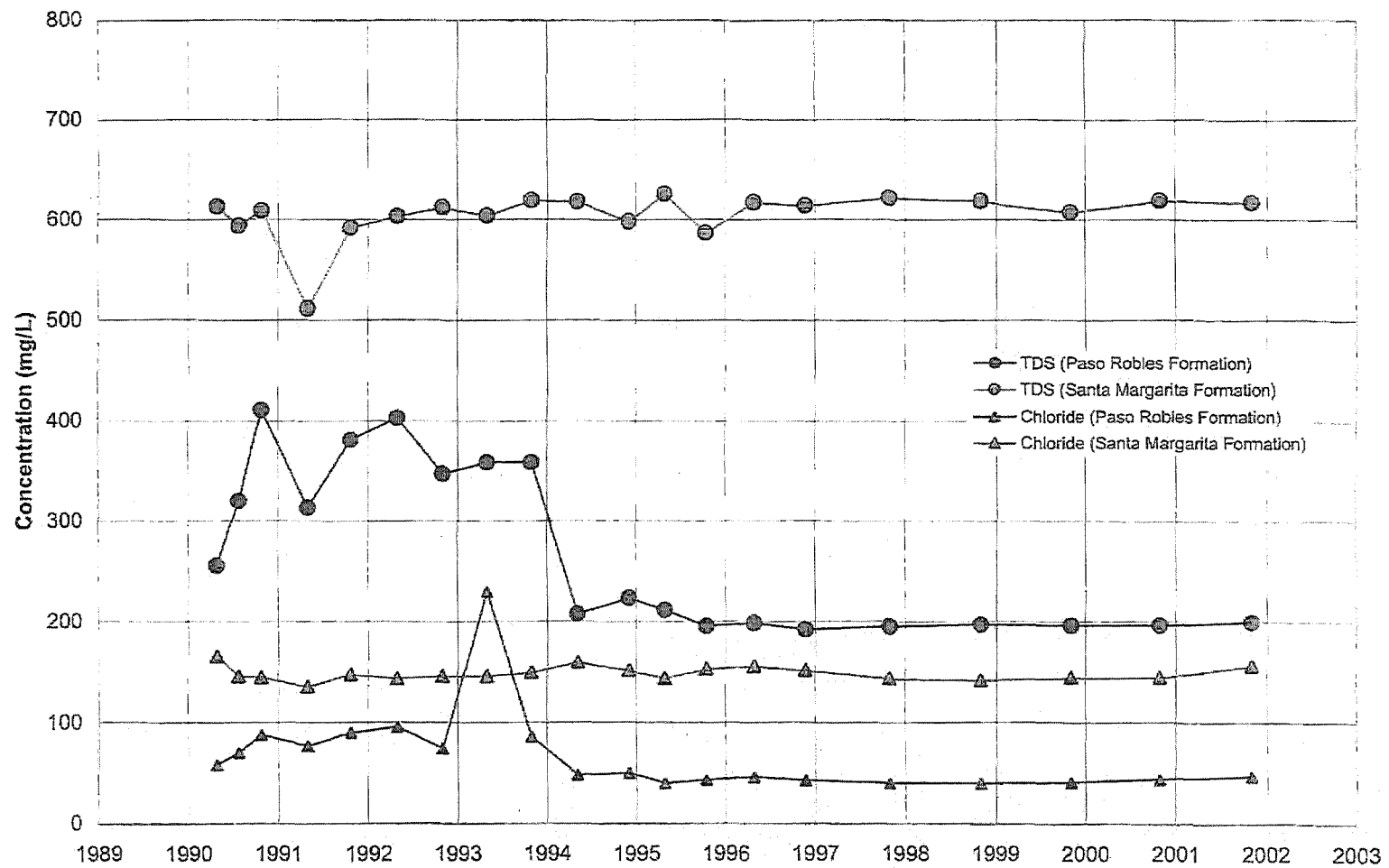
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**FIGURE 3-45
PCA WEST MONITORING WELL
TOTAL DISSOLVED SOLIDS
AND CHLORIDE**

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FIGURE 3-46
MSC MONITORING WELL
TOTAL DISSOLVED SOLIDS
AND CHLORIDE

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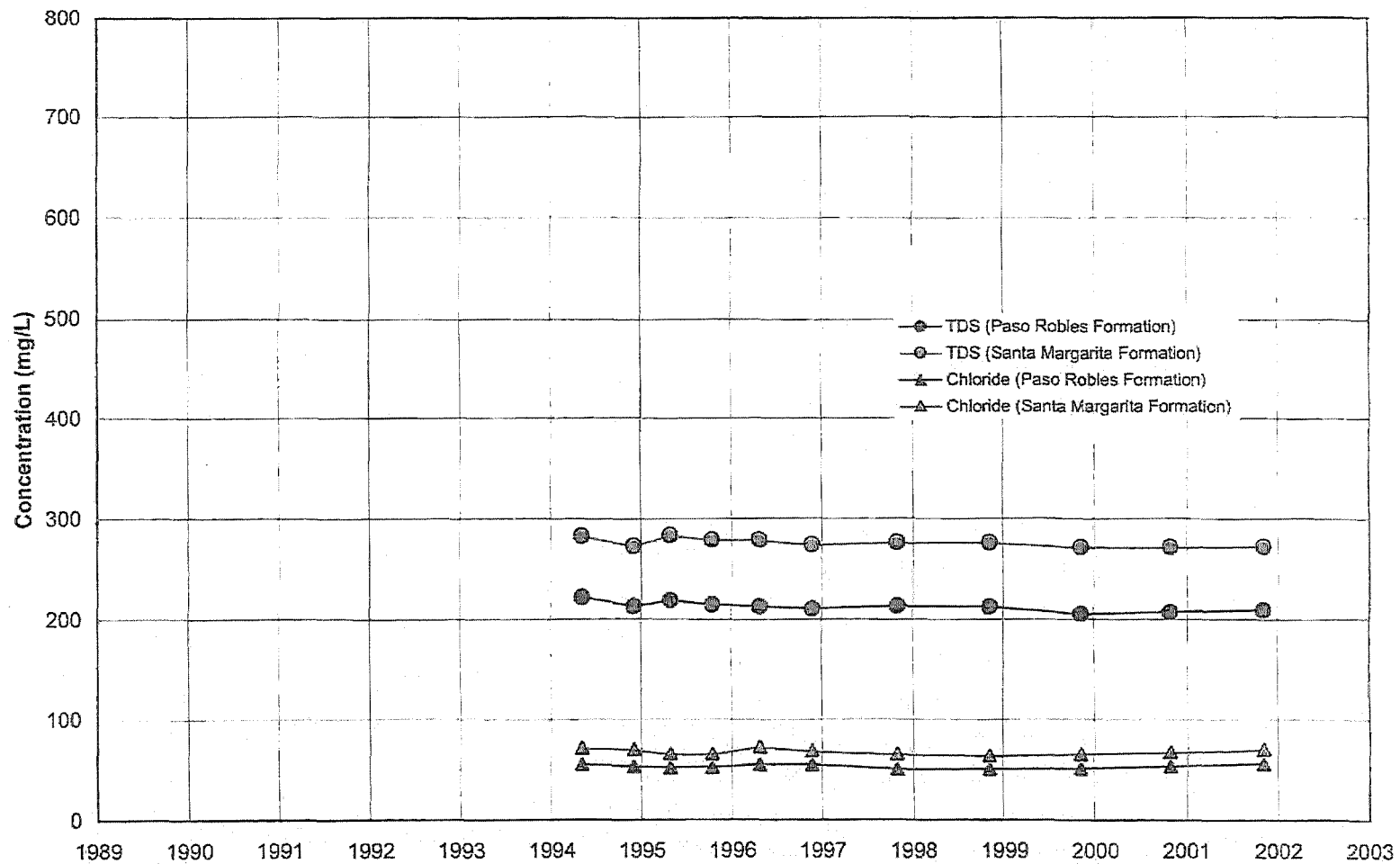


FIGURE 3-47
FO #9
TOTAL DISSOLVED SOLIDS
AND CHLORIDE

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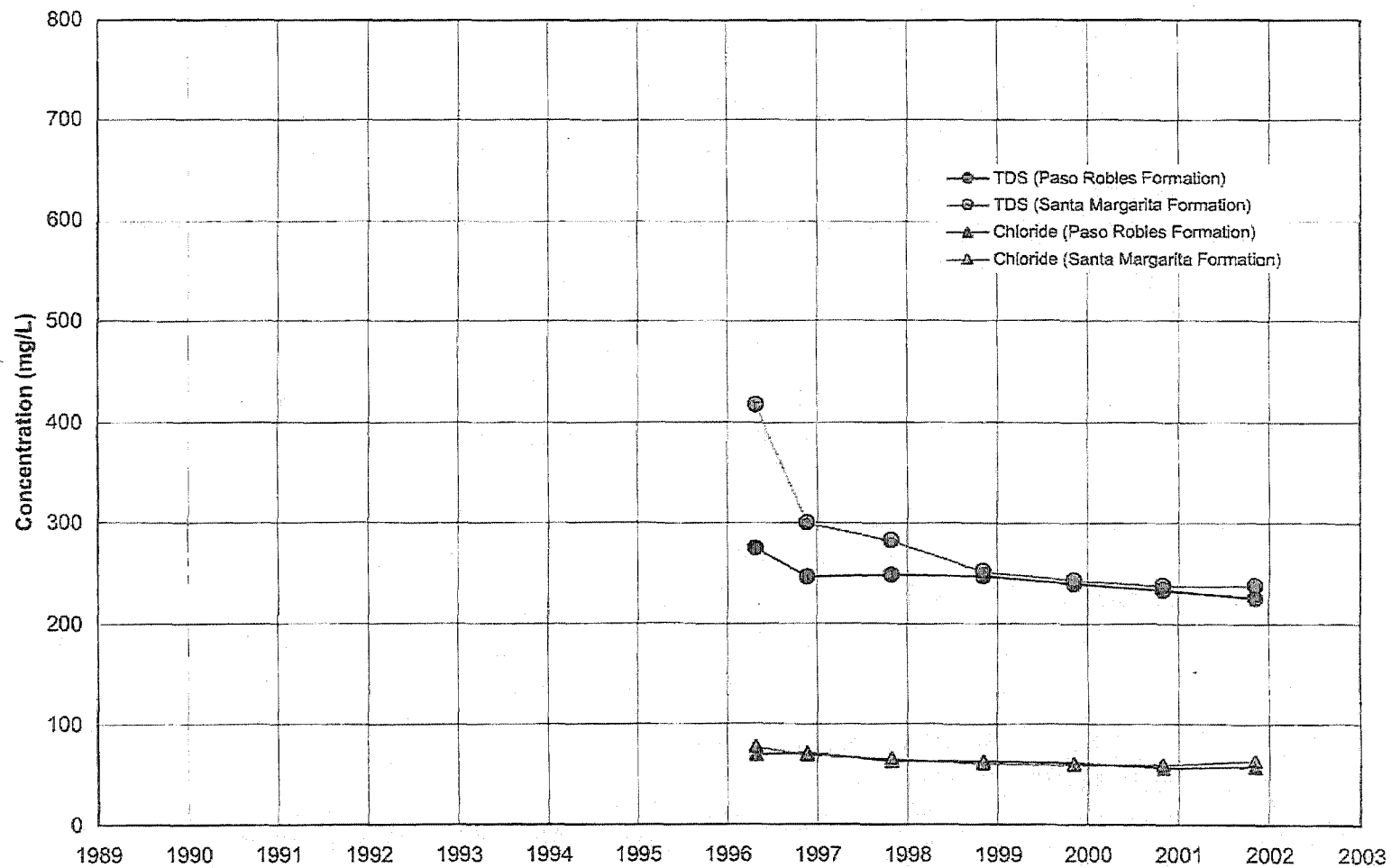


FIGURE 3-48
FO #10
TOTAL DISSOLVED SOLIDS
AND CHLORIDE

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4.0 Water Budget and Perennial Yield Analysis

A water budget was compiled for the Seaside Basin in order to quantify the primary sources of recharge to and discharge from the Basin. This analysis, coupled with information about the physical characteristics of the Seaside Basin, were utilized to develop an estimate of the perennial yield of the Basin for existing (current) conditions. The water budget and perennial yield analyses were also utilized to predict approximate changes in storage within the Seaside Basin for several scenarios representing incremental increases in groundwater withdrawal.

4.1 Definition of Water Budget

A water budget is a full accounting of all the sources of recharge to and discharge from a groundwater basin. This accounting is generally conducted for as long a period of time (i.e., "period of record") as practicable in order to evaluate variations in the water budget and to identify those components to which the basin is most sensitive. Some data are available via direct measurement (e.g., precipitation via rain gauge, or pan evaporation). Other data are more difficult to quantify, and require estimation via commonly used techniques and professional judgment. Each quantified component is then integrated, and when considered alongside information about the physical properties of a groundwater basin, they should lead to a predictable groundwater basin response (e.g., change in groundwater level) which accompanies temporal deficit or surplus conditions.

After verifying that the water budget approximates conditions within the groundwater basin for the period of record, the water budget can be utilized to quantify the basin's perennial yield, and current surplus or deficit. Each of these is discussed in greater detail below.

4.2 Methods of Calculation

Previous estimates of basin yield were based on the "practical rate of withdrawal" method. The practical rate of withdrawal method for estimating a water budget for, and the perennial yield of, a groundwater basin is discussed below. The current analysis utilized a full accounting method for estimating the water budget for the Seaside Basin (based on historical information - i.e., period of record), and ultimately for estimating the perennial yield of the Seaside Basin. Details for the current analysis are also provided below.

4.2.1 Practical Rate of Withdrawal

The majority of previous investigators estimated the yield of the Seaside Basin via the practical rate of withdrawal method. Estimates of yield based on these historical estimates vary amongst authors. The estimate is completed by identifying a period of stability in water levels (i.e., no change in groundwater basin storage), identifying as many other sources of recharge or discharge that can be quantified, and by making the assumption that the sum of those recharge and discharge components must equal zero (as predicated by the

no change in storage assumption). This is a useful method for evaluating the "bulk" yield of a basin without having to quantify individual components of recharge and discharge.

4.2.2 Full Accounting

A complete water budget for a groundwater basin should include a full accounting of all sources of recharge to or discharge from the basin, coupled with the ability to evaluate storage conditions through the use of groundwater elevation data. This full accounting should include an inventory and quantification of all recharge and discharge terms, as observed or estimated, for as long a period as possible. The full accounting method also requires an in-depth understanding of the geometry and physical characteristics of the groundwater basin. As described in Section 3.0, Hydrogeologic Setting, an extensive review of the physical characteristics of the Seaside Basin was conducted for this report. This information was used to determine total storage potential, usable storage, and dewatered storage (1963-2002) for the Seaside Basin. The physical properties of the Seaside Basin (primarily the aquifer storage coefficient) were integrated into the water budget, and allow expression of change in storage throughout the groundwater basin as a change in groundwater level elevation. The following sections describe the water budget analysis completed for the Seaside Basin.

4.3 Previous Water Budgets

Review of the documents described at the beginning of this study (Table 1-1) indicate that a full accounting of the primary components of discharge and recharge into the Seaside Basin was not completed in previous reports. Some components of a full accounting were provided, primarily as estimates for a recent period. Previous water budgets for the Seaside Basin appear to have utilized the practical rate of withdrawal method of estimation. Table 4-1 provides some previous estimates of Seaside Basin yield offered by other studies (Fugro 1997b). Estimates of perennial yield range from 2,000 to 4,375 afy.

TABLE 4-1
Previous Estimates of Seaside Groundwater Basin Yield

Author/Date	Yield Estimate (afy)
USGS 1982	2,000 - 3,000
Logan 1984	3,300 - 3,800
Staal, Gardner & Dunne 1987	3,475
Staal, Gardner & Dunne 1990	4,505
Fugro 1997b	4,375

Source: Fugro 1997b

4.4 Current Water Budget

CH2M HILL has completed a water budget for the period 1949-2002. This water budget sought to identify the primary sources of recharge to and discharge from the Seaside Basin

for that period. The following subsections summarize the nature of each source of recharge to or discharge from the Basin, as well as the observed or calculated range of values.

As previously described, the Seaside Basin is a relatively small, coastal groundwater basin. Several known hydrostratigraphic units are present at depth which provide water for agricultural, domestic, and municipal and industrial (M&I) uses through groundwater pumpage. The Seaside Basin has been subdivided by previous authors into five subareas: Fort Ord, North Coastal, South Coastal, North Inland, and Laguna Seca. Each of these subareas is defined by geologic or hydraulic boundaries, as mapped or inferred by previous authors. Some of these boundaries are static (e.g., Monterey Formation outcrops), while others are dynamic, and dependent on groundwater flow regimes which may vary temporally (e.g., the north boundary of the Basin). Recharge to, and discharge from, the Seaside Basin are controlled primarily by deep percolation of precipitation, underflow to and from the ocean at the coastal boundary, underflow across the northern boundary (see also previous discussions of this boundary in Section 3.1, Basin Boundary), and groundwater pumpage. Long- and short-term climatic conditions, superimposed on groundwater pumpage, drive storage conditions in the Basin, and underflow recharge to or discharge from the Seaside Basin is driven by this surplus or deficit (i.e., they are dependent on groundwater level elevations within the Basin).

4.4.1 Sources of Recharge

As previously described, the primary sources of recharge to the Seaside Basin include deep percolation of precipitation and underflow of groundwater into the Seaside Basin via the north and ocean boundaries. A lesser source of the water to the Seaside Basin is domestic (e.g., septic system) return flows. Total recharge to the Seaside Basin was estimated to range from 1,479 to 17,314 afy, and averaged 4,406 afy during the period 1949 through 2002 (including, in some periods, poor quality seawater) (Figure 4-1). Each of these sources of recharge to the Seaside Basin are described in greater detail below.

