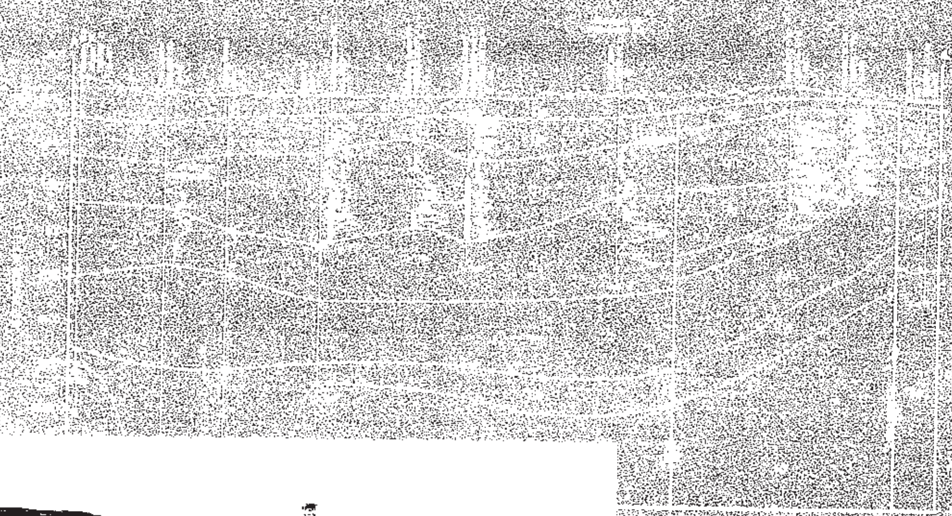
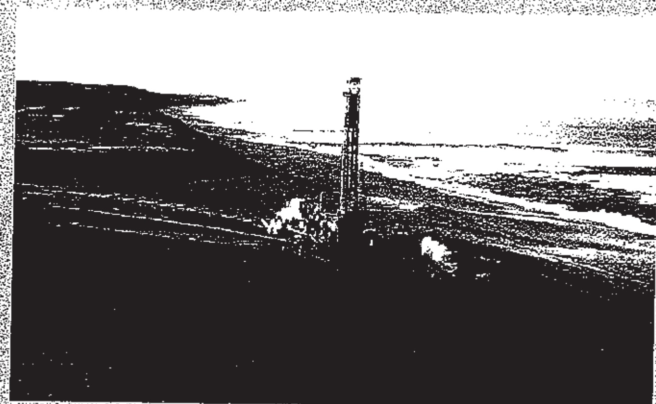
Marina Coast Water District

Deep Aquifer Investigative Study





RIME Water Resources & Information Management Engineering, Inc.

May 2003

WRIME Water Resources & Information Management Engineering, Inc.
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May 15, 2003

Marina Coast Water District
11 Reservation Road
Marina, CA 93933

Attn: Mr. Dave Meza

Subject: Deep Aquifer Investigative Study

Dear Mr. Meza:

WRIME, Inc. is pleased to submit the final report on "Deep Aquifer Investigative Study" to the Marina Coast Water District (MCWD).

WRIME, Inc. appreciates having this opportunity to work with the MCWD staff, the Technical Advisory Committee members and the DWR, to evaluate the feasibility of the Deep Aquifer as a short-term and long-term source of water supply to the MCWD.

Should you have any questions, please do not hesitate to contact us about this report.

Sincerely,

Water Resources &
Information Management Engineering, Inc.

Ali Taghavi, Ph.D., P.E.
Vice President

DISCLAIMER

This report was prepared for the Marina Coast Water District under a grant from the California Department of Water Resources. The in-progress findings were shared on two occasions with a Technical Advisory Committee (TAC) consisting of agency personnel (MPWMD, USGS, PVWMA, MCWRA, Santa Cruz County Public Works, DWR) and selected consultants. At the TAC meetings, input was solicited and the subsequent suggestions were incorporated, as appropriate, into the project. Scheduling of TAC meetings was difficult and consequently some TAC members had less-than-adequate time to fully review and evaluate the work performed. As such, the findings of this report are not necessarily endorsed by all members of the TAC. The findings provide new insights into the water resources of the area, insights that are in some ways contradictory with previous beliefs. The findings are considered preliminary and subject to further refinement, and are in no sense final.

Deep Aquifer Investigative Study

May 2003

Prepared For:

Marina Coast Water District

List of Preparers:

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SECTION 1 INTRODUCTION

The Marina Coast Water District (MCWD) in cooperation with the California Department of Water Resources (DWR) initiated an investigative study of the Salinas groundwater basin deep aquifer system.

The potable groundwater supplies in the coastal areas of Salinas Valley Groundwater Basin have been contaminated by intrusion of seawater from the Monterey Bay. The seawater has extended to approximately 8 miles inland in the upper (180-foot) aquifer, and to approximately 2 miles inland in the middle (400-foot) aquifer. Although there are no direct indications of seawater intrusion in the deep aquifer, there are concerns that continued and increased groundwater pumping may cause intrusion of seawater there as well.

Because MCWD relies on the deep aquifer for approximately 85 percent of its water supply, a long-term water management plan is of paramount importance to the District. As such, the District and DWR initiated investigating the reliability of the deep aquifer as a long-term water supply source.

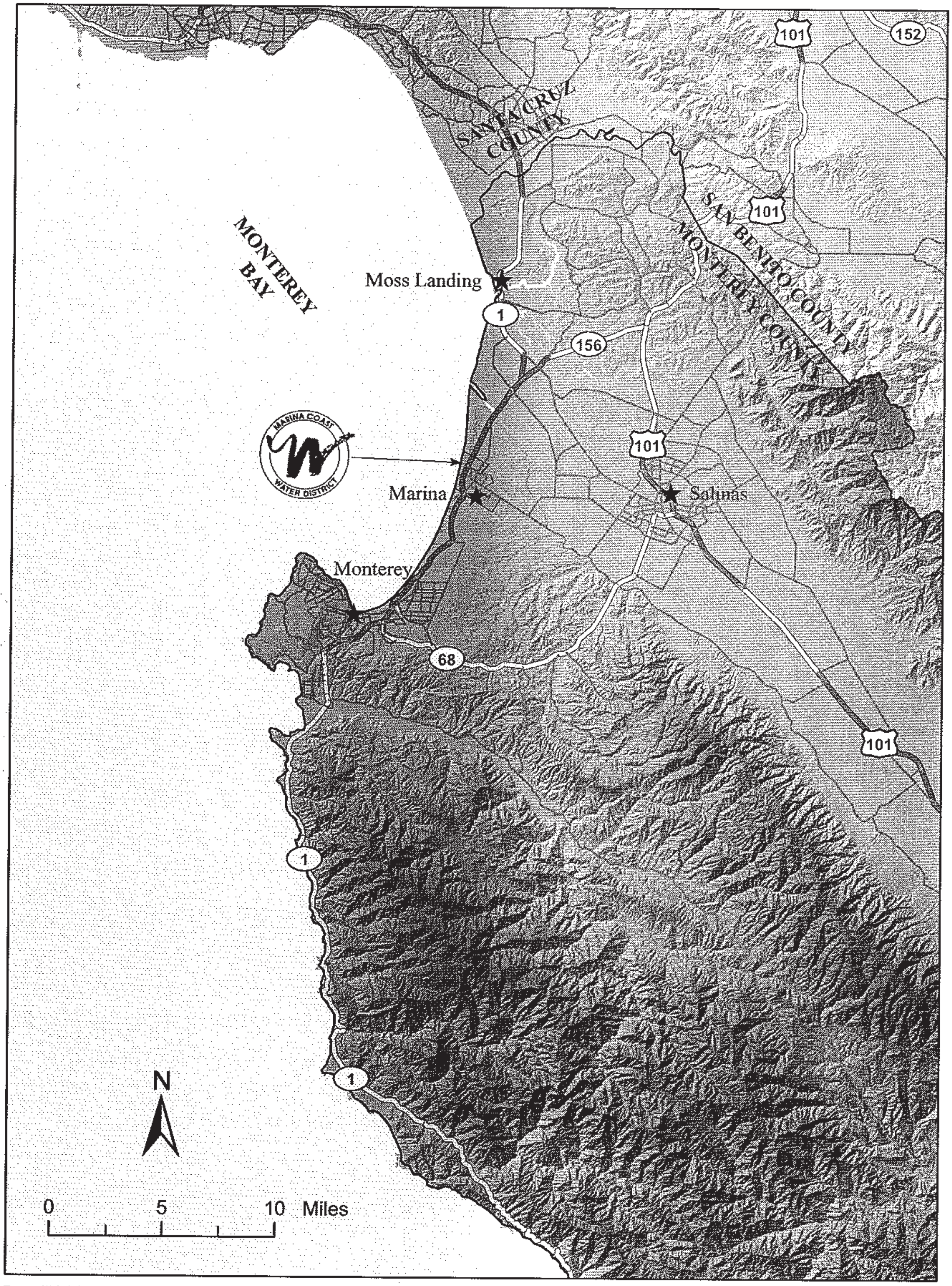
STUDY AREA

The study area is centered on the MCWD service area (Figure 1.1). Because of MCWD's geographical location relative to the advancing seawater in the 180- and 400-foot aquifers, the District was one of the first groundwater users forced to use the deep aquifers. Some agricultural users in the Castroville area also were forced to drill into the deeper sediments to provide water for agricultural purposes. The construction and operation of the Castroville Seawater Intrusion Project (CSIP) in 1998 allowed these agricultural users to abandon the use of their deep wells. As such, MCWD remains today the only significant user of the deep aquifer.

The study area is also defined by the availability of data. Relevant water well data are only available in those areas where deeper wells have been constructed and operated. Understandably, deeper wells have only been drilled in the intruded areas. Therefore, the available data are limited to this area. For this reason, the primary study area becomes those areas with, or threatened by, seawater intrusion in both the 180- and 400-foot aquifers.

DEEP AQUIFER DEFINITION

The term "deep aquifer" or "deep zone" has been part of the groundwater lexicon of the Salinas Valley for more than 25 years. Other alternative terms have included the "900-foot" and "1500-



Base: USGS 30-meter National Elevation Dataset (2001)

Figure 1.1 Vicinity map showing Marina Coast Water District foot" aquifers. However, these terms are defined vaguely and the "deep aquifer" is not necessarily located at these arbitrary depths. The use of the deep aquifer has been driven by the need to drill deeper to avoid seawater intrusion. Initially, wells were drilled to the next deeper elevation that had fresh-water-bearing materials. Subsequently, wells were drilled to greater depths further extending the bottom of the deep aquifer. As such, the term "deep aquifer" became defined primarily by depth of well. Little effort was expended to understand the geologic nature and origin of the sediments that make up the deep aquifer.

Accordingly, the current use of the term "deep aquifer" essentially aggregates all sediments below the 400-foot aquifer without respect to geology. This report attempts to provide geologic assignments for the sediments encountered in these deeper wells such that a hydrogeologic framework can be developed to assist the understanding of these aquifer systems.

Throughout this document, the term "deep aquifers" will be utilized in place of "deep aquifer" because available data strongly suggest a multiple-aquifer system.

STUDY OBJECTIVES

There have been many geologic and hydrogeologic data in the Coastal areas of Monterey Bay that have not been evaluated in the past. In addition, the basin-wide hydrologic model, the Salinas Valley Integrated Ground and Surface water Model (SVIGSM), has been used for analysis of impacts in many studies, including the Salinas Valley Water Project. However, SVIGSM does not include all the latest geologic and hydrogeologic data representing the deep aquifer system.

The objectives of this study, as laid out in the MCWD's request for proposals, are as follows:

- Identify all users and their use rates of the Salinas Basin deep aquifer.
- More fully characterize the deep aquifer.
- Identify the safe yield of the deep aquifer including more accurate characterization of recharge rates, transmissivity, and connectivity to the middle and upper aquifers.
- Update the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM) to be able to address yield and seawater intrusion questions related to aquifer use.
- Develop a deep aquifer groundwater management component to the Salinas Valley Water Plan through a consensus building, stakeholder process.

To achieve such goals, the following scope of work was developed:

Task 1 - Establish project management methods;

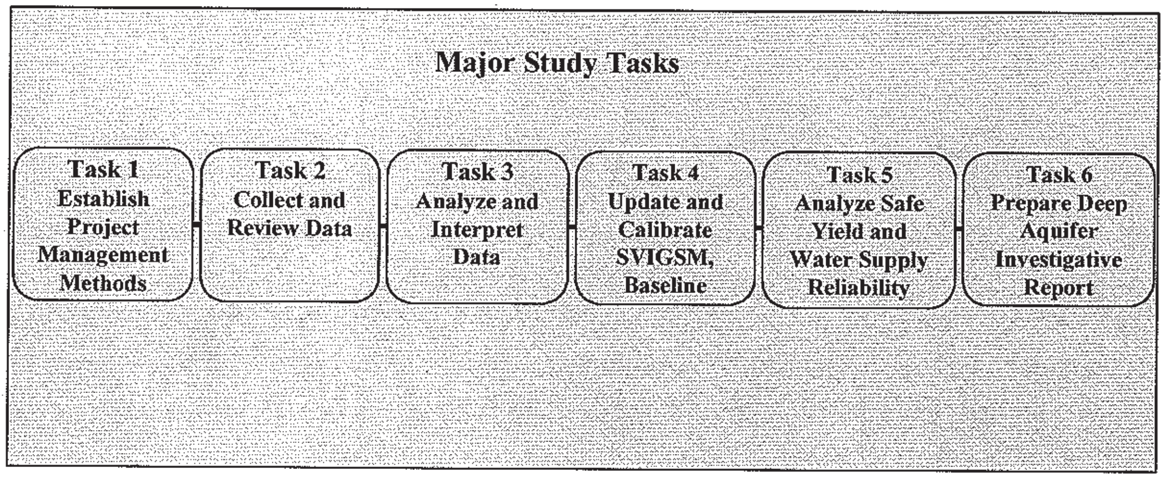
Task 2 - Collect and review data about the Deep Aquifer;

Task 3 - Analyze and interpret data about the Deep Aquifer;

Task 4 - Update the SVIGSM;

Task 5 - Estimate safe yield and analyze water supply reliability; and

Task 6 - Prepare Report and Presentation of Findings.



REPORT ORGANIZATION

This report provides documentation of the work performed and the findings of the study. The report is organized into the following sections:

Section 1: Introduction - Describes the purpose, project background, study area, scope of project, and organization of this report.

Section 2: Data Analysis and Synthesis - Describes the data collected, analysis of the time series data and its incorporation in the model, and estimation of missing data.

Section 3: SVIGSM Update - Describes the background of the model, impacts of updating the code and of updating the model database, and the efforts to mitigate those impacts.

Section 4: Water Supply Reliability and Safe Yield Analysis - Describes the definition of safe yield, the criteria developed and used to analyze safe yield, and impacts of several potential groundwater supply alternatives.

Section 5: Summary of Findings - Presents summary of study findings.

This section tabulates and analyzes the available hydrogeologic data from the coastal portion of the deep aquifers system of Monterey County. The deep aquifer designation derives from the history of water resource development in Monterey County. Advancing seawater intrusion, first in the 180-foot aquifer, then in the 400-foot aquifer, forced groundwater users to progressively drill deeper to find fresh water. The first deep aquifer water well was drilled in 1976; approximately nine more water wells have since been drilled into this aquifer system in the coastal area.

This section attempts to integrate all available data on the aquifer systems underlying the 180- and 400-foot aquifers of the Salinas Valley to develop an improved understanding of the groundwater resource. This refined understanding is then used to update the representation of the deep aquifer the SVIGSM. Several local-scale investigations into the hydrogeology of the deep aquifers have been performed over the last 20 years and provided useful insight into the understanding of the deep aquifers. However, this evaluation represents the first attempt to bring together all the data that have been developed since the preparation of the Deep Aquifer Report prepared in 1976 by Richard Thorup (unpublished draft report).

The available data set for the deep aquifers is scanty. These data are presented in this report with preliminary conclusions. Conclusions should be considered provisional and are subject to revision when more data become available. Much of the available data raises questions that cannot be adequately answered, or even speculated upon, within the existing framework of understanding. The data, corresponding interpretation, and conceptual understanding have been incorporated into the SVIGSM so that additional insight can be gained by evaluating the results of modeling analyses.

PREVIOUS REPORTS

The hydrogeology of the northern Salinas Valley has been the subject of many studies, such as the landmark 1946 Salinas Basin Investigation (DWR, 1946), and, more recently, the 1994 Salinas River Basin Water Resources Management Plan (Montgomery Watson, 1994). However, these studies focused on the shallow aquifers, commonly referred to as the 180-foot and the 400-foot aquifers, and not on the deep aquifers. Only several studies specifically focus on the deep aquifers and provide significant insight into its hydrogeology. The most significant are summarized below:

Thorup (1976, 1983)—In 1976, Richard Thorup issued a draft report discussing the results of a 1,718-foot-deep test well (Fontes well) for the proposed Castroville Irrigation Project (CIP). This well is significant because it was the first water well to test the deep aquifers. Based on his analysis of the test well and other oil and water wells, Thorup estimated that the "900-foot aquifer" extended from the mouth of the Salinas River southward to Greenfield and contained nearly 11 million acre-feet of fresh water. Thorup concluded that the Fontes well would not produce enough water for the CIP and recommended an alternate location at the Marihart Ranch, south of Spreckels. Thorup updated this report in 1983 to include the information from three additional wells subsequently perforated into what he considered the deep aquifer—the Monterey County Mulligan Hill well (14S/02E-06L01), Leonardini #3 (13S/02E-19Q03), and Monterey Dunes #1 (13S/01E-36J01). Accompanying the 1983 report were a series of geologic maps and cross sections that depicted the extent and geometry of the deep aquifers. Based on more refined data, Thorup calculated that the deep aquifers contained approximately 4.6 million acre-feet of usable groundwater and estimated a recharge rate of 65,500 acre-feet per year.

Grasty (1988)—As part of his M.S. thesis research, James Grasty performed and interpreted gravity and magnetic surveys across the Armstrong Ranch in the city of Marina. Grasty observed a northwest-trending gravity low and magnetic anomaly, which he interpreted as a shear zone related to the "King City fault" (Reliz fault). More germane to the present study of the deep aquifers is his hypothesis of "the presence of an anomalous area (bedrock depression) where a thick sequence of Quaternary sediment accumulated" between the Marina No. 10 and 11 wells (Grasty, 1988, p. 24–25). This is the first depiction of the "Marina trough."

Geoconsultants (1999)—At the American Association of Petroleum Geologists, Pacific Section, meeting in the city of Monterey, Jeremy Wire and his associates presented a paper showing a feature called the Marina trough, which is located between the Mulligan Hill well and the Reliz fault. Geoconsultants postulated the existence of the Marina trough based on the presence of an extremely thick section of sediments, which were identified as Pleistocene age, based on microfossil analysis by Dr. James Ingle of Stanford University.

Hanson and others (2002)—As part of a U.S. Geological Survey (USGS) research project, a 2,000-foot-deep monitoring well cluster was drilled in Marina. This report provides valuable information on stratigraphy, water levels, and water chemistry of the deep aquifers, in addition to the well construction. Of particular interest is the documentation of Pliocene-aged sediments from the depths of 950 to 2000 feet.

Montgomery Watson (1993) – This report presented, in draft form, the first version of the SVIGSM. The model was developed as a hydrologic model that integrates the groundwater and surface water flow systems, along with a water quality model. The model also simulates the operation of the Nacimineto and San Antonio reservoirs, regulating the flows to the Salinas River system. This report focuses on the development and calibration of the groundwater flow and quality models.

Montgomery Watson (1997) – This report presents the update of SVIGSM calibration. The model underwent substantial review and analysis as part of this effort.

Montgomery Watson (1998) – This report presents the update and applications of the SVIGSM. The SVIGSM was used to evaluate the historical hydrologic benefits of operation of Nacimiento and San Antonio reservoirs on the groundwater basin, as well as the Salinas River flows. The report also presents the analysis of flood control and economic benefits of historical operation of the reservoirs.

GROUNDWATER LEVEL DATA

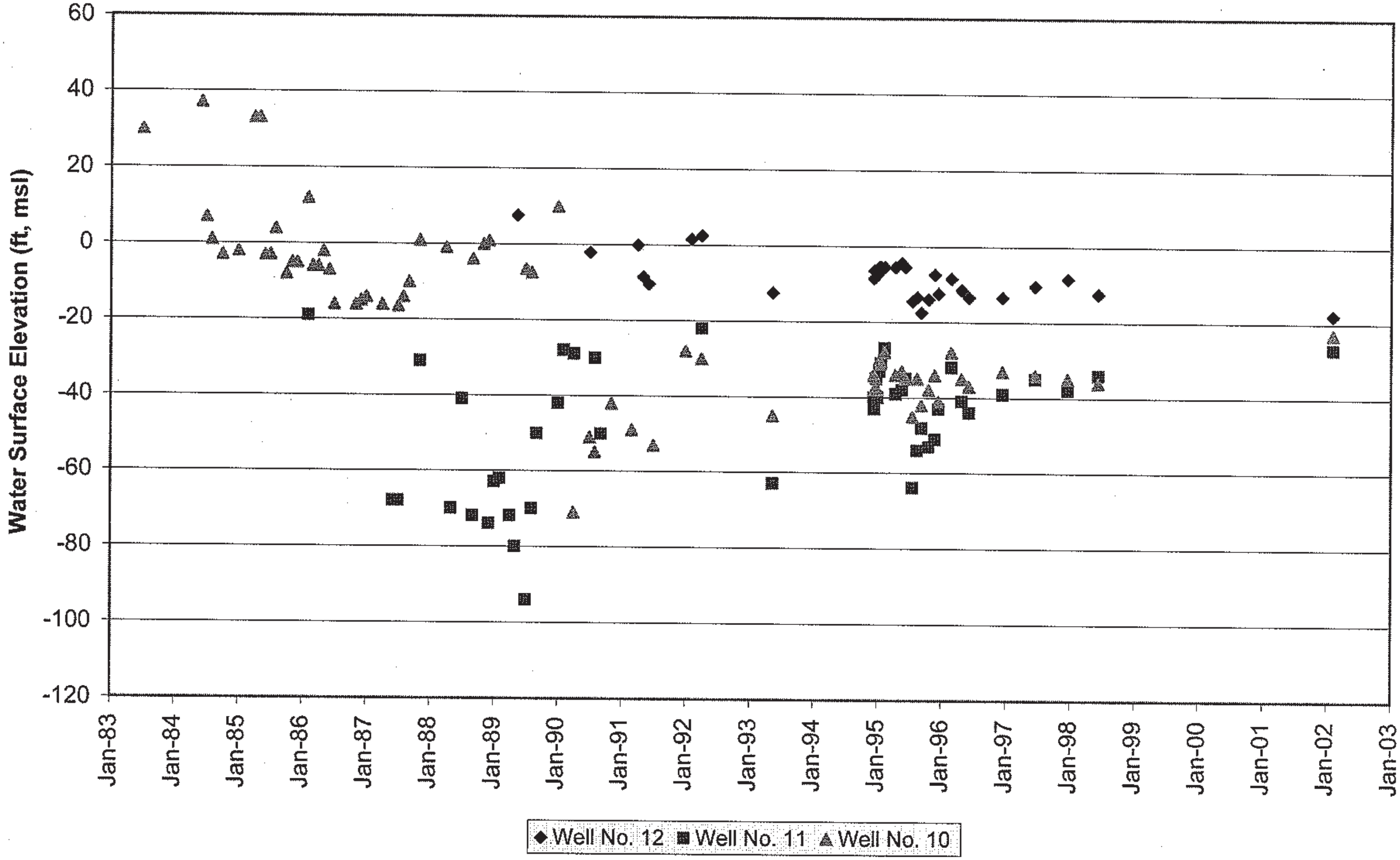
Water level data are available for wells in the deep aquifers in the Castroville area from the Monterey County Water Resources Agency (MCWRA). Intermittent water level data are also available from MCWD for their three production wells. Continuous water level data since June 2001 are available for the USGS Monitoring well cluster.

MARINA COAST WATER DISTRICT WELLS

A static water level history of MCWD wells can be assembled from various sources. MCWD has collected static water level data from these wells on an irregular schedule, creating several long data gaps. Other sources include data collected at the time of well construction and spot measurements collected by contractors as part of pump servicing. The most apparent data gap is the period from early 1998 until early 2002 for which no static water level data are available. Since beginning this investigation, static water level data have been collected on an almost continuous basis. The available water level data are presented on Figures 2.1 to 2.4b.

Although the record in Figure 2.1 is incomplete, the static water level history of all the wells shows a general pattern. Water levels at the time of well completion are close to sea level. During the first several years of operation, static water levels fall relatively rapidly. Then static water levels appear to level off and maintain a narrow range of fluctuation. All three of MCWD's wells have maintained water levels significantly below sea level since initiation of extractions. Well Nos. 10 and 11 display water levels averaging 40 feet below mean sea level. Well No. 12 displays average water surface elevation of approximately 15 feet below msl. Of interest are the strong vertical gradients maintained between these wells and the increasing head with increasing well depths.

Figure 2.1
Marina Coast Water District Deep Aquifer Wells Water Level Data



Figures Fig2.1-WL

Figure 2.2a MCWD Annual Production from Well 10

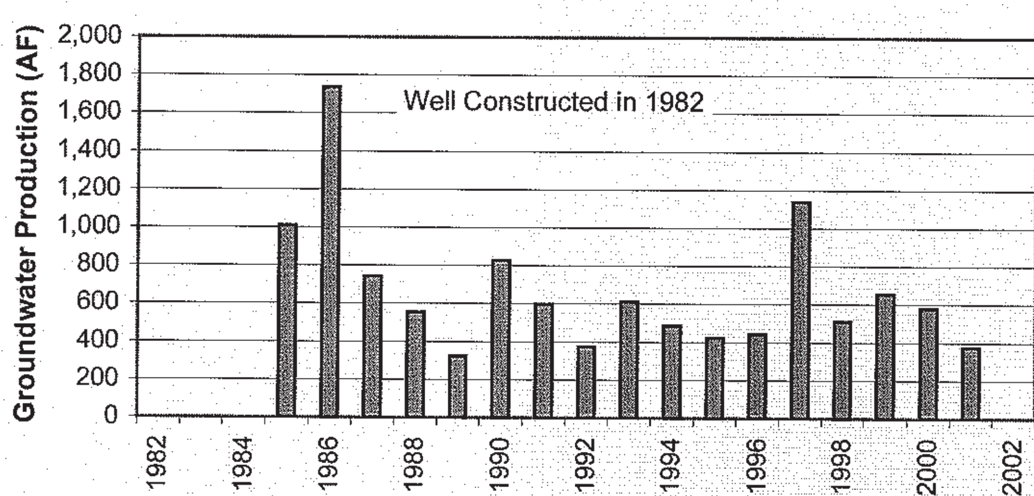


Figure 2.2b MCWD Groundwater Levels for Well 10

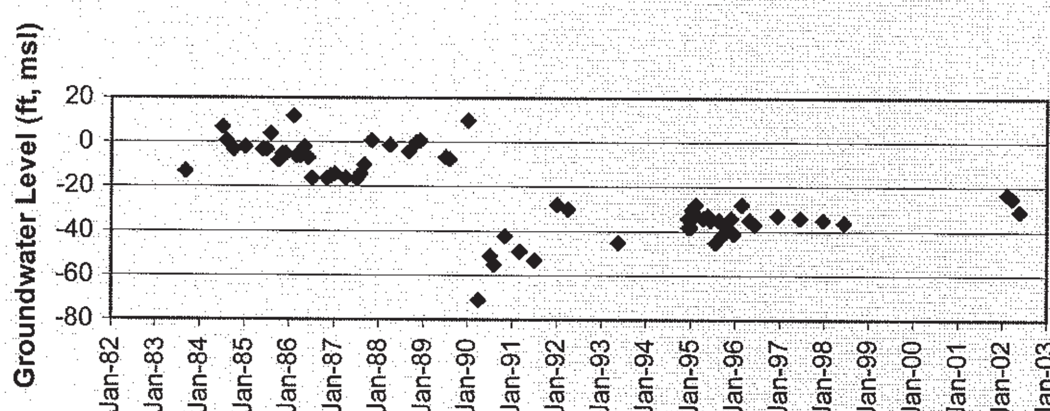


Figure 2.3a MCWD Annual Groundwater Production from Well 11

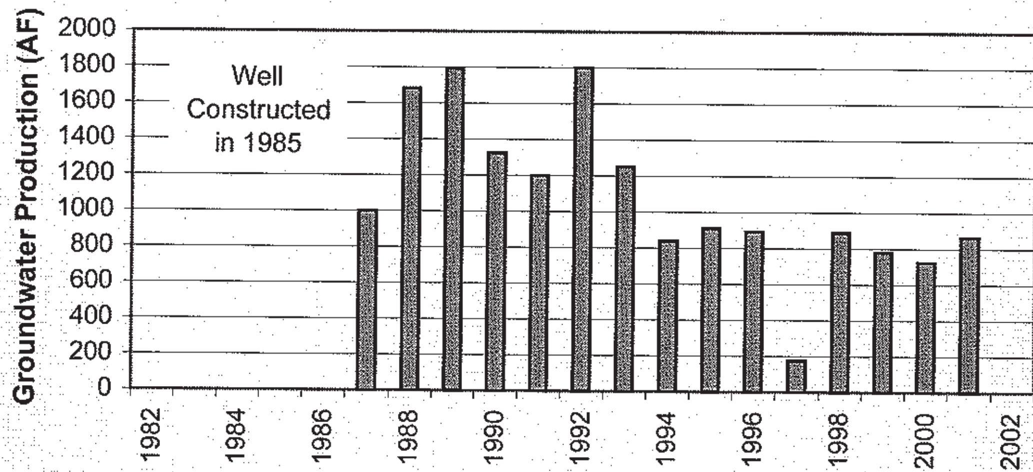


Figure 2.3b MCWD Groundwater Levels from Well 11

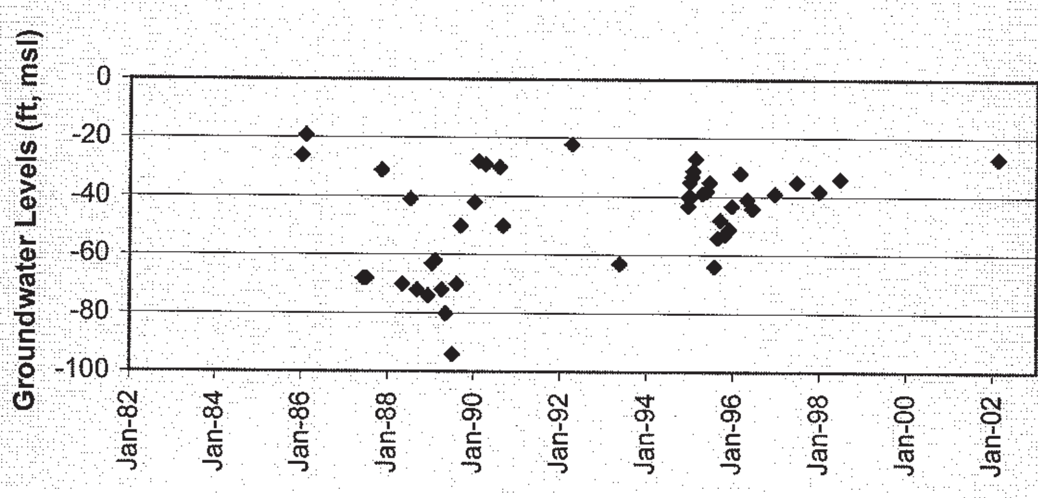


Figure 2.4a MCWD Groundwater Production from Well 12

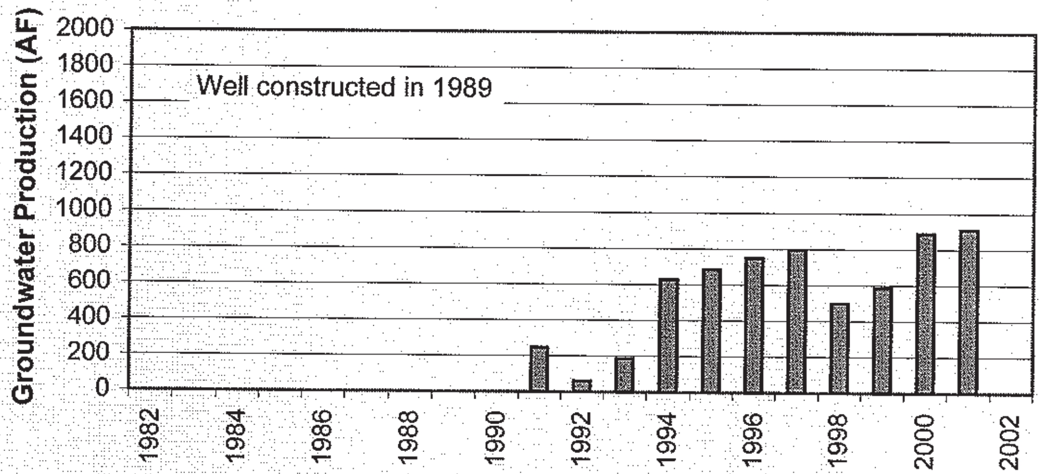
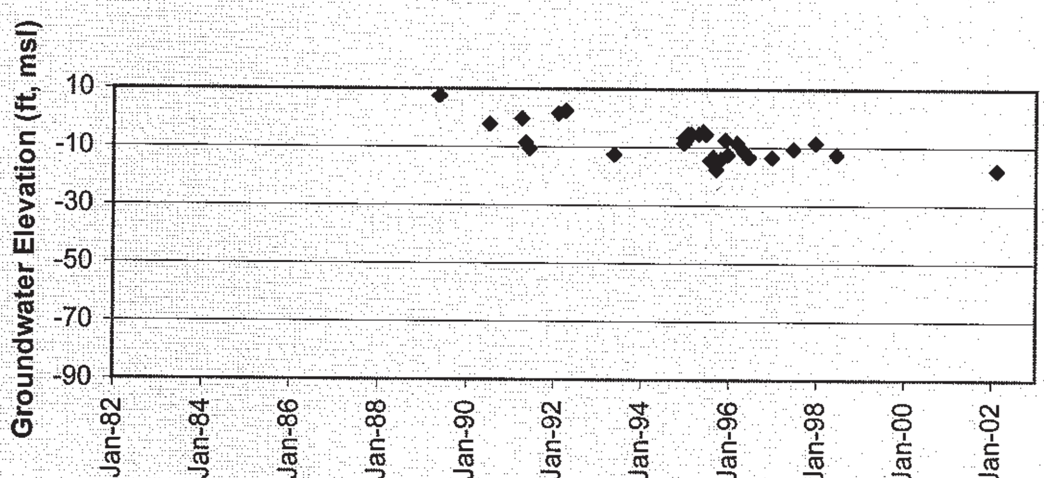


Figure 2.4b MCWD Groundwater Levels from Well 12



Figures 2.2a through 2.4b present annual production and static water level history for each of MCWD's wells. Water level data are generally too sparse to discern a strong linkage between extractions at Well Nos. 10 and 11. The record for Well No. 12 is clearer and shows a general decline in water level with increasing extractions. Taken together, the records from all the wells allow an understanding of how the overall operation of the well field impacts water levels at each well site. The water level record from Well No. 10 shows a large shift in average water level in 1989 (approximately). This is the period when production from Well No. 11 was coming on-line. As is discussed below, Well Nos. 10 and 11 display significant mutual interference effects. Beginning in 1987, water level records in Well Nos. 10 and 11 reflect the aggregate pumping from these wells. As discussed below, the hydraulic linkage between Well Nos. 10 and 11 and Well No. 12 is poor.

Figures 2.5a and b present monthly production and water levels from MCWD wells during the period from January 1995 to December 1997—the period with the most water level data. Figure 2.6 shows the seasonal fluctuations in water levels in response to demand variations. While the magnitude of the response differs, generally the observed fluctuation in water level is proportional to the variation in monthly production from a given well.

Castroville Area Wells

The MCWRA collects monthly data from five of the wells completed in the Castroville area deep aquifers. Monthly water level data extends back to approximately October 1986. These data are presented in Figure 2.7. The water level records display a strikingly similar response. The annual irrigation cycle is apparent in the records of all the wells, with all the wells displaying approximately 40 feet of annual water level fluctuation. Of interest is that the record from Well No. 13N/2E-32E05, an observation well, is essentially identical to the records of the surrounding production wells, suggesting a highly connected, confined system. The regional response of the aquifer system to the cessation of pumpage in 1998, with the onset of CSIP water deliveries, is also striking. Water levels in all wells recovered to above sea level elevations by 2000, again indicative of a connected, confined aquifer system.