4.4.1.1 Deep Percolation of Precipitation

Deep percolation of precipitation water to the Seaside Basin was estimated on a monthly basis utilizing a soil moisture budget approach. The soil moisture budget is an accounting program that considers all sources and sinks of water to the soil profile on a monthly basis. This information, when combined with information about local crops, evaporation, soil types and soil runoff characteristics, allows calculation of deep percolation to the groundwater system resulting from precipitation on land surface. A full description of the soil moisture budget used for this analysis, as well as calculated values for the Seaside Basin, are provided in Appendix C.

Annual values of precipitation (including minimum, maximum, and average observed) were presented previously in this report. The yearly distribution of precipitation follows what is typical for coastal California, with the bulk of rainfall occurring between the months of October and April. Evaporation varies seasonally based on temperature and other climate characteristics; it is highest during the summer months, and lowest during winter months.

There are four Soil Conservation Service soil types (A, B, C, and D) which occur in the vicinity of the Seaside Basin (Figure 4-2). Each of these soil types has different percolation

and water storage capacities, as described further in Appendix C. Land use within the Seaside Basin is dominated by native vegetation, urban areas, and urban landscaping.

Each of these components was evaluated at monthly time-steps for the Seaside Basin. Deep percolation of precipitation based on the soil moisture budget ranged from 1,479 to 16,163 afy for the Seaside Basin, and averaged 3,778 afy (Figure 4-3).

4.4.1.2 Underflow In

The boundaries of the Seaside Basin on the east and south side of the Basin are defined by geologic structures which isolate the Basin from adjacent areas. Boundaries on the west and north are hydraulic in nature, and subject to variation based on conditions outside of and within the Basin (i.e., they are driven by water level variations). Because the western boundary of the Seaside Basin is the Pacific Ocean, there is a constant source of water available, and as such, water moves from the Seaside Basin to the ocean in times of surplus, and from the ocean to the Seaside Basin (i.e., seawater intrusion) during periods of Basin deficit. Groundwater flow across these boundaries to the Seaside Basin was a water budget calibration parameter, with some groundwater gradient information included for the purposes of bracketing (i.e., some years with sufficient data to calculate hydraulic gradients across the boundaries).

Landward flow of groundwater to the Seaside Basin across the western boundary was estimated to occur during the period 1988 through 2002. The estimated quantity for that period ranged from 104 to 1,353 afy, and averaged approximately 940 afy. Landward flow of groundwater across this boundary is the result of increased groundwater development in the Basin during this period.

Recharge to the Seaside Basin across the northern boundary of the Basin was estimated to occur during the periods 1971 through 1982 and 1991 through 1992. For those years, the range of estimated recharge was 377 to 2,696 afy, and averaged approximately 1,490 afy. Flow out of the Basin across the north boundary typically occurs when groundwater production in the vicinity of the MCWD is high and/or increased recharge to the North Inland subarea creates mounding of water levels near the boundary.

4.4.1.3 Domestic (Septic) Return Flows

The only other notable source of recharge to the Seaside Basin included domestic return flows (e.g., septic systems). It was assumed that 10 percent of domestic water use (not inclusive of municipal and industrial use) returned to the groundwater system via percolation. Recharge due to domestic return flows ranged from 0 to 29 afy, and averaged 16 afy.

4.4.2 Sources of Discharge

Sources of discharge from the Seaside Basin include groundwater pumpage and underflow out of the Basin across the north and west (ocean) boundaries. Discharge from the Seaside Basin during the period 1949 through 2002 was estimated to range from 2,669 to 9,344 afy, and averaged 5,259 afy (Figure 4-4).

4.4.2.1 Groundwater Extraction

The primary source of discharge from the Seaside Basin is groundwater pumpage for M&I, agricultural, and domestic use. Total groundwater extraction during the period 1949 through 2002 ranged from 0 to 5,690 afy, and averaged 2,960 afy. The majority of groundwater extraction is associated with M&I pumpage. Table 4-2 provides a summary of the types and quantities of pumpage for each of the listed categories.

TABLE 4-2
Summary of Groundwater Extraction, Seaside Groundwater Basin, 1948 through 2002

Extraction Category	Estimated Minimum (afy)	Estimated Maximum (afy)	Estimated Average (afy)
Municipal and Industrial	0	5,290	2,600
Agricultural	0	861	195
Domestic	0	290	160

4.4.2.2 Underflow Out

As previously described, the boundaries on the west and north side of the Seaside Basin are hydraulic in nature, and subject to variation based on conditions outside of and within the Basin (i.e., they are driven by water level variations). Because the western boundary of the Basin is the Pacific Ocean, there is a constant source of water available, and as such, water moves from the Basin to the ocean in times of surplus, and from the ocean to the Basin (i.e., seawater intrusion) during periods of Basin deficit. Groundwater flow across these boundaries to the Seaside Basin was a water budget calibration parameter, with some groundwater gradient information for the purposes of bracketing.

Discharge from the Seaside Basin across the western boundary (surplus conditions) was estimated to occur during the period 1949 through 1988. The estimated quantity for that period ranged from 108 to 2,700 afy, and averaged approximately 2,050 afy.

Discharge from the Seaside Basin across the northern boundary of the Basin was estimated to occur during the periods 1983 through 1990, and 1993 through 2002. For those years, the estimated range of discharge was 540 to 3,775 afy, and averaged approximately 2,700 afy.

4.4.3 Storage

The total storage capacity of the Seaside Basin represents the total pore space available for saturation in the alluvial portion of the Basin. Storage calculations are based on an estimate of: (1) the specific yield, and (2) the volume of the saturated sediments as determined from the alluvial area, alluvial thickness, and average depth to water. Previous estimates of storage for the Seaside Basin range from about 572,000 to 730,000 af (USGS 1982; SGD 1987b). These values were estimated assuming a specific yield of 12 percent.

For the current water budget analysis, groundwater storage capacity is based on an alluvial area of 14,000 acres, a specific yield of nine percent, and an estimate of saturated thickness. Saturated thickness was estimated for the beginning (1949) and end (2002) of the water budget analysis. Saturated thickness was calculated using observed water levels in the Paso

Robles Formation in 1963 and 2002 and the depth to the Monterey Formation as interpreted from well logs and previous investigations (Figures 3-15, 3-18, and 4-5). For the beginning of the water budget analysis period (1949), saturated thickness was estimated using observed water levels for 1963. Available water level data for years prior to 1963 are scarce and insufficient for constructing a reasonable water level map. In addition, 1963 represents a period of average rainfall and little or no groundwater use within the Seaside Basin. The total saturated storage within the Seaside Basin calculated for the beginning of the water budget analysis is approximately 484,000 af. Storage of the coastal subareas during this period is about 147,000 af. Observed water levels in the Paso Robles Formation for 2002 were used to estimate saturated thickness for the end of the water budget analysis. Total saturated storage of the Seaside Basin for this period is about 449,000 af. The coastal subareas total about 134,000 af for the same period. For comparison purposes, the storage estimates of previous investigators were re-calculated using a specific capacity of 9 percent. Using this value of specific yield, previous estimates of storage for the Seaside Basin range from about 429,000 to about 547,000 af.

Estimated groundwater in storage in the Seaside Basin has steadily declined, with a few minor rebounds from its starting condition of 484,000 af to the 2002 level of 439,000 af — a net depletion of 45,000 af. Figure 4-6 provides a time-series plot of annual change in storage in the Seaside Basin (based on the water budget), and Figure 4-7 provides a time-series plot of cumulative change in storage in the Seaside Basin for the period 1949 through 2002.

Changes in storage closely mimic climatic trends for early portions of the period of record, but track them less closely in later years as groundwater demand increases due to population growth and the associated rise in M&I demand.

Based on an estimated bulk specific yield of Seaside Basin sediments of 9 percent, groundwater storage conditions were translated into fluctuations in water level elevations at wells. The existing "Luxton" well was used as a basis for calibration of the water budget. Figure 4-8 provides a hydrograph of observed water level elevations at this well, along with predicted water level elevations based on storage conditions calculated by the water budget and an estimated value of bulk specific yield for Basin sediments.

4.5 Perennial Yield Analysis

In order to evaluate the sustainability of operations related to discharge or recharge of groundwater from a basin, it is important to identify that basin's perennial yield. The perennial yield is the annual quantity of groundwater that can be removed from the groundwater basin without creating adverse impacts such as land subsidence, seawater intrusion, and long-term declining groundwater levels. The perennial yield calculation is based on a "base period," typically defined by long-term climate trends. The base period represents long-term, average hydrologic conditions. Criteria for selection of a base period must include at least one period each of overall wet conditions and overall dry conditions (relative to average annual conditions) and have an average precipitation that is the same or very close to the average precipitation for the entire period of record. Furthermore, the beginning of the base period should be during a period of overall dry conditions to eliminate the potential for any "in-transit" recharge water that might otherwise not be reflected in storage condition changes. Finally, the base period should begin and end at the

same point on the cumulative departure from mean annual precipitation in order to represent the average precipitation over the base period. The base period selected for the Seaside Basin (1962 through 1989) satisfies these criteria reasonably well and it represents current cultural conditions in the Basin.

Perennial yield was also assessed using a long-term period which accounts for all the available data for the period of record (1949 to 2002). The long-term period does not adhere to the same set of criteria used to define the base period but provides another benchmark against which to estimate the potential long-term yield of the basin.

The perennial yield of the Seaside Basin was calculated several ways (as described below), each based on the assumption that 700 afy of discharge from the Seaside Basin to the Pacific Ocean at the western boundary was required to prevent seawater intrusion. This assumption was made based on estimates of transmissivity, hydraulic gradient, and the cross-sectional area of the water-bearing strata along the coastal boundary of the Basin. Perennial yield is summarized in Table 4-3 for the following scenarios: (1) perennial yield during the identified base period which best represents existing conditions; (2) perennial yield for the period of record (long-term); (3) perennial yield for the base period assuming an additional 20 percent more deep percolation of precipitation due to uncertainties in the soil moisture model, especially precipitation and evapotranspiration; and (4) perennial yield for the long-term period assuming 20 percent more deep percolation of precipitation. In addition to the four scenarios listed above, an alternative perennial yield is provided, which represents the potential yield of the Basin should subsurface flow from the North Inland subarea be captured instead of migrating northward out of the Basin as predicted by current water level maps (see Figures 3-16 and 3-18 through 3-20).

TABLE 4-3
Summary of Perennial Yield Estimates for the Seaside Groundwater Basin

Scenario	Perennial Yield, No Capture ¹ (afy)	Perennial Yield, w/Capture ¹ (afy)
Base Period (1962-1989)	2,913	3,472
Long-Term (1949-2002)	2,581	3,481
Base Period plus 20% more deep percolation of precipitation (1962-1989)	2,625	3,754
Long-Term plus 20% more deep percolation of precipitation (1949-2002)	2,673	4,051

Note:

¹ "Capture" signifies capture of subsurface flow from North Inland subarea, as opposed to this flow migrating northward out of the Seaside Basin.

4.5.1 Scenarios

In order to evaluate the impact of future pumping on the Seaside Basin, the water budget used for perennial yield analyses was extended ten years through the year 2012. Estimates of the future recharge and discharge components were made using the long-term average for each water budget component. Estimated storage conditions (reflected as water levels) resulting from ten additional years of pumping at various rates were predicted by changing theoretical net extraction from the Basin at a constant rate for this period. In a typical

analysis, these iterative adjustments are bound by the requirement that the levels of groundwater in storage in the Basin never drop below the historic low storage; however, storage conditions in the Basin are currently at the historic low (Figures 4-7 and 4-8). The four net extraction rates analyzed were 2,500 af, 3,000 af, 4,000 af, and 5,000 af of total pumping. Figures 4-9 through 4-12 indicate that additional groundwater extraction from the Basin for ten years into the future will result in a steady decline in water levels past the Basin's historic water level low, which may lead to adverse impacts in the Basin.

4.6 Perennial Yield Discussion

Groundwater conditions within the Seaside Basin were quantified using a water budget, and perennial yield was estimated for multiple scenarios based on that water budget and observed Basin conditions and operations. The water budget indicates that storage conditions in the Seaside Basin are driven by precipitation recharge and groundwater levels within the Basin, and that periods of both deficit and surplus have been observed in the recent past. The perennial yield analysis provides a benchmark for management of the Basin, and demonstrates that increased yield can be obtained by capturing all local groundwater, while maintaining a seaward groundwater gradient. Estimates of perennial yield developed during this investigation are in general agreement with those made in previous investigations (see Tables 4-1 and 4-3). A discussion of the perennial yield assessment with and without additional recharge is presented below.

4.6.1 Perennial Yield (No Additional Recharge)

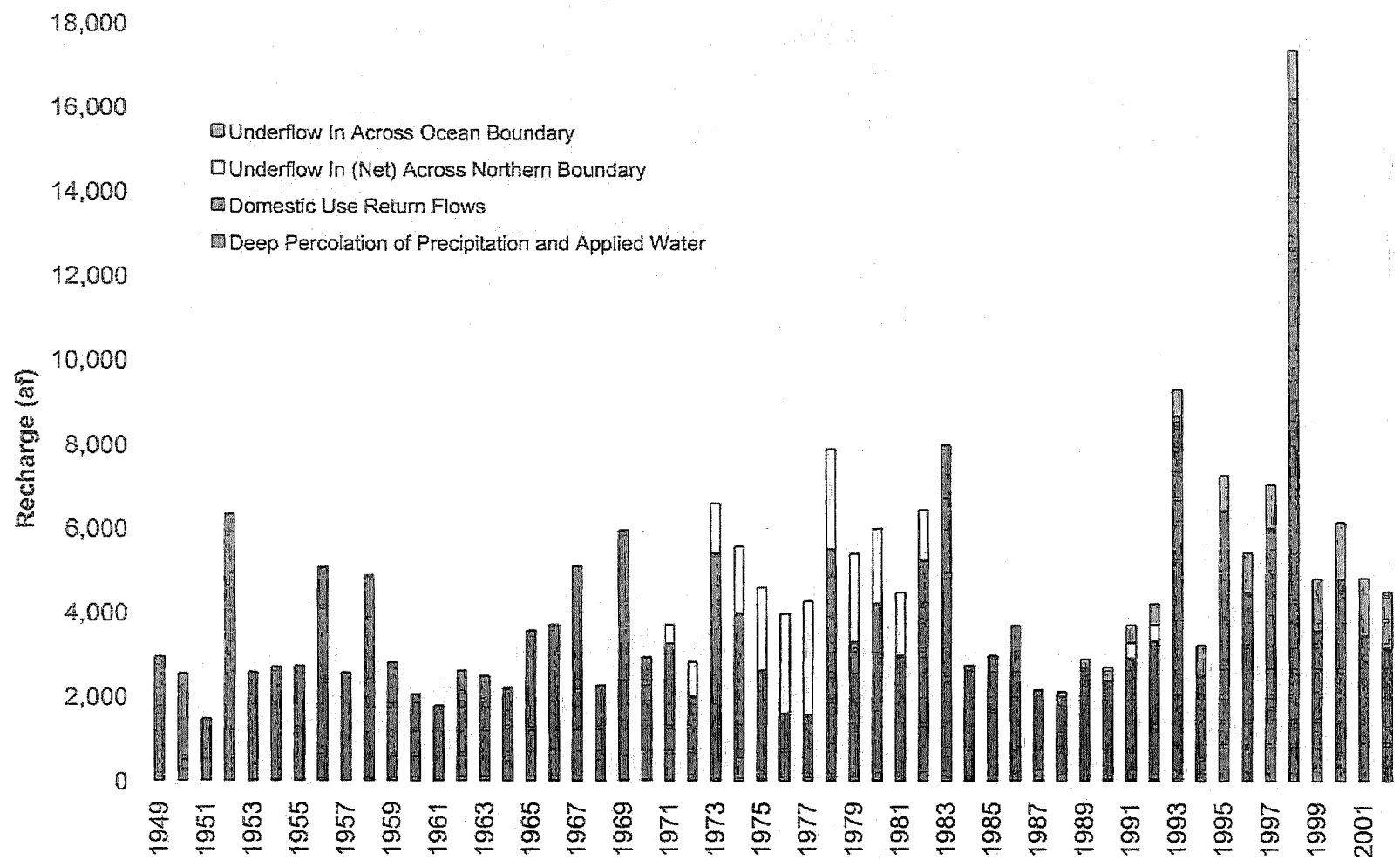
For reasons described above, the period that best represents conditions in the Seaside Basin is the existing conditions scenario for the base period 1962-1989. Results of the perennial yield assessments indicate that a net groundwater extraction of 2,913 afy over a similar climatic period could be sustained in the Seaside Basin without triggering an adverse impact (e.g., wells going dry or impacted by seawater intrusion). This perennial yield estimate could potentially increase to 3,472 afy if pumping operations are optimized to capture subsurface flow exiting the north boundary of the Basin. Perennial yield based on the long-term period, which incorporates all the data for the period of record, is 2,581 afy for existing conditions and 3,481 afy if production wells are positioned to capture subsurface flow exiting the north boundary of the Basin.

4.6.2 Perennial Yield (Additional 20 Percent Recharge)

Due to uncertainties in the soil moisture model, perennial yield was also estimated using an additional 20 percent deep percolation of precipitation for the same periods and scenarios described above. Results of perennial yield for the base period under existing conditions indicate that the net groundwater extraction that could be sustained in the Seaside Basin without triggering an adverse impact decreases to 2,625 afy. Results of this assessment suggest there is no net benefit of an additional 20 percent of recharge from deep percolation for this period. Because the North Inland area accounts for a large portion of the total recharge from deep percolation of precipitation, the groundwater gradient in the vicinity of the north boundary significantly increases under this scenario, which facilitates additional subsurface flow across the north boundary before reaching the coastal subareas and becoming recharge to wells. Similar to previous perennial yield assessments, the perennial

yield may potentially increase to 3,754 afy for this scenario if the subsurface flow exiting the north boundary of the Basin is captured.

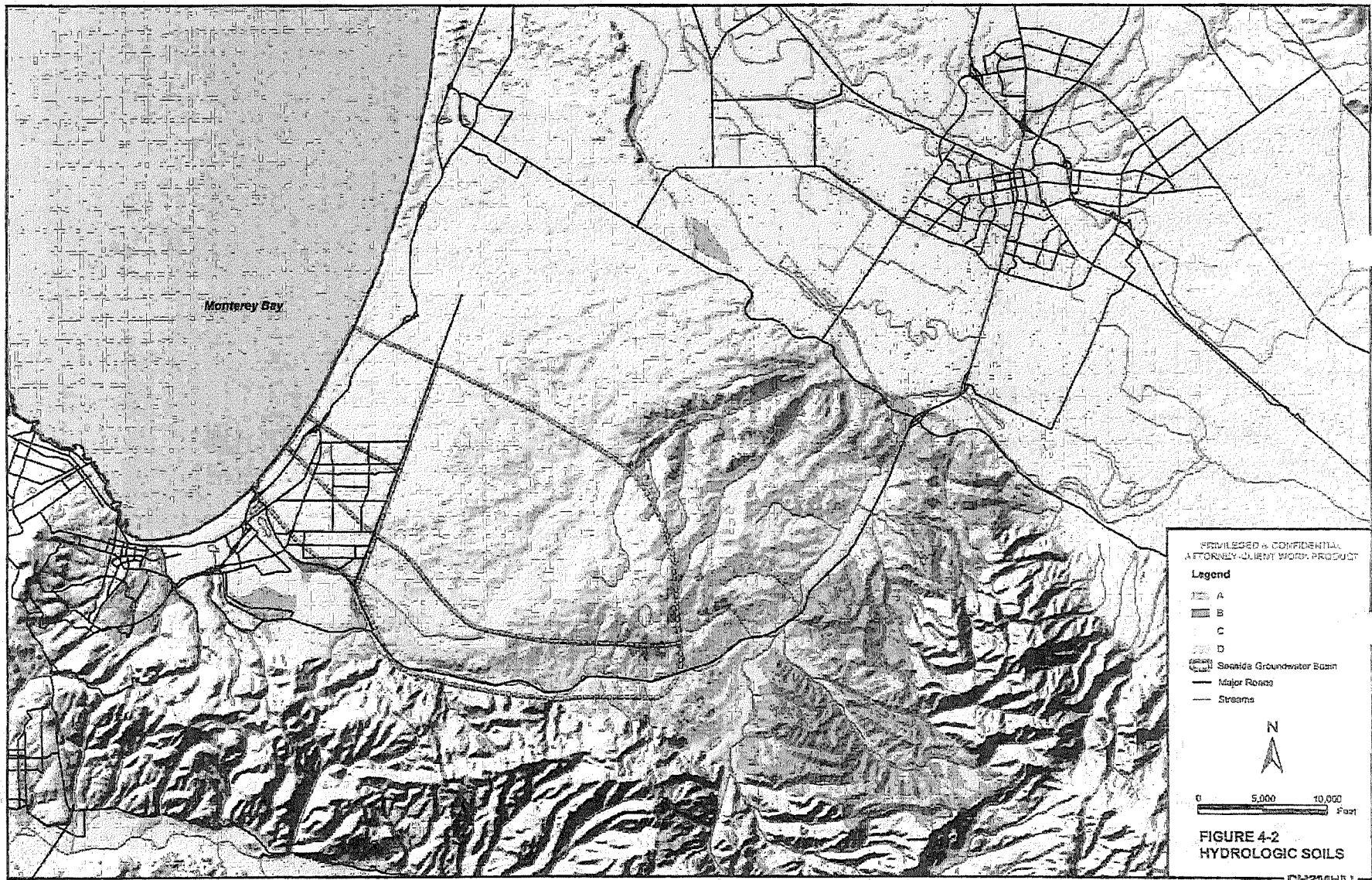
Current net groundwater extraction in the Seaside Basin is estimated to total approximately 4,800 afy, and was about 5,600 afy as recently as 1995 (Figures 4-13 and 4-14). This indicates that current extraction exceeds the perennial yield by as much as 40 percent for the base period. The disparity between the perennial yield estimate and current net groundwater extraction may decrease if subsurface flow exiting the Basin along the north boundary is captured. Because land use in the Seaside Basin is not expected to change dramatically, net groundwater extraction in excess of the perennial yield is expected to continue until an alternate source of water can be used in lieu of groundwater, and/or until pumping is reduced and additional flows in the North Inland subarea are captured before exiting through the north boundary of the Basin.



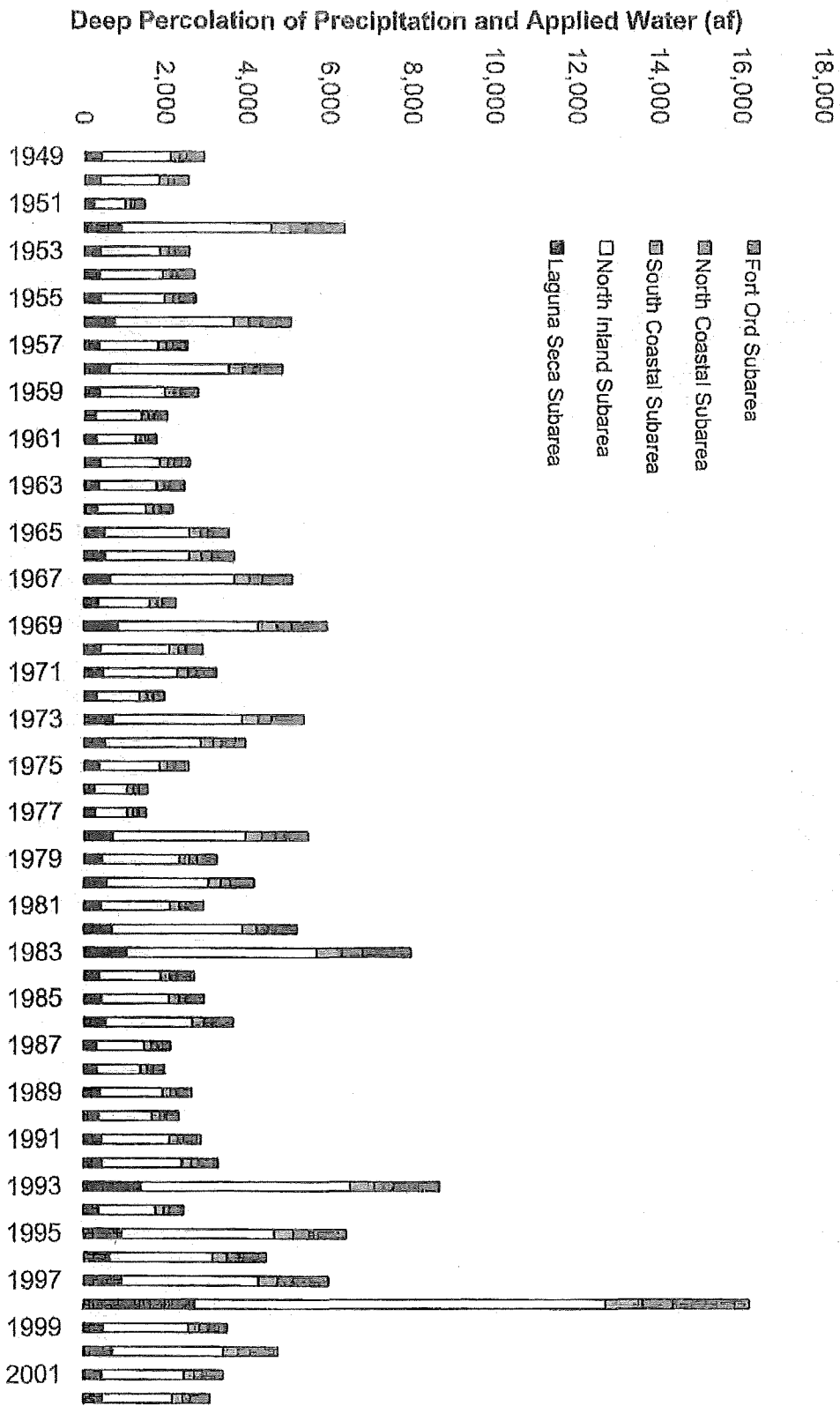
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FIGURE 4-1
SUMMARY OF
RECHARGE COMPONENTS

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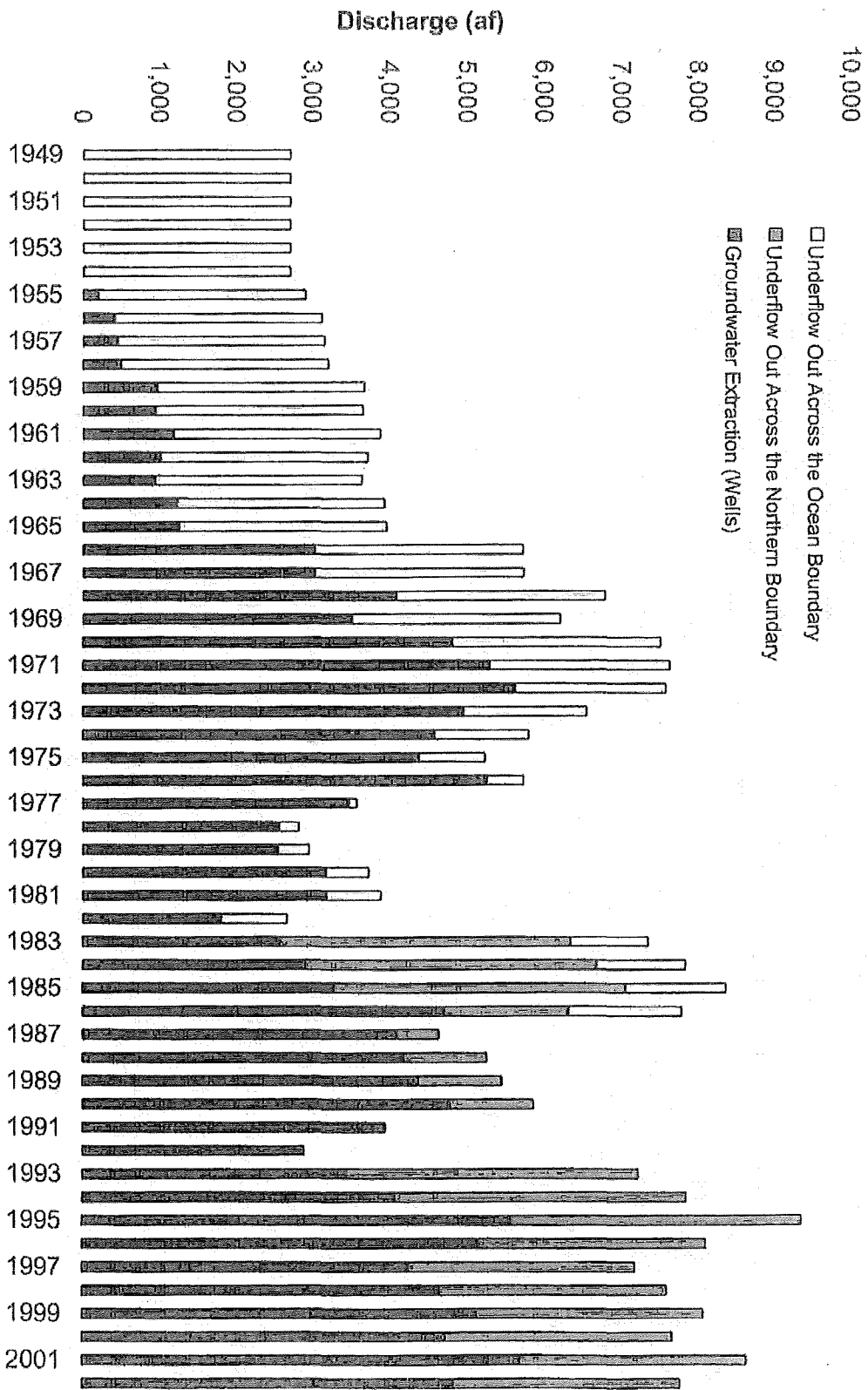


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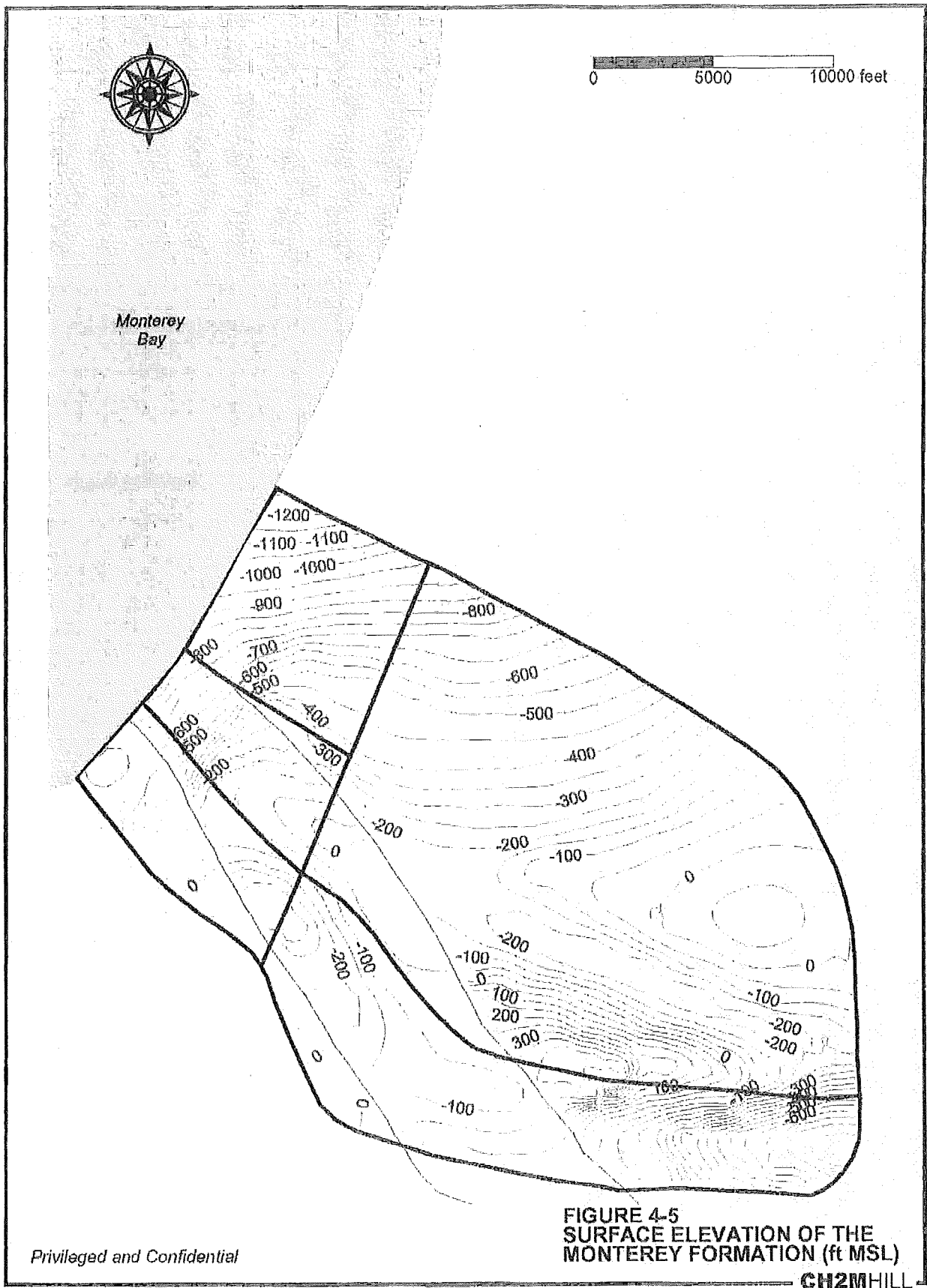
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**FIGURE 4-3
SUMMARY OF DEEP PERCOLATION
OF PRECIPITATION AND APPLIED
WATER BY SUBAREA**