Figure 2.8 presents the water level records from selected Castroville wells with the MCWD wells record. The cessation of pumpage due to CSIP water deliveries has provided for a significant relaxation of the aquifer in the Castroville area; however, the water level record from the MCWD's wells, although sparse, shows no apparent response to this regional relaxation.

Figure 2.5a MCWD Total Groundwater Production

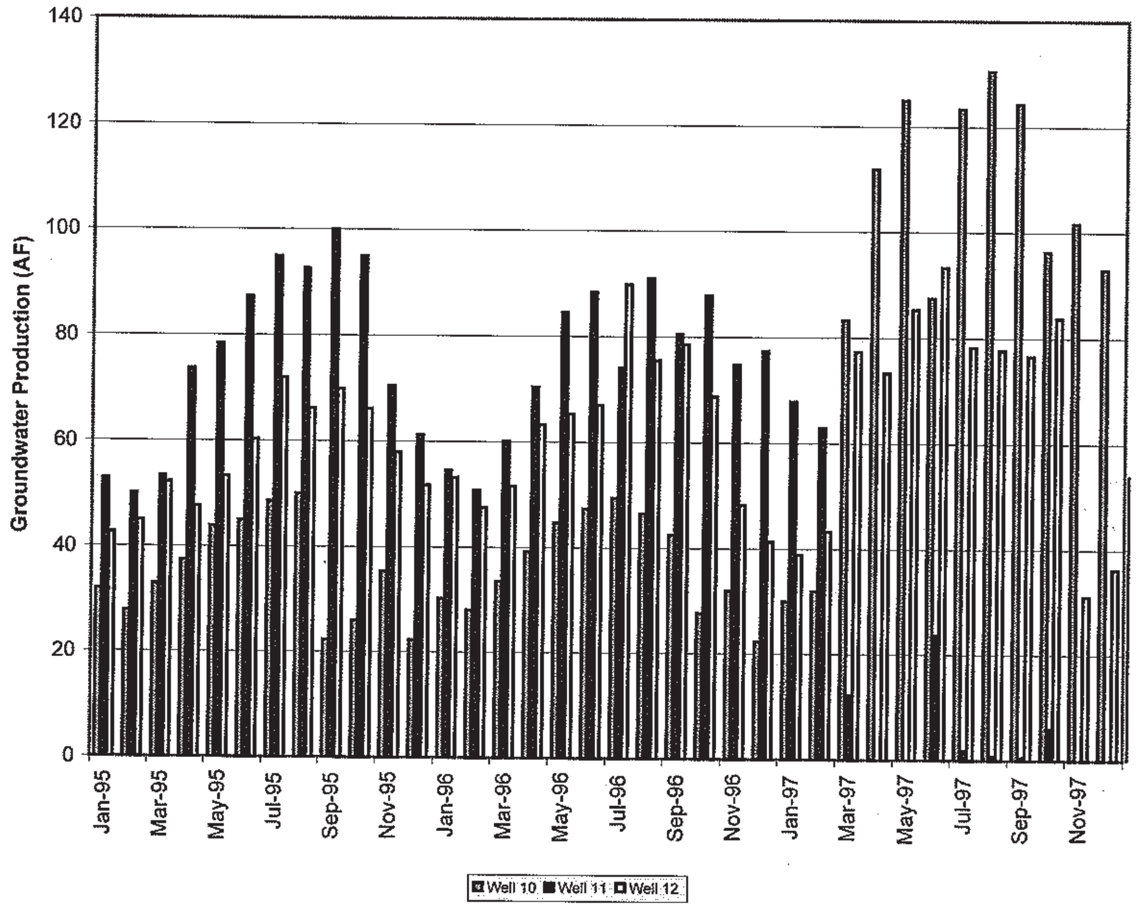


Figure 2.5b MCWD Groundwater Levels

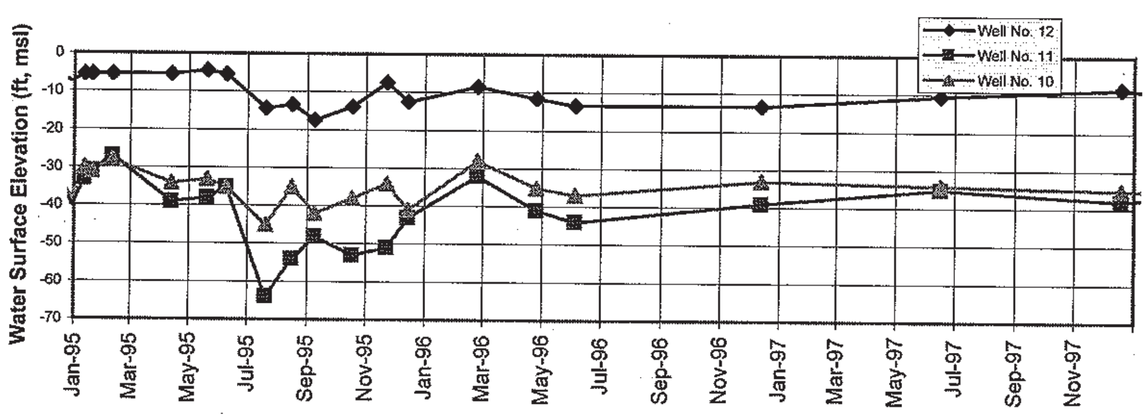


Figure 2.6
Water Level History Castroville and Marina Area Deep Zone Wells

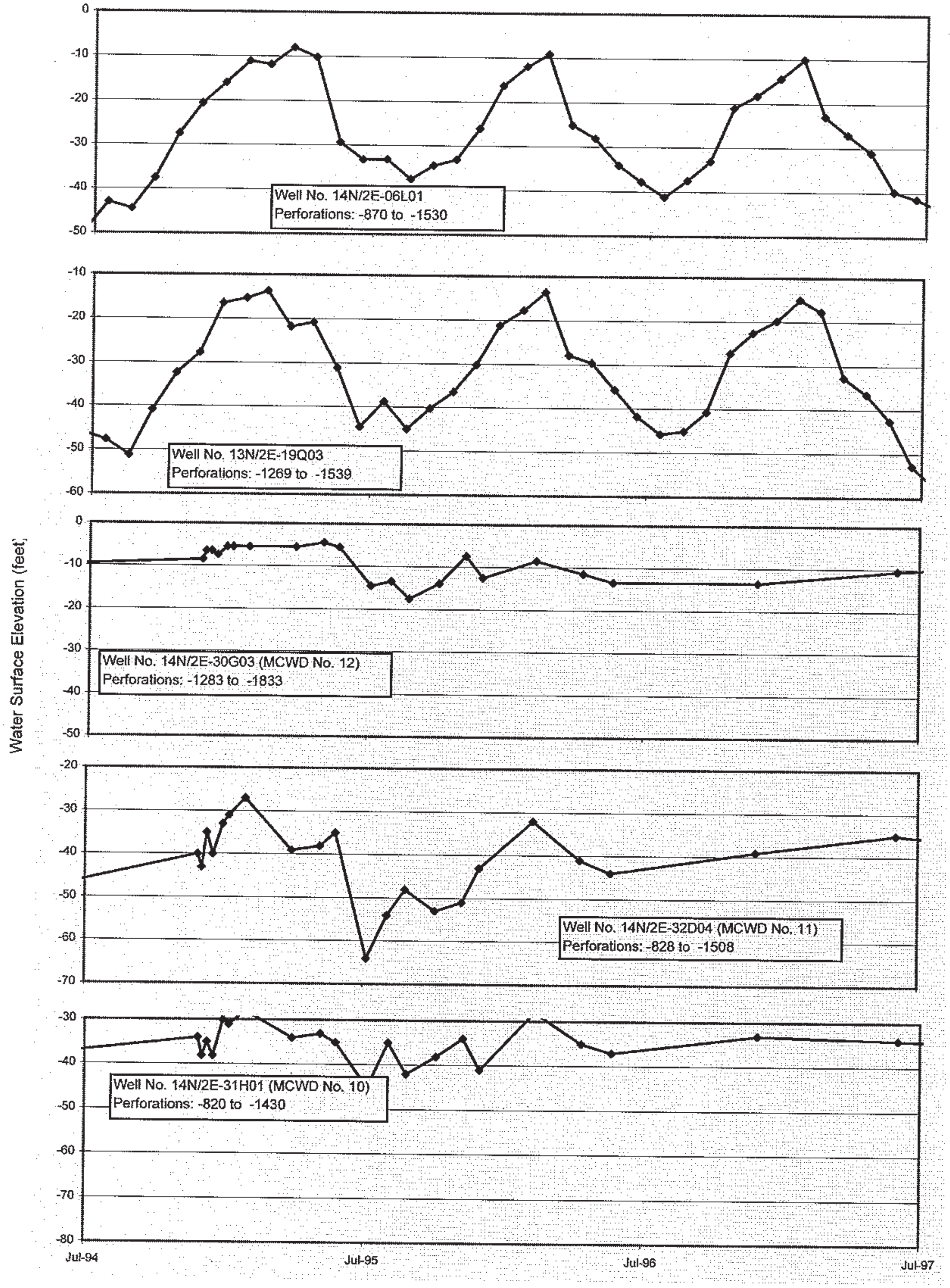
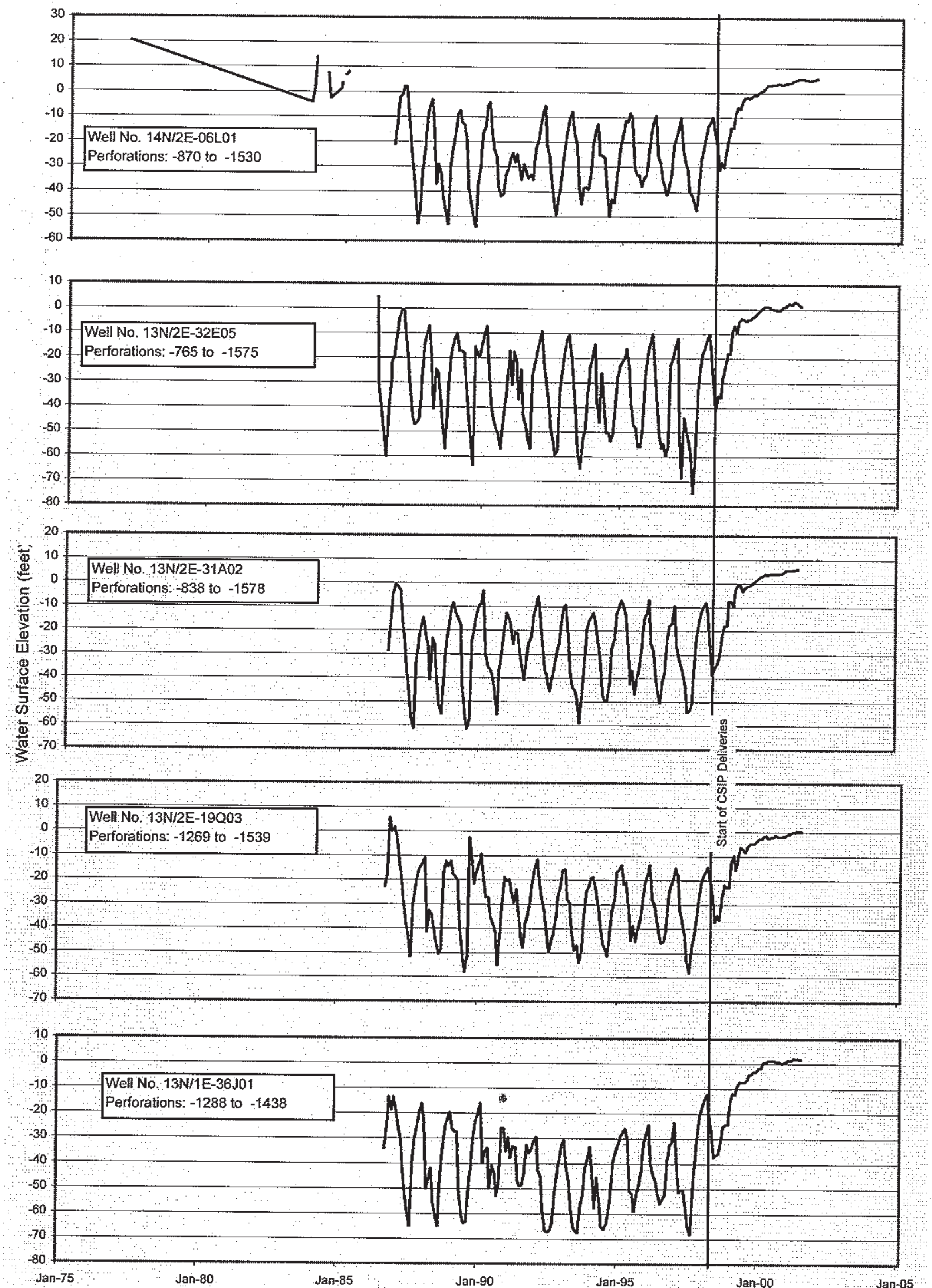
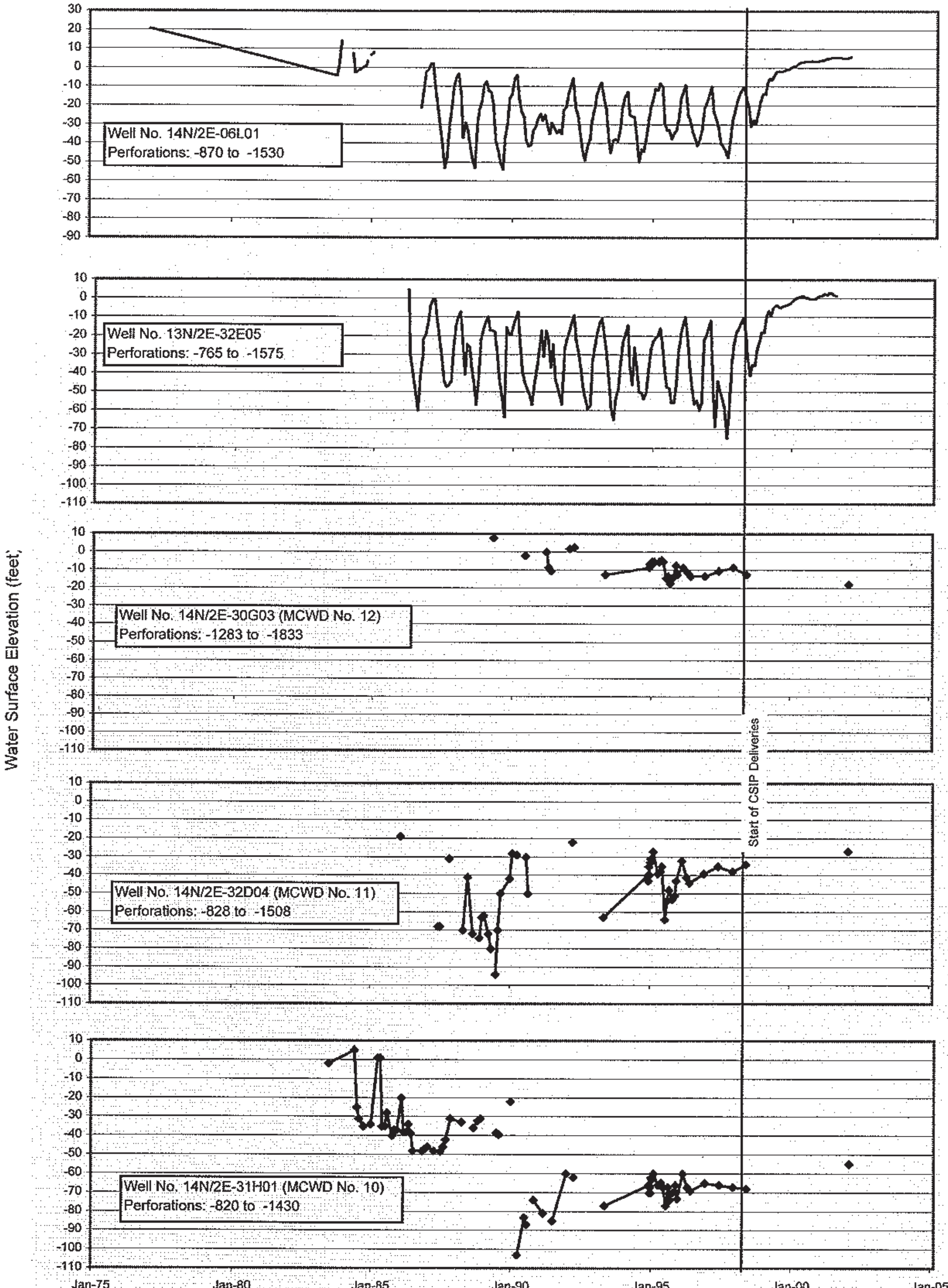


Figure 2.7
Water Level History
Castroville Area Deep Zone Wells



Figures\Fig 2.7-Castro Wells

Figure 2.8
Water Level History
Castroville and Marina Area Deep Zone Wells - CSIP Deliveries



Figures\Fig 2.8 Marina-Castro Wells

USGS MONITORING WELL

Working for MCWD and MCWRA, the USGS completed a well designed to monitor groundwater conditions in the deep aquifers. The well is located at MCWD's headquarters and consists of four separate wells completed in the same borehole. The wells were designed to monitor groundwater conditions at specific depths selected based on review of the borehole data and the consideration of construction of proximal wells. The well monitors four discrete zones ranging in thickness from 20 to 40 feet. After completing the monitoring well cluster, MCWRA equipped the monitoring wells with continuous water level recording devices. Water level data has been collected since June 2001. The average water level for each monitoring well, as well as for MCWD's production wells, is summarized in Table 2.1 below.

Table 2.1 Average Groundwater Levels for USGS Monitoring and MCWD Production Wells

Well	Elevation of Perforations (feet)	Average Water Surface Elevation (feet)
DMW-1-1	-1754 to –1804	-2.7
DMW-1-2	-1334 to –1354	2.3
DMW-1-3	-984 to –1004	-17
DMW-1-4	-874 to –894	-16.2
MCWD No. 10	-788 to –1398	-38
MCWD No. 11	-828 to –1508	-40
MCWD No. 12	-1283 to –1833	-12

Drawing conclusions from comparison of the groundwater elevation data in the USGS well with that of the production wells is difficult. The USGS wells are completed in thin, discrete zones while the production wells are completed across multiple zones. For example, the intervals within which DMW-1 and DMW-1-2 are completed are included in a single perforated interval of Well No. 12. The water surface in DMW-1-2 is substantially above that of Well No. 12 while DMW-1-1 is below it. The water level in Well No.12 is likely a composite head of several smaller zones of differing heads from which it produces.

GROUNDWATER PRODUCTION

Ten water wells have been installed in Monterey County to produce from the deep aquifers. MCWD operates three wells: MCWD Well Nos. 10, 11, and 12. Monthly production data from these wells are available from MCWD. The remaining seven wells are agricultural supply wells. Production data from these wells are reported to MCWRA, so are confidential and not available. However, because these wells are now idle due to construction and operation of

CSIP, the data from these wells are less important. Data from MCWD are summarized in Figure 2.8.

Figure 2.9a reveals annual production from the deep aquifers to have been relatively constant since the completion of Well No. 12 in 1990. Total production has averaged approximately 2000 acre-feet/year over this period. Figure 2.9b also shows monthly production for the period. The seasonal distribution of demand is apparent, with winter extractions as low as approximately 100 acre-feet/month (AF/M) and summer extractions exceeding 250 AF/M.

GEOLOGIC AND HYDROGEOLOGIC DATA

Geology: This section describes the geologic characteristics of the deep aquifers based on stratigraphic and structural information.

STRATIGRAPHY

Granitic basement — The oldest unit in the study area consists primarily of granitic rocks, secondarily of metamorphic rocks. These rocks form the Sierra de Salinas and Gabilan Range that border the Salinas Valley. In the subsurface, the granitic rocks underlie the Tertiary and Quaternary sedimentary rocks. Several of the wildcat oil wells drilled along the coast reached the granitic basement.

Lower to Middle Miocene sedimentary rocks — Overlying the granitic basement are a series of marine sedimentary rocks which include an unnamed arkosic sandstone formation and the Monterey Formation. These rocks crop out in the hills near Monterey, Corral de Tierra, and Carmel Valley. Because these formations have been uplifted, folded, and eroded, their total thickness is unknown. However, within the area of Cross Sections A and B, these sedimentary rocks are approximately 1,000 to 2,000 feet thick. One possible exception is the area beneath the Elba Capurro and Bayside Development Vierra wells where a thick section of sandstone indicates a possible buried canyon (Starke and Howard, 1968).

Upper Miocene to Pliocene marine sequence — As described by Clark (1981, p. 24), this sequence consists of a shallow-water transgressive sandstone unit (the Santa Margarita Sandstone), a deeper water, siliceous, organic mudstone unit (the Santa Cruz Mudstone) and a shallow-water unit (the Purisima Formation). In Monterey County, only the Santa Margarita Sandstone is exposed on land, whereas the Santa Cruz Mudstone and the Purisima Formation crop out offshore in Monterey Bay. Interpretation of drill hole data suggests that the thickness of the Purisima Formation ranges from 500 to 1,000 feet in the area of Cross Sections A, B, and

Figure 2.9a MCWD Annual Groundwater Production

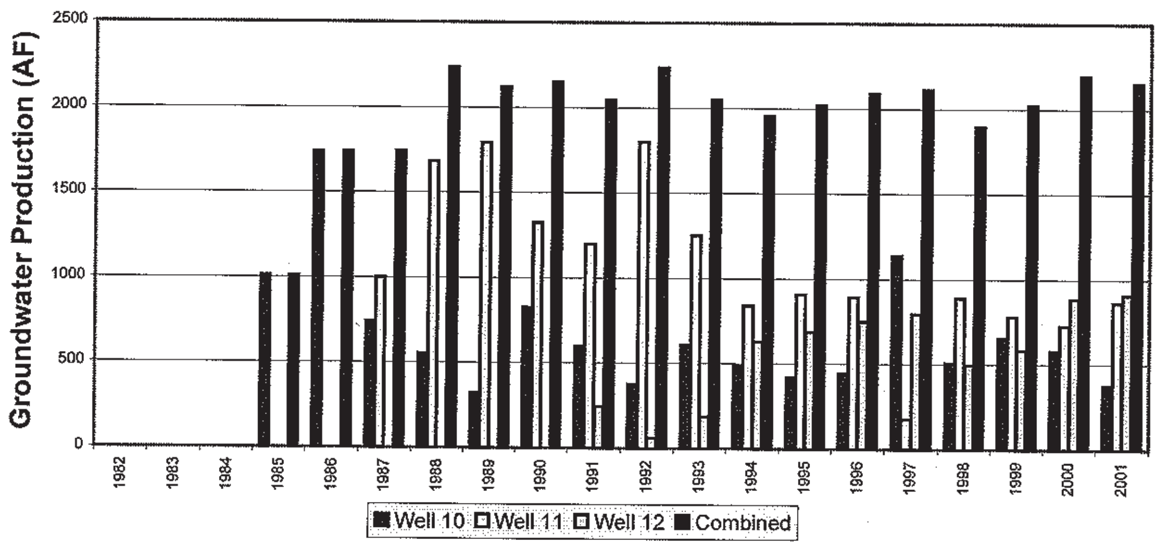
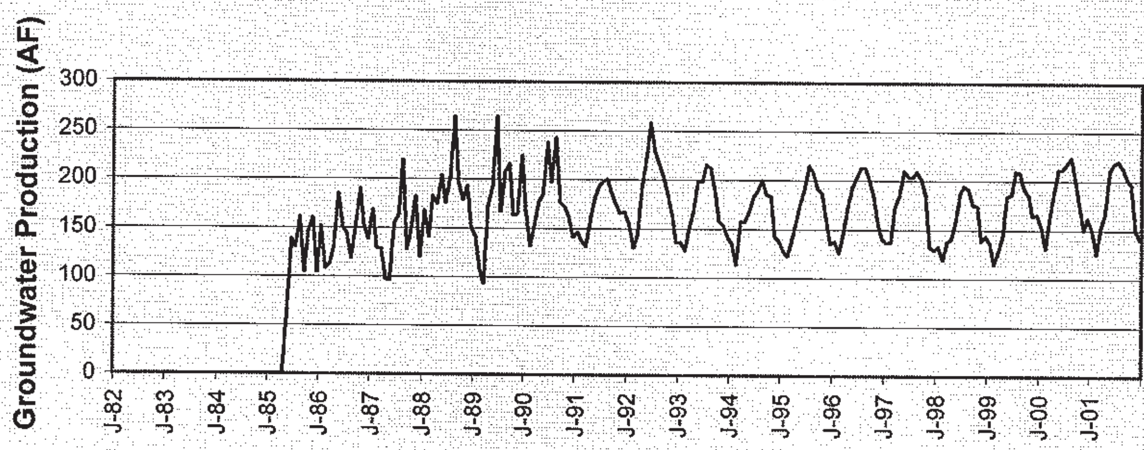


Figure 2.9b MCWD Monthly Groundwater Production



C. In the Gabilan Range and in the subsurface Salinas Valley, the Pliocene age Pancho Rico Formation is present. Although it was deposited in a different basin than the Purisima Formation, the Pancho Rico Formation contains fauna similar to and is litho logically identical to the Purisima Formation (Gribi, 1963). The thickness of the Pancho Rico Formation in the Marihart-Luckey well is about 1, 000 feet.

Pliocene and Quaternary nonmarine — This group includes three units — the Pliocene-Pleistocene Paso Robles Formation, the Pleistocene Aromas Sand, and undivided Quaternary surficial deposits. These sediments form most of the outcrops in the lower Salinas Valley and are widespread in the subsurface. Although aquifer recharge occurs through the Quaternary sediments, they do not constitute a major water supply sources. The surficial Quaternary sediments include floodplain deposits, alluvial fans, eolian deposits, fluvial and marine terraces, and basin deposits. The Paso Robles Formation and the Aromas Sand are important water sources for the Salinas Valley and include the 180-foot and the 400-foot aquifers.

Structure

Faults — The Salinas Valley is a tectonic depression between two structural highs, the Gabilan Range to the northeast and the Santa Lucia Range to the southwest (Dupré, 1991). Uplift of the Gabilan Range is largely due to transpressional forces from the San Andreas fault (Dohrenwend, 1975). One of the principal faults associated with uplift of the Santa Lucia Range is the San Gregorio fault; it is the primary fault west of the San Andreas Fault in central California, and extends northward from Big Sur across Monterey Bay to join the San Andreas Fault north of San Francisco. Some right-slip from the San Gregorio fault has been distributed eastward to intra-Salinian faults, including the Monterey Bay/Navy/Tularcitos fault zone. The Monterey Bay fault zone is a 6-to 9-mile-wide zone of short en echelon northwest-striking faults that are the offshore extension of the northwest-striking faults in the Salinas Valley and Sierra de Salinas (Greene and others, 1973). As shown on Cross Section B–B′, the Monterey Bay fault zone offsets Purisima Formation against Monterey Formation, with the southwest side upthrown. Another important strike-slip fault is the Rinconada fault that trends northwestward along the western side of the Salinas Valley. The Rinconada fault extends from Santa Margarita to Arroyo Seco. Near Arroyo Seco, the Rinconada fault dies out, steps east, and continues the Reliz fault. The Reliz fault extends at least as far north as Spreckels and likely joins the offshore Monterey Bay fault.

Gravity — A compilation map of isostatic gravity contours shows a prominent gravity low with a value of about -46 mGal near the western boundary of the former Fort Ord. This low extends as a northwest-southeast direction beneath the USGS DMW-1, Marina No. 11, Marina No. 12, and Fort Ord D wells (Langenheim and others, 2002). We interpret this gravity low as a concealed sedimentary basin with the deepest part near Marina and the former Fort Ord. This deep basin could partly explain the unusually thick section of Purisima Formation penetrated by the USGS DMW-1 well. The gravity low continues southeastward, forming a trough parallel to the axis of the Salinas Valley.

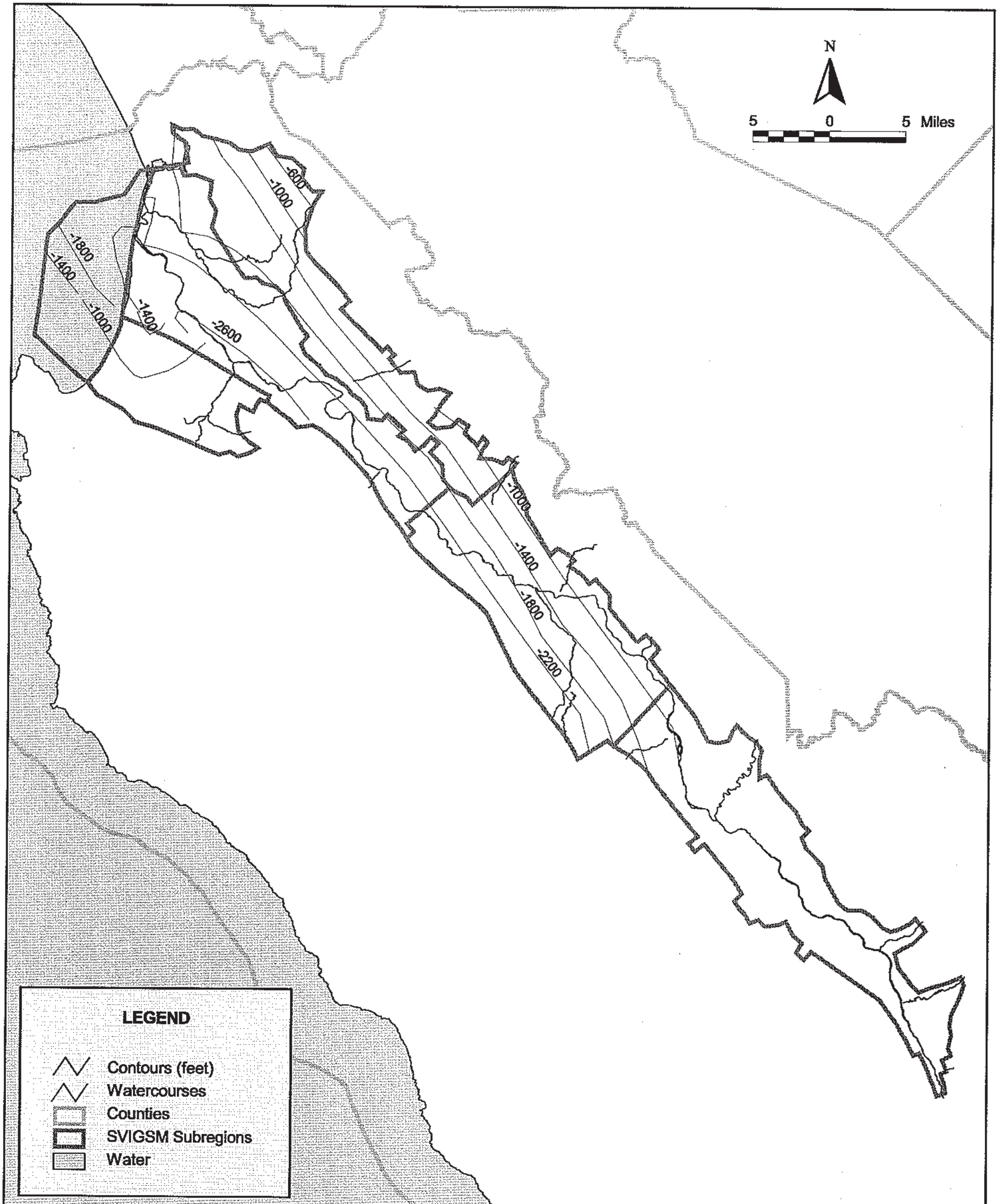
Monterey Formation subcrop — We contoured the top of the Monterey Formation and the bottom of the Upper Miocene to Pliocene marine sequence, which consists of the Purisima Formation near the coast and the Pancho Rico Formation in the central Salinas Valley. Picks were compiled from several sources. Sources included interpretation of well logs and gravity data in the coastal area (this study), previous work in the Seaside and Laguna Seco area (Rosenberg and Clark, 1994; Yates and others, 2002), and cross sections of the Salinas Valley (Thorup, 1983). The data from these sources were reconciled to develop a map encompassing the region from the coast southeastward to King City. The density of well control is greatest near the coast and decreases farther southeast. Likewise, the accuracy of the picks follows the same pattern.

The resulting structural contours were digitized and saved as ESRI shapefiles. Figure 2.10 shows the structural of the top of the Monterey Formation. To create a three-dimensional surface of the structure, the shapefiles were converted into ESRI grid format. The area between the contours was interpolated with the tension spline method using ArcView 8.2 Spatial Analyst software. The altitude of the structural contours was then joined to existing nodes of the Salinas Valley Integrated Groundwater and Surface Water Model for use in modeling flow in the Deep Zone.

Sources of Information

As part of modeling the deep aquifers, we developed three geologic cross sections. To construct the cross sections, a variety of sources were used. These include published geologic map compilations by Wagner and others (2002) and Rosenberg (2001), unpublished oil well records (on file at the California Division of Oil and Gas Resources (CDOGR), Santa Maria, California), unpublished scout reports (Gribi, E.A., and Thorup, R.R., unpublished notes), unpublished micro-paleontology reports (Chevron, undated; Ingle, 1989), and unpublished water well records (on file at the MCWRA, the MCWD, and the Monterey Peninsula Water Management District [MPWMD]). Information from these sources was integrated to form a coherent, internally consistent model of the subsurface geology extending from Moss Landing southward to Seaside, and from the offshore Monterey Bay southeastward to near Spreckels.