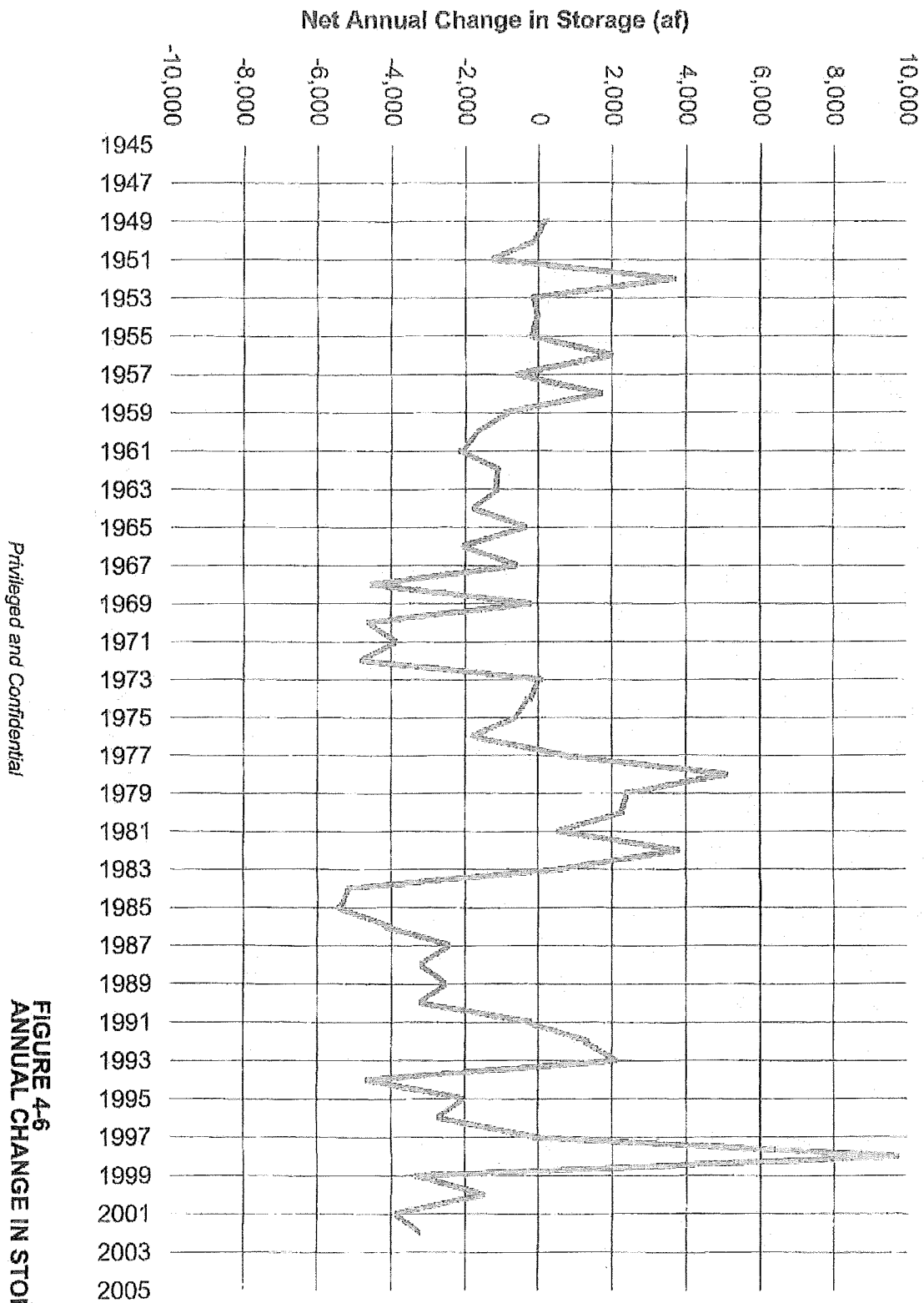


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FIGURE 4-4
SUMMARY OF DISCHARGE COMPONENTS



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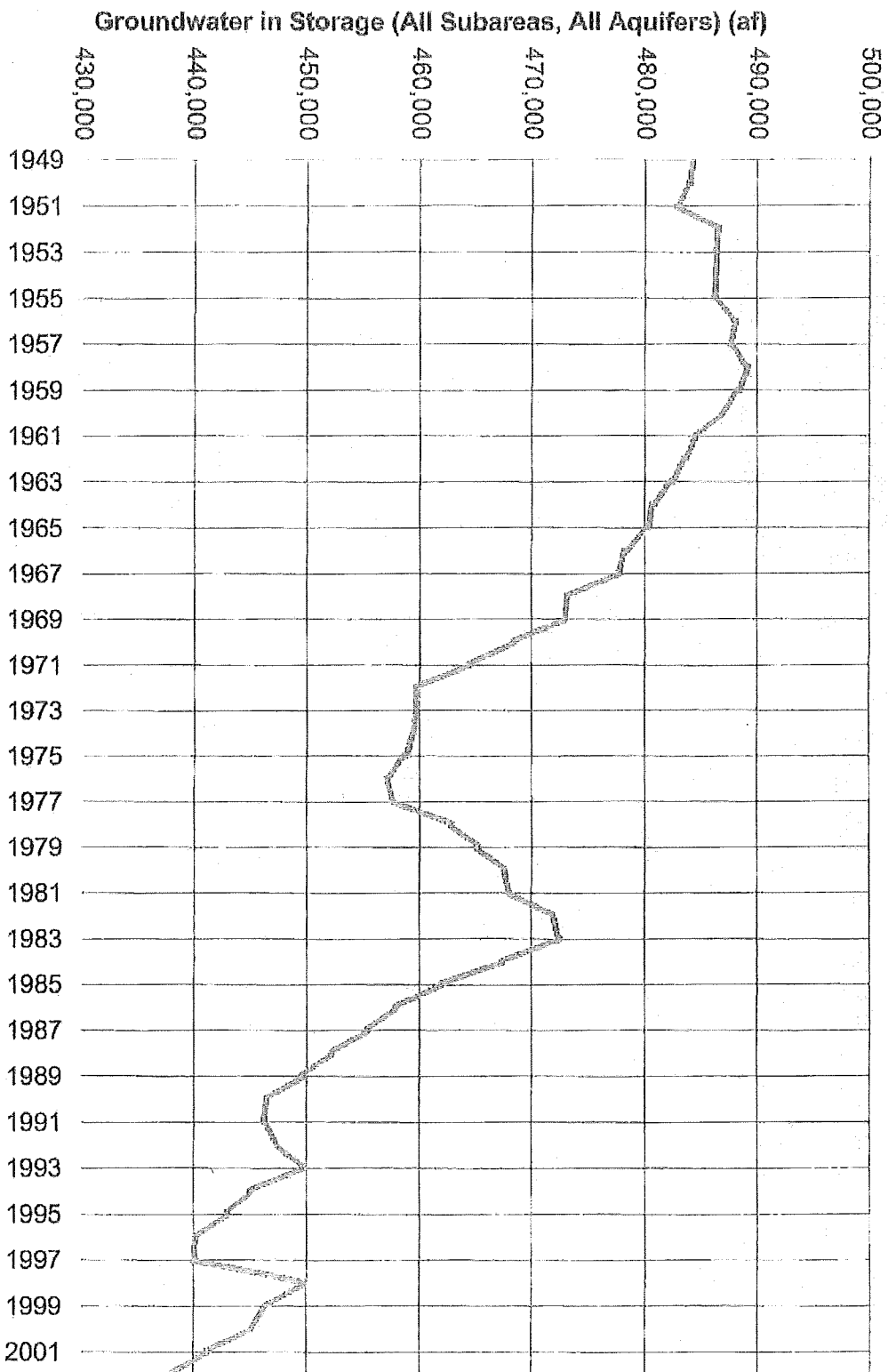


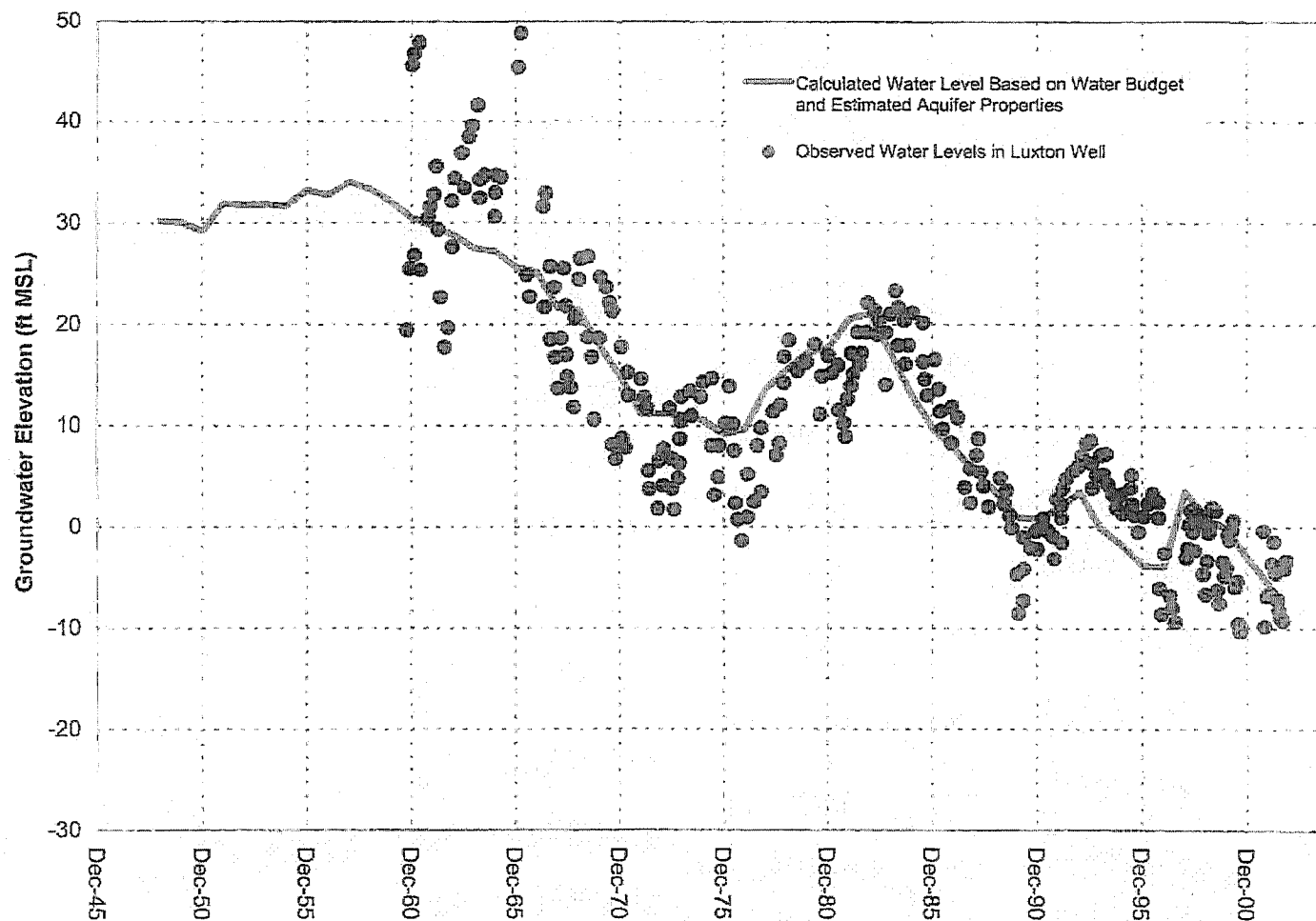
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FIGURE 4-6
ANNUAL CHANGE IN STORAGE

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FIGURE 4-7
CUMULATIVE CHANGE IN
GROUNDWATER IN STORAGE

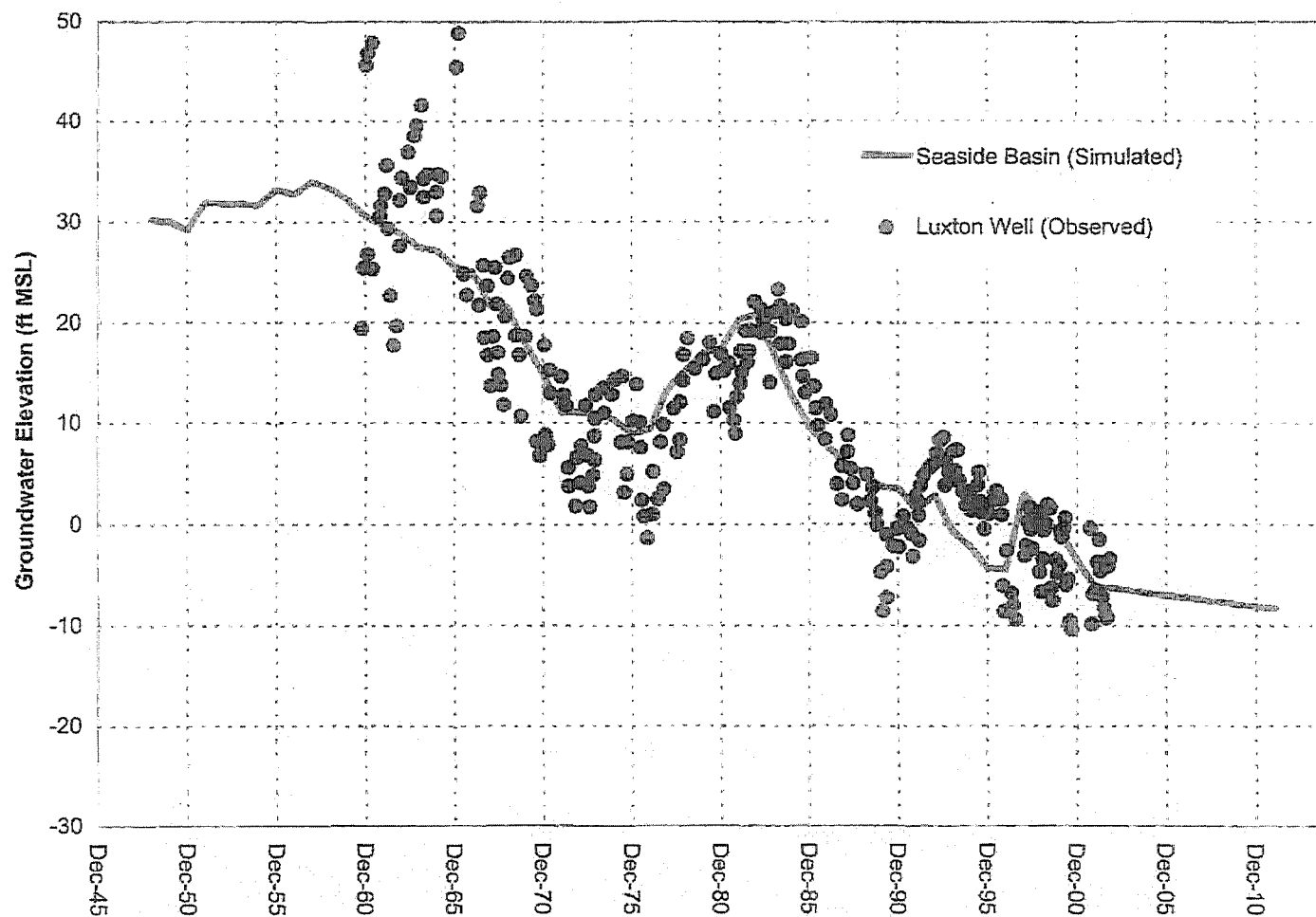




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**FIGURE 4-8
COMPARISON OF OBSERVED
AND CALCULATED WATER LEVELS**

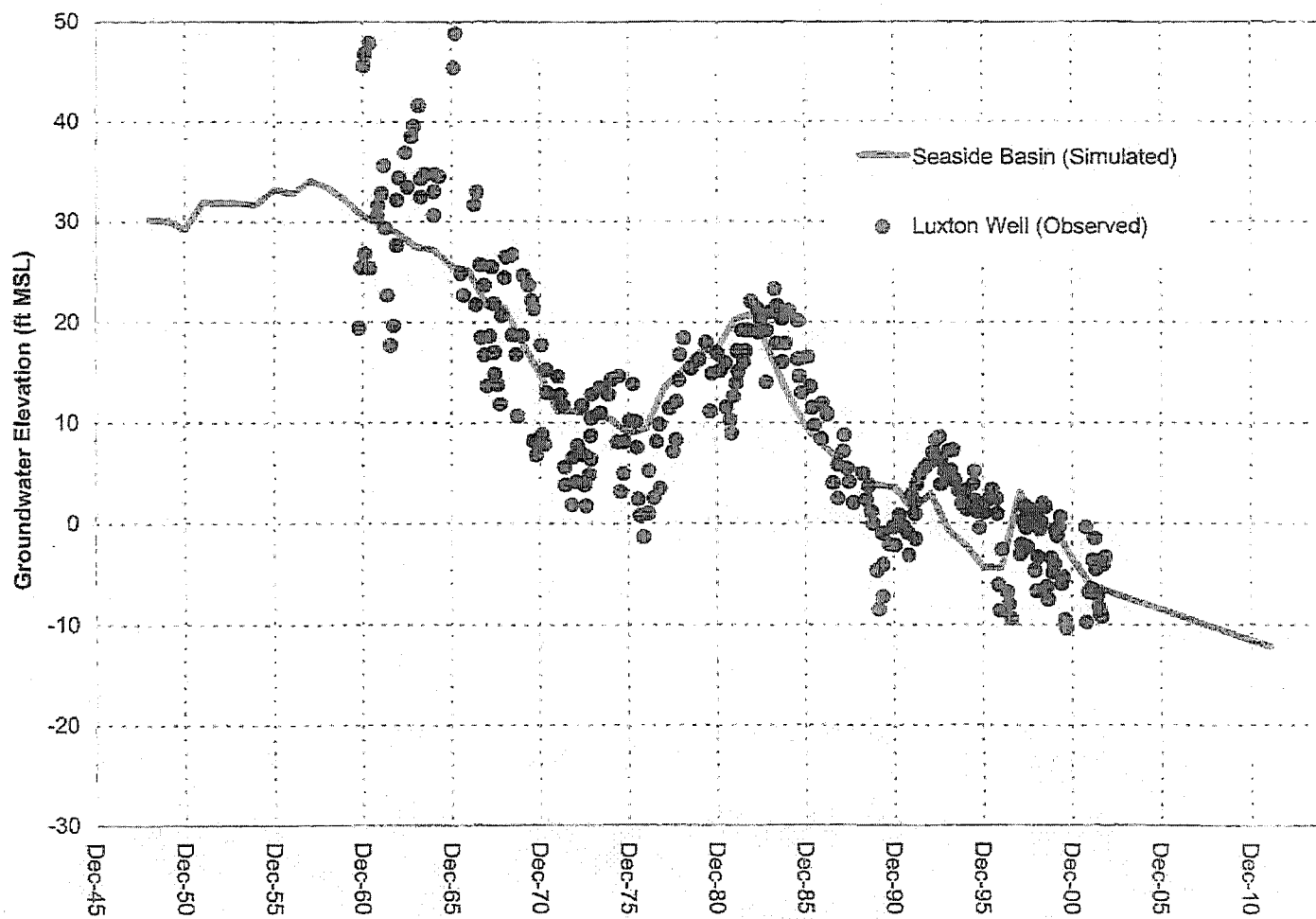
CH2MHILL



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FIGURE 4-9
FUTURE SCENARIO
2,500 afy