Figure 2.11 shows a cross section location map. Cross Section A-A' (Figure 2.12a) is parallel to the coast and extends from Seaside northward to the Elkhorn area. Cross Section B-B' (Figure 2.12b) is perpendicular to the coast and extends from approximately 9 miles offshore



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DEEP AQUIFER INVESTIGATIVE STUDY

Structural Contours for Top of Monterey Formation

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FIGURE 2.10

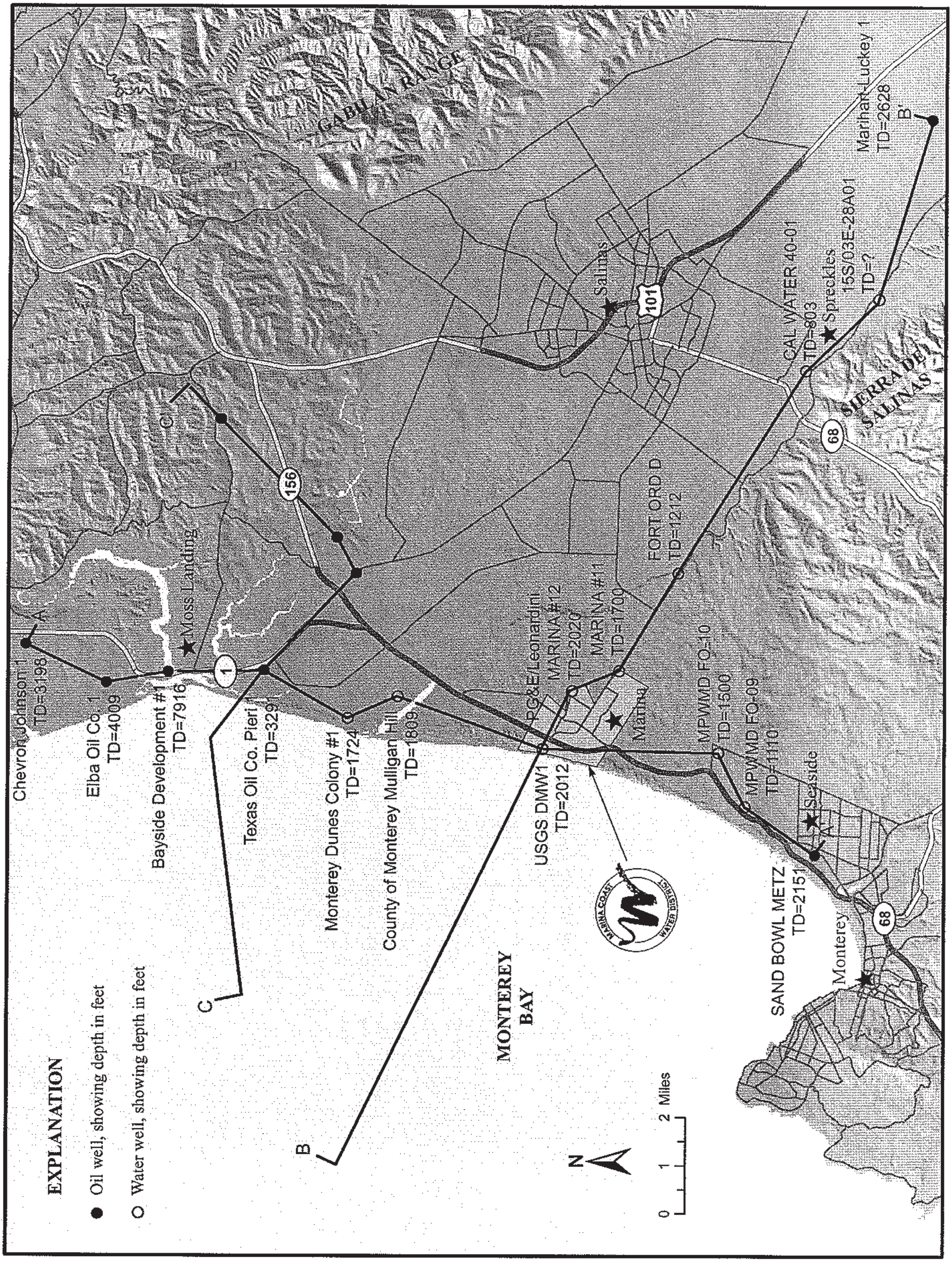
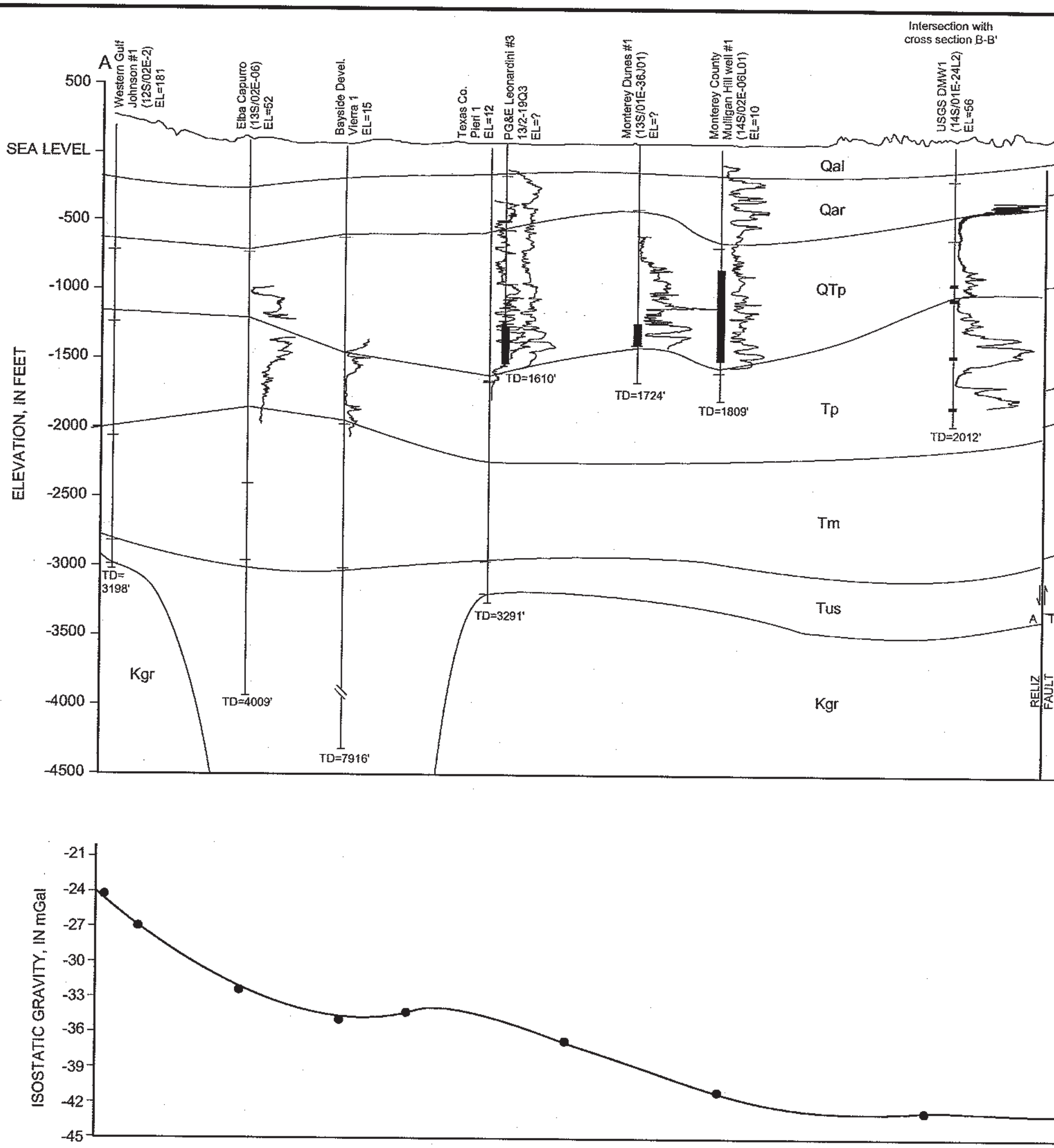


Figure 2.11 Cross Section Location Map



SOURCES OF DATA

Geologic data compiled from published mapping (Hanson and others, 2002; Wagner and others, 2002; Rosenberg, 2001), oil well logs (CDOG files), unpublished scout reports (Gribi, E.A., Thorup, R.R.), unpublished micro-paleontology reports (Chevron, undated; Ingle, J.C., 1989; McDougall, K., 2001), water well logs (MCWRA, MCWD, and MPWMD files).

Gravity data from USGS pubished mapping (Langenheim and others, 2002).

Topography from USGS National Elevation Dataset (30-m resolution). Bathymetry from Degnan and others, 2001 (30-m resolution) southeastward to near Spreckels. Cross Section C-C' (Figure 2.12c) is a modified version of a cross section by Geoconsultants (1996), with the area extended approximately 7 miles offshore and 4 miles northeastward to include the Fred Ash No. 2 wildcat oil well. The following descriptions discuss data for key wells used to constrain the cross sections.

Bayside Development Vierra 1 — According to CDOGR records, General Petroleum spudded this well in November 1944, drilling it to a depth of 5,739 feet. At that point Bayside Development took over the drilling, deepening the well to 7,818 feet, then abandoned it in February 1945. Lithologic picks are from e-logs, scout notes, Starke and Howard (1968), an unpublished correlation sheet by G.L. Harrington (1945), and unpublished data from the California Division of Mines and Geology (written communication to J.C. Clark, dated December 1967). The well never reached basement to its drilled depth.

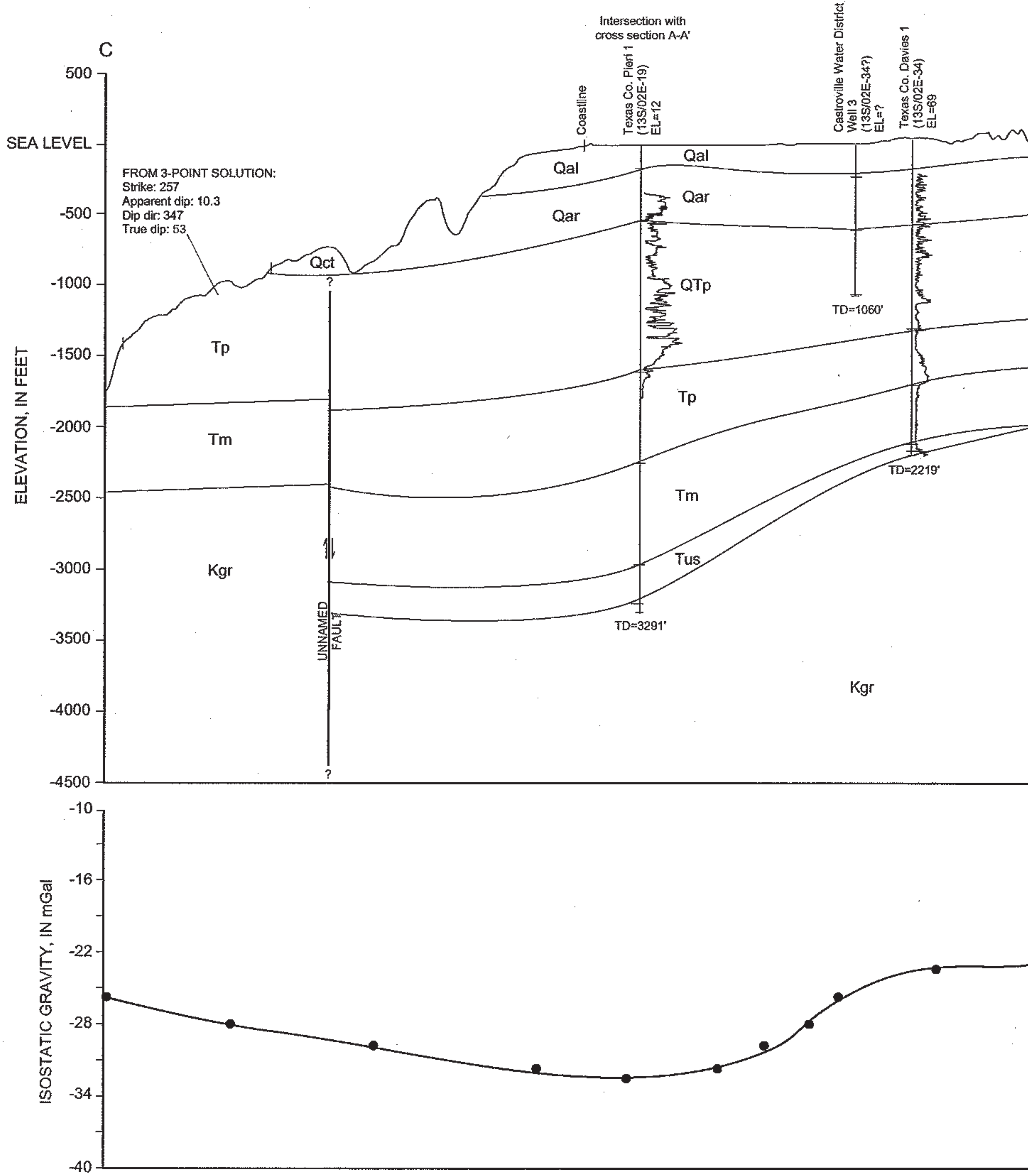
California Water Service 40-01 — This well was drilled in November 1983 to a depth of 912 feet. Picks are based on the DWR drillers log and an e-log. This well bottomed in the Paso Robles Formation.

Castroville Water District 3 — No drillers log was available for Castroville Water District Well 3. Picks were from an e-log contained in a report by Geoconsultants (1996). The well is 1,060 feet deep and bottoms in the Paso Robles Formation.

Elba Capurro — The Elba No. 1 well was drilled to a depth of 3,970 feet in April 1937 and abandoned in February 1939. There are no driller or geophysical logs of this well in CDOGR files. Picks were from a scout report (Gribi, E.A., and unpublished notes), a micropaleontology report (Goudkoff, P.P., 1937), an unpublished e-log (which shows a total depth of 4,009 feet, and unpublished paleontology records (Brabb, E.E., written communication, 2002). Of interest is a letter in the CDOGR files from the Deputy Supervisor of the Division of Oil and Gas, dated November 22, 1938, which reports fresh water to a depth of 1,280 feet, below which is brackish to salt water. The well never reached basement to its drilled depth.

Fort Ord D — The Fort Ord D well was drilled by Geotechnical Consultants to a depth of 1,162 feet in January–February 1995. Lithologic picks are from the geologic log and e-log. The well bottomed in the Paso Robles Formation.

Fred Ash & Sons 2 — Local water well driller Fred Ash drilled this well as a wildcat oil play in September 1966. The well was drilled to 1,959 feet and bottomed in "sticky blue green shale" which we interpret as the Monterey Formation. CDOGR records state that no oil shows were observed and the well was capped with the intent of converting it into a water well. Stratigraphic picks are based on driller's log and an e-log annotated by R.R. Thorup.



SOURCES OF DATA

Geologic data compiled from published mapping (Hanson and others, 2002; Wagner and others, 2002; Rosenberg, 2001), oil well logs (CDOG files), unpublished scout reports (Gribi, E.A., Thorup, R.R.), unpublished micro-paleontology reports (Chevron, undated; Ingle, J.C., 1989; McDougall, K., 2001), water well logs (MCWRA, MCWD, and MPWMD files).

Gravity data from USGS pubished mapping (Langenheim and others, 2002).

Topography from USGS National Elevation Dataset (30-m resolution). Bathymetry from Degnan and others, 2001 (30-m resolution)

Marihart-Luckey 1 — The Marihart-Luckey well was drilled by R.R. Thorup as a wildcat oil well to a depth of 2,628 feet in November 1958. No oil shows were noted according to CDOGR records so the well was abandoned. The CDOGR Report on Proposed Operations notes that non-marine strata were encountered from surface to total depth, and that the age of the bottom was Pliocene. Based on regional geologic mapping, we interpret these rocks as belonging to the Pancho Rico Formation.

Marina Well Nos. 11 and 12 — Well No. 11 was drilled in November–December 1985 to a depth of 1,700 feet. Well 12 was drilled in November 1988 to a depth of 2,020 feet. Geologic reports by Geoconsultants (1986, 1989) and a paleontology report by Ingle (1989) were used for the picks. However, one important difference in interpretations is that Ingle interprets Well Nos. 11 and 12 as bottoming in Pleistocene sediments, whereas we interpret them as bottoming in the Purisima Formation. Our interpretation is based on correlating e-log markers from the USGS DMW-1 well and the statement by Ingle (1989, p. 5) that "many of the species have a broad Pliocene-to-Recent age range" which allowed us to relax the interpretation that these wells were strictly in Pleistocene sediments.

Monterey County Mulligan Hill #1 — This well was drilled as a test well to a depth of 1,809 feet in September–December 1976. Based on paleontologic analysis of ditch and bit samples, Thorup reported that the well bottomed in Monterey Formation (1983, plate 10).

Monterey Dunes #1 — This well was originally drilled March–May 1972 to a depth of 687 feet. Subsequently, in late January 1977, it was deepened to 1,724 feet. Picks are from drillers logs and e-logs. The well bottomed in what we interpret as Purisima Formation.

MPWMD FO-09 and FO-10 — Well FO-09 was drilled in August 1994 to a depth of 1,100 feet and Well FO-10 was drilled in September 1996 to a depth of 1,500 feet. Picks were from MPWMD Technical Memorandums 94–07 and 97–04 (Oliver, 1994, 1997). Although these reports show the wells bottoming in the Santa Margarita Sandstone, we interpret them as reaching the Purisima Formation based on review of preliminary cross sections by the logging geologist J.W. Oliver (MPWMD).

PG&E Leonardini #3 — This well is near the Pieri well and was used to refine the upper stratigraphy. The well was drilled February–May 1980 to a depth of 1,610 feet. Picks are from the DWR driller's report and an e-log.

Sand Bowl Metz — The driller log in the CDOGR records is scanty (0–565': surface sand, 565-1,160': shale, 1,160–1,430': sand, 1,430–1,890': sandy shale, and 1,890–2,151': basement rock). The CDOGR files also contain an e-log for this well. To supplement these data, we used the driller's log and e-log from the nearby Monterey Sand Company water well (15S/01E-15P02) shown on Cross Section B–B′ of Staal, Gardner & Dunne (1990).

Texas Co. Davies — Scout records reveal that the Davies well was drilled as a play based on geophysical methods (E.E. Gribi, unpublished data). The Davies well was drilled and abandoned in August 1949. The well reached a depth of 2,219 feet and bottomed in granitic basement. Picks were from an e-log annotated by R.R. Thorup; ditch, sidewall, and core sample logs; and scout records by Gribi. Only the sidewall and core sample data are in the CDOGR files. Thorup's e-log notes show "Purisima" extending from 1,320 to 1,680 feet. Also of interest is a note on the CDOGR Well Summary Report, which lists the fresh water/salt water contact at 1,690 feet depth.

Texas Co. Pieri — The Pieri well was drilled and abandoned in August 1949 to a depth of 3,291 feet. Picks are from CDOGR records and an e-log. The well reached basement.

Western Gulf Johnson 1 — The Johnson 1 well was drilled in November–December 1932 to a depth of 3,198 feet. No records for this well were available from CDOGR. The picks were made from the Western Gulf Oil Company oil well log (dated February 17, 1933) and a Standard Oil Company of California paleolog (dated January 27, 1953). The well bottomed in granitic rock.

USGS DMW-1 — The USGS well is the most recent (2000) and most detailed well in the deep aquifer. Core samples, geophysical logs, and paleontologic analysis show that this well encountered a thick section of Purisima Formation. Picks are from Hansen and others (2002).

AQUIFER PARAMETER AND HYDRAULIC RELATIONSHIPS

Aquifer parameter data are limited. Transmissivity values are available from a few wells where formal aquifer tests were performed at the time of well completion. Additional transmissivity data can be estimated from specific capacity data utilizing the Logan approximation (Logan, 1964). Hydraulic conductivity data from slug testing are available for the four separate completions of the USGS monitoring well. Hydraulic conductivity tests are also available for a few sidewall cores from MCWD Well 10. No formal estimates of storativity have been advanced. The available aquifer parameter data are presented in Table 2.2.

Table 2.2 Aquifer Parameter Data

State Well No.	Name	Method	Screen Length (feet)	Transmissivity (gpd/ft) tested	Transmissivity (gpd/ft) estimated	Hydraulic Conductivity (ft/day)
T13N/R2E-19Q03	PG&E/Leonardini	SC	270		12,755	6.3
T13N/R2E-32M02	Sea Mist	SC	810		23,789	3.9
T14N/R2E-06L01	Co. of Monterey	SC	660		32,606	6.6
T14N/R2E-24L05	DMW-1-4	slug	20		359	2.4
T14N/R2E-24L04	DMW-1-3	slug	20		2086	13.8
T14N/R2E-24L03	DMW-1-2	slug	20		1137	7.6
T14N/R2E-24L02	DMW-1-1	slug	40		4338	14.5
T14N/R2E-30G03	MCWD No. 12	Pumping	240	29,700		16.5
T14N/R2E-32D04	MCWD No. 11	Pumping	200	24,300		16.4
T14N/R2E-31H01	MCWD No. 10	Pumping	210	40,000		25.4
T14N/R2E-31H01	MCWD No. 10 @ 842	lab	--	--	--	4.6
T14N/R2E-31H01	MCWD No. 10 @ 1460	lab	--	--	--	0.6
T13N/R1E-25R01	Mty Dunes Colony #3	SC	60		9,091	20.2

Methods: SC – Logan Approximation Pumping – Pumping test
Slug – Slug test Lab – sidewall sample in laboratory

WELL INTERFERENCE TESTS

MCWD Well Nos. 10, 11, and 12. In order to supplement the available aquifer parameter data and to better understand the interactions between MCWD wells for modeling purposes, a well interference test was performed. Each MCWD well was equipped with a water level data logger. Each of the wells was shut down for a week while the other two wells met system demand. The results of the test are presented in Figure 2.13.

Well No. 12 was shut down for the first week followed by Well 10 for the second week and Well No. 11 for the third week. During Week One, the Well No. 12 water level record displayed a conventional recovery response. The recovery curve was undisturbed by interference with other wells although the operational cycles of Well Nos. 10 and 11 during this period are obvious in their records. Well No. 10 was off for Week Two. Well No. 10 also showed a recovery curve; however, this curve was disturbed with a classic interference signature, corresponding to the operations of Well No. 11. During the third week and part of the fourth, Well No. 11 was off. Again, the recovery curve of this well was disturbed with the interference signature from Well No. 10, demonstrating the mutual interference between Well Nos. 10 and 11.

The interference between Well Nos. 10 and 11 is relatively consistent with the expected theoretical response utilizing the available aquifer parameters. The lack of measurable response in Well No. 12 suggests that this well is not in hydraulic communication with Well Nos. 10 and 11. The observed and predicted responses are presented in Table 2.3.

Figure 2.13 Well Interference Testing for MCWD Wells Nos. 10, 11, and 12

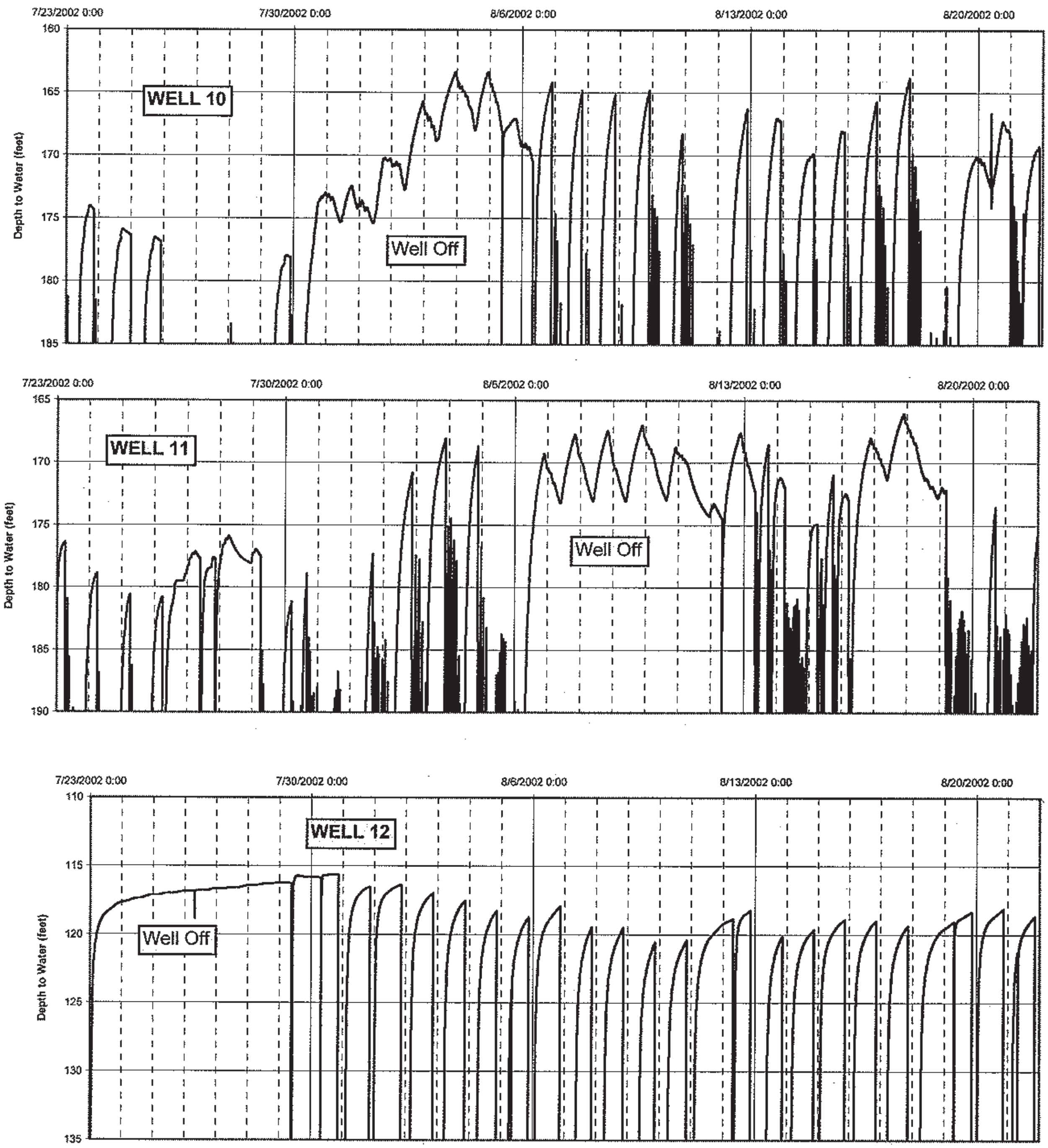


Table 2.3 The Observed and Theoretical Response from MCWD Wells

Wells	Distance (feet)	Discharge Rate (gpm)	Observed Drawdown Response (feet)	Theoretical Drawdown Response (feet)
Well 10 on 11	2,850	1,500	3	8.1
Well 11 on 10	2,850	1,800	5	9.7
Well 10 on 12	5,650	1,500	0	2.7
Well 11 on 12	3,950	1,800	0	6.1

Assumptions: Convention Theis Analysis, Transmissivity 31,000 gpd/ft, Storativity 0.0001, 0.25 days
Note: Storativity is assumed and regional leakage could not be determined due to insufficient data

The difference between observed and theoretical responses likely derives from the fact that each aquifer from which these wells produce is more accurately an aggregation of smaller aquifers, making invalid some of the assumptions required for theoretical prediction. Still, the magnitude of the observed interference in Well Nos. 10 and 11 is consistent with predicted responses. The lack of any interference response to the combined pumping of Well Nos. 10 and 11 on Well 12 is significant, suggesting hydraulic isolation of this well relative to the other two. This finding is consistent with the geologic interpretation that places Well No. 12 in the Purisima Formation, whereas Well Nos. 10 and 11 are largely in the Paso Robles Formation.

Close inspection of the recovery record of Well No. 12 shows minor variations in water levels superimposed on the recovery curve. Closer inspection of these data (Figure 2.14 the variations are a tidal signature that correlate directly with the tides in Monterey Bay.

USGS Monitoring Well verses MCWD Well No. 12. Three of the four wells at the USGS Monitoring Well are completed in the Purisima Formation (USGS, 2002). Geologic interpretation and the well interference data indicate that MCWD Well No. 12 is also completed in the Purisima Formation. Figure 2.15 compares water level data collected at the four USGS monitoring wells with data collected from Well No. 12 during the Well Interference exercise described above. Most evident in Figure 2.14 are the strong tidal signature in all of the USGS wells, and the strong correlation and lack of lag time with tides in Monterey Bay. Comparison of the pumping schedule of Well No. 12 and the water level records of the four monitors suggests a response in the deepest monitor (DMW-1-1), corresponding to the shut down and start-up of Well No. 12. There is a similar, although more subdued, response in the next deepest well (DMW-1-2). No evidence of response is apparent in the other two monitors (DMW-1-3 and -4). These results appear consistent with the perforated elevations of the monitoring wells and Well No.12. The latter is perforated between elevations -1283 to –1833

Figure 2.14 MCWD Well No. 12 -- Idle Period Record

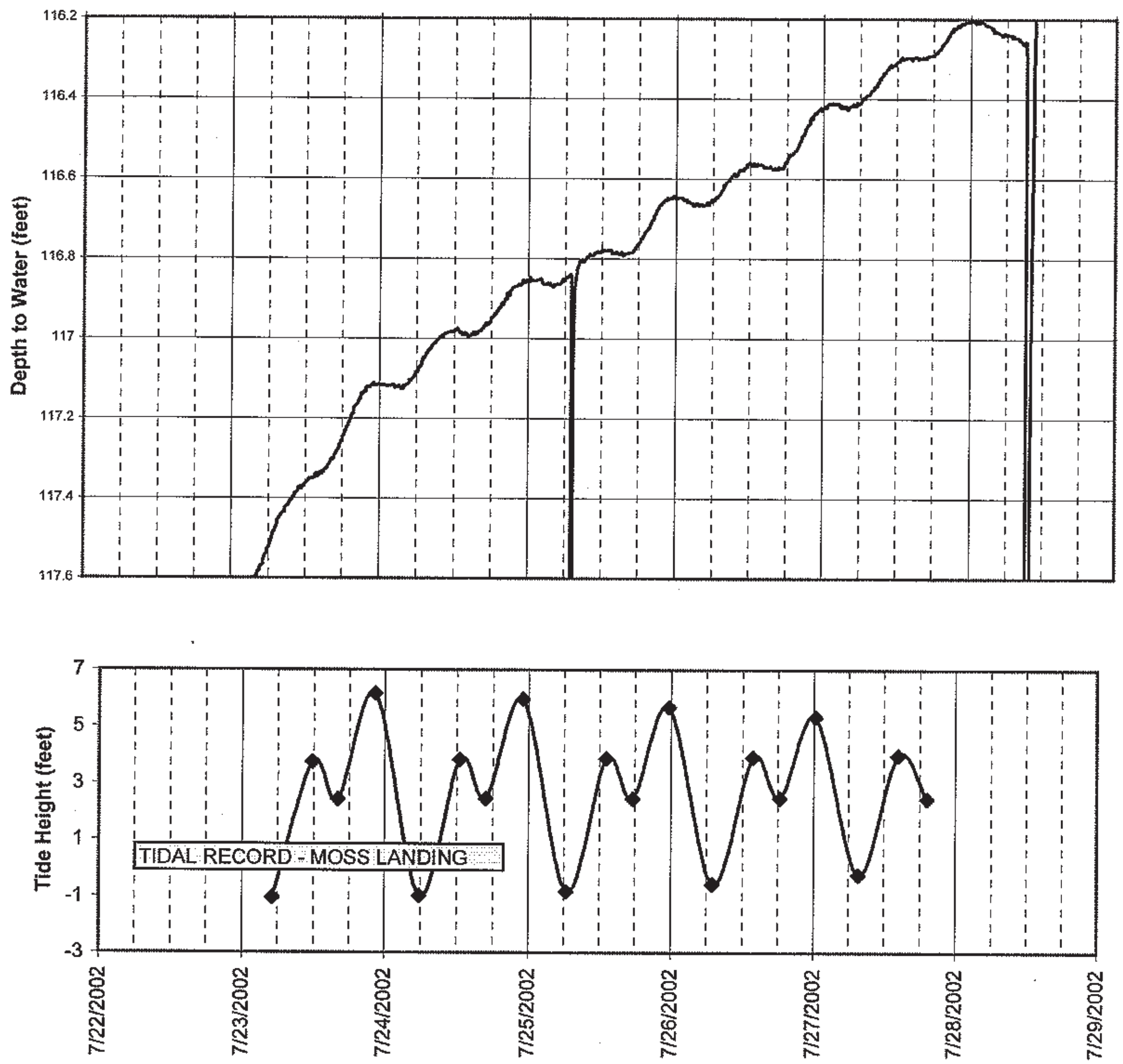
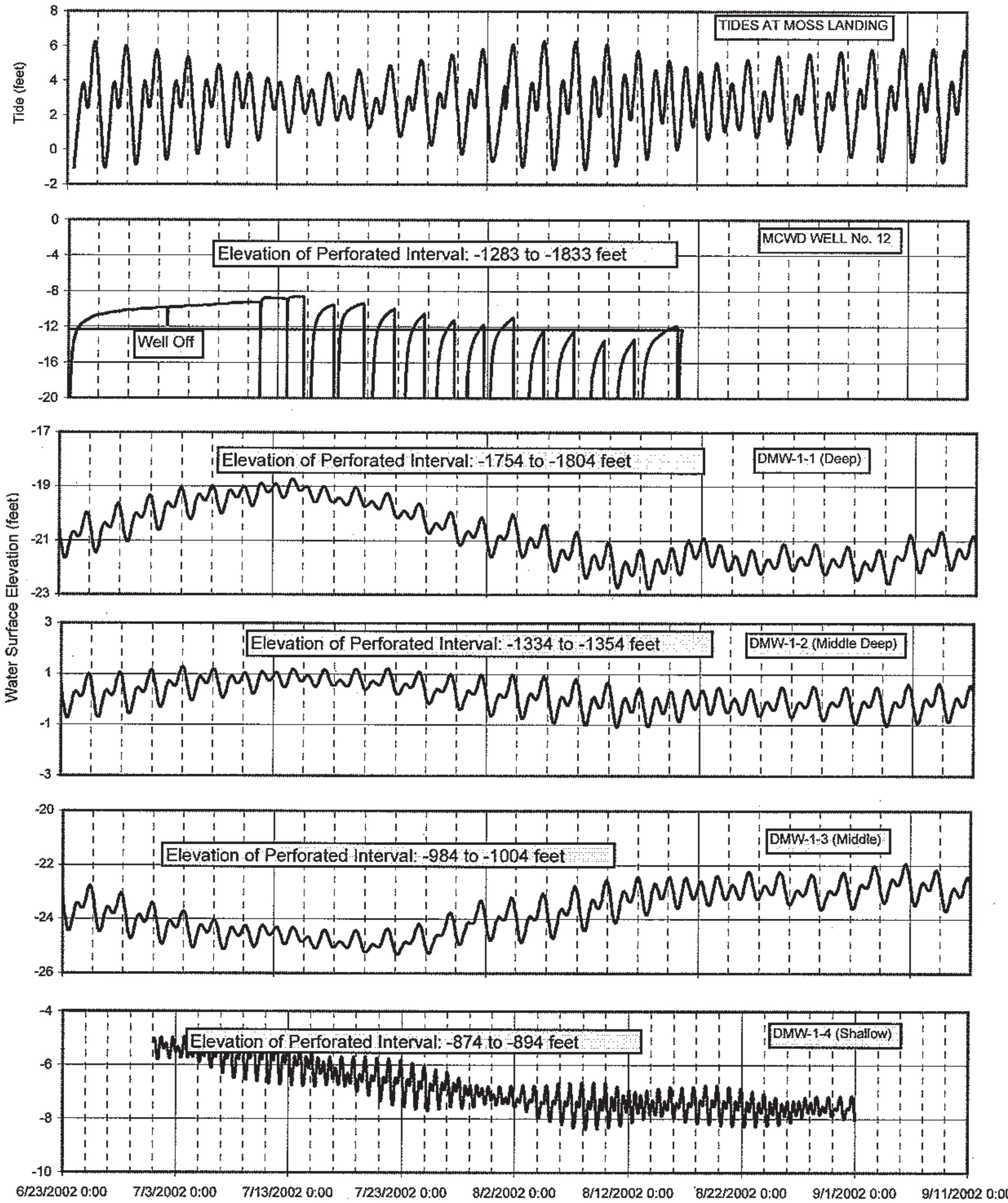


Figure 2.15. USGS Monitoring Well vs. MCWD Well No. 12



feet, whereas DMW-1-1 and DMW-1-2 are perforated at elevations -1754 to –1804 feet and -1334 to -1354 feet, respectively.

TIDAL FLUCTUATIONS

As noted above, the USGS monitoring wells, as well as other wells, all show a strong tidal signature. The water level data reveals no evidence of a significant time lag between the ocean and aquifer response. Because of the lack of lag time, it is speculated that the response is the result of cyclic loading of the aquifer, rather than hydraulic fluctuations at a possible outcrop.

Assuming cyclic loading, the tidal response data can be utilized to calculate a storage coefficient for these aquifer units. The ratio of aquifer water level change to tidal change is the tidal efficiency of the aquifer. In all four wells, the aquifer response is approximately 2 feet of change in response to 6 feet of tidal fluctuation, or a ratio of 0.33. Tidal efficiency can be related to storage coefficient utilizing the following equation (Lohman, 1972):

$$S = \theta \rho b \beta \, (1/1\text{-}TE)$$

Where:	θ = porosity	= 0.3
	ρ = specific weight of water	= 0.434 lbs/in^{2}ft
	b = aquifer thickness	= 20 feet
	β = Inverse of water elasticity	= 3.3×10^{-6} in^2/lb
	TE = tidal efficiency	= 0.33

Utilizing these values, a specific storage coefficient of 1.3×10^{-5} (dimensionless) can be calculated, a value considered very appropriate for confined conditions. This value is lower than that estimated from the well interference analysis. However, this value is not influenced by leakage effects that may be moderating drawdown at the production wells. For this reason the value derived from the tidal data may be more appropriate for the aquifer system as a whole.

IMPLICATIONS OF HYDROGEOLOGIC FINDINGS

Taken together, the overall conclusion that can be derived from the collected data and the preliminary analysis is that the deep aquifers from which MCWD extracts its water supply is actually two separate aquifer systems. Existing geologic and water chemistry data suggest that MCWD Well Nos. 10 and 11 produce primarily from the Paso Robles Formation, whereas MCWD Well No. 12 produces from the Purisima Formation. In contrast, the deep aquifers wells in the Castroville area are interpreted to produce from the Paso Robles Formation. Aquifer response data suggests these two aquifer systems are hydraulically isolated from each other.

RECHARGE CONSIDERATIONS

The hydrogeologic interpretation of the deep aquifers raises questions regarding the nature and magnitude of recharge to these aquifers. Well No. 12 is completed in and produces primarily from the Purisima Formation. The Purisima Formation is not exposed on land in Monterey County. The closest land exposure is in Soquel where the Formation is the primary source of water for the Soquel Creek Water District. Therefore, recharge for the Purisima Formation (Well 12) is primarily leakage from overlying aquifers. Some portions of extractions may be supported by depletion of groundwater storage. However, the low estimates for storage coefficients for this aquifer system suggest that the volume of groundwater that can be removed from storage is not large.