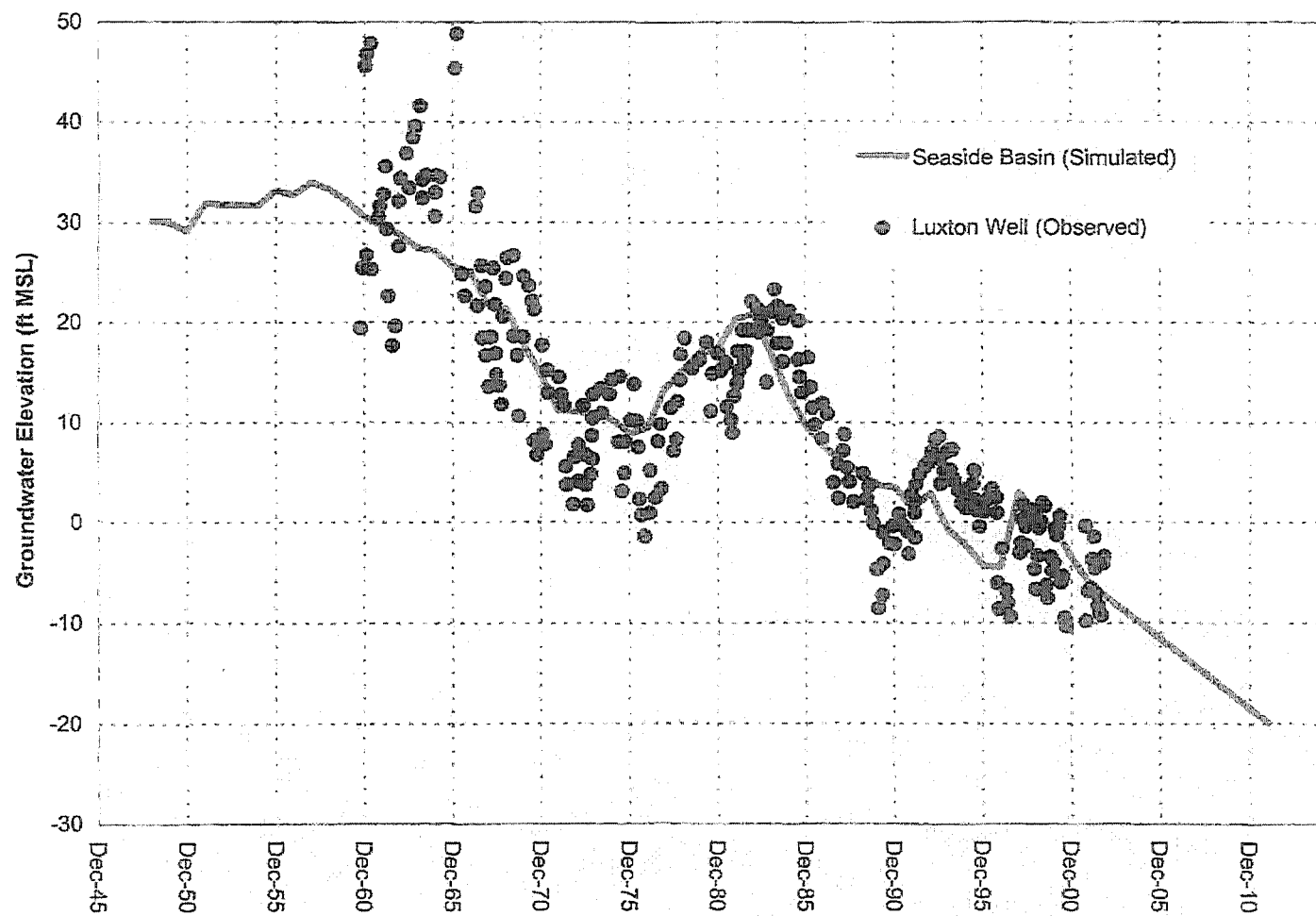
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FIGURE 4-10
FUTURE SCENARIO
3,000 afy

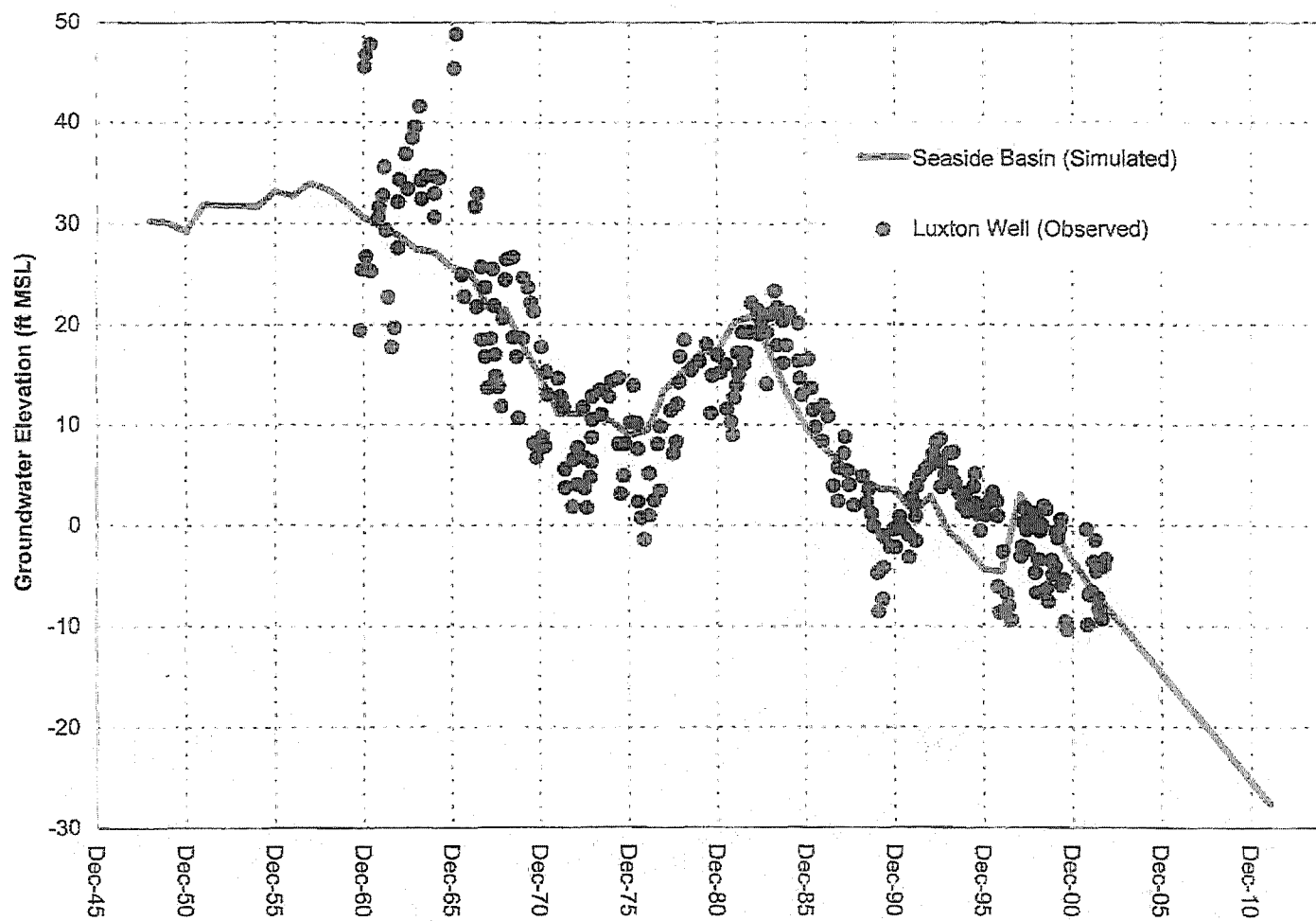
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FIGURE 4-11
FUTURE SCENARIO
4,000 afy

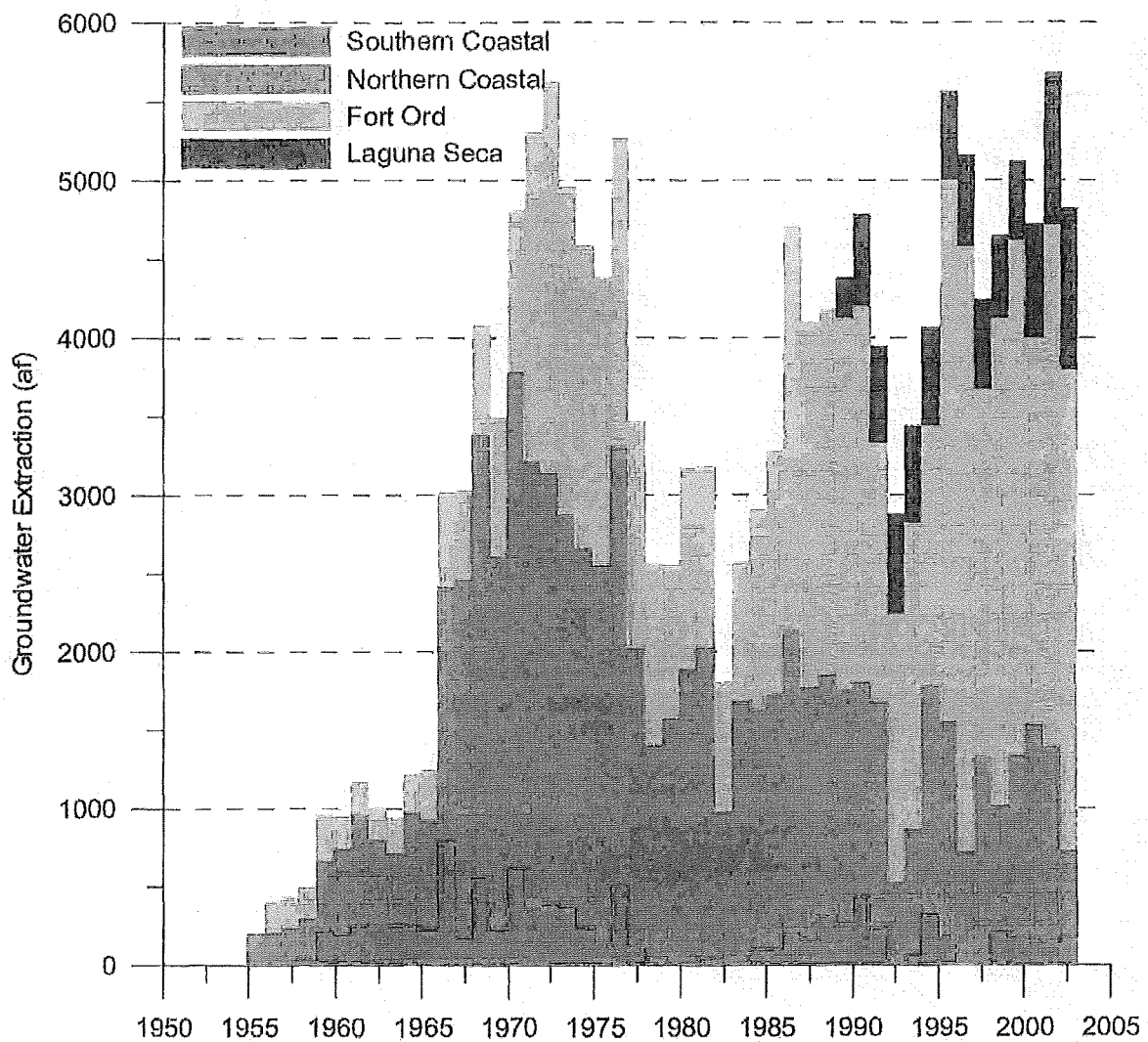
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FIGURE 4-12
FUTURE SCENARIO
5,000 afy

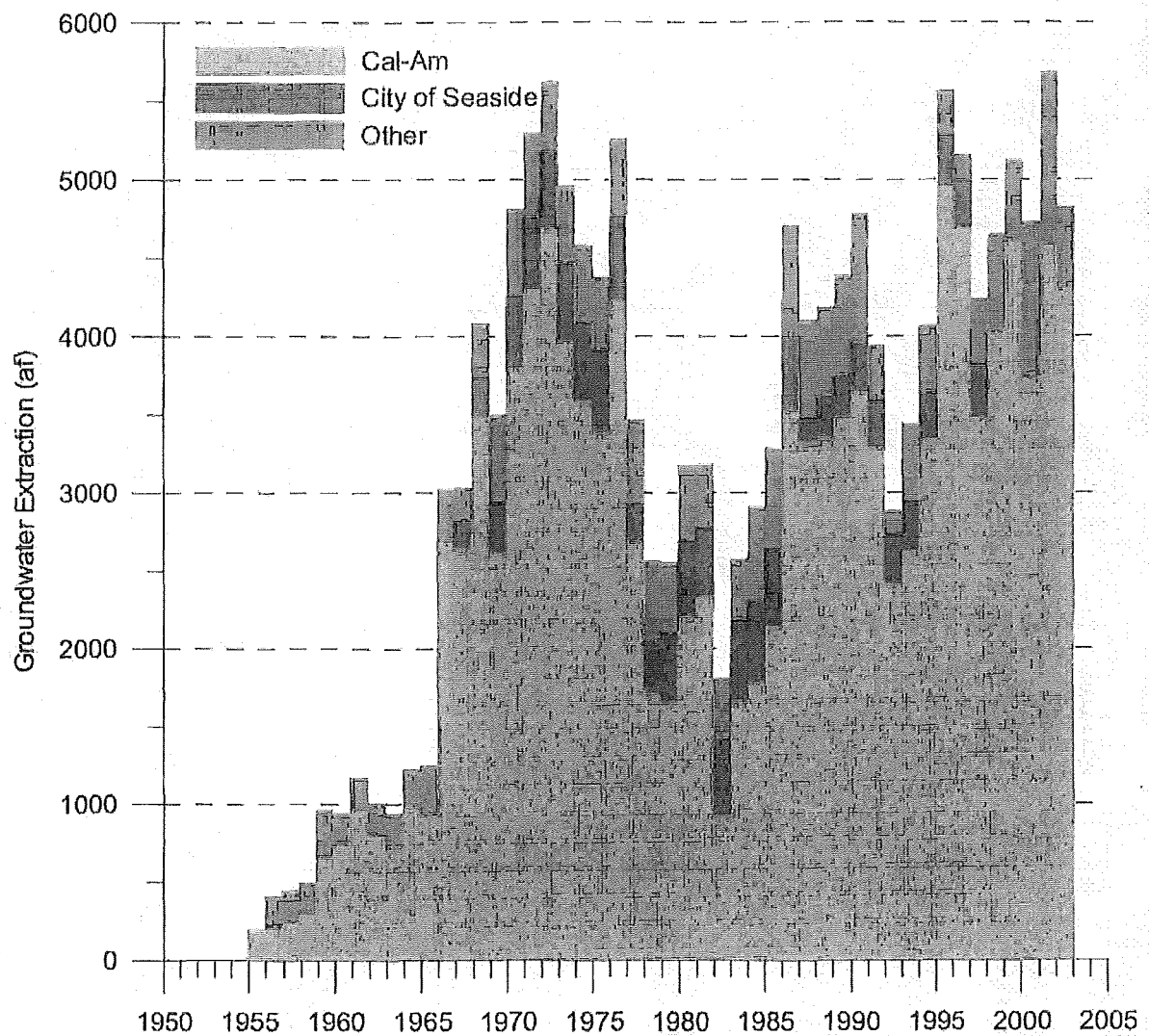
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**FIGURE 4-13
HISTORICAL GROUNDWATER
PUMPING BY SUBBASIN**

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**FIGURE 4-14
HISTORICAL PUMPING FOR
SEASIDE BASIN (BY OWNER)**

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CH2MHILL

5.0 Conclusions

Restricted water supply from the Carmel River, due to Board Order No. 95-10 issued by the SWRCB, has increased reliance on groundwater in the Seaside Basin to meet the current water supply demand of the communities. Current groundwater extraction in the Seaside Basin is estimated to total approximately 4,800 afy, and was about 5,600 afy as recently as 1995. Results of this study indicate that groundwater extraction in the Seaside Basin currently exceeds the estimated perennial yield by as much as 40 percent. Estimates of perennial yield calculated in this study range from 2,900 afy for existing conditions to 3,700 afy when estimated recharge is increased by 20 percent and additional subsurface flows in the North Inland area are captured. These estimates are based on water budget data available for a base period from 1962 to 1989 and are in general agreement with previous estimates of perennial yield made in earlier investigations.

Hydrographs for wells screened in the Paso Robles and Santa Margarita Formations show that water levels have reached historic lows, and in some cases are below sea level. The greatest impact from pumping is occurring in the Fort Ord and North Coastal subareas. Production from Cal-Am's Paralta well has had the greatest impact on water levels in the Fort Ord subarea and north of the Seaside Basin boundary as evidenced by recent hydrographs. The most pronounced impact from production of the Paralta well is in the confined Santa Margarita Formation. Response to Paralta's pumping north of the Basin boundary also suggests that this boundary is fluid and subject to change shape or migrate, which in turn will impact the Basin's perennial yield.

The most significant threat to the Seaside Basin while net extraction exceeds the perennial yield is induced landward migration of salt water into the freshwater aquifers underlying the Basin. Previous investigators have assumed that the aquifers in the Seaside Basin outcrop miles offshore; however, geologic maps used as part of this study indicate that the Aromas Sand and Paso Robles Formations outcrop immediately offshore from the Fort Ord and North Coastal subareas. Shallow aquifer subunits within these aquifers may therefore be in direct near-shore hydraulic communication with the Monterey Bay. Deeper subunits, such as the water-bearing strata present below the Seaside Clay in the Paso Robles Formation, may outcrop farther offshore, but are closer than assumed by previous investigators. Geologic mapping does not suggest that the Santa Margarita Formation outcrops offshore, and previous investigations have stated that the Formation likely pinches out near the Monterey Bay margin; however, installation of coastal monitoring wells indicates that the Santa Margarita Formation is still present at depth along the coast. Seawater intrusion has occurred extensively north of the Seaside Basin.