The Paso Robles Formation crops out extensively throughout the Salinas Valley region. However, in most locations, the Formation underlies the Salinas Valley alluvium and Aromas Sands that comprise the 180-foot aquifer and upper portion of the 400-foot aquifer. The alluvium receives recharge primarily from the river and irrigation return flows. In areas where Paso Robles is overlain by alluvium, recharge is from leakage from overlying aquifers.

There are 37,500 acres of Paso Robles Formation exposed in Monterey County. Of this area, 33 percent (or 12,400 acres) is exposed in the El Toro–Laguna Seca Area where the Formation constitutes as recharge area for these areas. The remaining acreage of Paso Robles Formation is exposed on the west side of the Salinas Valley. However, much of this area is in the rain shadow of the Santa Lucia Range. Annual rainfall on the outcrop areas is less than 12 inches. With this limited rainfall, direct recharge to the outcrops of Paso Robles Formation from precipitation is minimal, if any. Given the hydrogeologic setting, extractions from the Paso Robles Formation also appear to be primarily supported by leakage from the overlying shallow aquifer system.

The implications regarding recharge mechanisms are generally supported by the water level history of MCWD wells. All three of MCWD wells show a similar water level history: a rapid decline as local storage is depleted, then a stabilization as extractions equilibrate with leakage. This interpretation is best evaluated by modeling.

SECTION 3 SALINAS VALLEY INTEGRATED GROUND AND SURFACE WATER MODEL (SVIGSM) UPDATE

The purpose of this section is to describe the development of the SVIGSM, its applications in various studies, the modifications made to the deep aquifer layer of the model and any related changes to the hydrogeologic parameters, and the summary results of recalibrating the model.

The section is divided as follows:

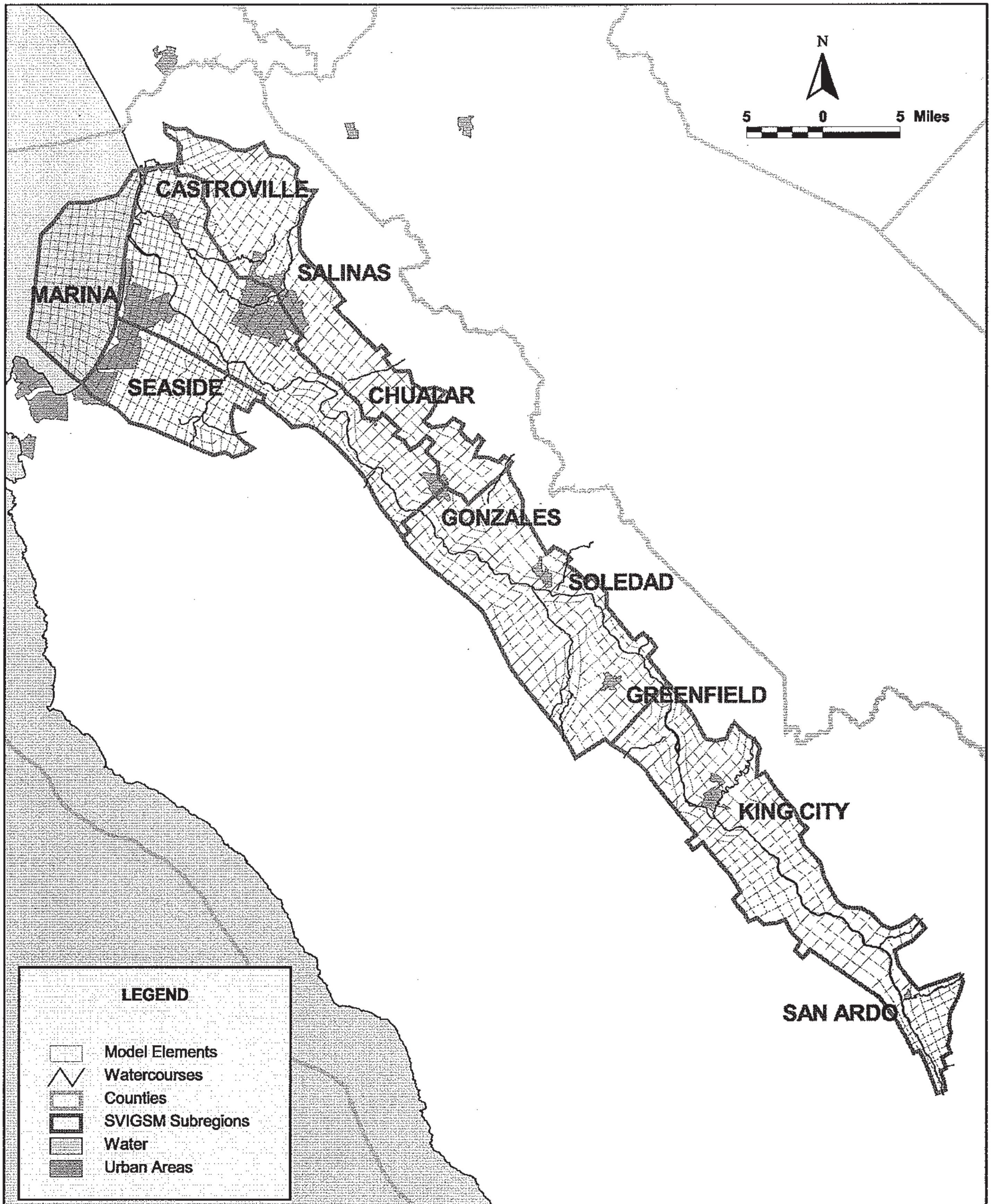
- SVIGSM Background provides information about the development of the model, updates and modifications to the model in the last 5 years, capabilities of the model, and applications of the model;
- Code Update provides information about older and recently released IGSM codes and the impacts of the code update on model results;
- Data Update provides information about the impacts on the model simulation due changes in model stratigraphy and the efforts to mitigate those impacts.

Model results presented in Section 3 are associated with historical water years 1959 through 1994, representing the historical record of when the Salinas River was regulated.

SVIGSM BACKGROUND

The SVIGSM is the most recent analytical tool that analyzes the hydrologic conditions in the Salinas Valley groundwater basin. Prior to the development of SVIGSM, there were two significant modeling efforts at a basin-wide level. The first model was developed in 1978 by the USGS and the second model was developed in 1986, based on the predecessor to IGSM, the FEGW14. Both models focused on the groundwater flow in the basin, and had limited interaction with the surface processes. The previous modeling efforts did not consider the special importance of the hydrologic processes of the Salinas Valley groundwater system with respect to land and water use processes and daily rainfall and runoff in the main watershed and tributary watersheds, and to the regulation of Salinas River flows by Nacimiento and San Antonio Reservoirs.

The SVIGSM, developed in 1993, utilized the databases from the previous modeling efforts with significantly additional data developed as part of the Salinas River Basin Management Plan (BMP). The model development is documented in the report on BMP Task 1.09 (Montgomery Watson, 1995). The SVIGSM model network is shown in Figure 3.1.



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SVIGSM Model Grid

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FIGURE 3.1

The SVIGSM has gone through substantial updates and revisions since its initial development. These updates are reported in the *Salinas Valley Integrated Ground Water and Surface [water] Model Update* (Montgomery Watson, 1997), *Salinas Valley Historical Benefits Analysis (HBA)* (Montgomery Watson, April 1998), and *Update of the Historical Benefits Analysis (HBA) Hydrologic Investigation in the Arroyo Seco Cone Area: Monterey County Water Resources Agency* (Ali Taghavi and Associates, February 2000). The following summarizes the data and model revisions performed as a result of these studies. The reader is referred to the individual reports for additional discussion.

The following was specifically revised as a result of the 1997 work:

1. 1989/1991 land use and irrigated crop acreages were included;
2. assumptions associated with the Truck crop acreages that remain idle during crop rotation were finalized and included in the model;
3. the vegetation corridor along the Salinas River was coded as riparian as opposed to native vegetation;
4. distribution of hydraulic conductivity was modified; and
5. aquifer parameters were revised to ensure the proper calibration of model results to the historical groundwater conditions for the period from October 1969 to September 1994.

The following was specifically revised as a result of the April 1998 work:

1. the October 1969 to September 1994 simulation period was extended to October 1949 to September 1994;
2. land use and irrigated crop acreages were updated to reflect the lengthened simulation period;
3. crop evapotranspiration and irrigation efficiencies were changed from a static data set to a transient data set to allow for changes in agricultural technology and techniques over the 50-year simulation period;
4. urban water demand and surface water diversions were updated to reflect the lengthened simulation period;
5. groundwater pumping distribution was updated to reflect the lengthened simulation period and to reflect changes in land development over that time;
6. specific capacities and hydraulic conductivities in the Arroyo Seco Cone area were updated based on studies conducted by others;

7. soil parameters were adjusted to provide better consistency and to improve the overall water balance of the valley; and

8. model simulation results were verified with observed data.

Figure 3.2 shows the location of calibration wells used in the 1998 work. Figures 3.3a through 3.3e show a statistical evaluation of the SVIGSM (v. 4.18, 1998) calibration performance associated with the 1998 work.

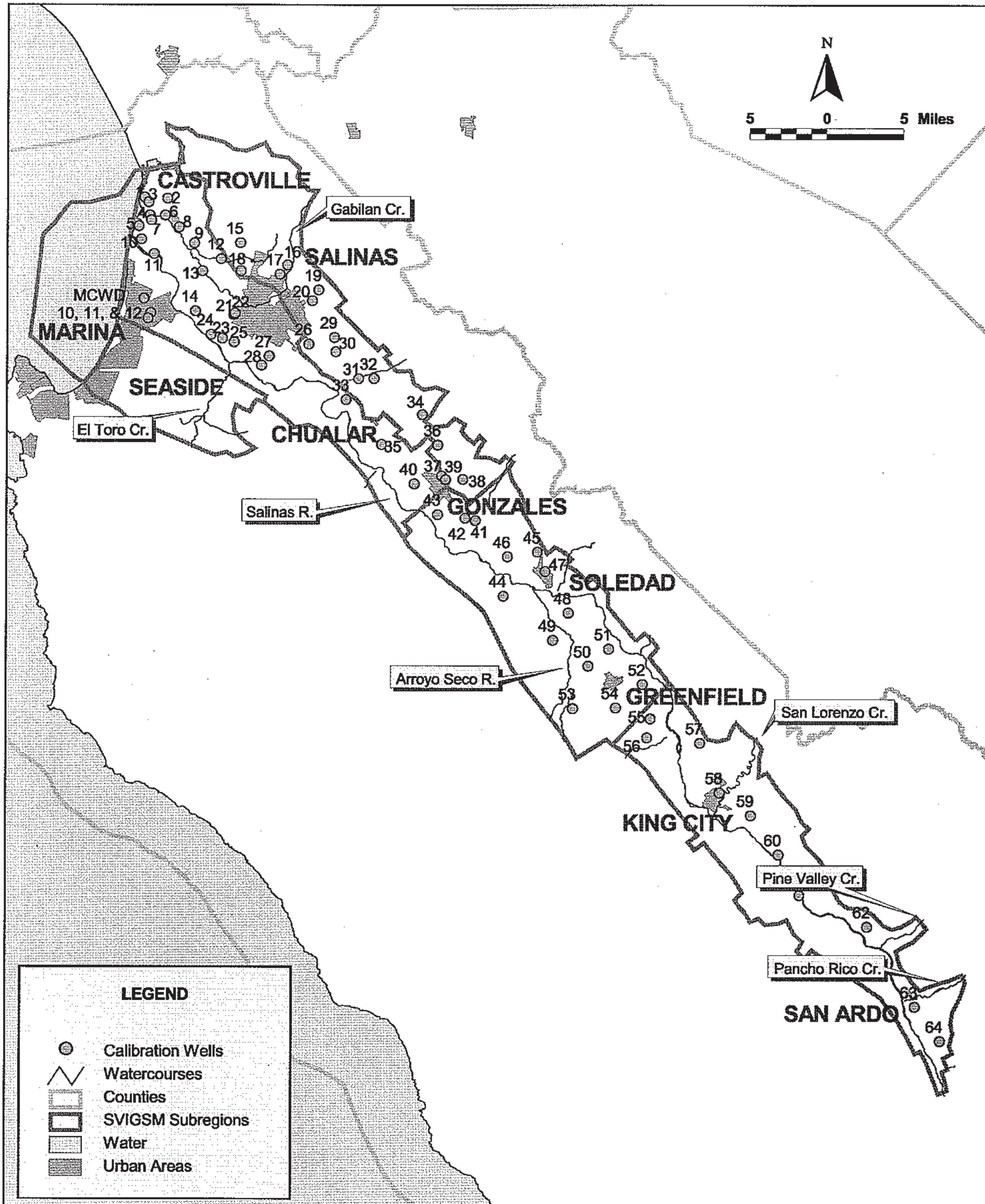
The following was specifically revised as a result of the February 2000 work:

1. the SVIGSM calibration in the Arroyo Seco Cone area was refined to include the latest streamflow and hydrogeologic data available, and

2. reservoir operation routine was revised to more appropriately simulate the potential diversions of the water from the Nacimiento reservoir by San Luis Obispo County, under the baseline and alternative scenario analyses.

The SVIGSM contained the following features as a result of these updates:

- Simulation of the vertical and horizontal groundwater flow in the Salinas Valley through water-bearing formations in the valley:
    - The 180-foot, 400-foot, and the Deep Aquifer in the Pressure subregion;
    - The East Side Shallow, East Side Deep, and the Deep Aquifer in the East Side subregion;
    - The Shallow and Deep Aquifers in the Forebay subregion; and
    - The unconfined aquifer in the Upper Valley
- Simulation of the Salinas River and its major tributaries from Nacimiento and San Antonio Reservoirs to the Monterey Bay;
- Simulation of the interaction of the Salinas River, and its tributaries, with the groundwater system;
- Simulation of Nacimiento and San Antonio Reservoirs based on specific operational rules for water supply and flood control;
- Simulation of reservoir operations that can satisfy those diversion requirements that derive from water rights and environmental flow requirements;
- Simulation of the rate and extent of seawater intrusion;



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Location of Calibration Wells

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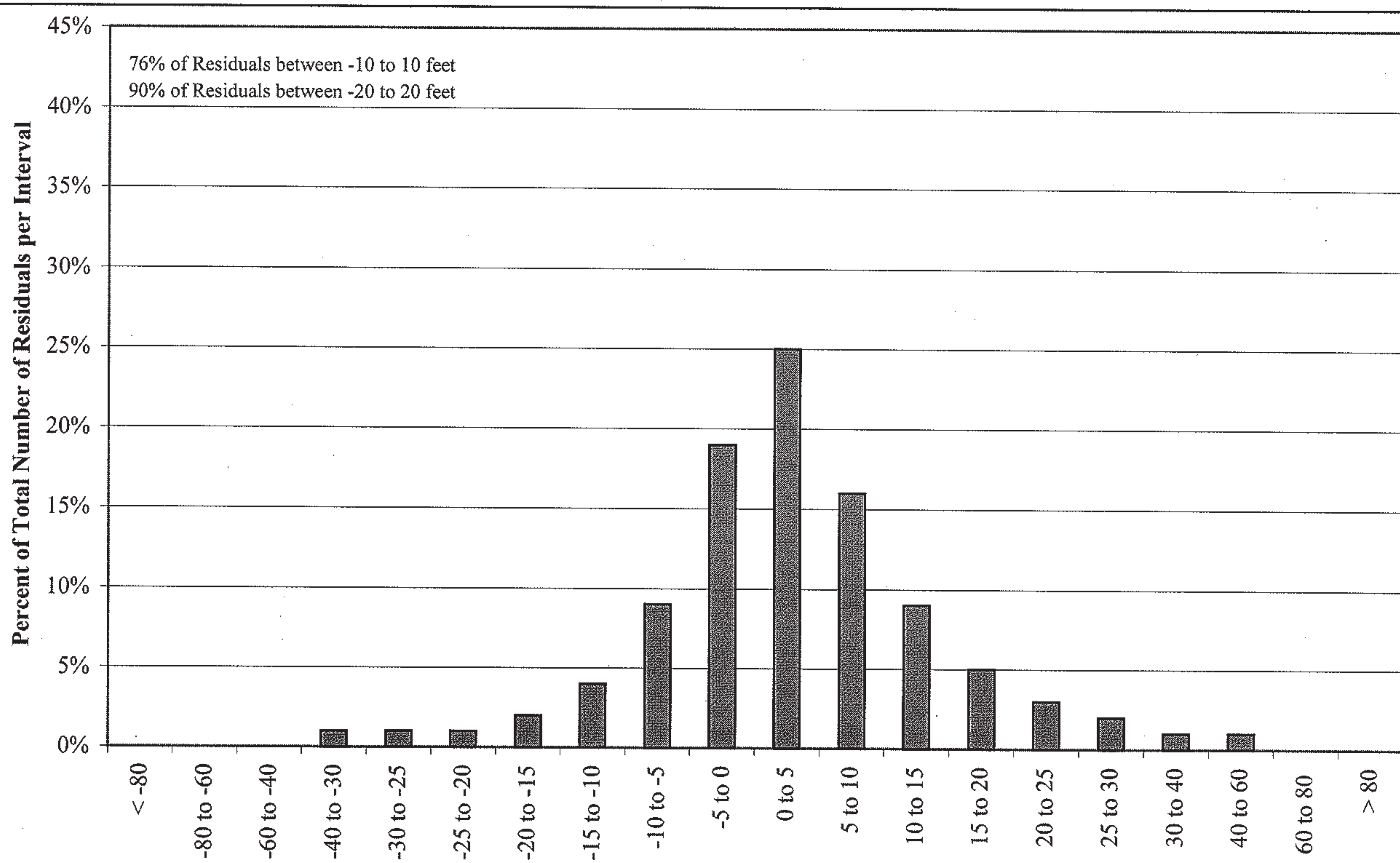
FIGURE 3.2



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Histogram of Residual Groundwater Levels between SVIGSM Version 4.18 and Historic Data for Water Years 1959 through 1994

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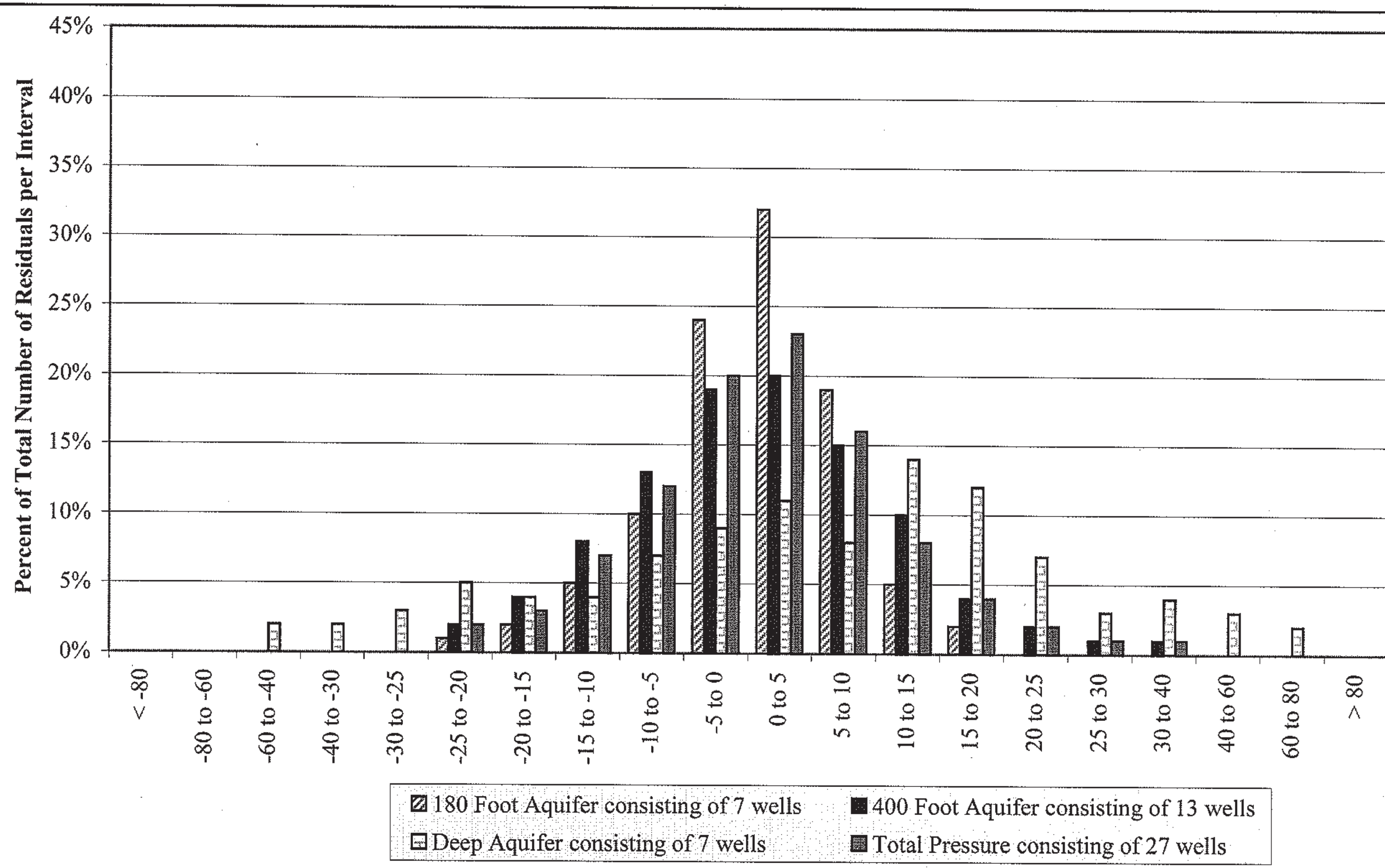
FIGURE 3.3a



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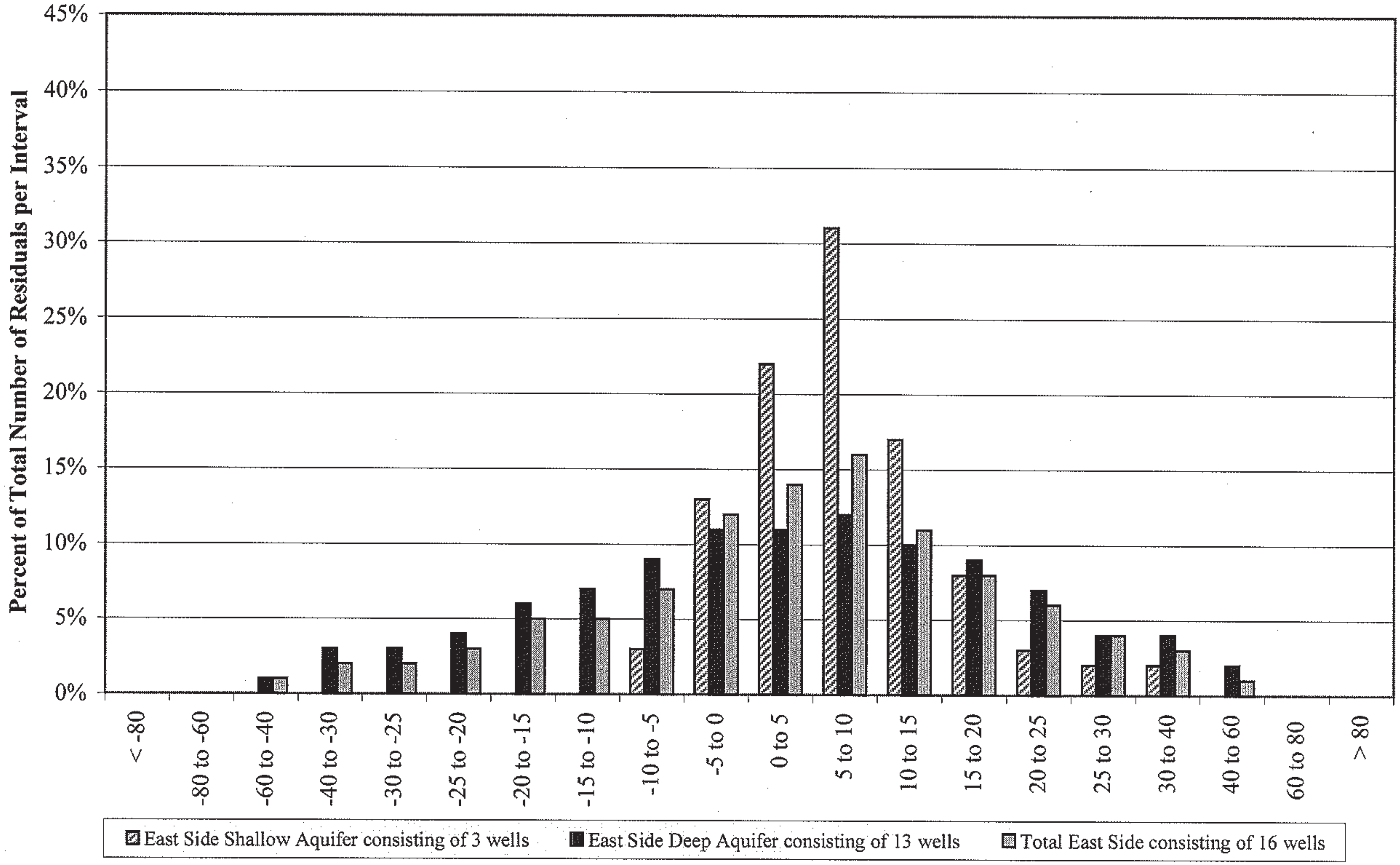
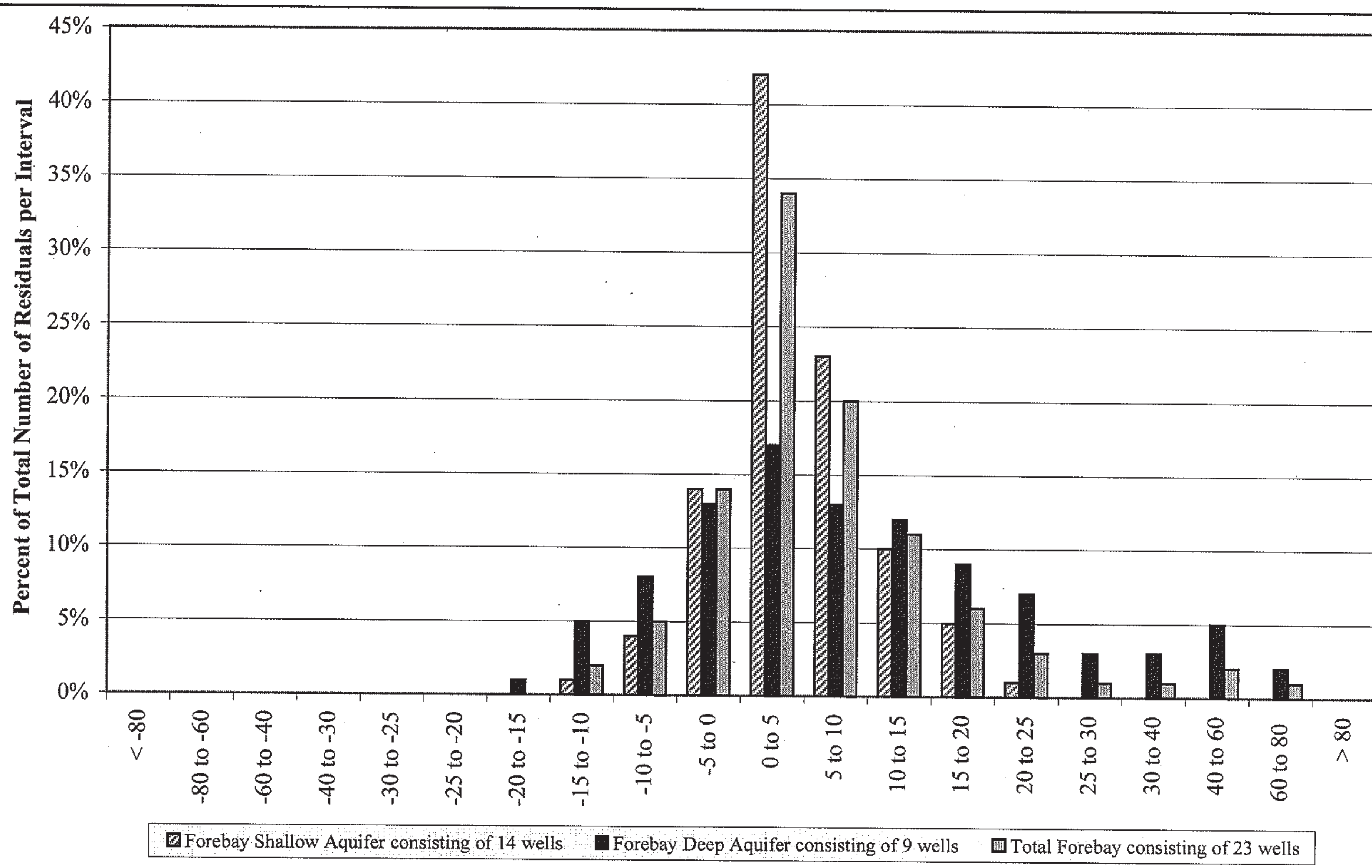
Histogram of Residual Groundwater Levels between SVIGSM Version 4.18 and Historic Data in Pressure Subarea for Water Years 1959 through 1994

MAY 2003

FIGURE 3.3b



RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Histogram of Residual Groundwater Levels between SVIGSM Version 4.18 and Historic Data in East Side Subarea for Water Years 1959 through 1994**	MAY 2003 FIGURE 3.3c



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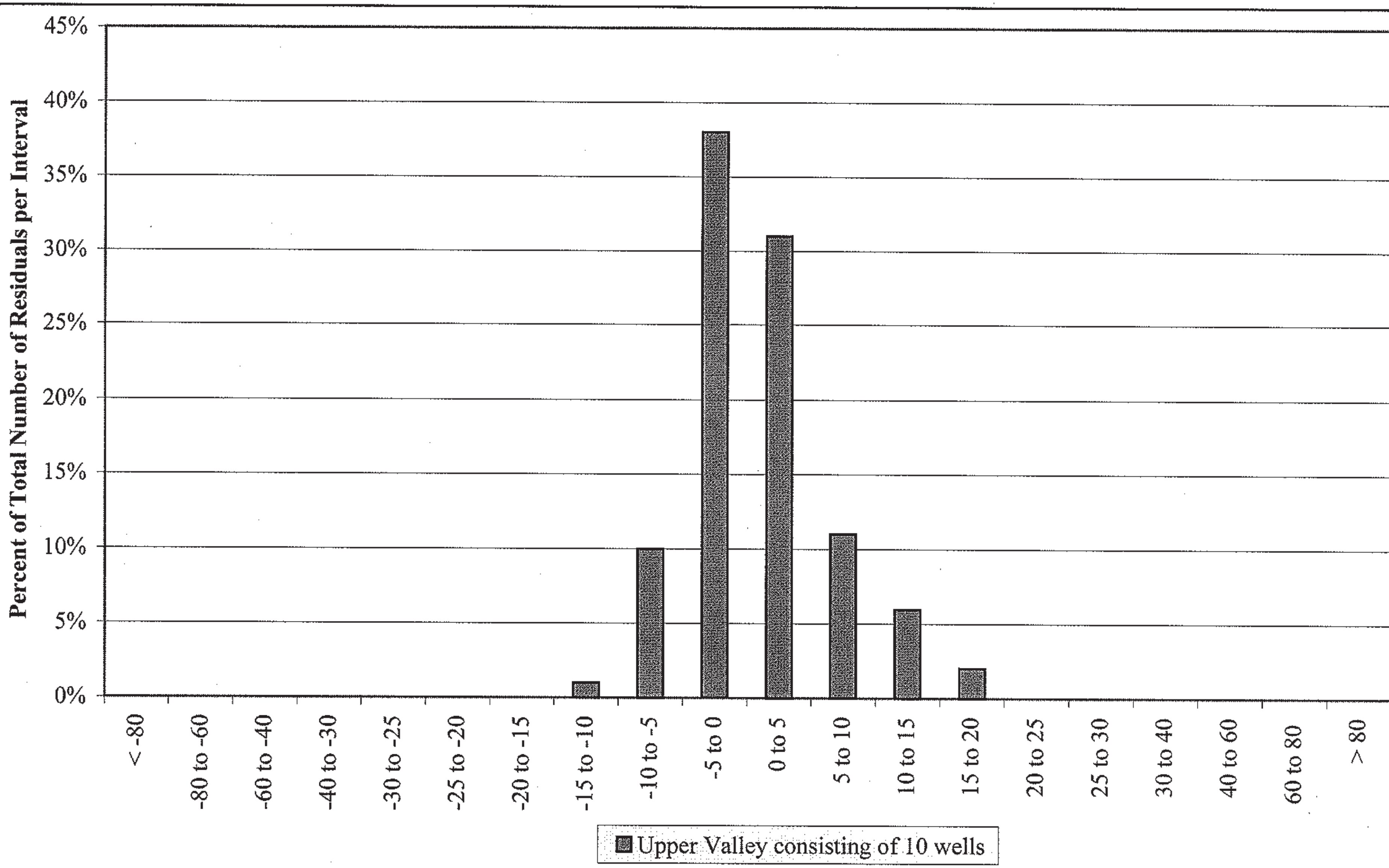
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Histogram of Residual Groundwater Levels between SVIGSM Version 4.18 and Historic Data in Forebay Subarea for Water Years 1959 through 1994

MAY 2003

FIGURE 3.3d



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MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Histogram of Residual Groundwater Levels between SVIGSM Version 4.18 and Historic Data in Upper Valley Subarea for Water Years 1959 through 1994

MAY 2003

FIGURE 3.3e

- Simulation of the agricultural water use requirements based on crop irrigated acreage, crop potential evapotranspiration, minimum soil moisture requirements, and crop efficiency; and
- Simulation of direct runoff and deep percolation from rainfall and irrigation applied water.

The SVIGSM model was developed to address basin-wide hydrologic and water supply operational issues. As such, the SVIGSM has been applied to many studies since its initial development:

- Evaluating the impacts of the Castroville Seawater Intrusion Projects;
- Providing a better understanding of the nature of the physical and hydrologic processes in the Salinas River Basin. This includes natural and operational factors that influence seawater intrusion and coastal groundwater flow from Monterey Bay;
- Analyzing the hydrologic impacts of the Salinas River Basin Management Plan so that sufficient information was provided for alternatives screening and preferred alternative selection;
- Conducting a Historical Benefits Analysis to identify and quantify the hydrologic, flood control, and economic benefits of Nacimiento and San Antonio Reservoirs;
- Analyzing the effects reservoir re-operation scenarios and
- Analyzing impacts of the Salinas Valley Water Project, a proposed project currently undergoing the final stages of environmental permitting process.

CODE UPDATES

IGSM was initially released in 1990 as part of the Central Valley Groundwater and Surface water Model (CVGSM). It has been modified over the years for different project applications; this resulted in different versions of IGSM as related to specific projects. In 2000, DWR initiated a study to combine into a single IGSM version all features from various versions used in local and statewide applications. This effort resulted in IGSM version 5.0, which is currently used in several modeling efforts throughout California. DWR initiated a review process of the IGSM 5.0 code and its application to California's Central Valley. This process resulted in refinement of several major modules of IGSM, including the groundwater simulation daily time-step, simulation of the stream-aquifer interaction based on non-linear methodology, and refined non-linear soil moisture accounting routine. These code refinements were released as a new version of the code: IGSM2 version 1.0 (December 2002). Currently IGSM2 does not provide simulation capabilities for reservoir operations and multiple models. Also, it is not backwards compatible for datasets of earlier versions of IGSM. Due to the release schedule of IGSM2, as well as its limitations on simulation of reservoir operations and multi-model integration, the results of the DWR review were incorporated into a revised version of the original IGSM. This new version is released as beta version of IGSM version 6.0, which is being developed to meet specific project requirements for the conjunctive use projects under study by DWR, Alameda County Water District (ACWD), and East Bay Municipal Utility District (EBMUD) (WRIME, Inc. 2003). IGSM 6.0 simulates the groundwater and surface water flows and their interaction on a daily and/or monthly time-step; and has the option to simulate stream-aquifer hydraulic interaction using both linear and non-linear methods; and simulate general head boundary condition using both linear and non-linear methods. The program is also backward compatible with IGSM 3.2 and later versions. This version of IGSM is currently under final review and will be official released in June, 2003 then the project application for Stony Creek Fan Conjunctive Use project is complete. Therefore, IGSM 5.0 was selected for use in the Marina Coast study since it is the most recent, officially released version of IGSM possessing all the features needed to properly simulate hydrologic conditions in the Salinas Valley groundwater basin. It is anticipated that with the official release of IGSM 6.0, the conversion to IGSM 6.0 would be straightforward, requiring limited time to evaluate the calibration and make necessary refinements. Formal documentation of IGSM 6.0 and its application in Northern Sacramento Valley, California will be available in June 2003. Documentation regarding the application of IGSM 6.0 in Alameda County, California will be available by September 2003.

IGSM 5.0 is backwards compatible with IGSM 4.18, meaning that the data files developed for SVIGSM 4.18 are compatible with SVIGSM 5.0. As such, no modifications of the data file structure were necessary to use SVIGSM 5.0.

Several comparisons were made to measure the impacts of changing the IGSM code, without changing the geologic database of the model. These comparisons are:

1. change in groundwater levels between SVIGSM versions 4.18 and 5.0;
2. change in groundwater levels between observed groundwater levels and SVIGSM 5.0;
3. change in average annual coastal flow rate between the SVIGSM versions; and
4. change in average annual stream depletion rate between the SVIGSM.

In general changing the code did not result in any significant changes to the performance of the calibrated model.

SVIGSM DATABASE UPDATES

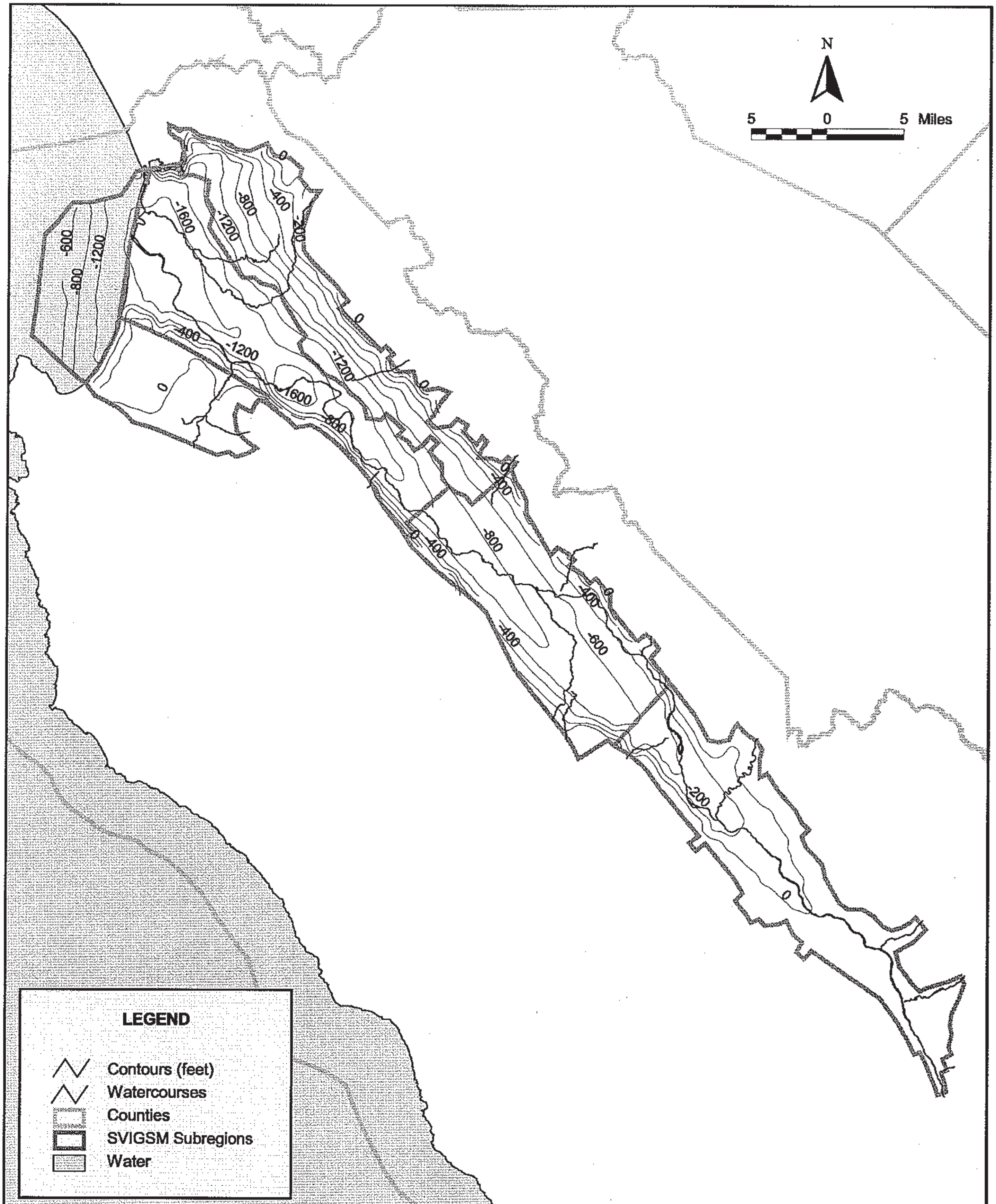
There were two major changes made to the SVIGSM database due to recently conducted studies. These changes, discussed in detail below, are in regard to the new interpretation of the deep aquifers and the capability of the Reliz Fault to inhibit groundwater flow.

DEEP AQUIFER MODIFICATIONS

As discussed previously, the Salinas River groundwater system was conceptually viewed as a three-layer aquifer system in the Pressure Subarea, a two-aquifer system in the East Side and Forebay Subareas, and a single aquifer in the Upper Valley. The deep aquifers or its hydrogeologic extensions were present in all subareas except for the Upper Valley. All data regarding the deep aquifers has been reviewed, analyzed, and incorporated into a new interpretation of the deep aquifers. Based on this new interpretation, the deep aquifers are better represented as two distinct aquifers. The new interpretation was included in the SVIGSM stratigraphy database. The SVIGSM revised stratigraphy data was developed using a Geographic Information Systems (GIS) process of contouring thickness and bottom elevation data, then attributing those contoured values to specific SVIGSM nodes; this process was discussed in Section 2 of this report.

Figures 3.4 through 3.8 illustrate the changes that have been made to the deep aquifers' geology and hydrogeology. Figure 3.4 shows the bottom elevation contours of deep aquifers prior to the recent study. Figure 3.5 shows the bottom elevation contours of upper deep aquifer (the Paso Robles Formation) as a result of this study's findings. Figure 3.6 shows the bottom elevation contours of the lower deep aquifer (the Purisima Formation). In order to properly simulate the hydraulic connection and leakance between the upper and lower deep aquifers, a 10-Ft aquitard is assumed between these layers. The thickness of this aquitard is not based on geologic data and information; rather it is for modeling purposes to provide better control in model calibration and simulation. Figures 3.7 and 3.8 show the total aquifer system for old stratigraphy interpretation and the new stratigraphy interpretation, respectively. Note that the total thickness of the revised deep aquifers is approximately 500 to 1,000 feet greater than the original thickness in the model. Without proper changes to the hydraulic conductivity distribution in the model, this additional thickness would impact the transmissivity of the aquifer system; this impact will be discussed in the next section.

Several stratigraphic cross-sections were developed for the revised model aquifer system. Figure 3.9 shows the location of geologic cross-sections developed as part of this effort; Figures 3.10a through 3.10h are the geologic cross-sections themselves..



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Bottom Elevation of Original Model Layer 3

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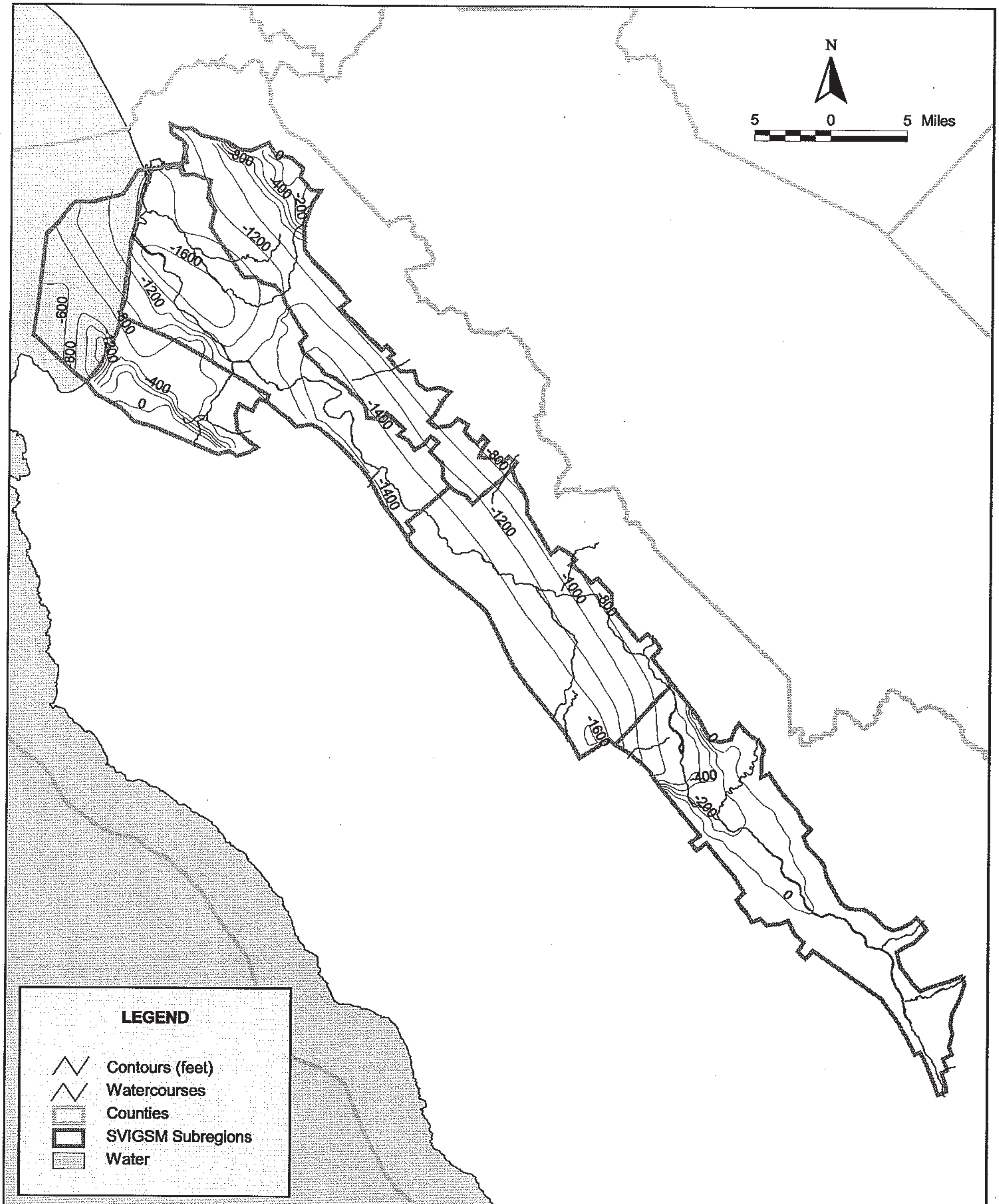
FIGURE 3.4



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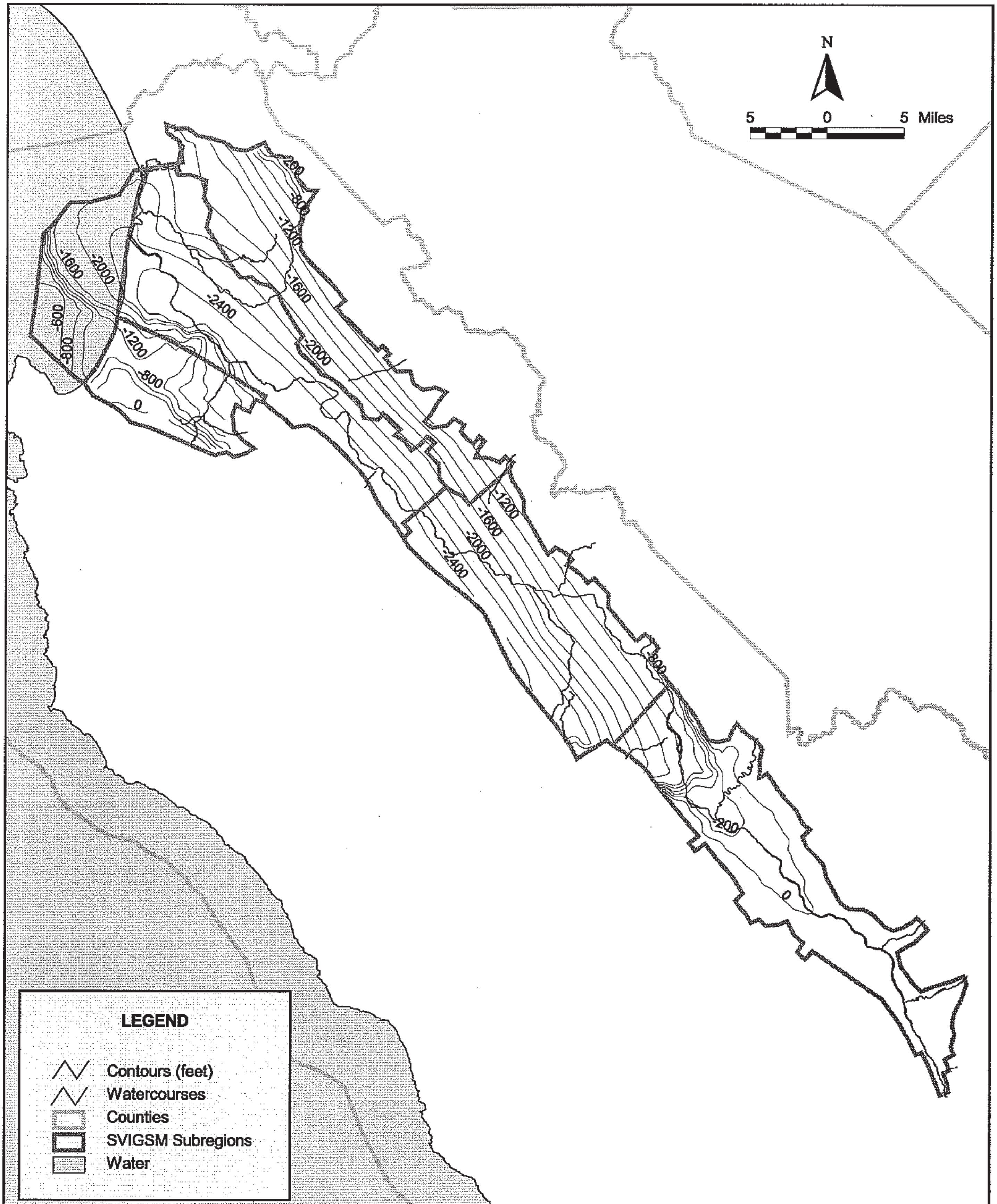
DEEP AQUIFER INVESTIGATIVE STUDY

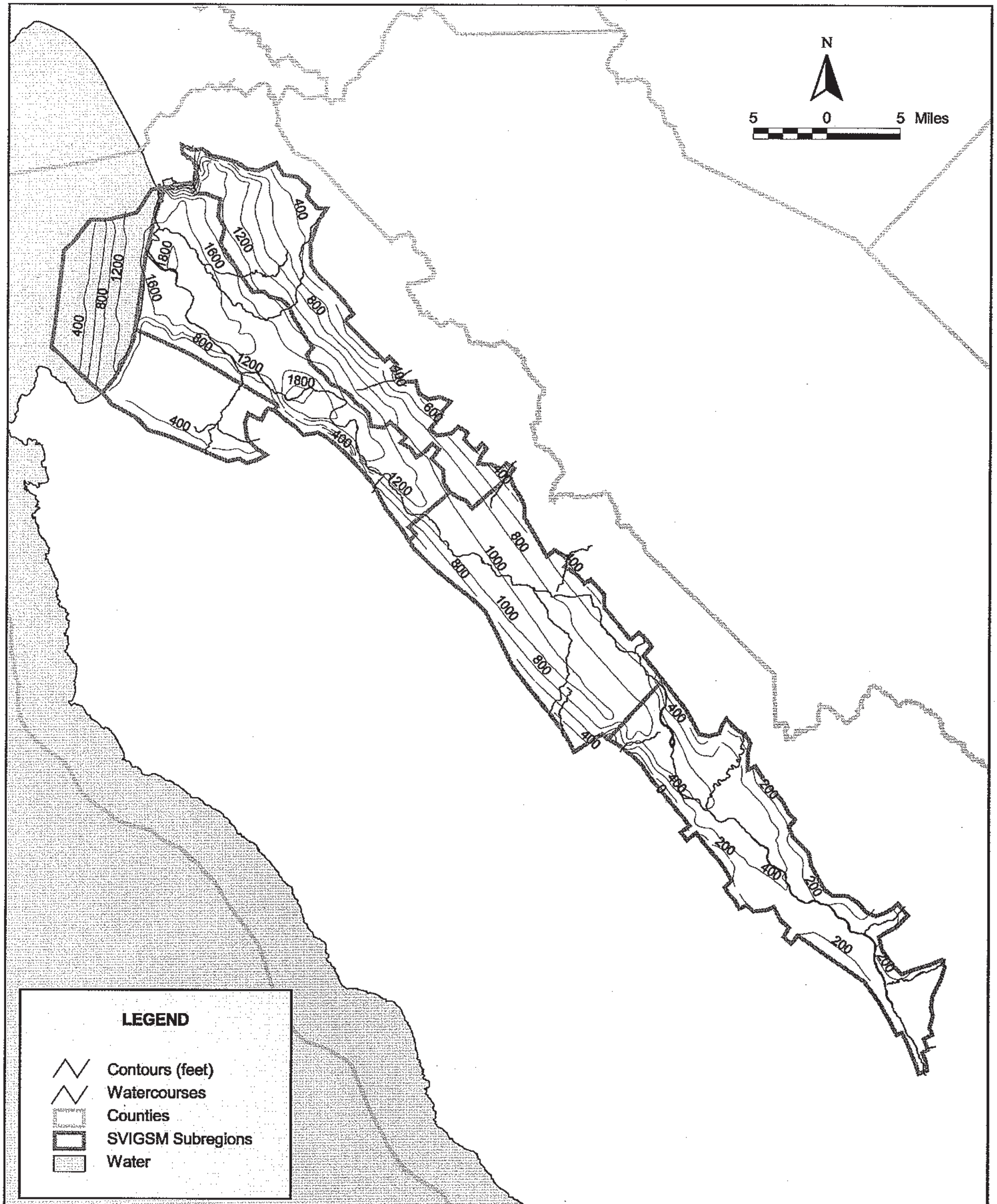
Bottom Elevation of Revised Model Layer 3

MAY 2003

FIGURE 3.5



RIME Water Resources & Information Management Engineering, Inc.	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Bottom Elevation of Model Layer 4**	MAY 2003 FIGURE 3.6



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DEEP AQUIFER INVESTIGATIVE STUDY

Aquifer System Thicknesses for Original Model

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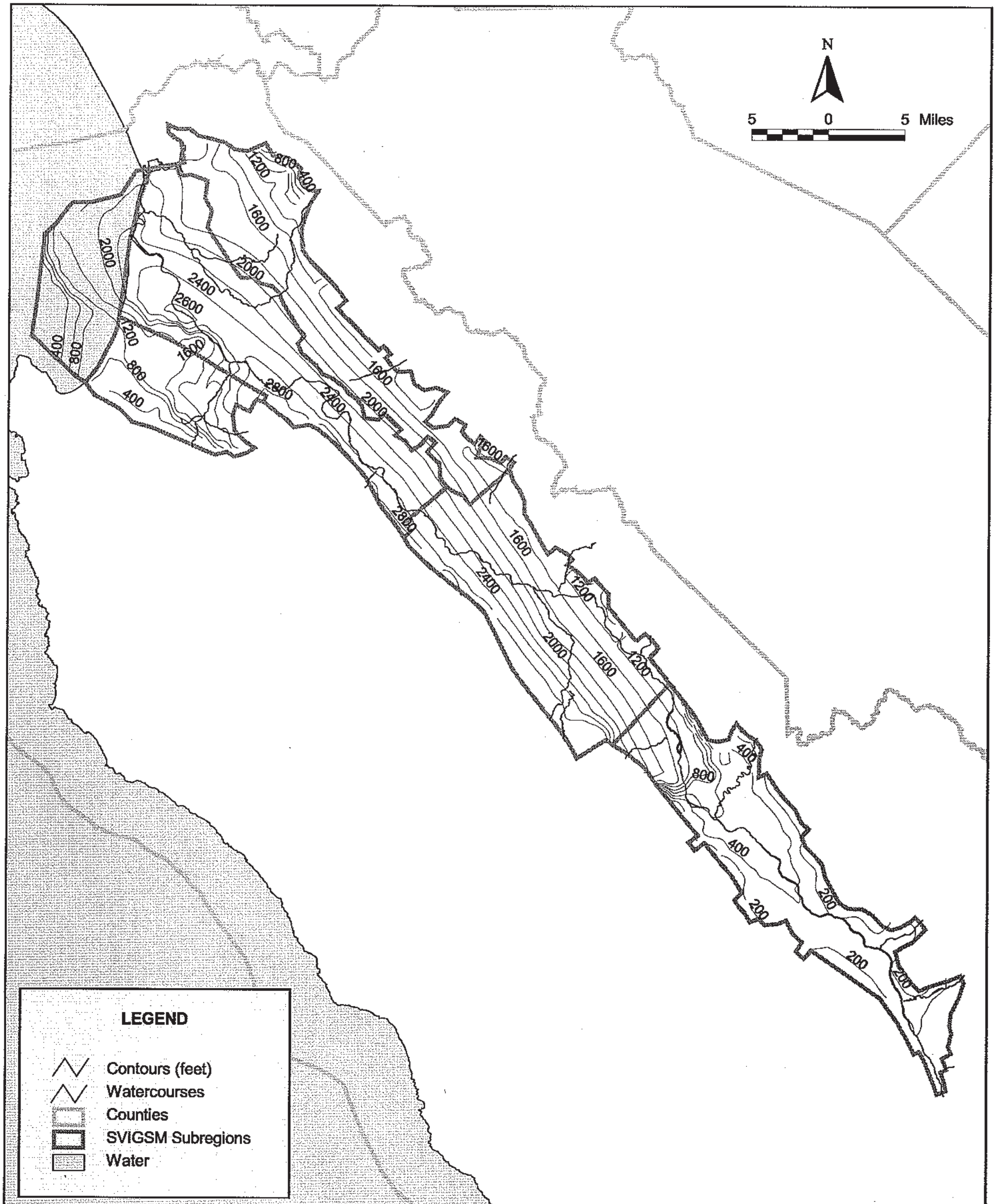
FIGURE 3.7



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Aquifer System Thicknesses for Revised Model

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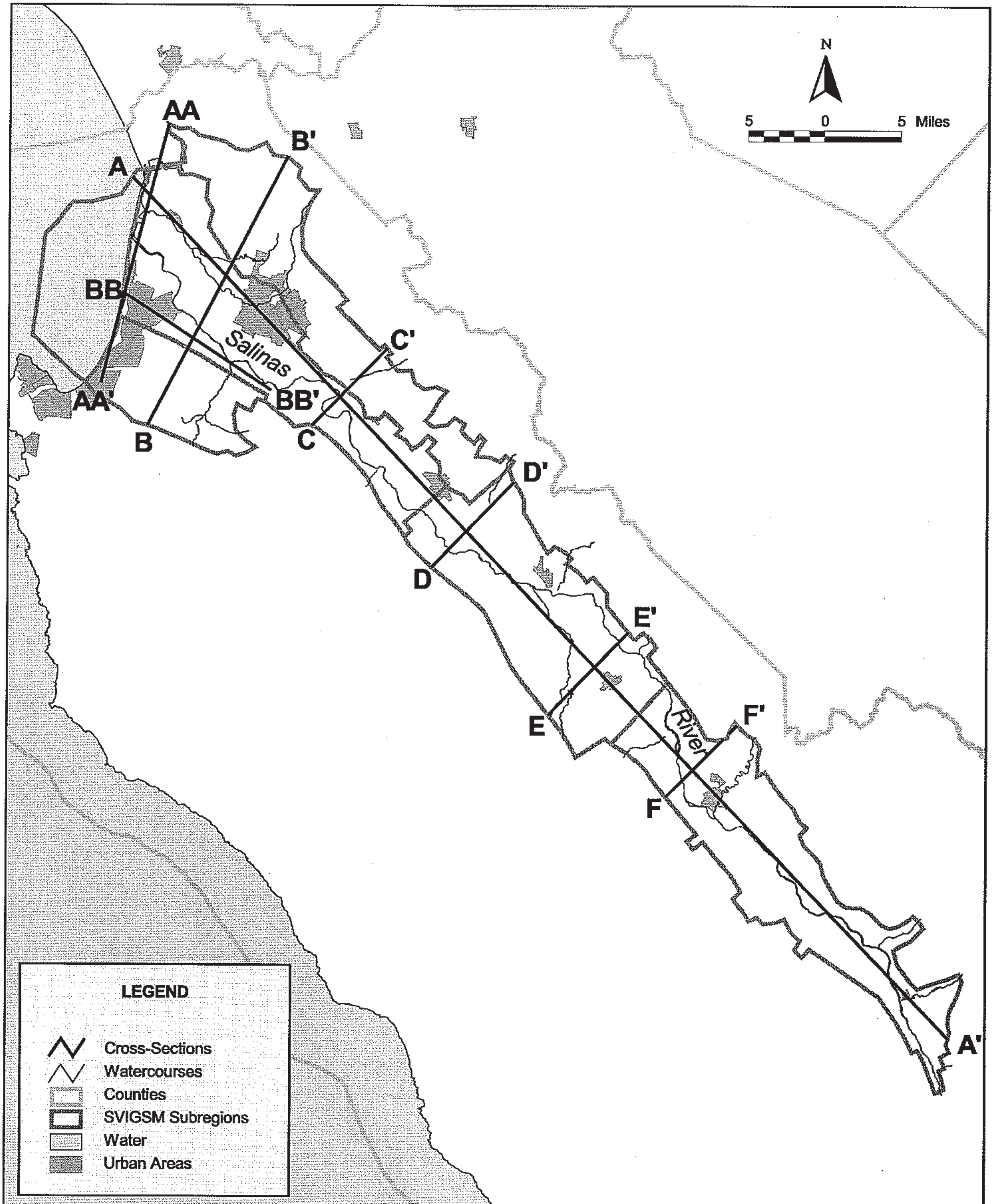
FIGURE 3.8



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SVIGSM Geologic Cross-Section Location Map

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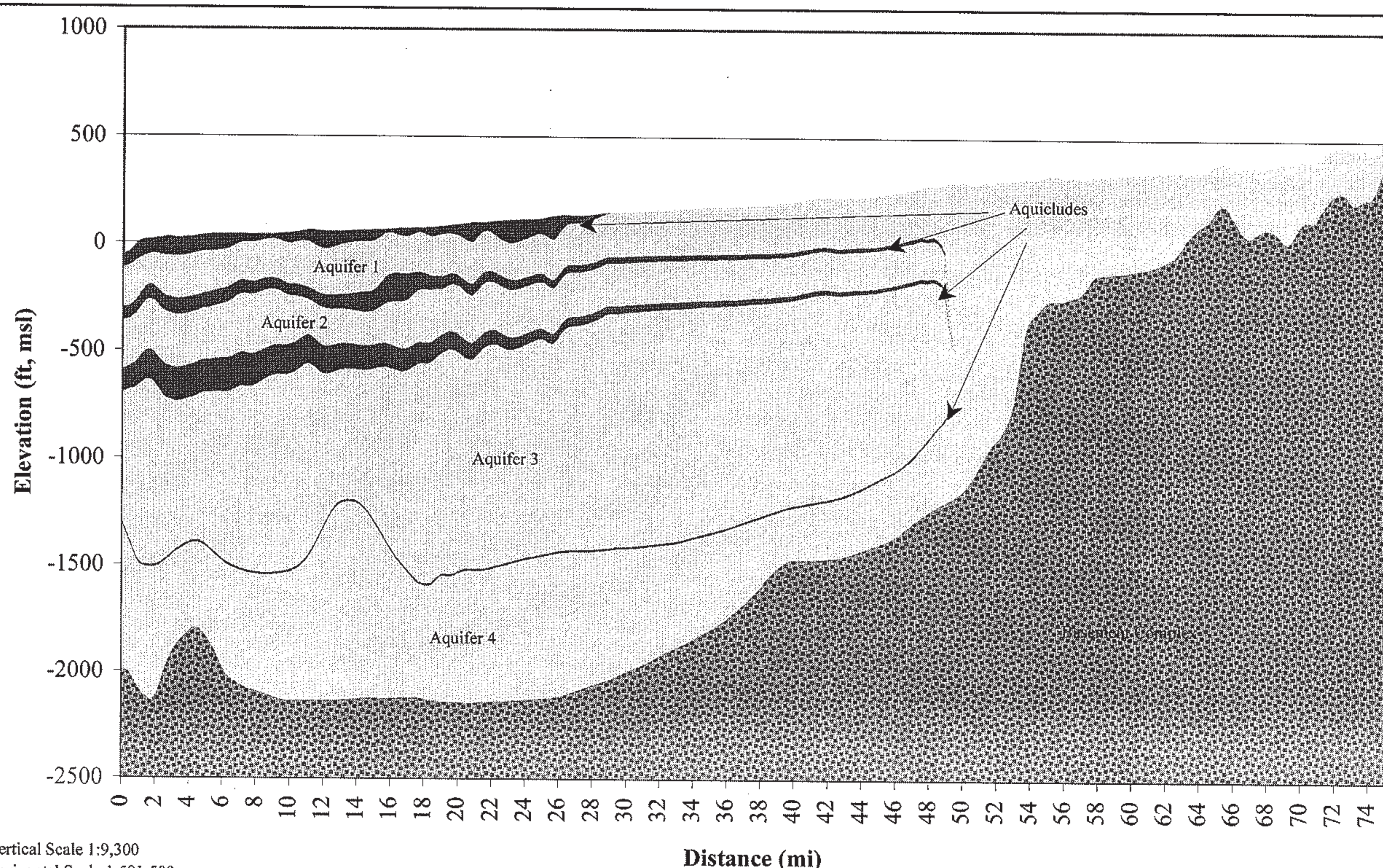
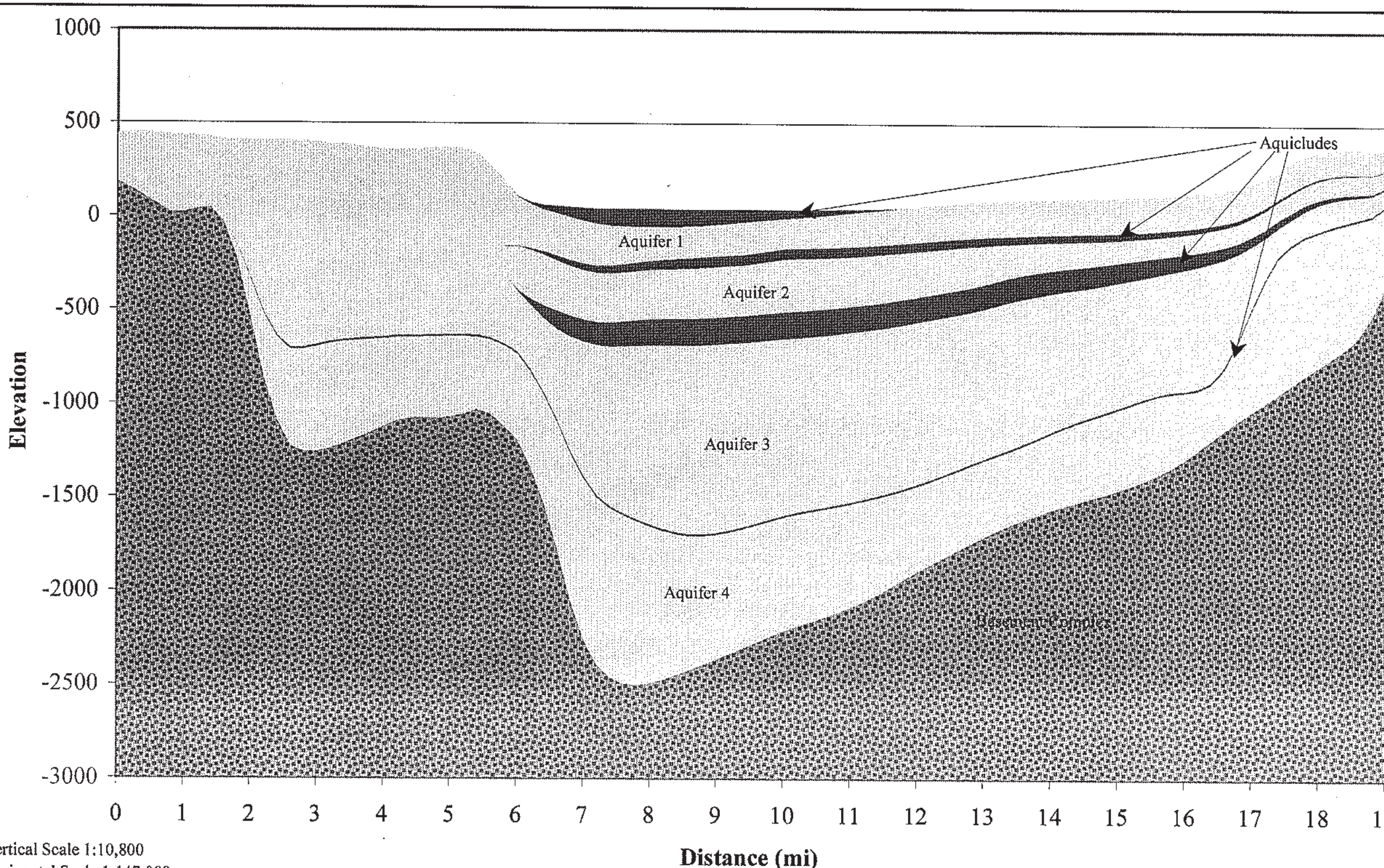
FIGURE 3.9



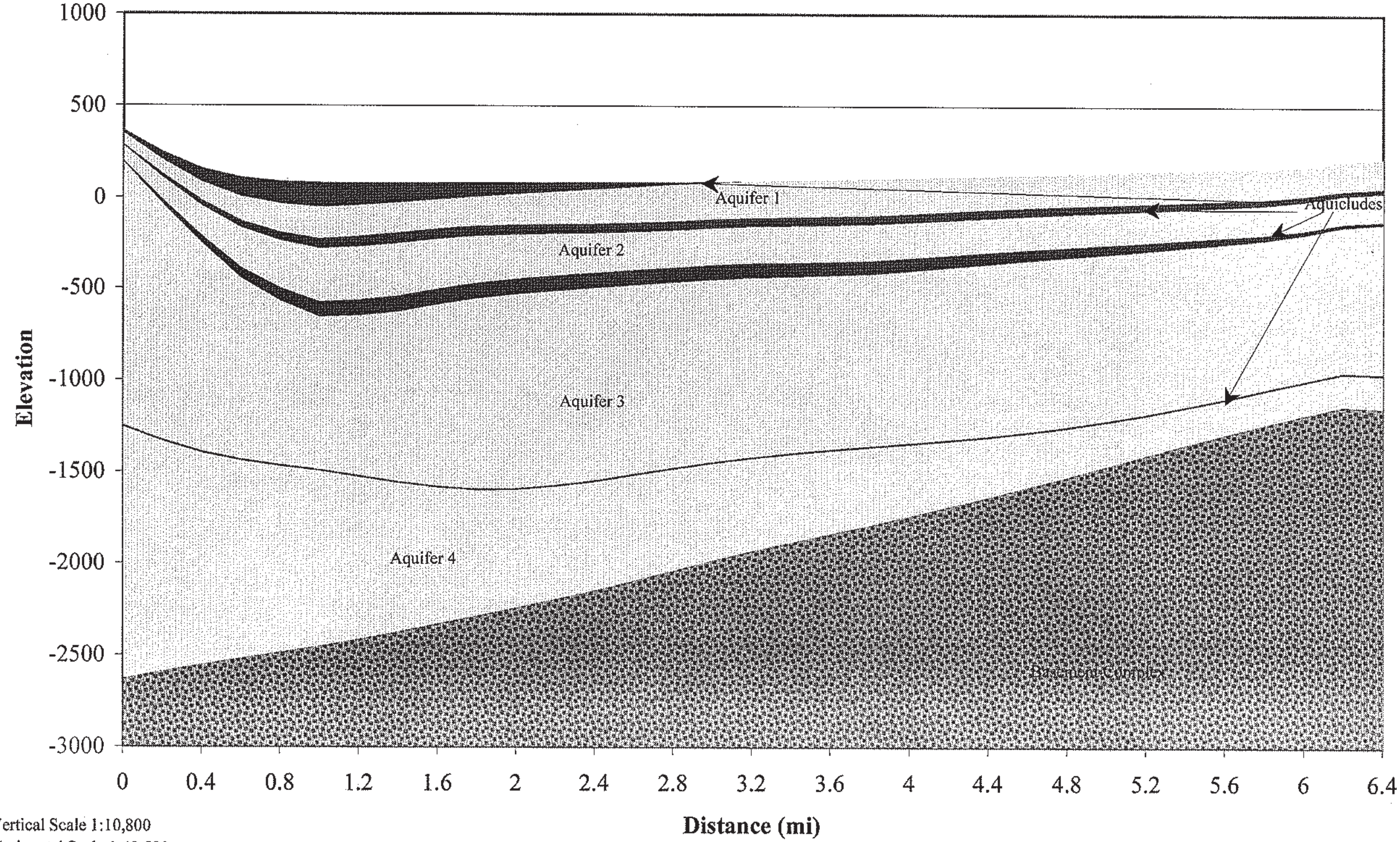
Vertical Scale 1:9,300
Horizontal Scale 1:581,500

RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Geologic Cross-Section A-A'**	MAY 2003 FIGURE 3.10a



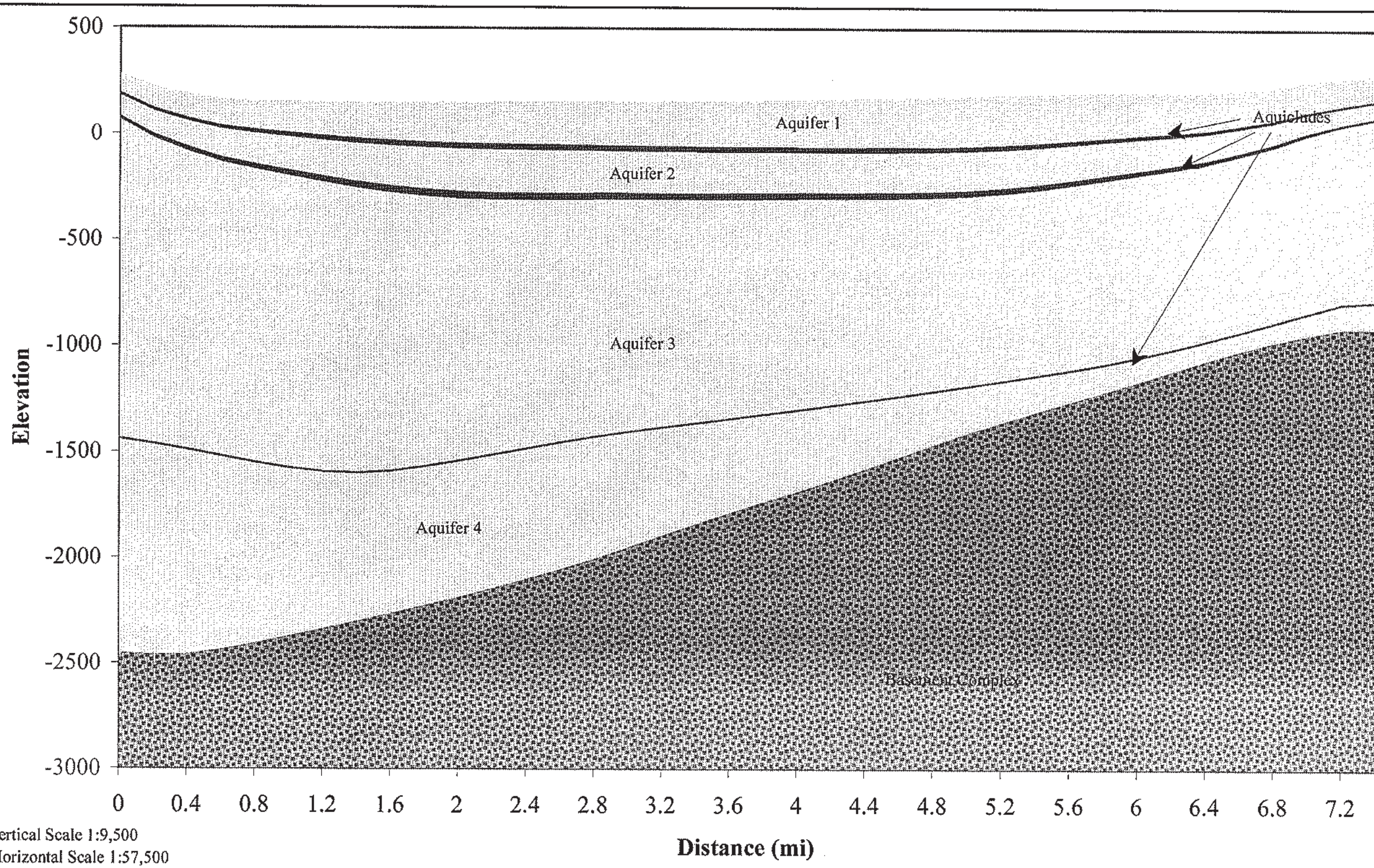
Vertical Scale 1:10,800
Horizontal Scale 1:147,000

RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Geologic Cross-Section B-B'**	MAY 2003 FIGURE 3.10b



Vertical Scale 1:10,800
Horizontal Scale 1:49,500

PRIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Geologic Cross-Section C-C'**	MAY 2003 FIGURE 3.10c



Vertical Scale 1:9,500
Horizontal Scale 1:57,500

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DEEP AQUIFER INVESTIGATIVE STUDY

Geologic Cross-Section D-D'

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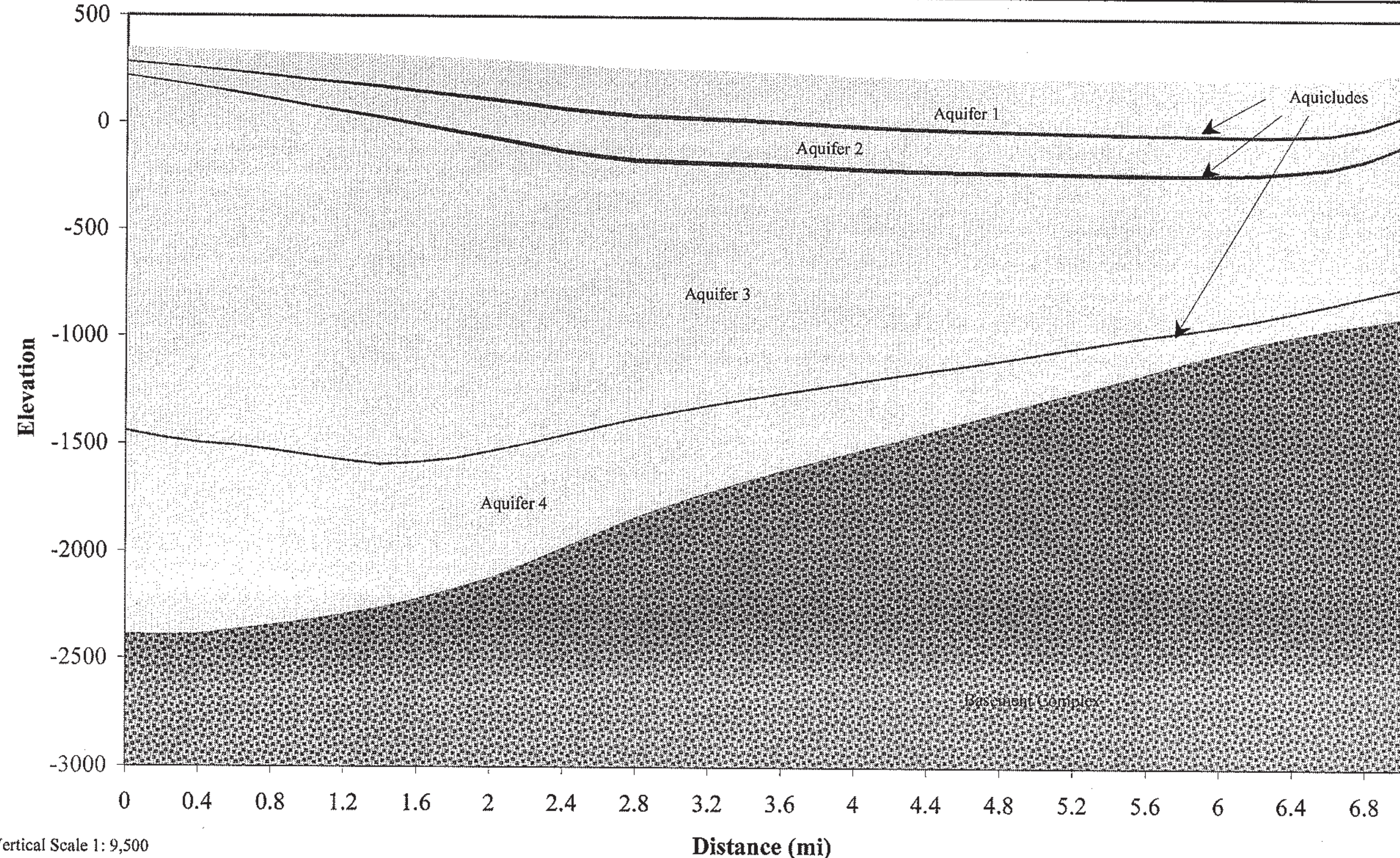
FIGURE 3.10d



Vertical Scale 1: 9,500
Horizontal Scale 1:54,300

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DEEP AQUIFER INVESTIGATIVE STUDY

Geologic Cross-Section E-E'

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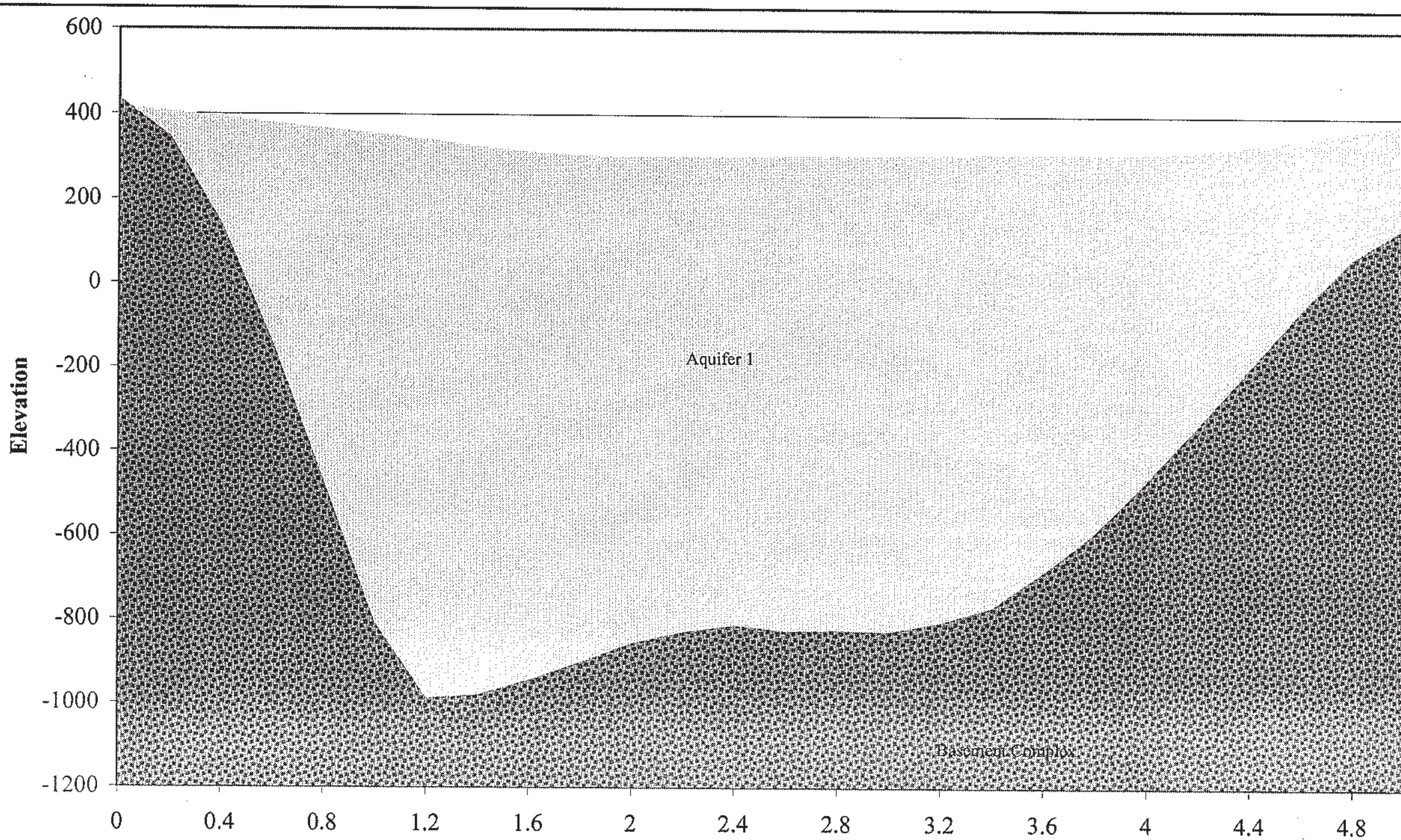
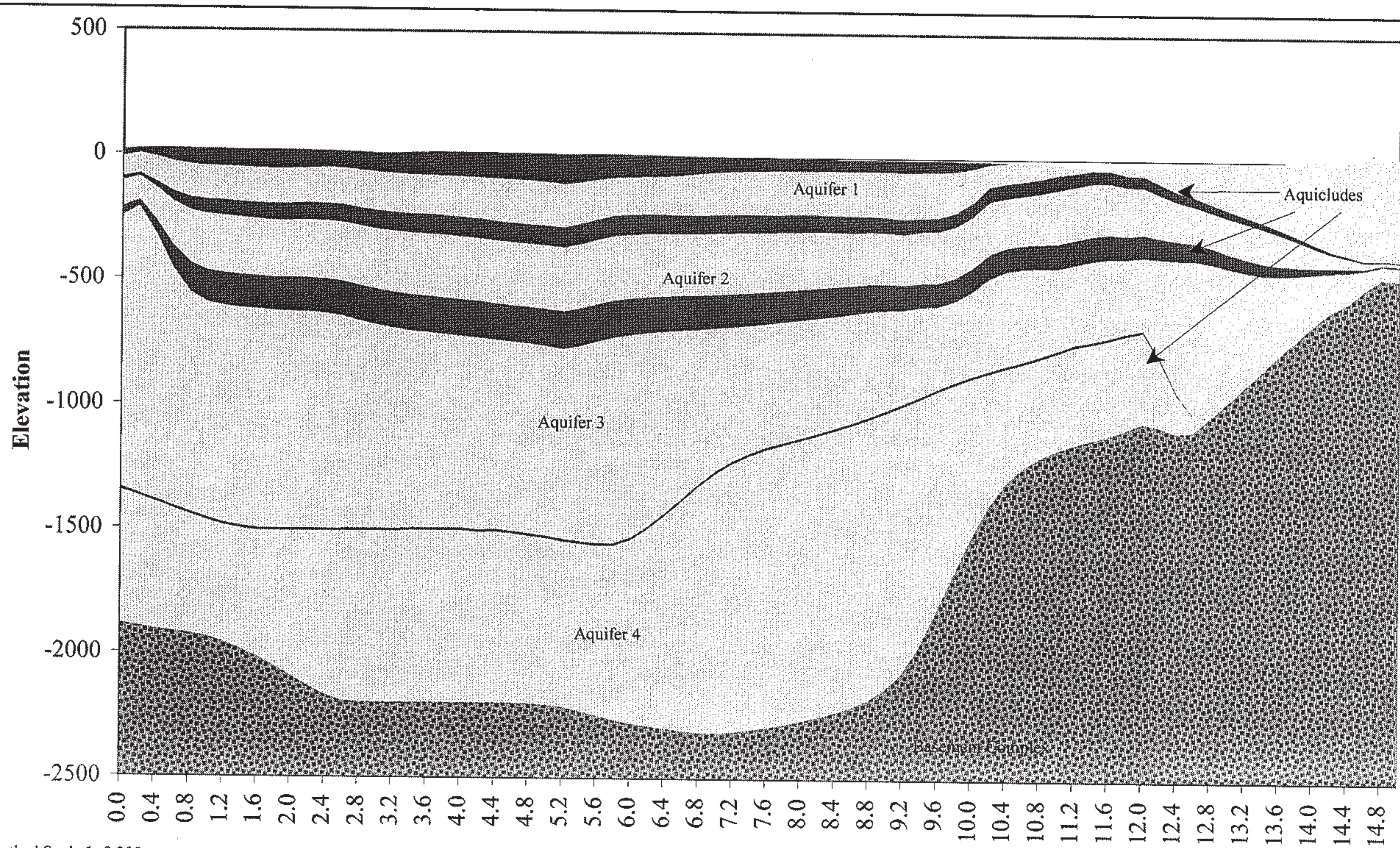
FIGURE 3.10e



Vertical Scale 1:4,900
Horizontal Scale 1:38,600

RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Geologic Cross-Section F-F'**	MAY 2003 FIGURE 3.10f



Vertical Scale 1: 8,300
Horizontal Scale 1:116,300

PRIME

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY
Geologic Cross-Section AA-AA'

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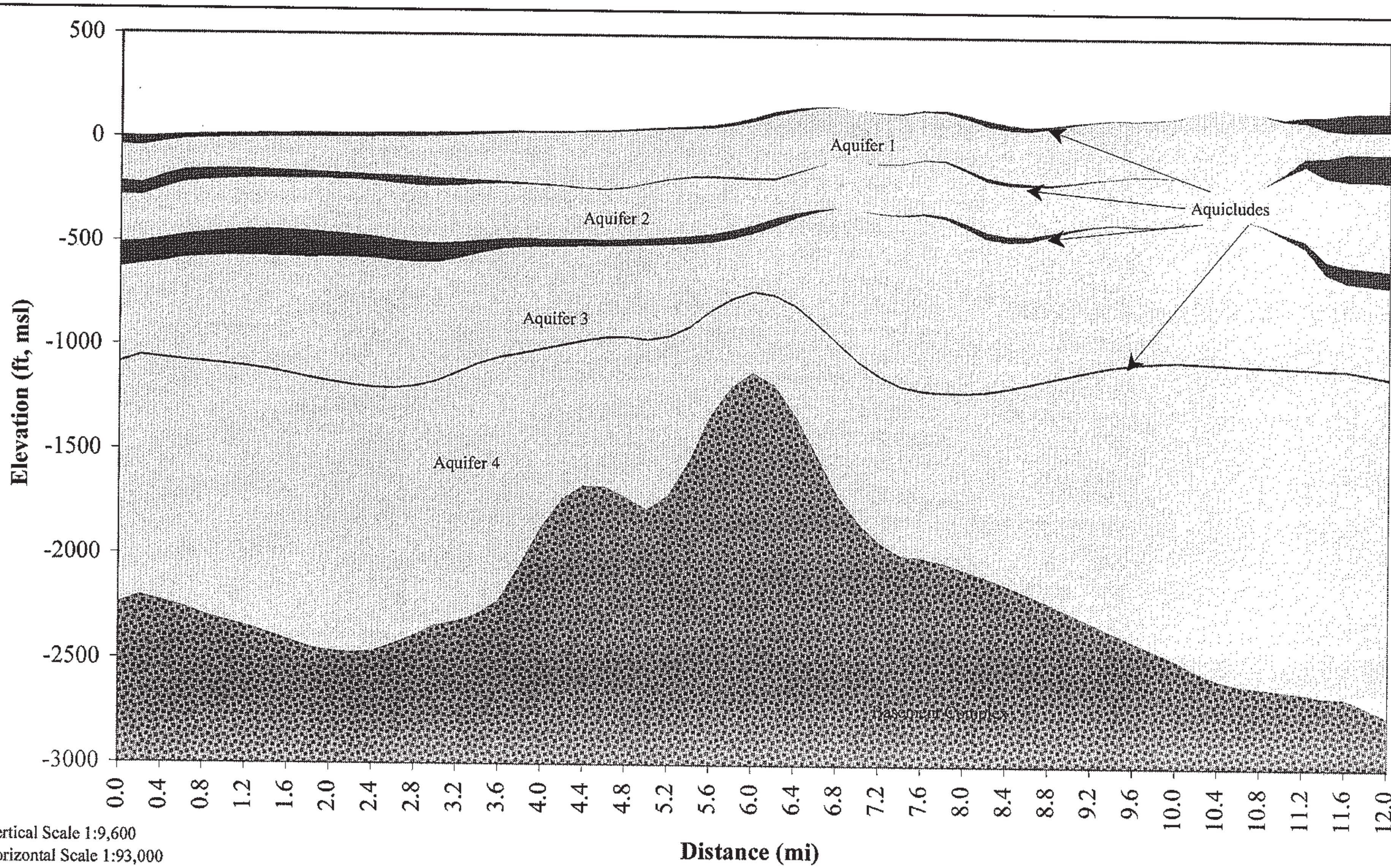
FIGURE 3.10g



Vertical Scale 1:9,600
Horizontal Scale 1:93,000

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DEEP AQUIFER INVESTIGATIVE STUDY

Geologic Cross-Section BB-BB'

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FIGURE 3.10h

Based on Figures 3.4 and 3.5, the lowest elevation of the deep aquifers and upper deep aquifer is approximately 1,600 feet below mean sea level (msl). It can be concluded that the two aquifers have a similar lowest elevation. The shape of the aquifers has changed substantially, though. The deep aquifers originally pinched out at the sides of the valley. In comparison, the upper deep aquifer does not pinch out and has a bottom elevation of over 1,500 feet msl along the western boundary of the SVIGSM. In addition, the location and degree of outcrops of the upper and lower deep aquifer in the Monterey Bay is now different enough that the rate of simulated subsurface flow across the coastline in the deep aquifers is also now different. This change in the outcrop condition and its associated hydraulic effects in the deep aquifers also affects the hydraulic conditions in the 400-foot and 180-foot aquifers along the coastline, such that the simulated subsurface flow rates are expected to be different in these aquifers, because the aquifer system geometry, corresponding volume, and aquifer parameters have substantially changed. From Figure 3.7, the lower deep aquifer has a similar shape to the upper deep aquifer and their lowest bottom elevation is in excess of 2,400 feet below msl. Figures 3.8 and 3.9 show that the aquifer system thickness has increased by over 2,400 feet in some areas. However, due to low storage coefficients in the lower deep aquifer, the added thickness in the lower deep aquifer does not necessarily equate to larger storage volume and higher yield from this formation.

Reliz Fault Modifications

At the time of developing the original SVIGSM, the King City (Reliz) fault was understood to impede groundwater flow between the Pressure subarea and Fort Ord. As such, a row of finite elements between the Pressure subarea and Fort Ord were assigned a low hydraulic conductivity. Review of hydrogeologic data and groundwater levels across the fault, conducted as part of this study, suggests that although the Reliz fault has deformed units as young as the Paso Robles Formation, the fault itself does not appear to affect groundwater flow. Based on this work, the fault conditions (low hydraulic conductivities, approximately 1.1×10^{-2} ft/day) were removed from the SVIGSM database, and hydraulic conductivities comparable to ones in the neighboring elements were assigned to the fault elements (ranging from 5 to 30 ft/day).

Coastal Boundary Conditions

The SVIGSM finite element network includes the portion of the Monterey that overlies the Salinas basin aquifer systems. The grid nodes in this part of the model network are assigned as general head boundary condition such that proper hydraulic gradient at the coastline is simulated. This hydraulic gradient was adjusted during model calibration so that the simulated groundwater heads at the coastal wells in the 180-foot, 400-foot, and the deep aquifer wells (in the Castroville area) are reasonably close to the observed groundwater heads in these wells.

This general head boundary condition accounts for changes in hydraulic head due to seawater density relative to fresh water. As a result of changes in the stratigraphy of deep aquifers in this study, the sensitivity of simulated groundwater levels to this boundary condition was evaluated, and as a result no changes to this boundary condition was necessary.

SVIGSM Recalibration

Due to changes in the stratigraphic conditions of the deep aquifers, the following is a list of parameters that were changed as part of the recalibration effort.

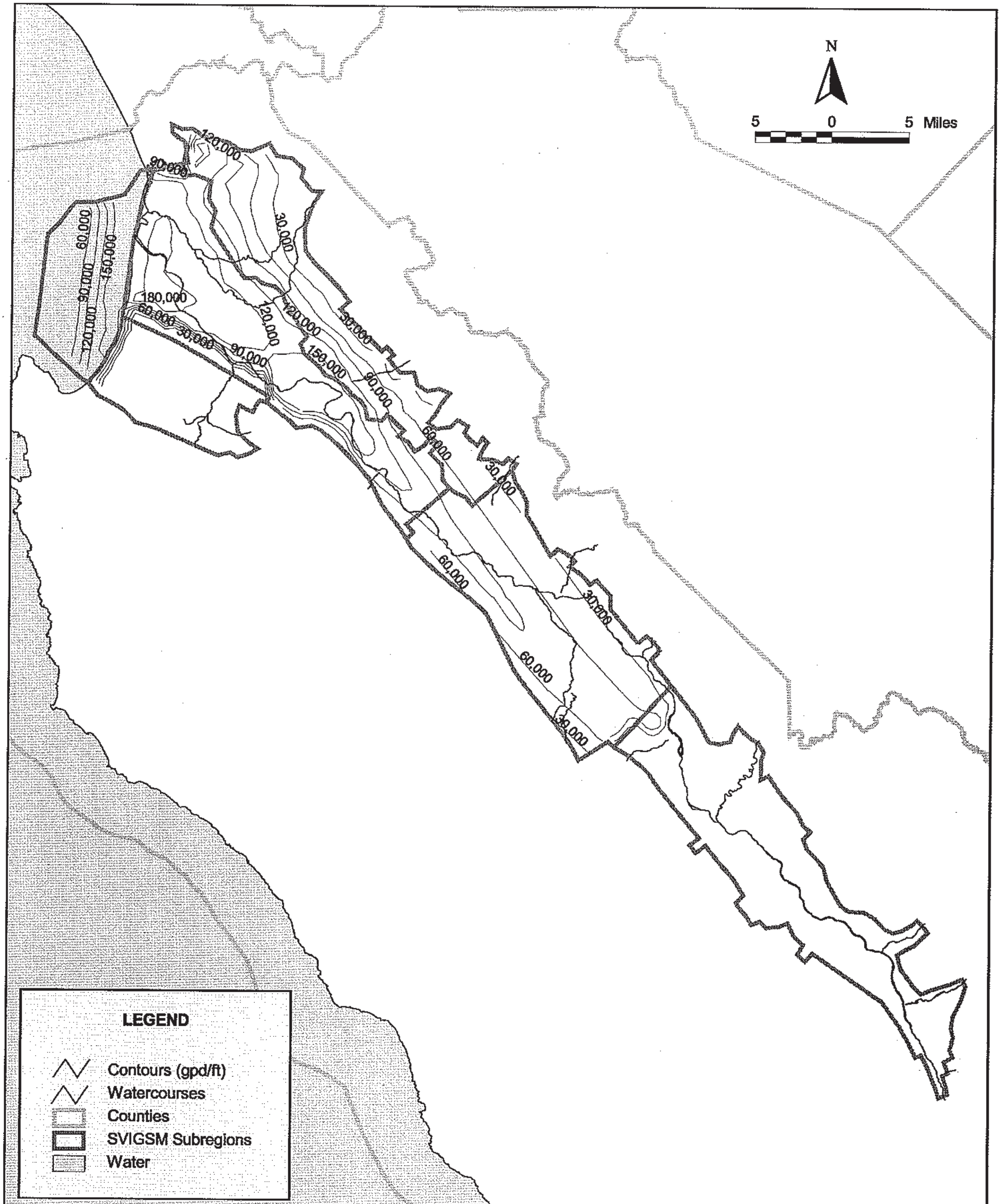
1. Horizontal hydraulic conductivity,
2. Storativity of the deep aquifers,
3. Vertical hydraulic conductivity of the aquitard above upper deep aquifer, and between the upper and lower deep aquifers; and
4. Streambed Parameters

Following is a brief discussion of the modifications:

Horizontal Hydraulic Conductivity

The model hydraulic conductivity parameters are adjusted to bring the model into calibration. Because the transmissivity values for the deep aquifers in the original model was based on model calibration with observed groundwater heads, the goal of this recalibration effort was to preserve the range of original transmissivity values. In addition, Table 2.2 provides additional set of data for model recalibration. Therefore, the changes to the model hydraulic conductivity values were first achieved by replacing the original parameters with equivalent ones, so that the total transmissivity of each model layer remained about the same as in the three-layer model. It was assumed that the transmissivity of model layer 3 (upper deep aquifer) and layer 4 (lower deep aquifer) are similar. Figure 3.11 shows the transmissivity for Layer 3 in the original model. Figures 3.12 and 3.13 show the hydraulic conductivity for Layer 3 in the original and revised models, respectively. Figure 3.14 shows the hydraulic conductivity for Layer 4 in the revised model. Subsequently, additional localized refinements were made to incorporate information from Table 2.2 into the model.

Based on the contour maps of saturated thickness from Thorup, and as discussed in Section 2 of this report, the total saturated thickness of the aquifer system in the Upper Valley area is more in the revised model than in the original model. As such, an equivalent hydraulic conductivity for the one-layer aquifer system in the Upper Valley was also developed based on the same



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Transmissivities in gpd/ft for Original Model Layer 3

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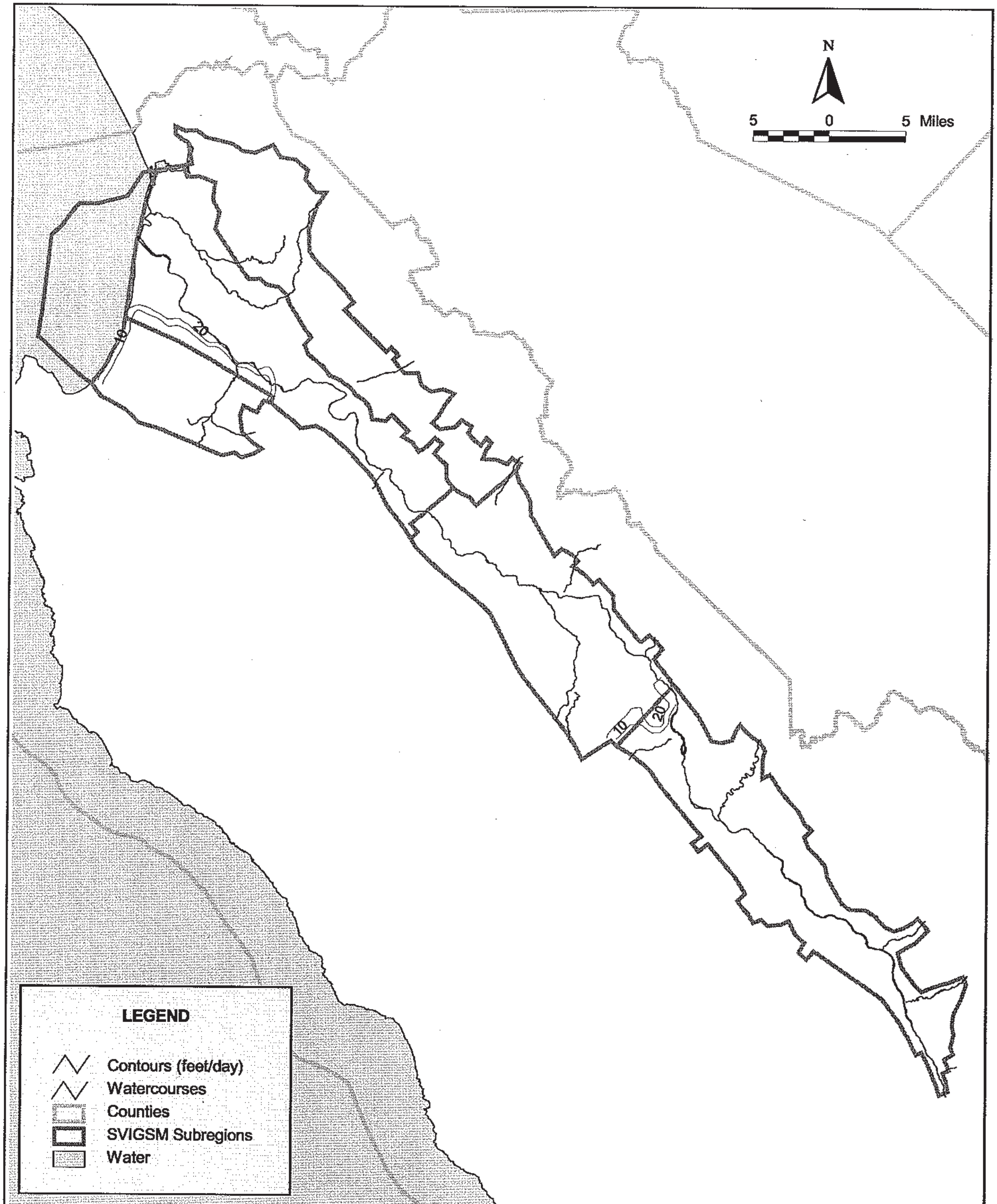
FIGURE 3.11



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Hydraulic Conductivities for Original Model Layer 3

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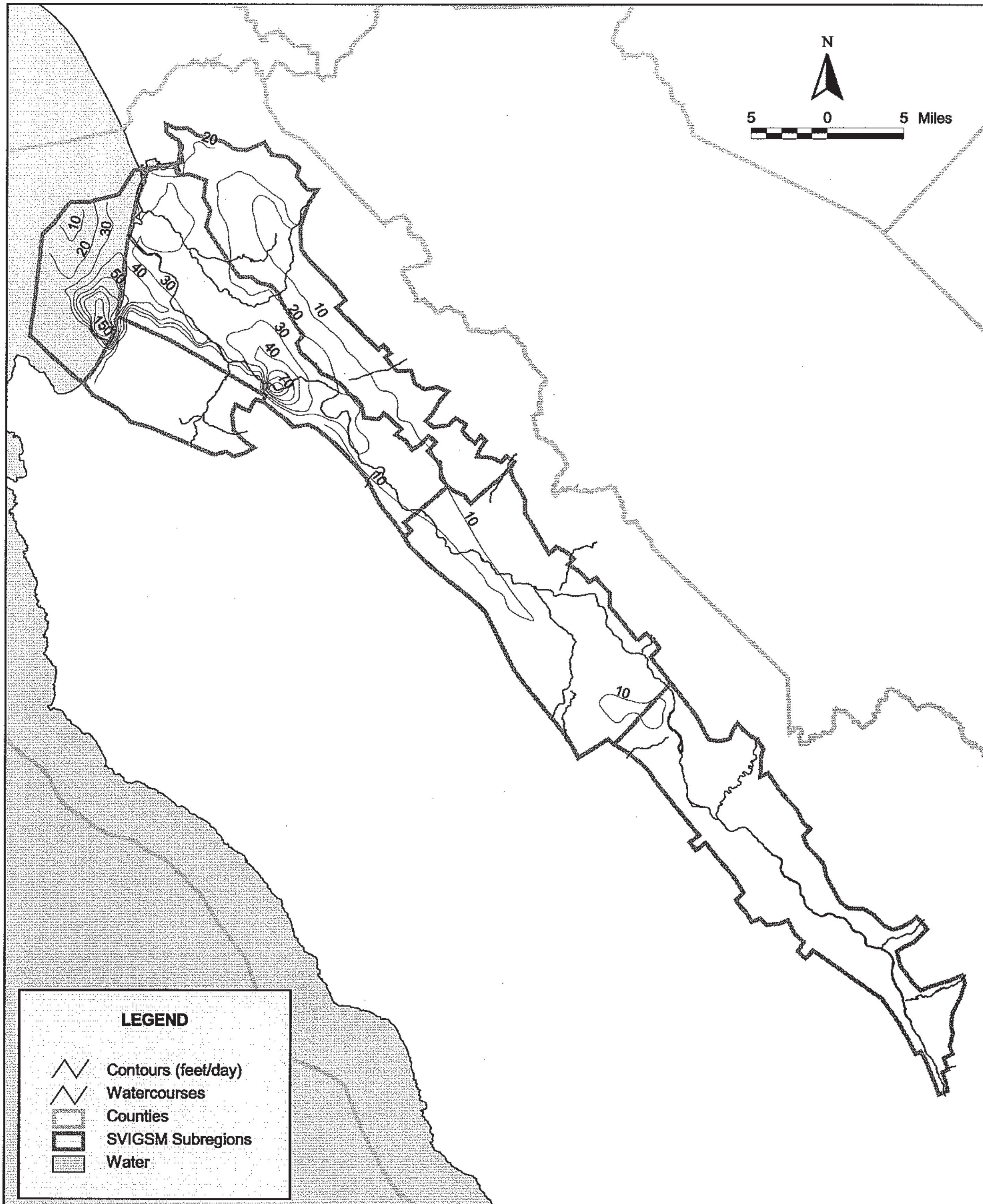
FIGURE 3.12



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Hydraulic Conductivities for Revised Model Layer 3

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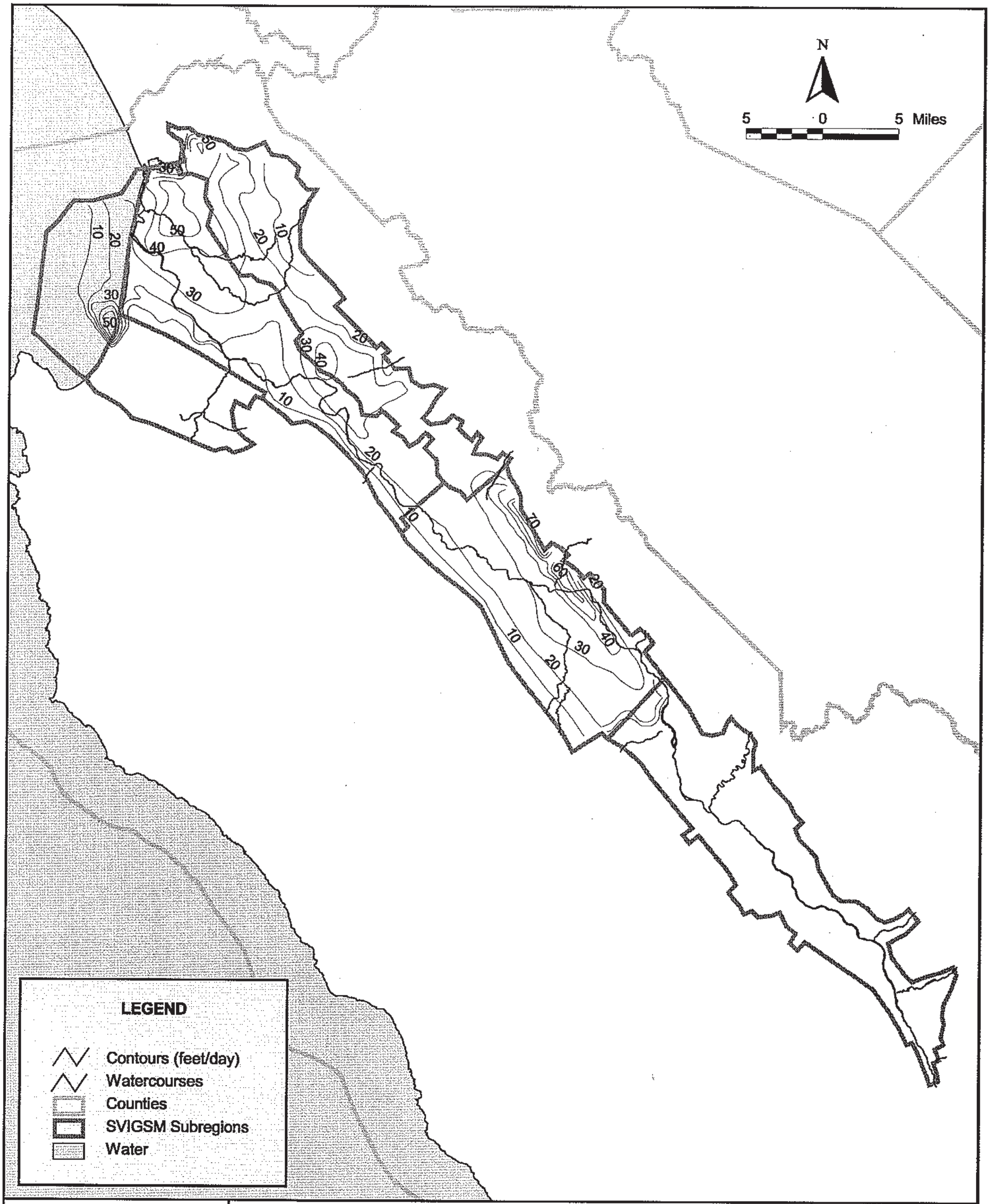
FIGURE 3.13



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Hydraulic Conductivities for Revised Model Layer 4

MAY 2003

FIGURE 3.14

method as used in the deep aquifers system. Figures 3.15 and 3.16 show the hydraulic conductivities of the original model and the revised model layer 1.