6.0 Recommendations

Currently, extraction from the Seaside Basin exceeds estimates of perennial yield developed as part of this study. Potential adverse impacts, such as seawater intrusion, may occur if the current rates of groundwater extraction continue in the Seaside Basin. Development of a supplemental supply to relieve over-production will take an estimated five to eight years according to Cal-Am. To protect and manage Seaside Basin's groundwater assets on a sustainable basis while supplemental supplies are pursued, the following are recommended:

1. **Maintain groundwater production from the Basin at the current rates and/or reduce production where and when appropriate.** Precipitation during much of the 1990s has been above average resulting in significant recharge to the Seaside area, and some stabilization in groundwater levels, especially in the Paso Robles Formation. In addition, the deeper portions of the Paso Robles and the Santa Margarita Formations are somewhat protected from seawater intrusion on a short-term basis due to the hydrogeologic conditions in the Seaside Basin. Therefore, current levels of groundwater production may be temporarily sustained in excess of the perennial yield, which will result in borrowing against future production. During this period, groundwater levels in the Basin should be monitored to assess storage conditions in the Basin. Groundwater may continue to be mined in the deeper aquifers (Santa Margarita and lower parts of the Paso Robles). Groundwater may also be withdrawn from storage in the shallower aquifers as long as an appropriate gradient toward the ocean is maintained. An annual assessment should be made to determine the extent to which pumping in excess of perennial yield can be sustained or if pumping patterns and rates should be modified in the following year based on then current groundwater storage conditions. Eventually, groundwater extraction from the Basin should be reduced to within the perennial yield.
2. **Develop a numerical groundwater flow model of the Seaside Basin and adjacent areas.** A calibrated groundwater flow model of the Basin can be used as a groundwater management tool to evaluate and optimize future operational scenarios that may optimize yield from the Seaside Basin and aid in the assessment of temporarily pumping in excess of perennial yield. Development of the groundwater model should occur within the next year so that various management scenarios can be evaluated more thoroughly as soon as possible.
3. **Evaluate the potential for redistributing pumpage to capture subsurface flow from the North Inland subarea that would otherwise exit the Basin across the northern boundary.** Consider installing several monitoring wells in the former Fort Ord Military Reservation to evaluate the hydrogeologic conditions beneath the North Inland subarea and the northern boundary. Water levels collected from these wells would be beneficial to understanding the gradient and direction of groundwater flow in the upland areas and the quantity and timing of subsurface flow available for recharge to downgradient wells. Evaluation of this option would also be dependent on available land access to the former Fort Ord Military Reservation and results of groundwater modeling.

4. **Perform additional studies to assess the lateral and vertical extent of the Santa Margarita Formation underlying the Seaside Basin.** This should include construction of several test wells in favorable portions of the Basin that may be used for pumping tests. If results of these studies indicate that conditions are favorable (i.e., reasonable aquifer properties and little or no potential for seawater intrusion), temporarily mining the Santa Margarita Formation may be considered as a short-term management option to increase yield as described above. Additional consideration includes evaluating the potential need for temporary treatment facilities to remove hydrogen sulfide in groundwater produced from the formation. Hydrogen sulfide is present in relatively high concentrations in the Santa Margarita Formation and groundwater from the Paralta well is currently treated to remove excess hydrogen sulfide. Groundwater modeling would also be used to assess the potential impacts of temporarily over-pumping the Formation.
5. Previous investigators have divided the Paso Robles Formation into two distinct water-bearing subunits, an upper unconfined unit and a lower confined unit separated by the Seaside Clay. **The lateral extent of these subunits and the Seaside Clay within the Fort Ord and Northern subareas should be investigated to evaluate the feasibility of installing production wells in only the lower confined unit.** Construction details of existing wells should also be reviewed to evaluate the potential for lowering pumps or installing packers to seal off screened zones in the shallow subunit. Production from the lower water-bearing subunit may temporarily reduce the risk of seawater intrusion to the Paso Robles Formation.
6. **Develop and implement a groundwater level and water quality monitoring program.** Development would include identifying existing monitoring wells that could be used in the monitoring network and installing an additional monitoring well cluster in the North Coastal subarea west of monitoring well FO9. A monitoring well cluster in this location would serve as a sentinel well for early detection of seawater intrusion and augment data collected from coastal monitoring wells PCA-East and PCA-West. Collection and evaluation of groundwater level data can also be used to assess the impacts of pumping in the Basin. This will be particularly important should the Santa Margarita Formation continue to be temporarily mined. Collection of water level data should occur on at least a quarterly basis. Water quality data would also be collected on a semi-annual basis to determine if seawater intrusion is occurring. It is recommended that the water quality analysis include chloride, boron, and bromide data used individually and/or as paired ratios to indicate seawater intrusion in a more sensitive fashion. The potential benefits of deuterium-oxygen and tritium isotopic sampling to assess the sources of groundwater should also be evaluated.
7. **Suitable wells in the Seaside Basin should be identified and retrofitted for aquifer storage and recovery operations.** In the event of a particularly wet period, any additional flows from the Carmel River may then be used for conjunctive use operations.
8. **A review of all water level and water quality data collected should be assessed on an annual basis to re-evaluate the Basin's perennial yield and update the groundwater model.** Decisions based on groundwater modeling may then dictate whether the

perennial yield could be expanded on a short-term basis to reflect favorable climatic changes or if pumping patterns and rates should be modified.

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Appendix A
Summary of Hydrogeologic Properties

TABLE A-1
Summary of Hydrogeologic Properties

Subbasin	Well	Date	Top Perf	Bot Perf	B	Q	s	T ¹	T ²	T ³	K	S	Source
Fort Ord	Paralta	1991	420	840	420	1,400	-	132,354	-	-	265	0.014	Fugro 1997b
	PCA	1966	200	632	432	600	40	-	27,000	30,000	63	-	SGD 1987b
	PCA	1990	200	632	432	500	65	9,100	-	15,385	21	-	SGD 1990a
Northern	City No. 1	1976	245	275	30	290	21.5	-	24,300	26,977	810	-	Logan 1982
	City No. 1	1977	245	275	30	290	8.5	-	61,400	68,235	2047	-	Logan 1982
	City No. 1	1977	245	275	30	305	19	-	28,900	32,105	963	-	Logan 1982
	City No. 1	1977	245	275	30	280	20	-	25,200	28,000	840	-	Logan 1982
	City No. 2	1977	-	-	-	260	17	-	27,500	30,588	-	-	Logan 1982
	City No. 2	1977	-	-	-	351	15	-	42,100	46,800	-	-	Logan 1982
	City No. 3	1974	340	540	200	910	65	-	25,200	28,000	126	-	Logan 1982
	City No. 3	1974	340	540	200	550	42	-	23,600	26,190	118	-	Logan 1982
	City No. 3	1976	340	540	200	580	32	-	32,600	36,250	163	-	Logan 1982
	City No. 3	1977	340	540	200	580	28	-	37,300	41,429	187	-	Logan 1982
	City No. 3	1977	340	540	200	580	37.5	-	27,800	30,933	139	-	Logan 1982
	City No. 3	1977	340	540	200	583	36.5	-	28,800	31,945	144	-	Logan 1982
	Darwin	1964	124	224	100	300	87	-	6,210	6,897	62	-	Logan 1982
	Harding	1957	141	225	84	135	78	-	3,114	3,462	37	-	SGD 1987b
	LaSalle 1	1955	150	236	86	550	103	-	9,600	10,680	112	-	SGD 1987b
	LaSalle 2	1959	178	326	148	175	66	-	4,770	5,303	32	-	Logan 1982
	LaSalle 2	1959	178	326	148	250	86	-	5,230	5,814	35	-	Logan 1982
	Luxton	1960	150	277	127	100	180	-	1,000	1,111	8	-	SGD 1987b
	Luzern	1966	212	266	54	1910	65	-	52,900	58,769	980	-	Logan 1982
	Military	1966	184	264	80	315	52	-	11,016	12,115	138	-	SGD 1987b
	Ord Grove	1968	353	478	125	1550	59	-	47,300	52,542	378	-	Logan 1982
	Ord Village	1982	205	707	502	450	13	-	15,500	69,231	31	-	SGD 1987b
	Playa #3	1967	188	218	30	580	98	-	10,656	11,837	355	-	SGD 1987b

TABLE A-1
Summary of Hydrogeologic Properties

Subbasin	Well	Date	Top Perf	Bot Perf	B	Q	s	T ¹	T ²	T ³	K	S	Source
Southern	Amador	1973	135	168	33	100	38	-	4,740	5,263	144	-	Logan 1982
	Elm	1968	-	-	-	160	34	-	8,280	9,412	-	-	SGD 1987b
	Harcourt	1967	-	-	-	110	120	-	1,656	1,833	-	-	SGD 1987b
	MGT	1954	187	307	120	63	18	-	6,300	7,000	53	-	SGD 1987b
	Monte	1966	32	80	48	20	19	-	1,890	2,105	39	-	SGD 1987b
	Orange	-	70	110	40	643	76	-	15,228	16,921	381	-	SGD 1987b
	Plumas 1	1958	120	276	156	610	79	-	13,900	15,443	89	-	Logan 1982
	Plumas 2	1958	105	275	170	140	27	-	9,330	10,370	55	-	Logan 1982
	Plumas 2	1958	105	275	170	315	60	-	9,450	10,500	56	-	Logan 1982
	Plumas 3	1961	109	283	174	290	80	-	6,512	7,250	37	-	SGD 1987b
Marina Coast	DMW1-4 ⁴	2001	930	950	20	-	-	48-40	-	-	2.4-2.0	-	USGS 2002
	DMW1-3 ⁴	2001	1040	1060	20	-	-	279-224	-	-	13.8-11.2	-	USGS 2002
	DMW1-2 ⁴	2001	1410	1430	20	-	-	152-124	-	-	7.6-6.2	-	USGS 2002
	DMW1-1 ⁴	2001	1820	1860	40	-	-	580-464	-	-	14.5-11.6	-	USGS 2002
	MCWD #12	-	-	-	240	-	-	29,700	-	-	16.5	-	Feeney and Rosenberg 2002
	MCWD #11	-	-	-	200	-	-	24,300	-	-	16.4	-	Feeney and Rosenberg 2002
	MCWD #10	-	-	-	210	-	-	40,000	-	-	25.4	-	Feeney and Rosenberg 2002
	MCWD #10 @842	-	-	-	-	-	-	-	-	-	4.6	-	Feeney and Rosenberg 2002
	MCWD #10 @1460	-	-	-	-	-	-	-	-	-	0.6	-	Feeney and Rosenberg 2002

Notes:

¹ Transmissivity calculated from Time/Drawdown Analysis² Transmissivity calculated using specific capacity (Logan 1982)³ Transmissivity calculated using specific capacity (Driscoll 1995)⁴ Transmissivity calculated from slug tests

B = thickness

Q = pumping rate

s = drawdown

T = transmissivity

K = hydraulic conductivity

S = storage coefficient

Appendix B
Summary of Water Quality Data

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top	Bttm.	Temp	pH	Conduc.	TDS	Sulfide	Ca	Na	Mg	K	Fe	Mn	HCO ₃	SO ₄	Cl	Silica	Boron	N (NO ₃)
		feet	feet	°C		umho/cm	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Calabrese ¹	01/29/93	-	150	22	6.9	1633	1047	0	132	127	41	8	0.1	<0.03	172	61	411	25	0.27	-
Darwin ¹	01/29/93	124	224	18	6.8	416	267	0	24	49	10	3	0.22	<0.03	78	24	72	19	0.38	-
Delmonte OW ¹	01/29/93	155	174	21	7	301	193	0	17	38	6	3	2.71	0.087	83	8.6	55	20	0.42	-
Fort Ord Golf Course ¹	01/29/93	160	208	-	7.2	429	275	0	29	51	8	2	0.11	<0.03	95	14	92	20	0.41	-
La Salle-2 ¹	01/29/93	178	326	16	6.9	845	542	0.08	72	94	18	5	0.16	0.035	249	67	140	22	0.27	-
Luzern ^{1,2}	01/29/93	212	266	24	6.9	833	534	0.03	72	96	22	5	0.44	0.038	248	57	139	21	0.3	-
	02/28/79			-	7.5	920	588	-	75	97	19	-	0.09	-	250	61	139	-	0.33	5.6
Military ¹	01/29/93	184	264	22	7.3	682	437	0	58	71	15	4	0.13	<0.03	169	71	113	21	0.46	-
Mission Mem. Pk. ¹	01/29/93	360	400	20	6.9	685	439	0	51	50	15	3	0.1	<0.03	243	22	43	21	0.52	-
Monterey Sand (Metz) ¹	01/29/93	400	710	28	7.2	1028	659	2.3	76	136	19	7	0.3	0.045	354	46	189	21	0.26	-
Ord grove-2 ^{1,2}	01/29/93	296	376	23	7	960	615	0.04	72	95	10	5	0.1	<0.03	253	71	141	22	0.31	-
	02/28/79			-	7.2	1000	640	-	87	97	21	-	0.06	-	293	84	133	-	0.3	1.6
Playa-3 ^{1,2}	01/29/93	188	218	18	6.9	860	551	0	61	95	18	5	0.13	0.031	168	81	153	21	0.55	-
	02/28/79			-	7.9	920	584	-	63	98	22	-	0.03	-	202	93	134	-	0.26	12.4
Plumas-3 ¹	01/29/93	105	288	19	6.7	482	309	0	12	62	11	2.3	0.6	<0.03	50	17	90	19	0.46	-
PCA Production ^{2,4}	09/25/80	200	632	-	-	380	243	-	-	-	-	-	-	-	-	-	56	-	-	-
	07/16/90	200	632	-	7.5	370	244	-	24	18	20	2.7	<0.05	<0.02	-	51	48	-	-	<0.1
Playa-4	12/17/92	385	580	20	7.2	1247	799	6.2	85	174	22	7	0.38	0.054	334	53	273	22	0.54	-
Playa-4	12/17/92	385	580	20	6.8	1258	806	6.2	89	175	22	8	0.2	0.053	327	49	279	21	0.57	-
Playa-4	12/17/92	385	580	22	6.9	1600	1026	-	86	174	22	7	0.31	0.056	324	47	279	22	0.57	-
Playa-4	12/17/92	530	580	16	7.3	1300	833	0.4	83	147	22	7	0.66	0.052	303	47	233	22	0.37	-
Playa-4 (530')	12/18/92	530	550	15	7.4	1130	724	0	69	139	20	-	0.42	0.034	303	43	173	22	0.31	-
Playa-4 (550')	12/18/92	550	580	19	7	1800	1154	3	124	192	29	8	1.38	0.105	303	59	413	22	0.55	-
FO #7 (shallow) ³	07/15/94	600	640	-	7.9	1692	1083	-	79	230	14	7.6	<0.1	<0.03	-	77	374	-	-	7

SFO\SEASIDE_HYDROGEO_ASSESS V2_LT.DOC

B-1

Privileged and Confidential Settlement Communication (Cal. Evidence Code §§ 1152 and 1154); Subject to Confidentiality Agreement Relating To The Settlement Negotiations For The Seaside Ground Water Basin Adjudication (Monterey Superior Court Case No. M66343).

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top	Btm.	Temp	pH	Conduc.	TDS	Sulfide	Ca	Na	Mg	K	Fe	Mn	HCO ₃	SO ₄	Cl	Silica	Boron	N (NO ₃)
		feet	feet	°C		umho/cm	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FO #7 (deep) ³	07/15/94	900	940	-	7.8	751	481	-	61	76	10	5.6	<0.1	0.19	-	34	99	-	-	2
FO #8 (shallow) ³	08/01/94	740	780	-	11.2	613	392	-	56	55	<1	6.9	<0.1	<0.03	-	57	64	-	-	3
FO #8 (deep) ³	08/01/94	900	940	-	7.9	797	510	-	59	87	11	5.7	<0.1	0.03	-	67	100	-	-	1
FO #9 (shallow) ³	08/19/94	610	650	-	9.5	315	202	-	12	57	4	5.8	0.31	<0.03	-	47	55	-	-	2
FO #9 (shallow) ³	05/03/95	610	650	-	8.4	348	223	-	23	34	4.0	3.6	<0.10	<0.30	-	19	56	-	-	<1.0
FO #9 (shallow) ³	11/30/95	610	650	-	8.4	334	214	-	23	35	4.0	3.7	<0.10	<0.03	-	12	54	-	-	<1.0
FO #9 (shallow) ³	04/25/96	610	650	-	7.9	343	220	-	22	33	4.0	3.7	<0.10	<0.03	-	11	53	-	-	<1.0
FO #9 (shallow) ³	10/11/96	610	650	-	7.8	336	215	-	22	35	4.0	4.0	<0.10	<0.03	-	13	53	-	-	<1.0
FO #9 (shallow) ³	04/21/97	610	650	-	6.9	333	213	-	22	35	4.0	3.7	<0.10	<0.03	-	13	56	-	-	<1.0
FO #9 (shallow) ³	11/19/97	610	650	-	8.0	330	211	-	23	33	5.0	3.7	<0.10	<0.03	-	13	56	-	-	<1.0
FO #9 (shallow) ³	10/27/98	610	650	-	7.4	334	214	-	23	36	4.0	3.9	<0.10	<0.03	-	16	51	-	-	<1.0
FO #9 (shallow) ³	11/02/99	610	650	-	8.1	333	213	-	21	32	4.0	3.6	<0.10	<0.03	-	13	51	-	-	<1.0
FO #9 (shallow) ³	11/02/00	610	650	-	8.1	322	206	-	22	34	4.0	3.7	<0.10	<0.03	-	12	52	-	-	<1.0
FO #9 (shallow) ³	10/25/01	610	650	-	8.1	325	208	-	23	40	4.0	3.6	<0.10	<0.03	-	12	54	-	-	<1.0
FO #9 (shallow) ³	11/01/02	610	650	-	8.1	328	210	-	21	30	4.0	2.9	<0.10	<0.03	-	13	57	-	-	<1.0
FO #9 (deep) ³	08/19/94	790	830	-	8.1	822	526	-	51	88	10	4.5	0.57	0.07	-	62	102	-	-	6
FO #9 (deep) ³	05/03/95	790	830	-	8.3	442	283	-	27	52	4.0	3.4	<0.10	<0.03	-	12	72	-	-	<1.0
FO #9 (deep) ³	11/30/95	790	830	-	8.3	427	273	-	27	51	4.0	3.6	0.30	<0.03	-	17	70	-	-	<1.0
FO #9 (deep) ³	04/25/96	790	830	-	8.0	443	284	-	25	51	4.0	3.5	0.63	<0.03	-	15	66	-	-	<1.0
FO #9 (deep) ³	10/11/96	790	830	-	7.7	436	279	-	27	53	4.0	3.9	0.29	<0.03	-	13	66	-	-	<1.0
FO #9 (deep) ³	04/21/97	790	830	-	7.3	436	279	-	26	51	4.0	3.5	0.19	<0.03	-	15	73	-	-	<1.0
FO #9 (deep) ³	11/19/97	790	830	-	8.0	429	275	-	28	50	4.0	3.6	<0.10	<0.03	-	15	69	-	-	<1.0
FO #9 (deep) ³	10/27/98	790	830	-	7.4	432	276	-	27	49	4.0	3.6	<0.10	<0.03	-	16	66	-	-	<1.0
FO #9 (deep) ³	11/02/99	790	830	-	8.2	432	276	-	26	50	4.0	3.5	<0.10	<0.03	-	14	64	-	-	<1.0

SFO/SEASIDE_HYDROGEO_ASSESS V2_LT.DOC

B-2

Privileged and Confidential Settlement Communication (Cal. Evidence Code §§ 1152 and 1154); Subject to Confidentiality Agreement Relating To The Settlement Negotiations For The Seaside Ground Water Basin Adjudication (Monterey Superior Court Case No. M56343).