Storativity of Deep Aquifers

The changes in the thickness of the deep aquifers from the original model require modifications to the storativity parameters so that seasonal responses of the simulated groundwater levels are similar to those in the observed groundwater level data. The storage coefficient in the 3-Layer SVIGSM was $5x10^{-5}$. The storage coefficient of the deep aquifers was reduced by approximately one order of magnitude, such that the resulting Storage coefficient ranges from $1x10^{-6}$ to $5x10^{-6}$. These changes were focused on the northwestern area of the model.

Vertical Hydraulic Conductivity of Aquitards

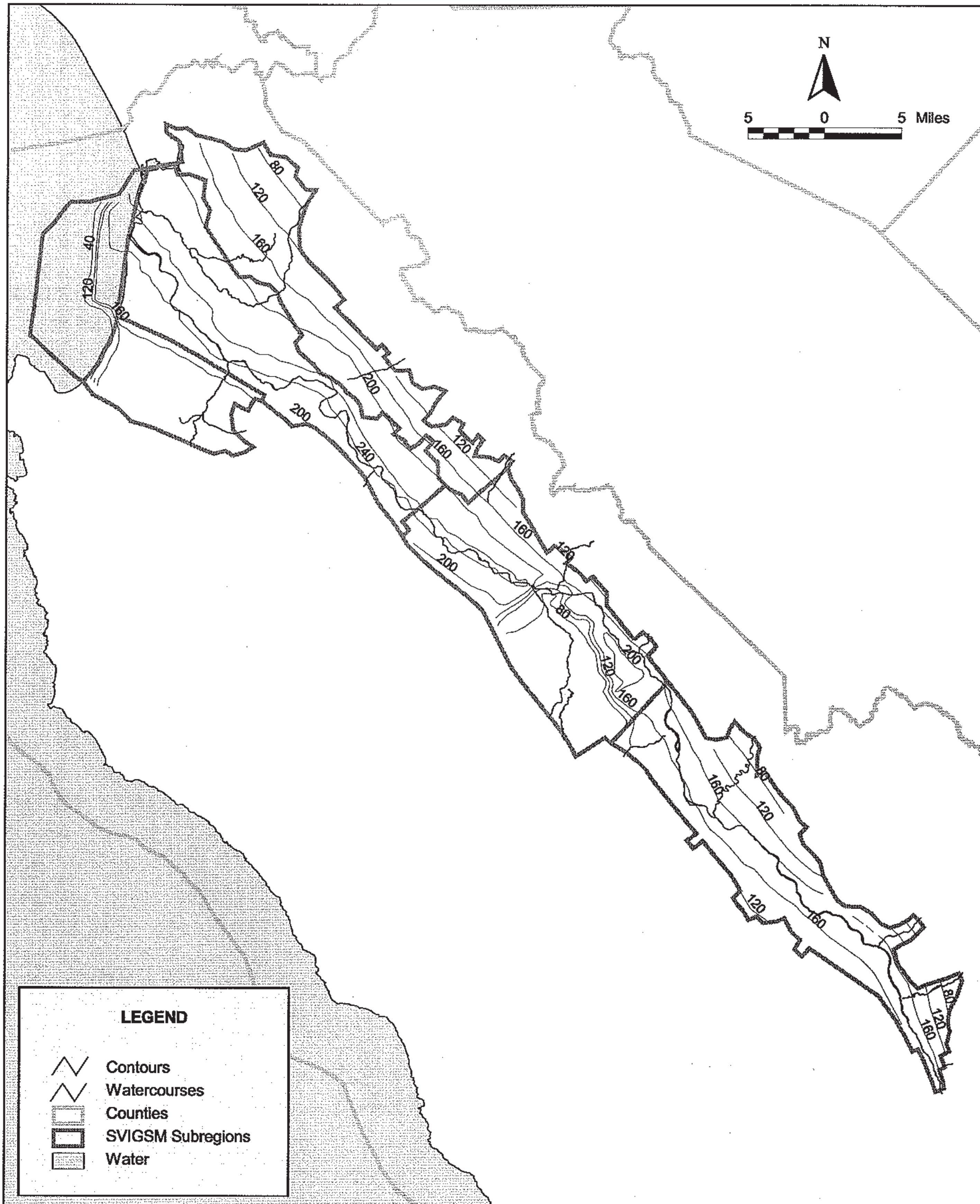
As a result of changes to the thickness of the upper deep aquifer, the hydraulic connection between the upper deep and the 400-foot aquifers need to be revised. The vertical hydraulic conductivity for the aquitard above the upper deep aquifer is modified to ensure that the model leakage between the 400-foot and the upper deep aquifer remains approximately the same as the original model. The vertical hydraulic conductivity in the MCWD area is $3.6 x10^{-3}$ ft/day and the aquitard thickness ranges from about 50 to 150 feet in and around MCWD.

As discussed in Section 2 of this report, the observed groundwater heads in wells 10, 11, and 12 indicate that there may be a separation in hydraulic connection between the upper and lower deep aquifers. In order to simulate this condition, as well as calibrate the model to the observed groundwater heads at these wells, a 10-Ft aquitard is assumed between the upper and lower deep aquifers. This aquitard thickness is merely to add calibration control for modeling purposes, and is not based on any hydrogeologic information. The vertical hydraulic conductivity between the upper and lower deep aquifers, in the MCWD area, is $3.6x10^{-4}$ ft/day

Streambed Parameters

Average annual streamflow depletions in the previous version of the SVIGSM were compared with the updated version of SVIGSM. Due to changes in hydraulic conductivity of model layer 1, the streamflow depletions of the two model versions did not match. Hydraulic conductivity values of the streambed were modified so that a better match of simulation streamflow depletion values was achieved. The following represents the changes made to the streambed hydraulic conductivities from the original model:

1. Salinas River conductivities were increased in the Upper Valley subarea;



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Hydraulic Conductivities for Original Model Layer 1

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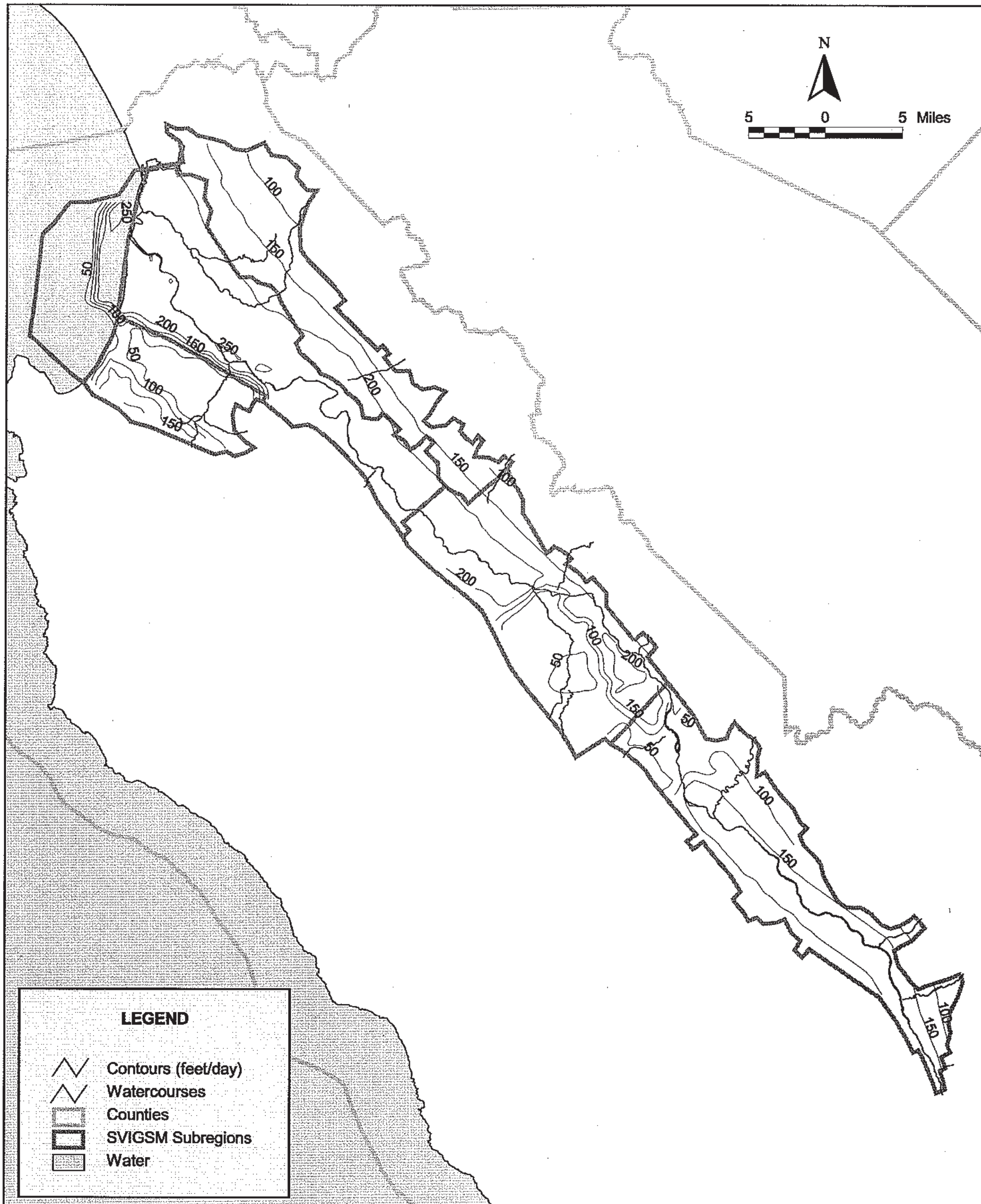
FIGURE 3.15



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Hydraulic Conductivities for Revised Model Layer 1

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FIGURE 3.16

2. Arroyo Seco River conductivities were slightly reduced in the Forebay Subarea; and

3. Salinas River conductivities in the Pressure Subarea above El Toro Creek were increased.

As a result of the recalibration efforts, there was a better match of simulated groundwater levels with the previously simulated groundwater levels and with observed groundwater levels. Figures 3.17a through 3.17d show the distribution of residuals for each subarea over the simulation period. Figures 3.18a through 3.18e show the distribution of errors in the simulated and historic groundwater levels in the entire model area as well as in each subarea. The distributions of residual groundwater levels show the percentage or residuals within the specified ranges. Again, a higher percentage of residuals near zero and one that is more centered on zero indicate a better simulation of historical conditions. Model performances for the entire model area and each subarea are summarized below based on these statistical evaluations. A comparison of Figures 3.2a–3.2d and 3.18a–3.18e indicates that quality of model calibration in the revised version of SVIGSM is as good as or better than the original version.

Model Area. Nearly all simulated groundwater levels (approximately 91%) for the entire model area are within 20 feet of observed groundwater levels. Approximately 80% of simulated groundwater levels are within 10 feet of observed groundwater levels. These are better statistical results than what was determined in the previous version of SVIGSM.

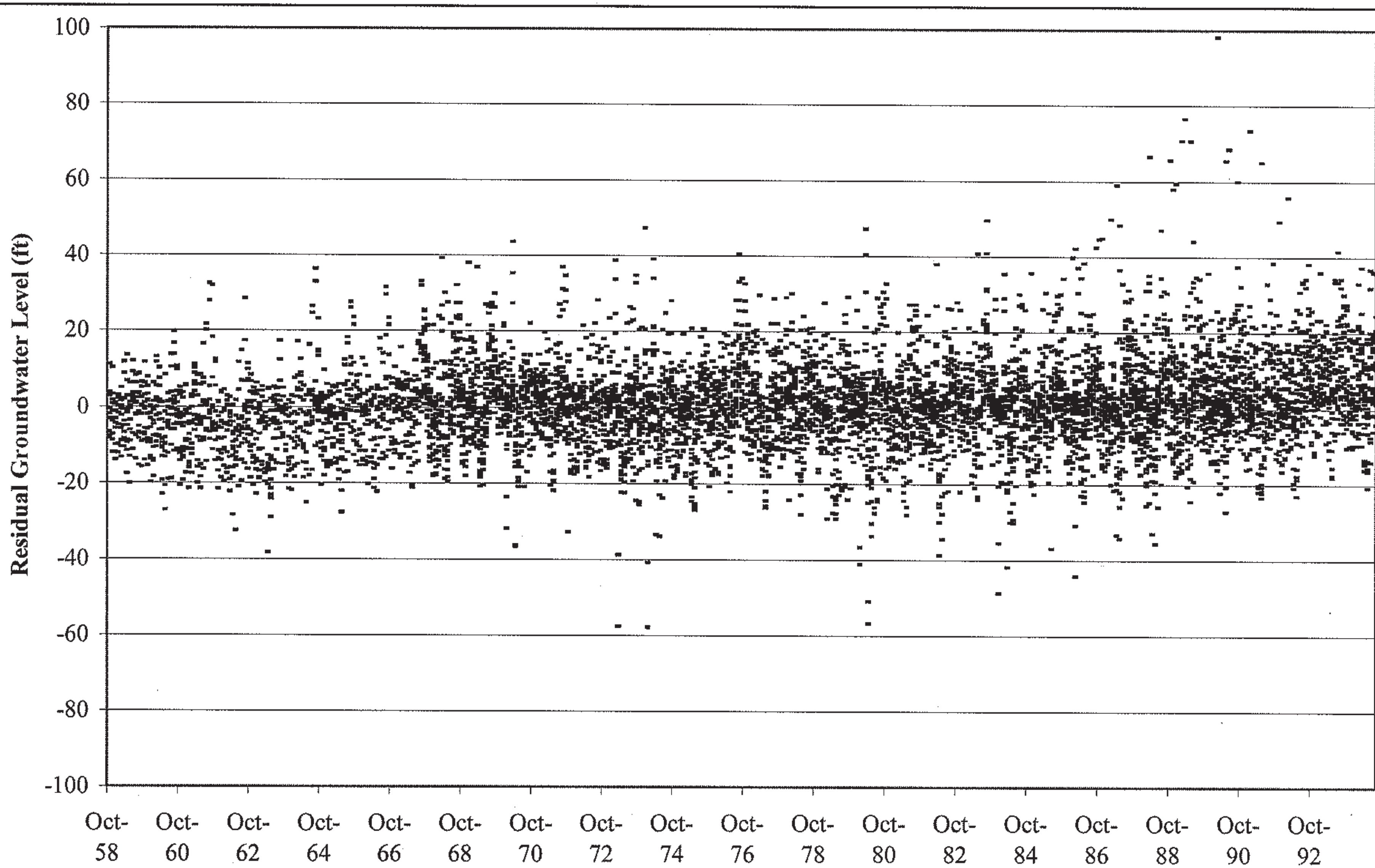
Pressure Subarea. The majority of the simulated groundwater levels (approximately 80%) lie within 10 feet of observed groundwater levels.

East Side Subarea. Distributions of the residuals show that approximately 55% of simulated groundwater levels are within 10 feet of observed groundwater levels. This is consistent with the previous SVIGSM version.

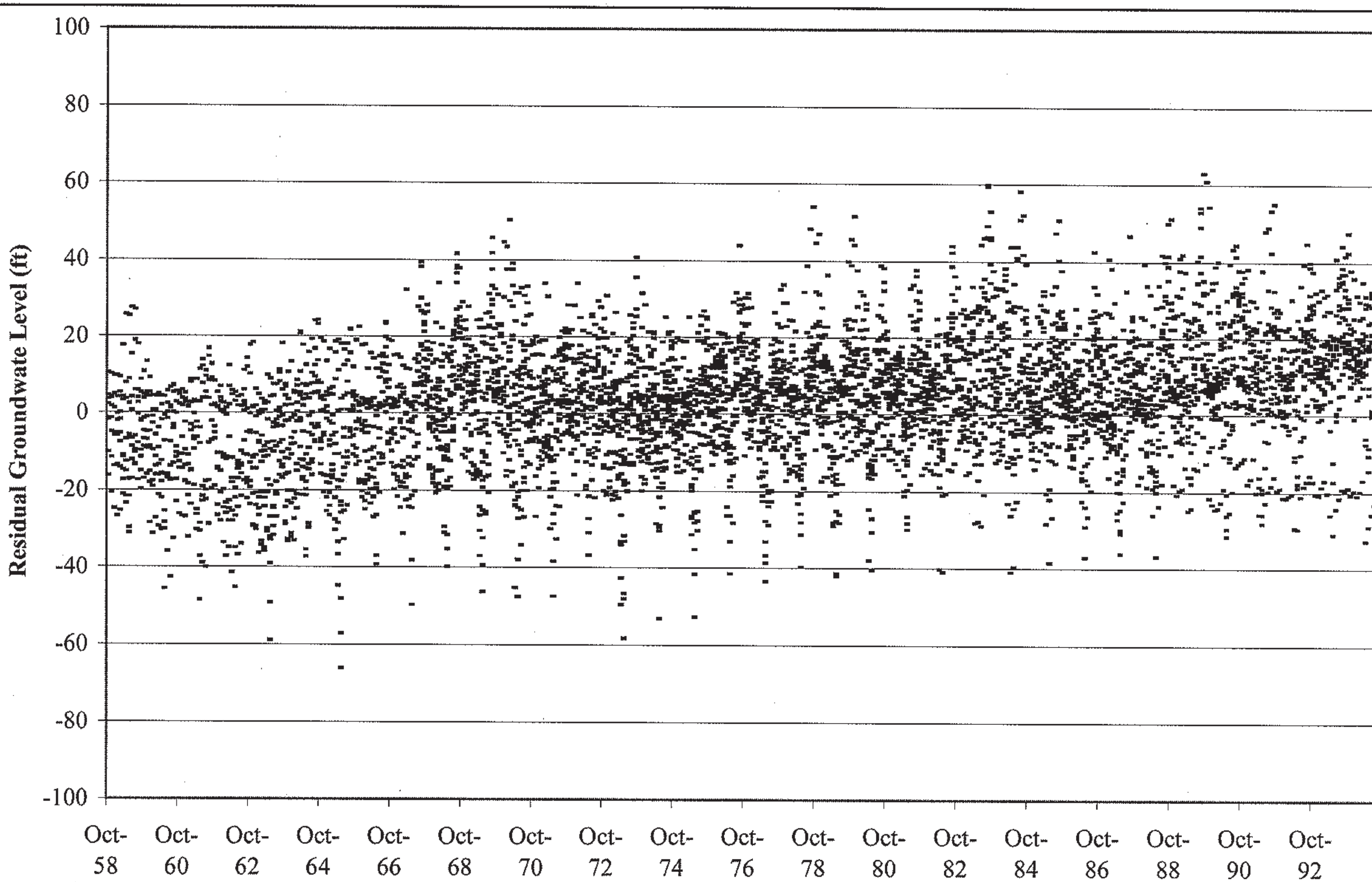
Forebay Subarea. The distribution of residuals shows good calibration between simulated and observed groundwater levels. Overall, 75% percent are within 10 feet of each other. The distributions appear to be normally shaped except for the Forebay deep aquifers that show a bias of the model in underestimating groundwater levels. These results are not as good as the statistical results from the previous SVIGSM version.

Upper Valley Subarea. Simulated groundwater levels tend to match observed groundwater levels. All simulated values are within 20 feet of observed groundwater levels.

Figure 3.2 shows the location of the calibration wells, including the MCWD production wells. Figures 3.19 through 3.21 show the hydrographs for each of the wells. These Figures indicate



RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Residual Groundwater Level between SVIGSM Version 5.0 and Historic Data in the Pressure Subarea - 4 Layer Model for Water Years 1959 through 1994**	MAY 2003 FIGURE 3.17a



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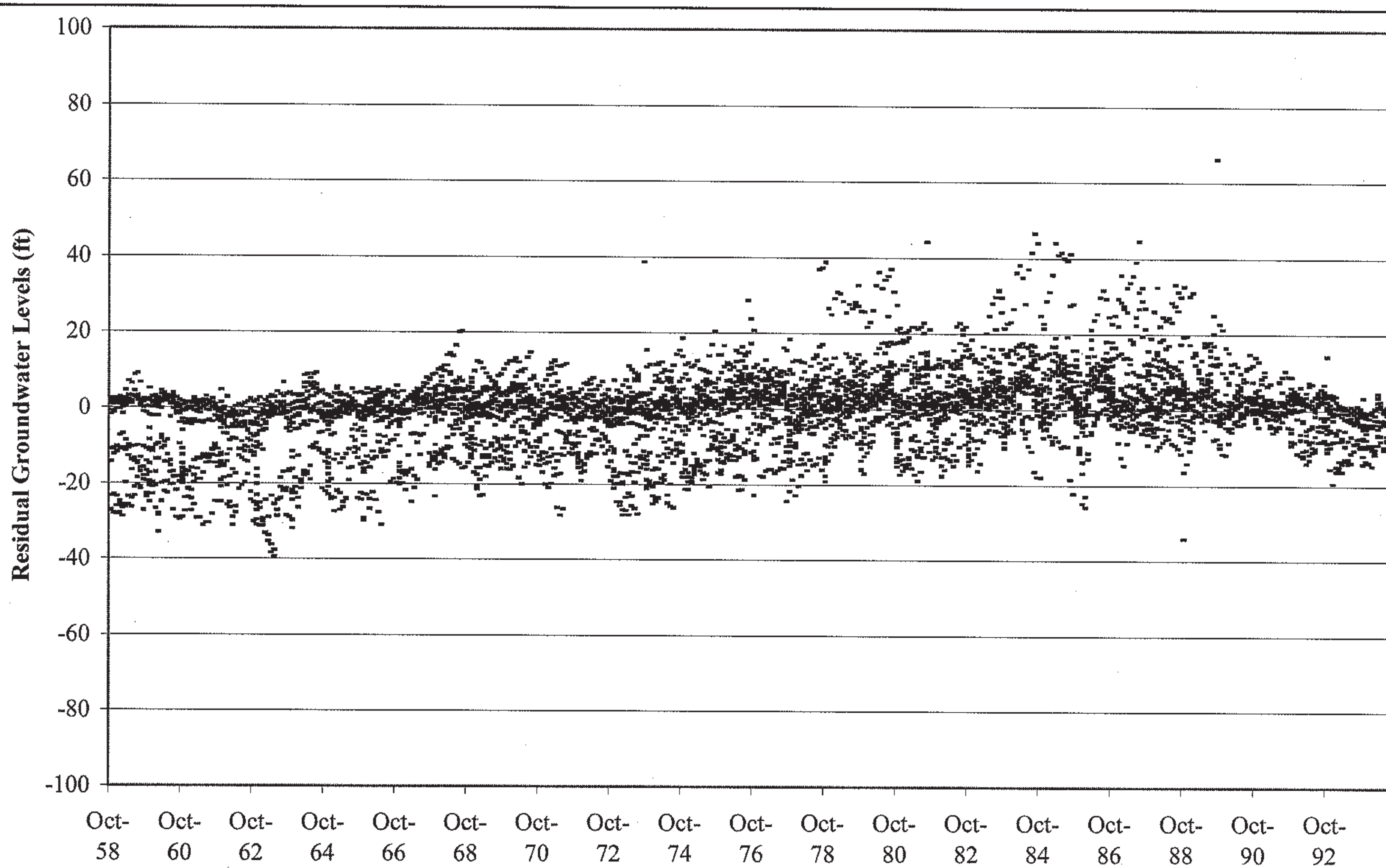
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Residual Groundwater Level between SVIGSM Version 5.0 and Historic Data in the East Side Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.17b



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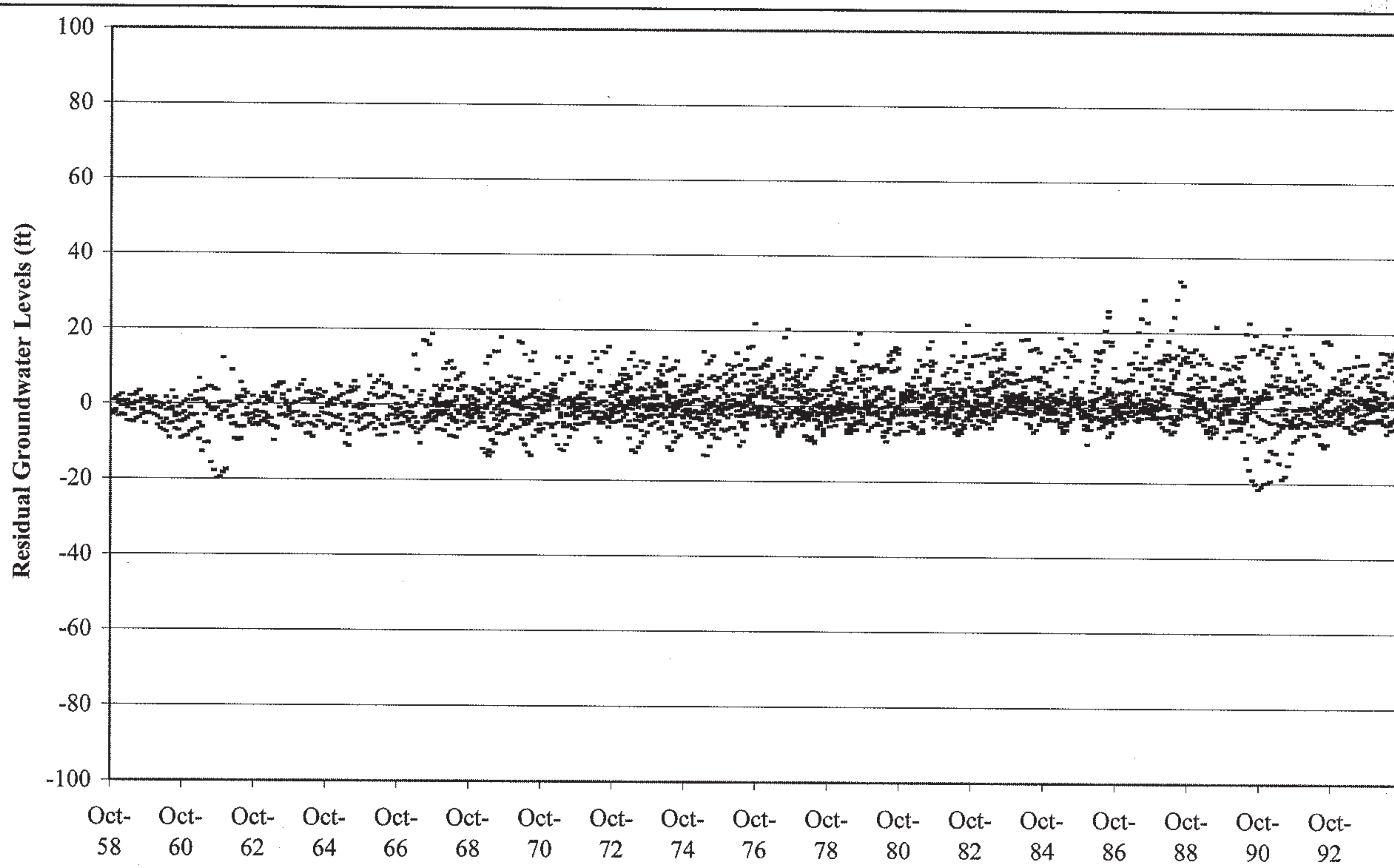
DEEP AQUIFER INVESTIGATIVE STUDY

Residual Groundwater Level between SVIGSM Version 5.0 and Historic Data in the Forebay Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.17c



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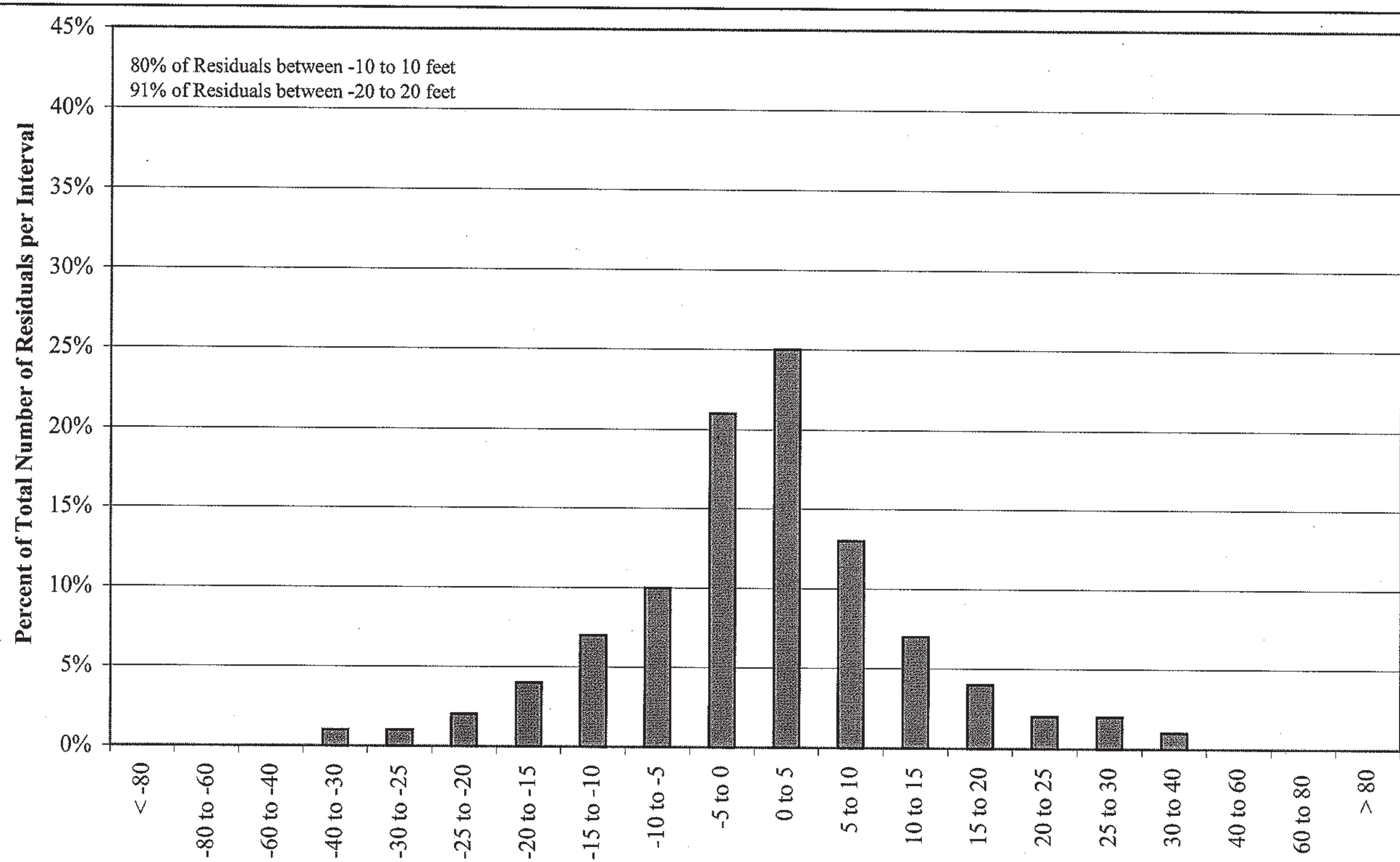
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Residual Groundwater Level between SVIGSM Version 5.0 and Historic Data in the Upper Valley Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.17d