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top	Bttm.	Temp	pH	Conduc.	TDS	Sulfide	Ca	Na	Mg	K	Fe	Mn	HCO ₃	SO ₄	Cl	Silica	Boron	N (NO ₃)
		feet	feet	°C		umho/cm	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FO #9 (deep) ³	11/02/00	790	830	-	8.1	425	272	-	26	50	4.0	3.5	<0.10	<0.03	-	14	66	-	-	1.0
FO #9 (deep) ³	10/25/01	790	830	-	8.2	425	272	-	32	49	4.0	3.8	<0.10	<0.03	-	14	68	-	-	<1.0
FO #9 (deep) ³	11/01/02	790	830	-	8.1	426	273	-	25	45	4.0	2.7	<0.10	<0.03	-	15	71	-	-	<1.0
FO #10 (shallow) ³	09/20/96	620	640	-	7.7	910	582	-	91	45	18	4.4	4.69	1.01	-	9	73	-	-	<1
FO #10 (shallow) ³	04/24/97	620	640	-	7.5	430	275	-	28	43	8	2.4	0.15	0.06	-	25	71	-	-	<1
FO #10 (shallow) ³	11/19/97	620	640	-	7.9	386	247	-	24	40	8	2.2	<0.1	<0.03	-	14	72	-	-	1
FO #10 (shallow) ³	10/27/98	620	640	-	7.5	389	249	-	24	40	7	2.3	<0.1	<0.03	-	14	64	-	-	<1
FO #10 (shallow) ³	11/02/99	620	640	-	8.1	387	248	-	23	38	7	2.2	<0.1	<0.03	-	13	64	-	-	1
FO #10 (shallow) ³	11/02/00	620	640	-	8.1	375	240	-	23	40	7	2.3	<0.1	<0.03	-	12	62	-	-	2
FO #10 (shallow) ³	10/26/01	620	640	-	8.1	365	234	-	24	44	6	2.0	<0.1	<0.03	-	16	57	-	-	1
FO #10 (shallow) ³	11/01/02	620	640	-	8.2	353	226	-	20	34	5	2.1	<0.1	<0.03	-	17	58	-	-	1
FO #10 (mid) ³	09/20/96	990	1020	-	7.2	1031	660	-	114	59	18	6	0.75	1.27	-	11	81	-	-	<1
FO #10 (deep) ³	09/20/96	1380	1410	-	7.8	1447	926	-	148	107	25	7.2	1.22	0.84	-	27	136	-	-	<1
FO #10 (deep) ³	04/24/97	1380	1410	-	7.7	652	417	-	41	55	8	4.2	<0.10	0.20	-	12	78	-	-	<1
FO #10 (deep) ³	11/19/97	1380	1410	-	7.9	469	300	-	36	46	10	3.1	0.76	0.15	-	12	70	-	-	<1
FO #10 (deep) ³	10/27/98	1380	1410	-	7.5	442	283	-	30	46	8	4.2	<0.10	0.20	-	46	66	-	-	<1
FO #10 (deep) ³	11/02/99	1380	1410	-	8.2	394	252	-	24	39	6	2.6	0.97	0.09	-	11	61	-	-	<1
FO #10 (deep) ³	11/02/00	1380	1410	-	8.1	380	243	-	23	41	6	2.6	0.84	0.04	-	16	60	-	-	1
FO #10 (deep) ³	10/26/01	1380	1410	-	8.2	372	238	-	25	46	6	2.6	0.48	0.09	-	13	60	-	-	1
FO #10 (deep) ³	11/01/02	1380	1410	-	8.2	372	238	-	21	36	6	1.8	0.33	0.04	-	13	64	-	-	<1
FO #11 (shallow) ³	10/31/96	700	730	-	7.7	516	330	-	56	47	12	4.2	1.48	0.36	-	25	75	-	-	1
FO #11 (deep) ³	10/31/96	1090	1120	-	7.8	353	226	-	34	39	5	2.5	1.14	0.17	-	19	42	-	-	<1
PCA-East (shallow) ⁴	04/27/90	350	400	-	7.3	350	212	-	27	16	19	8	<0.05	<0.01	-	71	62	9.5	-	2.2
PCA-East (shallow) ⁴	04/28/92	350	400	-	7.9	290	186	-	16	39	3.8	1.9	<0.02	-	-	8	46	-	-	2.1

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top feet	Btm. feet	Temp °C	pH	Conduc. umho/cm	TDS ppm	Sulfide mg/L	Ca mg/L	Na mg/L	Mg mg/L	K mg/L	Fe mg/L	Mn mg/L	HCO ₃ mg/L	SO ₄ mg/L	Cl mg/L	Silica mg/L	Boron mg/L	N (NO ₃) mg/L
PCA-East (shallow) ⁴	06/01/92	350	400	-	-	-	-	-	16	39	3.8	2.3	<0.02	-	-	8	45	-	-	2.0
PCA-East (shallow) ⁴	11/30/95	350	400	-	8.5	306	196	-	17	40	4.0	1.8	0.10	<0.03	-	<5	46	-	-	3.0
PCA-East (shallow) ⁴	11/02/99	350	400	-	8.2	384	246	-	40	40	10.0	3.1	4.8	0.26	-	14	51	-	-	<1
PCA-East (shallow) ⁴	11/01/00	350	400	-	8.2	314	201	-	20	40	4.0	2.1	3.8	0.74	-	8	49	-	-	2.0
PCA-East (shallow) ⁴	10/26/01	350	400	-	8.1	302	193	-	22	38	5.0	2.7	2.07	0.06	-	8	49	-	-	2.0
PCA-East (deep) ⁴	04/26/90	650	700	-	7.4	1080	656	-	59	81	60	24	<0.05	0.3	-	214	142	29	-	<0.4
PCA-East (deep) ⁴	04/27/90	650	700	-	7.4	1080	691	-	59	81	60	24.0	<0.05	0.30	-	214	142	-	-	<0.4
PCA-East (deep) ⁴	04/28/92	650	700	-	7.2	900	576	-	77	114	16	5.0	<0.08	-	-	41	135	-	-	0.3
PCA-East (deep) ⁴	06/02/92	650	700	-	-	-	-	-	75	110	15	4.9	-	-	-	-	-	-	-	-
PCA-East (deep) ⁴	06/04/92	650	700	-	-	-	-	-	74	114	16	5.3	<0.08	-	-	40	134	-	-	<0.1
PCA-East (deep) ⁴	11/30/95	650	700	-	8.0	968	620	-	65	105	15	4.7	0.10	0.11	-	45	142	-	-	<1.0
PCA-East (deep) ⁴	11/02/99	650	700	-	8.1	941	602	-	73	103	15	4.8	0.50	0.15	-	44	132	-	-	<1
PCA-East (deep) ⁴	11/01/00	650	700	-	8.0	900	576	-	72	102	14	4.6	0.87	0.13	-	42	130	-	-	<1
PCA-East (deep) ⁴	10/26/01	650	700	-	8.3	880	563	-	78	99	13	4.6	0.46	0.12	-	43	126	-	-	<1
PCA-West (shallow) ⁴	04/26/90	525	575	-	7.3	340	218	-	19	16	23.0	7.7	<0.05	<0.01	-	57	68	-	-	4.0
PCA-West (shallow) ⁴	06/14/90	525	575	-	-	340	218	-	-	-	-	-	-	-	-	-	50	-	-	-
PCA-West (shallow) ⁴	06/17/90	525	575	-	-	330	211	-	-	-	-	-	-	-	-	-	50	-	-	-
PCA-West (shallow) ⁴	04/26/91	525	575	-	7.8	311	199	-	19	33	5.4	2.7	-	-	-	21	48	-	-	4.0
PCA-West (shallow) ⁴	07/24/91	525	575	-	7.9	321	205	-	21	33	5.2	2.5	<0.10	<0.03	-	-	44	-	-	-
PCA-West (shallow) ⁴	10/21/91	525	575	-	8.2	326	209	-	19	36	-	-	-	-	-	-	53	-	-	-
PCA-West (shallow) ⁴	04/29/92	525	575	-	7.7	280	179	-	20	35	5.1	2.4	<0.01	-	-	11	44	-	-	4.4
PCA-West (shallow) ⁴	06/03/92	525	575	-	-	-	-	-	20	35	5.2	2.3	<0.01	-	-	-	-	-	-	-
PCA-West (shallow) ⁴	10/20/92	525	575	-	8.2	302	193	-	20	36	5.0	2.3	<0.10	<0.05	-	16	50	-	-	4.6
PCA-West (shallow) ⁴	04/28/93	525	575	-	8.2	311	199	-	19	34	5.0	2.2	<0.10	<0.05	-	13	46	-	-	4.6

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top feet	Btm. feet	Temp °C	pH	Conduc. umho/cm	TDS ppm	Sulfide mg/L	Ca mg/L	Na mg/L	Mg mg/L	K mg/L	Fe mg/L	Mn mg/L	HCO ₃ mg/L	SO ₄ mg/L	Cl mg/L	Silica mg/L	Boron mg/L	N (NO ₃) mg/L
PCA-West (shallow) ⁴	10/28/93	525	575	-	8.2	327	209	-	19	32	5.0	2.3	1.1	<0.05	-	20	42	-	-	6.0
PCA-West (shallow) ⁴	10/28/94	525	575	-	8.2	338	216	-	23	35	5.0	2.0	<0.10	<0.03	-	20	46	-	-	5.0
PCA-West (shallow) ⁴	05/03/95	525	575	-	8.6	317	203	-	21	34	5.0	2.7	1.1	<0.03	-	12	48	-	-	6.0
PCA-West (shallow) ⁴	11/30/95	525	575	-	8.3	315	202	-	20	33	5.0	2.2	0.20	<0.03	-	6	52	-	-	4.0
PCA-West (shallow) ⁴	04/25/96	525	575	-	7.9	319	204	-	19	33	5.0	2.2	0.11	<0.03	-	11	44	-	-	5.0
PCA-West (shallow) ⁴	10/11/96	525	575	-	7.8	315	202	-	17	32	4.0	2.2	<0.10	<0.03	-	9	44	-	-	4.0
PCA-West (shallow) ⁴	05/21/97	525	575	-	6.3	314	201	-	18	34	5.0	2.1	<0.1	<0.03	-	10	44	-	-	4.0
PCA-West (shallow) ⁴	11/19/97	525	575	-	8.0	311	199	-	20	33	6.0	2.2	<0.1	<0.03	-	12	50	-	-	4.0
PCA-West (shallow) ⁴	10/30/98	525	575	-	8.0	316	202	-	20	35	5.0	2.3	<0.1	<0.03	-	13	44	-	-	4.0
PCA-West (shallow) ⁴	11/02/99	525	575	-	8.2	315	202	-	20	33	5.0	2.3	<0.1	<0.03	-	11	43	-	-	4
PCA-West (shallow) ⁴	11/01/00	525	575	-	8.2	311	199	-	19	34	5.0	2.2	<0.1	<0.03	-	10	45	-	-	4.0
PCA-West (shallow) ⁴	10/25/01	525	575	-	8.1	308	197	-	24	34	5.0	2.7	<0.1	<0.03	-	11	46	-	-	4.0
PCA-West (shallow) ⁴	10/31/02	525	575	-	8.0	307	196	-	18	28	5.0	1.6	<0.1	<0.03	-	11	48	-	-	<1
PCA-West (deep) ⁴	04/26/90	825	875	-	7.2	1080	660	-	51	81	64	24	<0.05	0.06	-	214	144	29	-	<0.4
PCA-West (deep) ⁴	04/26/91	825	875	-	7.7	978	626	-	63	114	17	6.8	-	-	-	60	156	-	-	1.3
PCA-West (deep) ⁴	07/24/91	825	875	-	7.9	1034	662	-	57	110	18	6.7	<0.10	<0.03	-	-	150	-	-	-
PCA-West (deep) ⁴	10/21/91	825	875	-	7.9	1065	682	-	68	114	-	-	-	-	-	-	153	-	-	-
PCA-West (deep) ⁴	04/29/92	825	875	-	7.5	900	576	-	76	117	18	5.9	-	-	-	38	135	-	-	0.5
PCA-West (deep) ⁴	06/02/92	825	875	-	-	-	-	-	73	113	18	6.1	<0.01	-	-	-	-	-	-	-
PCA-West (deep) ⁴	10/20/92	825	875	-	8.1	926	593	-	66	113	17	5.9	<0.1	<0.05	-	68	152	-	-	<0.5
PCA-West (deep) ⁴	04/28/93	825	875	-	8.0	1012	648	-	64	108	19	6.0	<0.1	<0.05	-	42	150	-	-	<0.5
PCA-West (deep) ⁴	10/28/93	825	875	-	7.8	1033	661	-	65	108	17	5.5	0.2	0.07	-	41	148	-	-	<1.0
PCA-West (deep) ⁴	10/28/94	825	875	-	7.9	1011	647	-	72	107	17	5.6	0.8	0.11	-	71	152	-	-	<1
PCA-West (deep) ⁴	05/03/95	825	875	-	7.9	1016	650	-	73	112	18	5.3	0.98	0.14	-	44	162	-	-	<1

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters					General Chemistry											
		Top	Bttm.	Temp	pH	Conduc.	TDS	Sulfide	Ca	Na	Mg	K	Fe	Mn	HCO ₃	SO ₄	Cl	Silica	Boron	N (NO ₃)
		feet	feet	°C		umho/cm	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
PCA-West (deep) ⁴	11/30/95	825	875	-	8.0	992	635	-	68	102	18	5.4	0.40	0.10	-	42	154	-	-	<1
PCA-West (deep) ⁴	04/25/96	825	875	-	7.8	1003	642	-	66	107	18	5.3	0.11	0.08	-	46	144	-	-	<1
PCA-West (deep) ⁴	10/11/96	825	875	-	7.6	967	619	-	63	107	17	5.6	<0.10	0.07	-	39	150	-	-	<1
PCA-West (deep) ⁴	05/21/97	825	875	-	6.9	916	586	-	64	109	17	5.4	0.20	0.06	-	42	158	-	-	<1
PCA-West (deep) ⁴	11/19/97	825	875	-	7.7	969	620	-	71	106	20	5.3	0.18	0.05	-	46	150	-	-	<1
PCA-West (deep) ⁴	10/30/98	825	875	-	7.7	970	621	-	79	109	18	5.4	<0.1	0.08	-	42	146	-	-	<1
PCA-West (deep) ⁴	11/02/99	825	875	-	8.0	964	617	-	75	105	12	5.8	0.49	0.11	-	43	145	-	-	4
PCA-West (deep) ⁴	11/01/00	825	875	-	7.9	976	625	-	76	103	18	5.1	<0.1	0.09	-	43	149	-	-	<1
PCA-West (deep) ⁴	10/25/01	825	875	-	8.2	960	614	-	90	103	17	5.2	1.25	0.11	-	42	146	-	-	<1
PCA-West (deep) ⁴	10/31/02	825	875	-	7.9	960	614	-	75	98	17	4.1	0.88	0.11	-	44	159	-	-	<1
MCWD #9 ⁵	Avg. 2000	-	-	-	7.77	680	408	0.006	39	69.9	17.2	2.8	0	0	159	71.1	67.1	-	0.00	0
	Avg. 2001	-	-	-	7.89	659	410	0.001	38	80	17	3.7	0	0	180	69.9	62.7	-	0.09	0.37
MCWD #10 ⁵	Avg. 2000	788	1398	-	8.04	521	304	0.02	24.1	67.2	6.67	1.89	0	0	124	43.7	47.6	-	0.13	0
	Avg. 2001	788	1398	-	8.24	481	310	0.02	23	76	6	2.4	0	0	141	36.7	52	-	0.12	0.006
MCWD #11 ⁵	Avg. 2000	828	1508	-	7.95	636	366	0.01	25.1	91.1	7.74	2.27	0	0	157	55.9	64.9	-	0.19	0
	Avg. 2001	828	1508	-	7.99	626	400	0.005	25	100	7.4	2.9	0	0	181	55.3	62.1	-	0.14	0
MCWD #12 ⁵	Avg. 2000	1283	1833	-	8.19	715	340	0.19	4.2	110	0	2.3	0	0	121	38.9	111	-	0.09	0
	Avg. 2001	1283	1833	-	8.19	715	340	0.19	4.2	110	0	2.3	0	0	121	38.9	111	-	87.5	0
DMW-1-1 ⁶	2001	1754	1804	26	8.31	881	506	-	15.3	164	1.9	3.8	<0.01	0.01	-	74	153	23.9	0.11	-
DMW-1-2 ⁶	2001	1334	1354	21.5	8.46	459	318	-	7.71	81.1	2.74	5.2	<0.01	0.01	-	32	47.8	64.4	0.09	-
DMW-1-3 ⁶	2001	984	1004	22.5	7.07	28,500	23,800	-	2,570	2,770	1,080	31.9	<0.15	0.38	-	1,510	10,800	29.4	0.25	-
DMW-1-4 ⁶	2001	874	894	21	7.82	672	417	-	31.8	94	11.1	0.17	<0.01	0.02	-	61.5	68.6	45.8	0.15	-

TABLE B-1
Summary of Water Quality Data

Well ID	Date	Well Screen		Field Parameters				General Chemistry												
		Top	Btm.	Temp	pH	Conduc.	TDS	Sulfide	Ca	Na	Mg	K	Fe	Mn	HCO ₃	SO ₄	Cl	Silica	Boron	N (NO ₃)
		feet	feet	°C		umho/cm	ppm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L

Sources:

1. CH2M HILL 1993a
2. USGS 1982
3. Unpublished Monterey Peninsula Water Management District data
4. SGD 1990a and 1990b
5. Marina Coast Water District (no date)
6. USGS 2002

Appendix C
Soil Moisture Budget Model Documentation

Soil Moisture Budget Model Documentation

Introduction

The quantity and distribution of precipitation runoff, infiltration, and deep percolation to groundwater are governed by the atmospheric conditions, topography, land use, vegetation, and soil characteristics. These parameters, while temporally and spatially highly variable, are important components of water balances. Deep percolation of precipitation and applied irrigation water is often a significant contribution to groundwater basin recharge. Runoff from precipitation is often the most significant contribution to stream flow. Applied water demands for agricultural crops, lawns, landscaping, etc. often drive the use of both surface water and groundwater supplies. Direct measurement of each of these parameters is generally not possible. The Soil Moisture Budget (SMB) model described herein estimates direct runoff, infiltration, deep percolation, evapotranspiration (ET), and applied water from climatic inputs. Climatic inputs include precipitation, reference ET, geographic inputs of land use, vegetation, and soil characteristics.

Soil Moisture Accounting

The SMB model performs an accounting of soil moisture in the root zone by estimating direct runoff, infiltration, deep percolation of precipitation and irrigation, ET, and irrigation applied water. The soil moisture accounting is currently performed on a monthly time step. Precipitation is first partitioned into direct runoff and infiltration. Infiltration contributes to either soil moisture, interflow, or deep percolation to groundwater. Depending on the land use, soils, and climatic conditions, soil moisture is either held in storage or consumptively used through ET. In irrigated areas, additional water applied to the land for irrigation is also consumptively used through ET or held in soil moisture storage. Soil moisture in excess of the maximum holding capacity of the root zone is assumed to contribute to deep percolation. The soil moisture accounting process is represented by Equation 1.

$$SM^t = SM^{t-1} + I_p^t + AW^t - ET_a^t - DP^t \quad (\text{Eq. 1})$$

where:

SM	=	soil moisture in the root zone
I_p	=	infiltration of precipitation
AW	=	irrigation applied water
ET_a	=	actual evapotranspiration
DP	=	deep percolation of precipitation and applied water to groundwater

Each of the parameters required for the solution of Equation 1 are described in more detail below.

Direct Runoff

Direct runoff of precipitation is computed from the Soil Conservation Service (SCS) runoff curve number method (SCS 1972). The SCS method consists of determining a runoff curve number (CN) based on the land use, soil, and hydrologic condition of the area evaluated. An empirical relationship has been developed by the SCS, and founded on field studies, that relates precipitation and curve number to direct runoff:

$$R_p^t = (P^t - 0.2 S) / (P^t + 0.8 S) \quad \text{if } P > 0.2 S \quad (\text{Eq. 2a})$$

$$R_p^t = 0 \quad \text{if } P \leq 0.2 S \quad (\text{Eq. 2b})$$

where R_p is the direct runoff of precipitation in inches, P is the rainfall in inches, and S is the retention parameter. The curve number and retention parameter are related as shown in Equation 2c.

$$S = (1000 / \text{CN}) - 10 \quad (\text{Eq. 2c})$$

For the purposes of the SMB model, the curve number is selected based on SCS antecedent moisture condition (AMC) II. Curve numbers are input into the model for the pervious areas and impervious areas separately. Composite curve numbers should not be used. Currently, it is assumed that impervious areas have a curve number of 98.

Based on experiments on small watersheds, SCS has estimated the initial abstraction (the amount of rainfall that accumulates prior to the beginning of runoff) to be equal to $0.2 S$ in the formulation of Equation 2. To compensate for the variability of precipitation over the monthly computational time step in the SMB model (i.e., multiple storms are more likely, so that the monthly abstraction will be greater than that for a single storm), the retention parameter is increased based on the monthly precipitation. For monthly precipitation greater than P_o , the expression $0.2 S$ is replaced with $0.2 (P/P_o) S$. Evaluation of monthly rainfall-runoff measured data for small watersheds in southern California has provided an estimate of 3 inches for P_o . For monthly precipitation less than P_o , no modification is made to Equation 2a-b.

Infiltration

While infiltration of precipitation is not explicitly represented in the SCS method, it can be estimated as the difference between precipitation and direct runoff:

$$I_p^t = P^t - R_p^t \quad (\text{Eq. 3})$$

Evapotranspiration

Evapotranspiration by the crop, or other vegetative cover, causes depletion of soil moisture. The potential evapotranspiration (ET_c) is estimated from the California Irrigation Management Information System (CIMIS) method for determining reference evapotranspiration (ET_o) and crop coefficients (K_c) for various vegetative covers (CIMIS 2000). CIMIS utilizes the modified Penman and Penman-Monteith equations and numerous weather stations to determine the ET rate of a reference crop (grass). The ET rate for all other

crops are related to this reference ET. The general equation used in this SMB model is shown below.

$$ET_c^t = ET_o^t K_c^t \quad (\text{Eq. 4a})$$

Note that ET_c is the actual ET for irrigated crops, but may not be the actual ET for non-irrigated vegetative covers such as native vegetation which may rely solely on precipitation. Actual ET (ET_a) is limited by the soil moisture available to the vegetative crop, as shown in Equation 4b:

$$ET_a^t = \min(ET_c^t, SM^{t-1} + P_e^t + AW^t) \quad (\text{Eq. 4b})$$

where P_e is the monthly effective rainfall and AW is the irrigation applied water. The determination of these components is described in the following sections.

Effective Rainfall

Effective rainfall is the amount of rainfall that is available for crop consumptive use. The computation is based on the SCS method that relates monthly rainfall and consumptive use to an estimate of monthly effective rainfall (SCS 1970). This empirical method was developed from a comprehensive analysis of precipitation and climatic conditions and computed soil moisture balances at various locations. Monthly effective rainfall is computed as:

$$P_e^t = (0.70917 P^t 0.82416 - 0.11556) 100.02426u f \quad (\text{Eq. 5a})$$

where:

- P = monthly rainfall in inches
- u = average monthly consumptive use in inches
- f = depth of water application factor

The depth of application factor, f , is computed as:

$$f = 0.531747 + 0.295164 D - 0.057697 D^2 + 0.003804 D^3 \quad (\text{Eq. 5b})$$

where D is the net depth of application in inches. In the SMB model, D is approximated as the maximum available soil moisture in the root zone for the particular vegetative cover and u is estimated as the potential ET rate (ET_o).

Applied Water

For irrigated crops, a computation is included in the SMB model to estimate the amount of water that is required to satisfy the ET demand and minimum soil moisture requirements associated with irrigation practices. The model first determines the available soil moisture for crop consumptive use considering only precipitation supplies. Unmet ET demand, termed ET of applied water (ET_{aw}), is then assumed to be satisfied through irrigation. In addition, the amount of water needed to bring the soil moisture to the minimum specified monthly values (soil moisture deficit [SMD]) represents an irrigation demand. These terms are computed as:

$$ET_{aw}^t = ET_c^t - \min(ET_c^t, SM^{t-1} + P_e^t) \quad (\text{Eq. 6a})$$

$$SMD^t = \max[SM_{min}^t - (SM^{t-1} + P_e^t - \min(ET_c^t, SM^{t-1} + P_e^t)), 0] \quad (\text{Eq. 6b})$$

The total applied water demand is computed as:

$$AW^t = (ET_{aw}^t + SMD^t) / IE \quad (\text{Eq. 6c})$$

where IE is the irrigation efficiency.

Deep Percolation

Deep percolation of precipitation and applied water is computed in a two-stage process in the SMB model. First, precipitation in excess of direct runoff, effective rainfall, and interflow storage is assumed to contribute to deep percolation:

$$DP_1^t = P^t - R_p^t - P_e^t - R_s \quad (\text{Eq. 7a})$$

where R_s is the interflow retention storage and is assumed to equal 0.1 inch.

Precipitation and applied water in excess of the maximum soil moisture capacity are then assumed to percolate to groundwater, which is computed as:

$$DP_2^t = \max(SM^{t-1} + I_p^t + AW^t - ET_a^t - DP_1^t - SM_{max}^t, 0) \quad (\text{Eq. 7b})$$

where SM_{max} is calculated as the product of root depth and fractional available water capacity (or field capacity minus wilting point).

Distribution uniformity is an important element of on-farm irrigation efficiencies. It is a measure of the variation in the amount of water applied to the soil throughout the irrigated area (DWR b-160 1998) and affects the magnitude of deep percolation. In the SMB model, it is assumed that 25 percent of the irrigated area is over-irrigated by 30 percent, 25 percent of the area is under-irrigated by 30 percent, and the remaining 50 percent of the area is irrigated at the average amount.

The total deep percolation amount is the sum of the two components:

$$DP^t = DP_1^t + DP_2^t \quad (\text{Eq. 7c})$$

Input Data Requirements

The SMB model has been developed at a level of detail appropriate for basin-scale analyses and for which data are commonly available. In general, the model is designed to work with GIS spatial data, time series climatic data, and relational tables that define characteristics of the spatial attributes. This section describes the input data requirements and data sources that have proved valuable.

Spatial Data

Spatial data requirements for the SMB model include delineation of study area boundaries, distribution of soils, and land use information. The basic requirement is that each unique combination of soil type and land use is delineated as a polygon and acreage computed. The polygons serve as the computational unit for the soil moisture accounting. Soils information for many counties in the U.S. can be obtained from the USDA Natural Resources Conserva-

tion Service SSURGO GIS Database (http://www.ftw.nrcs.usda.gov/ssur_data.html). Land use information can generally be obtained from local planning agencies and/or state water planning agencies. In California, the Department of Water Resources Division of Planning and Local Assistance performs county land and water use surveys for statewide planning purposes (<http://www.waterplan.water.ca.gov/landwateruse/landuse/ludataindex.htm>). An intersection of the soils and land use information is usually sufficient for generating the unique computational polygons.

Time Series Data

Climatic data are input in the SMB model as monthly time series information. Precipitation and reference ET at any number of representative stations are included. These data can be obtained from local cities, state water planning agencies, or the National Oceanic and Atmospheric Administration (<http://www.noaa.gov/>). For the western United States, the Western Regional Climate Center (<http://www.wrcc.dri.edu/>) maintains a database of historical climate information. In California, CIMIS maintains weather stations throughout the state and houses a database of the detailed climate information generated from these stations, including reference ET (<http://www.cimis.water.ca.gov/>). Note that pan evaporation is not equal to reference ET and that values from other data sources may need to be scaled appropriately.

Relational Data

There are a number of soil, crop/irrigation, runoff, and other hydrologic characteristics that are necessary to perform the soil moisture budget and that are related to the spatial data. The key soil characteristics are the SCS hydrologic soil group (needed for the computation of direct runoff) and available water capacity, and are accessible through the SSURGO database. The ET crop coefficients for various crops and landscaping can be obtained from CIMIS. Rooting depths, soil moisture minimums, irrigation efficiency, and distribution uniformity can be estimated with assistance from local agricultural extension personnel or taken from published data sources. These factors, particularly rooting depth for native vegetation, tend to be the most uncertain input parameters used in the model. Runoff curve numbers can be estimated from SCS tables (SCS 1972, 1986) or county hydrology manuals. Percent imperviousness is best estimated from aerial photos.

Limitations

The SMB model has been developed with the primary purpose to estimate deep percolation of precipitation and applied water on a basin or subbasin scale to assist in estimating groundwater basin budget components. Direct runoff and applied water demands are also important outputs from the model and may be used in estimating surface runoff and agricultural demands supplied by groundwater pumping, surface water diversions, or imported supplies. Simplifying assumptions have been made to accommodate monthly model time step and general availability of data. The modification of the initial abstraction in the computation of direct runoff is an example. Typically, SCS runoff curve numbers are calibrated for surface water flow evaluations where it is possible to measure the outflow of a watershed or sub-watershed. Sensitivity analysis should be performed for areas in which it is not possible to calibrate surface flows. Likewise, the input data assumptions for root depth, minimum soil moisture requirement, and irrigation efficiency should be screened for

appropriateness. The use of these parameters represents a simplification of complex soil-water processes and agricultural practices.

The SMB model estimates deep percolation of precipitation that falls directly on pervious surfaces only. Runoff from each polygon is not routed to streams or ponds/lakes where additional groundwater recharge may occur. Likewise, indoor water use and water used for purposes other than irrigation are not accounted. Other methods for estimation of these types of water demands and associated recharge are likely more appropriate.

References

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- California Department of Water Resources. 1998. *The California Water Plan Update, Bulletin 160-98, Volume 1*.
- California Irrigation Management Information System (CIMIS). 2000. *Agriculture Resource Book*.
- Cooperative Extension of University of California, Division of Agriculture and Natural Resources. No date. *Using Reference Evapotranspiration (ET_0) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Agronomic Crops, Grasses, and Vegetable Crops*. Leaflet 21427.
- Cooperative Extension of University of California, Division of Agriculture and Natural Resources. No date. *Using Reference Evapotranspiration (ET_0) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Trees and Vines*. Leaflet 21428.
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- Soil Conservation Service. 1986. *Urban Hydrology for Small Watersheds*. Technical Release No. 55 (2nd Edition).

TABLE C-1

Seaside Recharge Analysis - Assumptions Summary

DWR Land Use Type ¹	CIMIS Crop Coefficient ²	Rooting Depth (in) ³	Available Water Capacity (%) ⁴	Maximum Soil Moisture Capacity (in) ⁵	Irrigated	SCS Runoff Curve Number ⁶ (by Hydrologic Soil Group)				Percent Impervious ⁷
						A	B	C	D	
Native vegetation	0.90	48.0	9%	4.32	No	31	57	71	78	0 %
Urban	0.70	24.0	11%	2.64	Yes	39	61	74	80	60 %
Urban commercial	0.70	24.0	11%	2.64	Yes	39	61	74	80	80 %
Urban industrial	0.70	24.0	11%	2.64	Yes	39	61	74	80	80 %
Urban landscape	0.70	24.0	11%	2.64	Yes	49	69	79	84	25 %
Urban residential	0.70	24.0	11%	2.64	Yes	39	61	74	80	60 %
Pasture	0.85	24.0	9%	2.16	Yes	39	61	74	80	10 %
Truck crops	0.90	48.0	9%	4.32	Yes	65	75	82	86	10 %
Semi-agricultural	0.70	24.0	9%	2.16	Yes	39	61	74	80	10 %
Surface water	0.65	—	—	—	—	—	—	—	—	0 %
Vacant	0.70	24.0	11%	2.64	Yes	39	61	74	80	0 %
Unknown	0.70	24.0	11%	2.64	Yes	39	61	74	80	0 %

Notes:¹ Source: California Department of Water Resources Land Use Survey² Source 1: Cooperative Extension of University of California, Division of Agriculture and Natural Resources. No date. *Using Reference Evapotranspiration (ET_o) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Agronomic Crops, Grasses, and Vegetable Crops*. Leaflet 21427.Source 2: Cooperative Extension of University of California, Division of Agriculture and Natural Resources. No date. *Using Reference Evapotranspiration (ET_o) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Trees and Vines*. Leaflet 21428.³ Crop potential ET is determined by multiplying reference evapotranspiration by crop coefficient. Outdoor areas only.³ Source: California Department of Water Resources. 1979. *A Computer Program to Estimate Monthly Consumptive Use and Water Requirements*.⁴ Source: U.S. Department of Agriculture, Natural Resources Conservation Service. *Monterey County Soil Survey* (GIS coverages). Estimated from major soil type within the land use category.⁵ Calculated by multiplying rooting depth by available water capacity percentage.⁶ Source: U.S. Department of Agriculture, Soil Conservation Service. 1968. "Hydrology" supplement A to Sec. 4, *Engineering Handbook*. Pervious areas only.Urban areas assumed to be representative of *Open Space in Good Hydrologic Condition*. Impervious areas assigned constant curve number of 98.⁷ Estimated from digital aerial photos.