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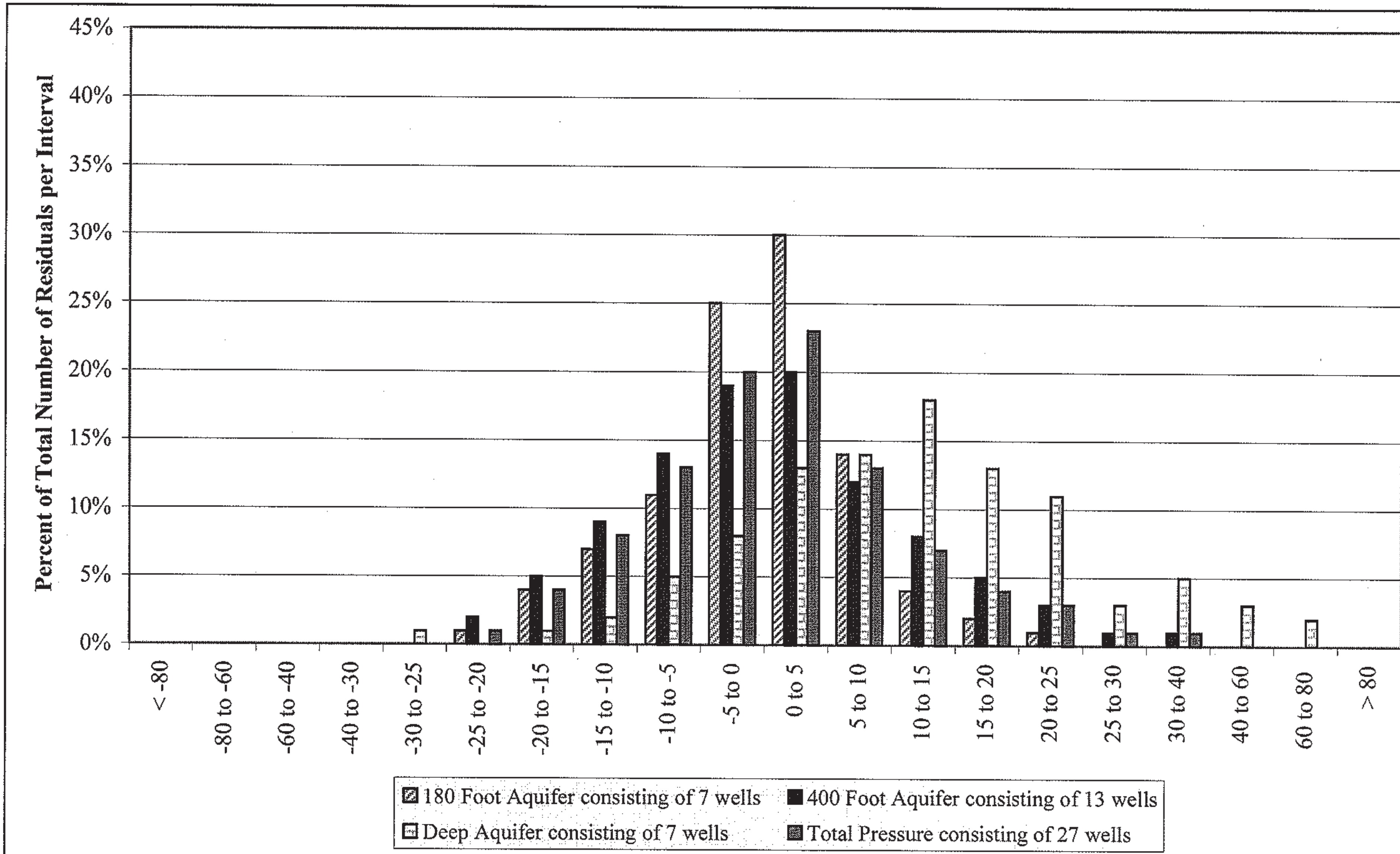
DEEP AQUIFER INVESTIGATIVE STUDY

Histogram of Residual Groundwater Levels between SVIGSM Version 5.0 and Historic Data - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.18a



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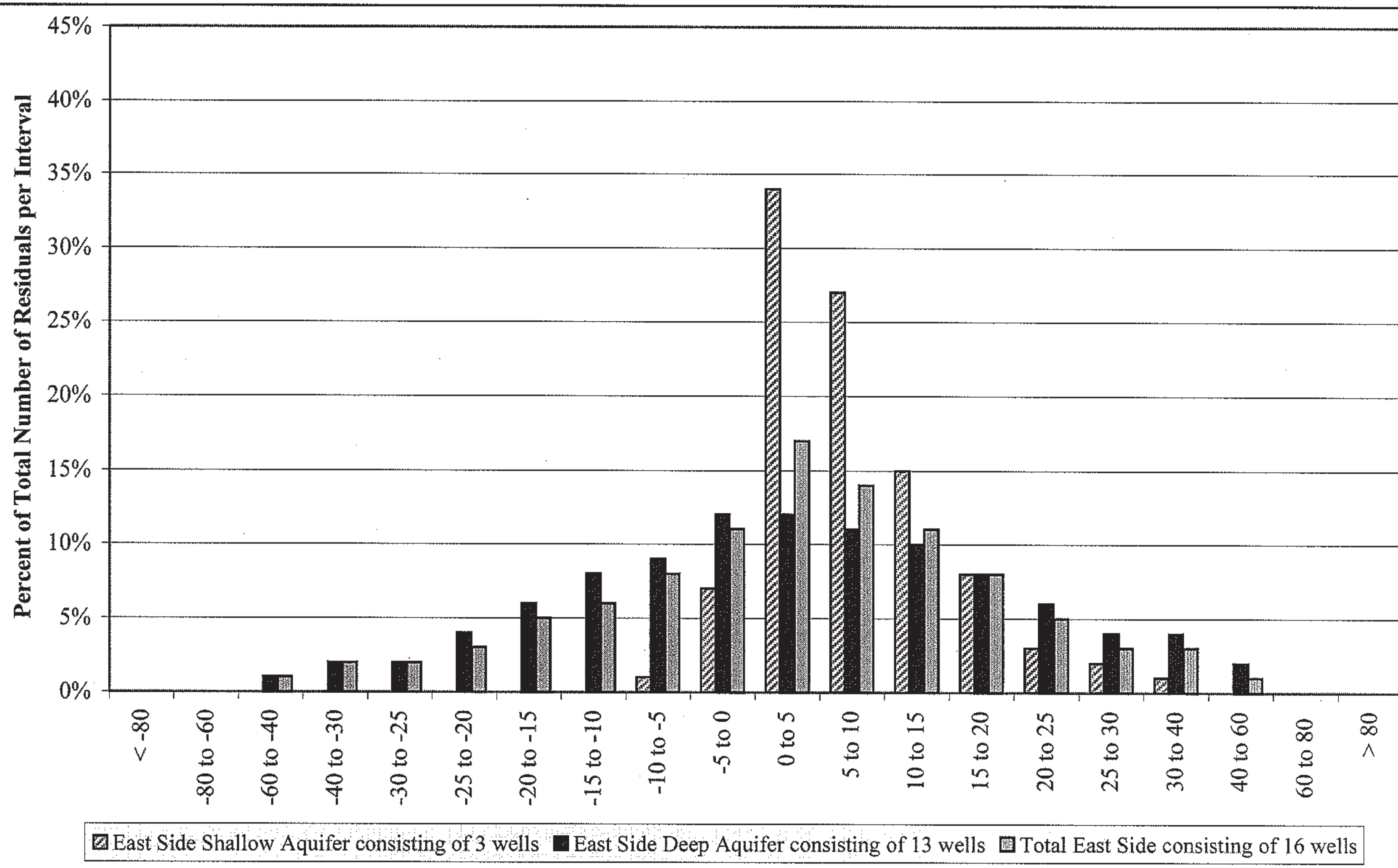
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Histogram of Residual Groundwater Levels between SVIGSM Version 5.0 and Historic Data in Pressure Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.18b



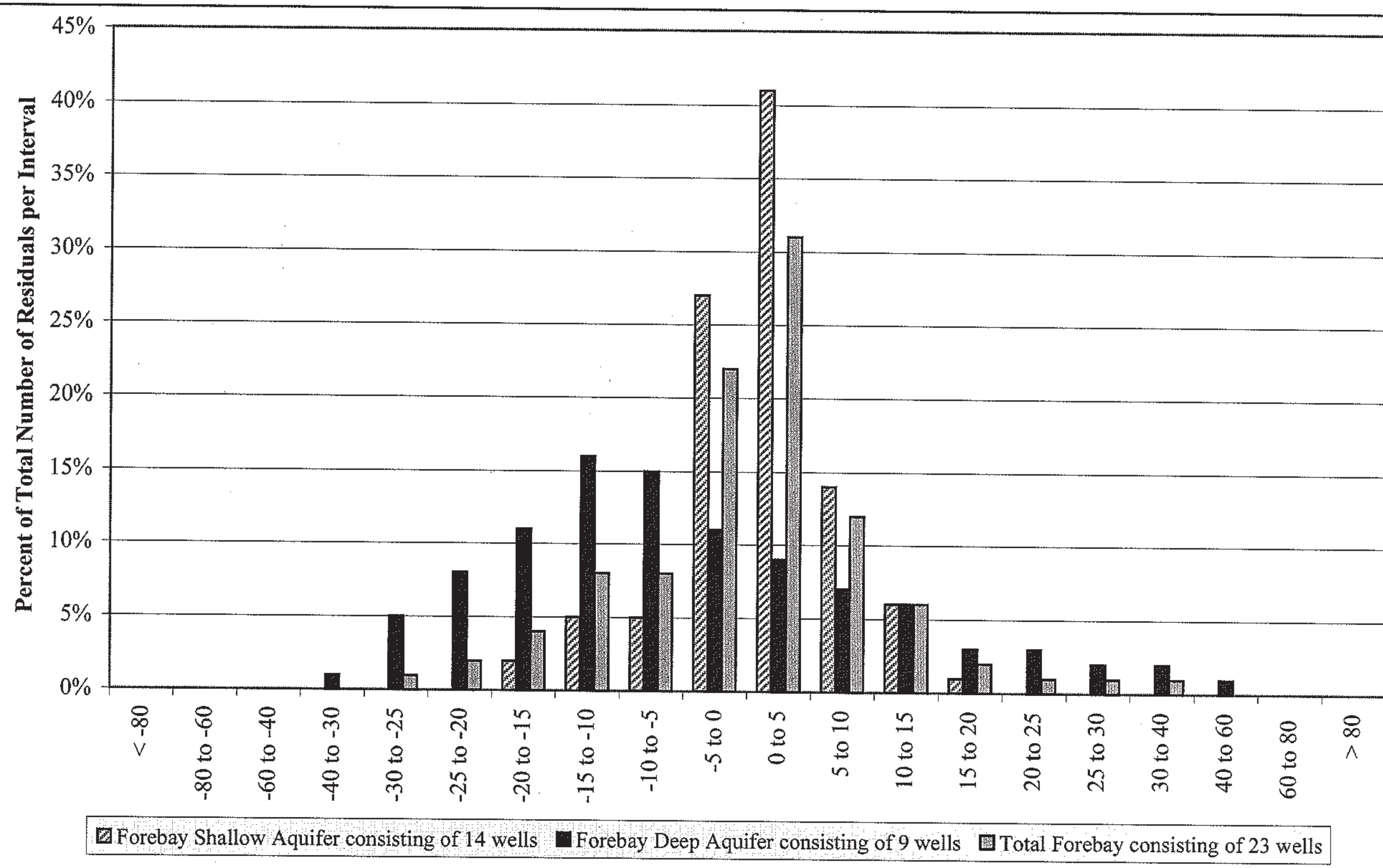
RIME

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

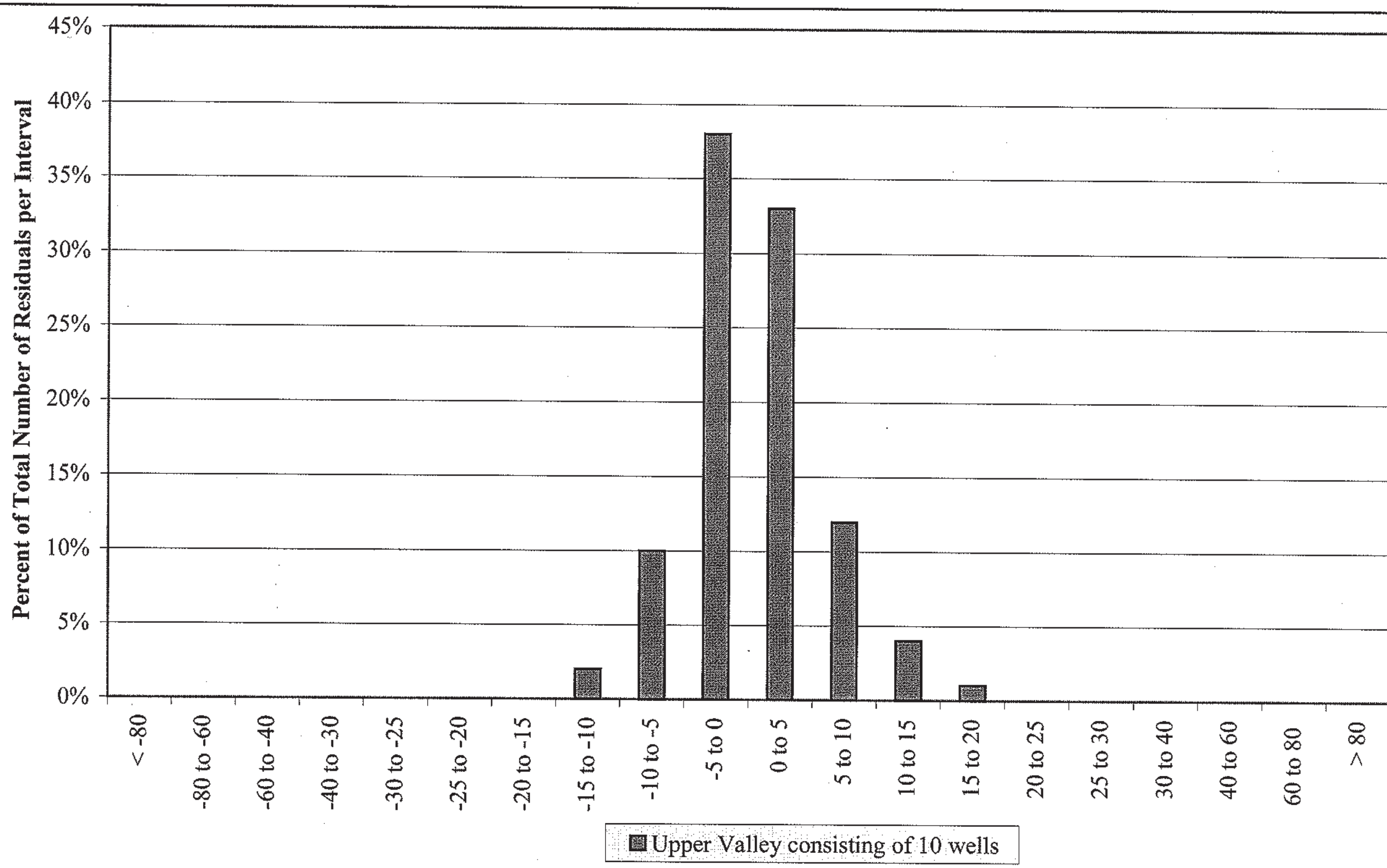
Histogram of Residual Groundwater Levels between SVIGSM Version 5.0 and Historic Data in East Side Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

FIGURE 3.18c



RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Histogram of Residual Groundwater Levels between SVIGSM Version 5.0 and Historic Data in Forebay Subarea - 4 Layer Model for Water Years 1959 through 1994**	MAY 2003 Figure 3.18d



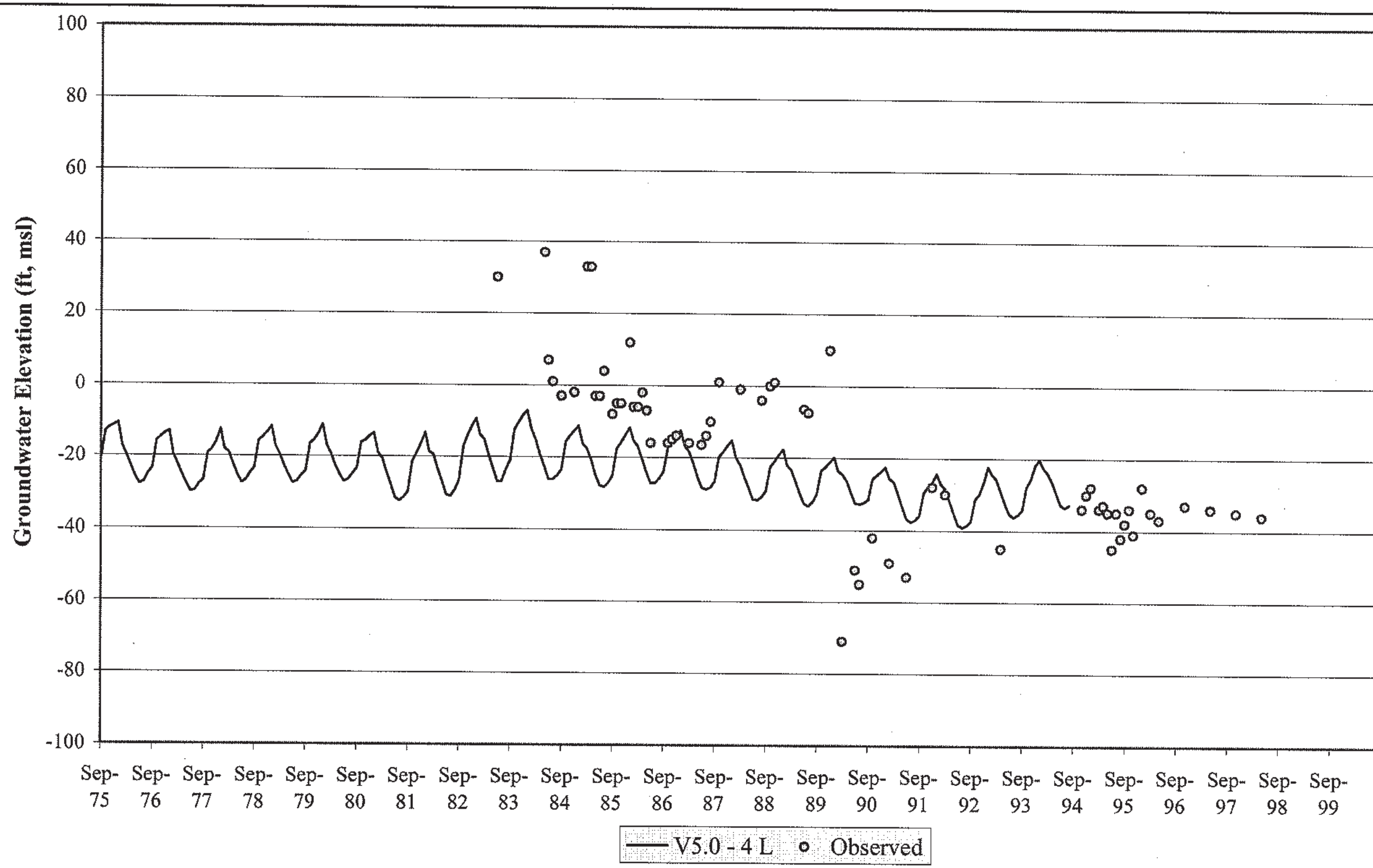
RIME

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Histogram of Residual Groundwater Levels between SVIGSM Version 5.0 and Historic Data in Upper Valley Subarea - 4 Layer Model for Water Years 1959 through 1994

MAY 2003

Figure 3.18e

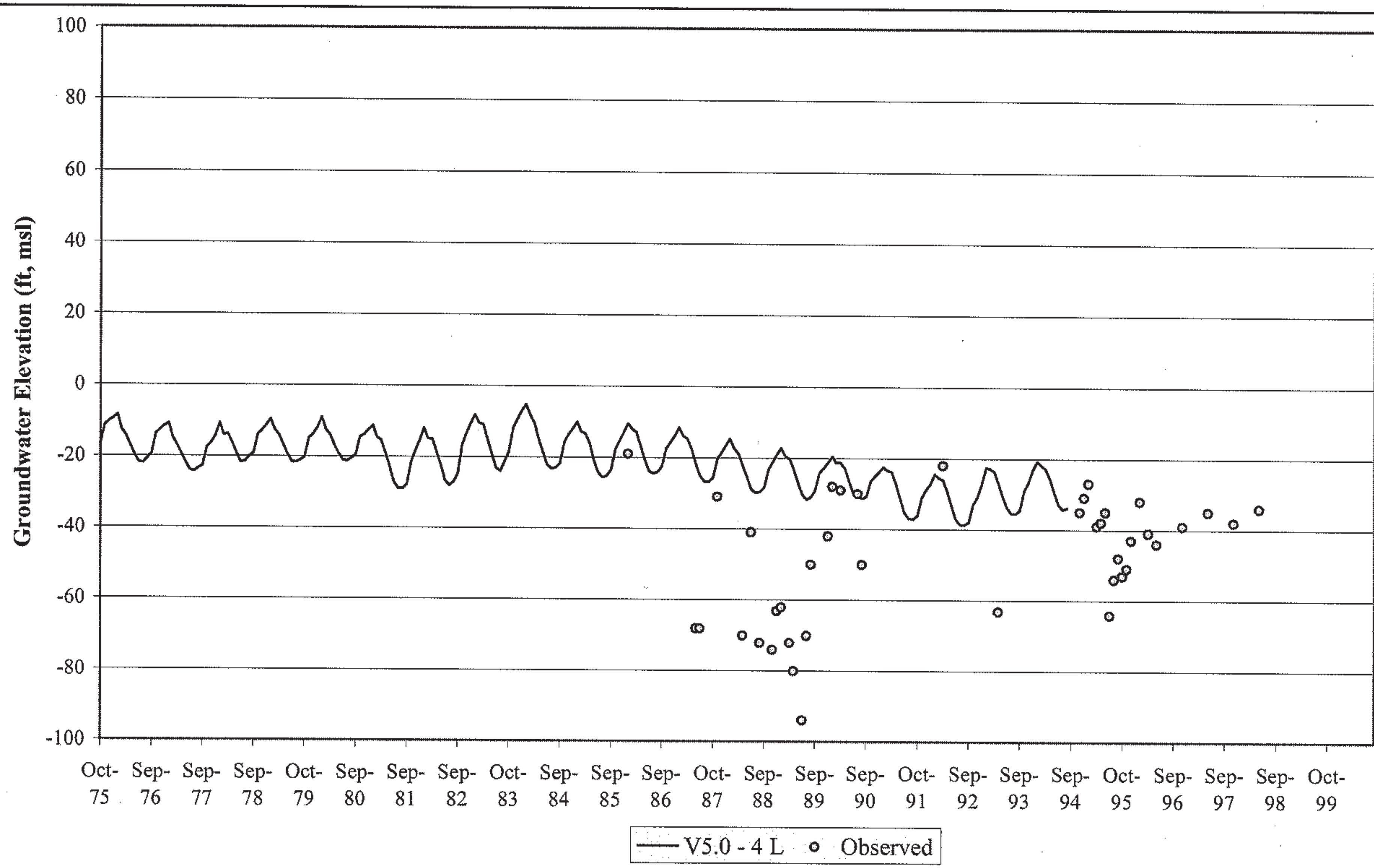


RIME

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY
Calibration Well 74 - Pressure Subarea MCWD #10 - Upper Deep Aquifer

MAY 2003

FIGURE 3.19



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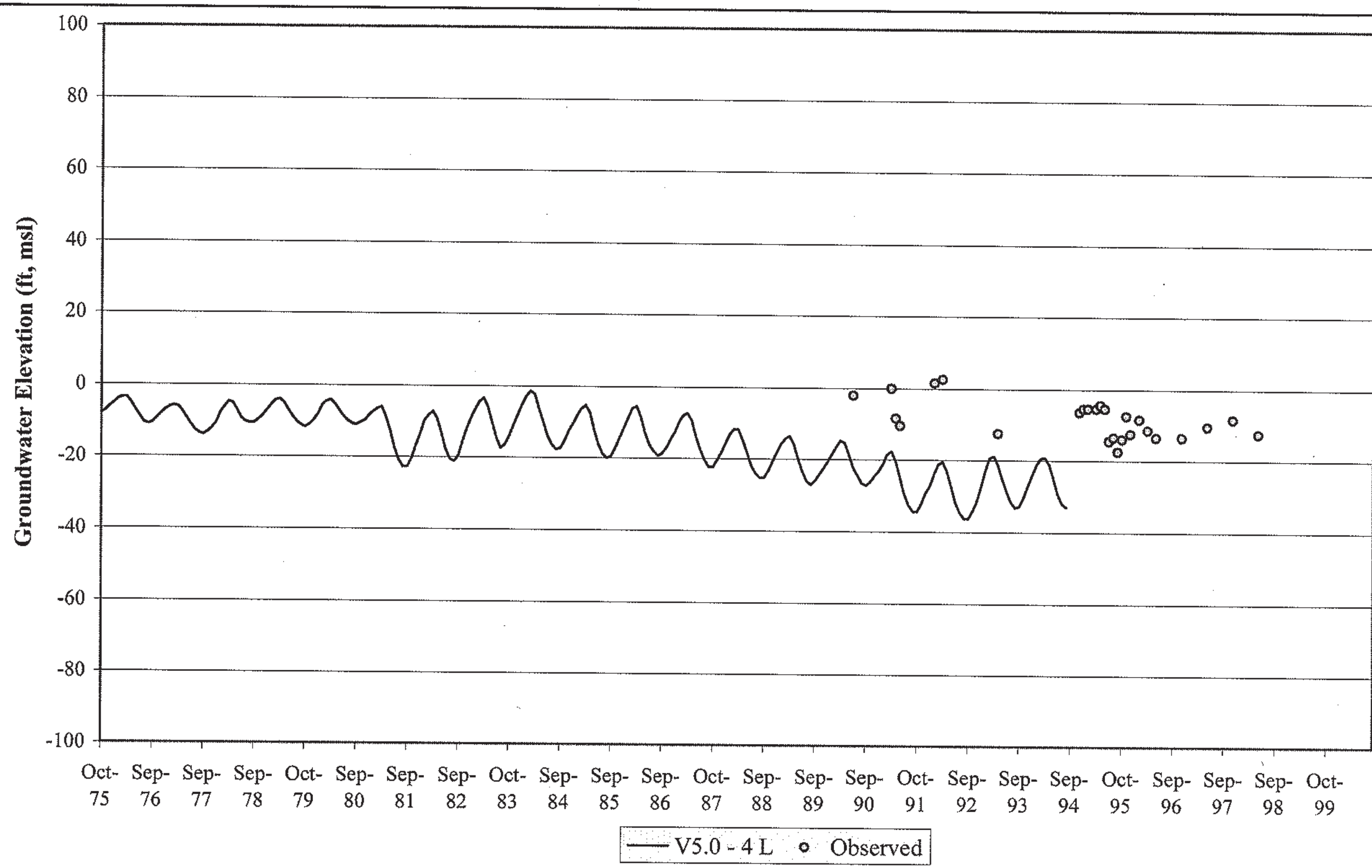
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Calibration Well 75 - Pressure Subarea MCWD #11 - Upper Deep Aquifer

MAY 2003

FIGURE 3.20



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MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Calibration Well 76 - Pressure Subarea MCWD #12 - Upper Deep Aquifer

MAY 2003

FIGURE 3.21

that the model is reasonably simulating the annual trends as well as the seasonal fluctuations in the MCWD wells although the levels may not match. It is noteworthy that these wells are currently assigned as pumping wells in the model. As such, the simulated groundwater heads potentially represent dynamic heads.

BASELINE CONDITION

The baseline conditions developed for the Salinas Valley Water Project were adopted for this effort. The following are changes made to the baseline conditions scenario:

1. Updated stratigraphy data were included;
2. Updated groundwater pumping for MCWD was simulated using MCWD wells at a rate of approximately 2,400 AFY;
3. MCWD wells 10 and 11 pump from Layer 3 and accounts for 73% of groundwater production and Well 12 pumps from Layer 4 and accounts for 27% of groundwater production; and
4. Updated aquifer and streambed parameters were included.

The baseline conditions were simulated and used in the Water Supply Reliability and Safe Yield analysis.

DEFINITION

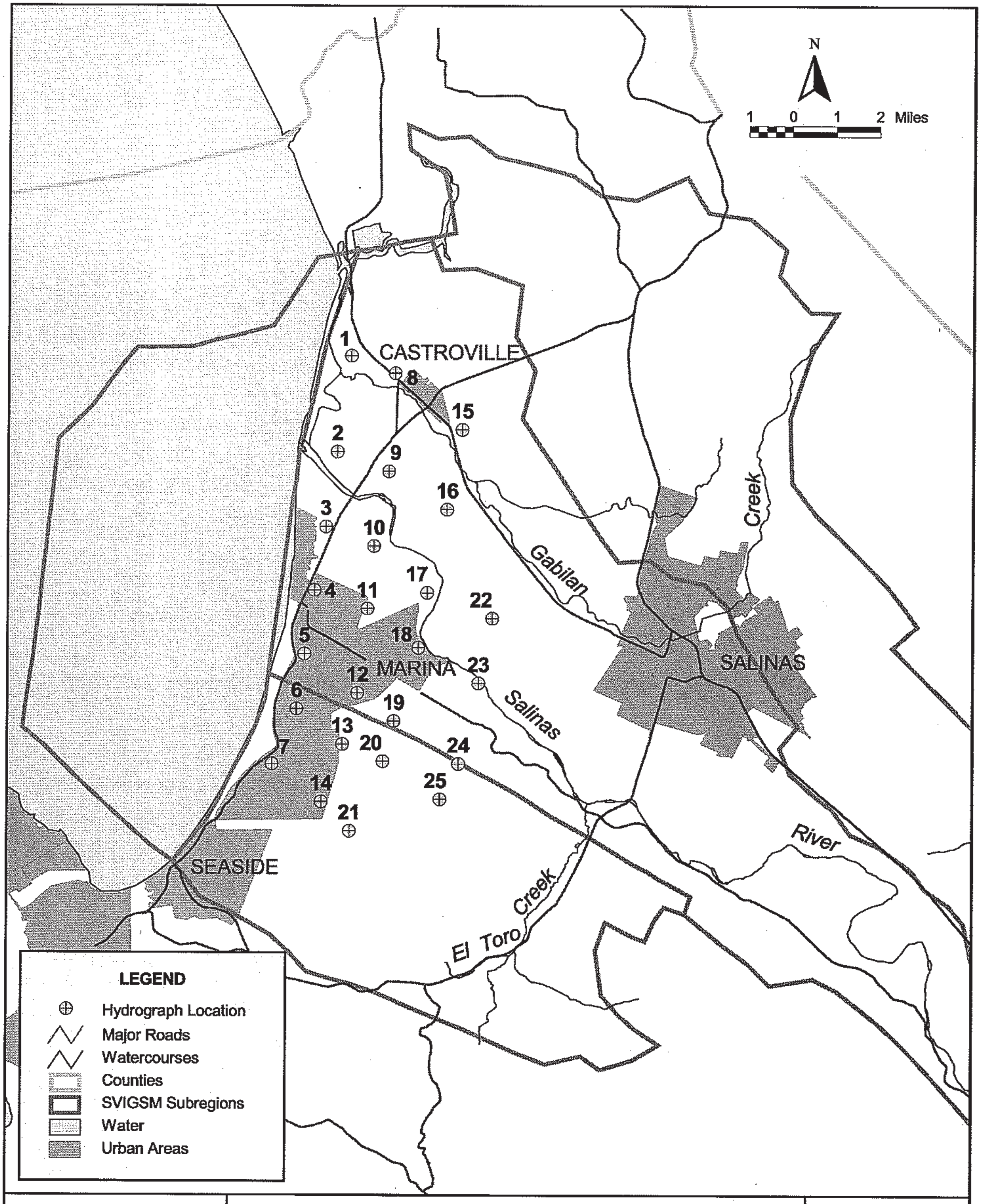
The textbook definition of "safe or sustainable yield" of an aquifer system is the average annual withdrawal that can be taken from the groundwater system without causing a long-term degrading effect in the quantity or quality of the groundwater. This limited definition assumes that the groundwater system is an isolated system without interaction with the surface water processes, such as a stream system. Moreover, the definition is not applicable to an integrated and multi-layered groundwater system in which the operation of one layer affects the groundwater levels in the adjacent layers. In general, safe or sustainable yield may depend on the following factors:

1. The hydrologic period considered to estimate the safe yield;
2. The importance of the groundwater system as a source of supply, compared to other potential sources; and
3. The degree of tolerance in the degradation of quality or decline in quantity of groundwater.

Therefore, a more practical definition for the safe or sustainable yield of a multi-layered and integrated aquifer system is the average annual withdrawal from the aquifer layer or the aquifer system, such that the long-term quantity and quality of the aquifer system as a whole is not degraded.

SAFE YIELD ANALYSIS

To evaluate the safe or sustainable yield of the deep aquifers, a set of response curves are developed to represent the impacts of changing groundwater pumping in MCWD wells. The baseline groundwater pumping at the three MCWD wells is 2,400 AFY; 1,750 AFY from layer 3, and 650 AFY from layer 4. These curves relate changes in MCWD baseline groundwater pumping in the following: 1) average groundwater levels in each layer; 2) groundwater flow across the coast; and 3) vertical groundwater flow between the aquifer layers. In order to monitor the changing groundwater levels in the coastal areas, a set of monitoring locations were assigned in the model. Figure 4.1 shows the locations of 25 points used to monitor changing groundwater levels over time. Figures 4.2 through 4.5 show the response of average groundwater levels to changes in MCWD baseline groundwater pumping.



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Pumping Sensitivity Analysis
Hydrograph Location Map

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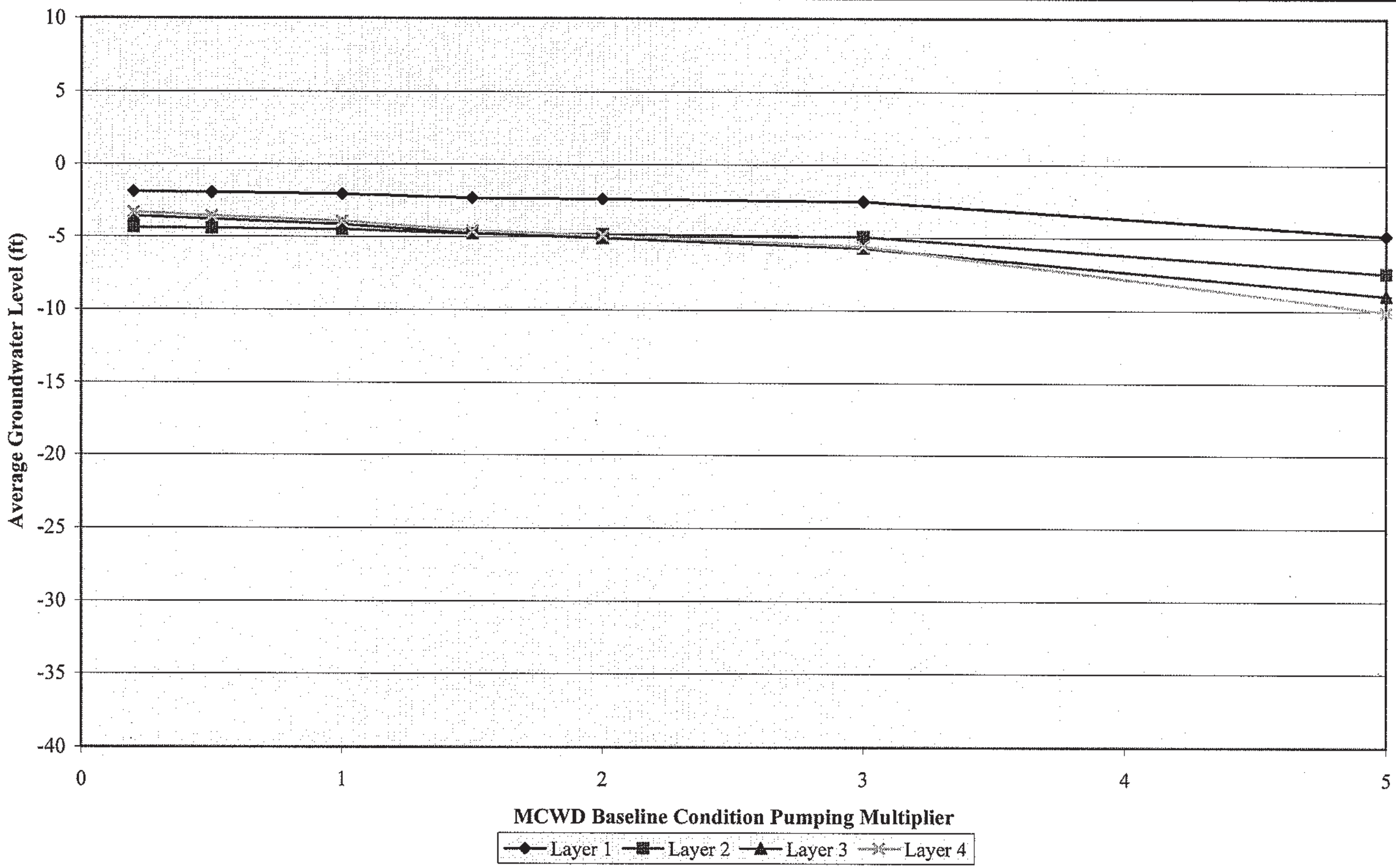
FIGURE 4.1



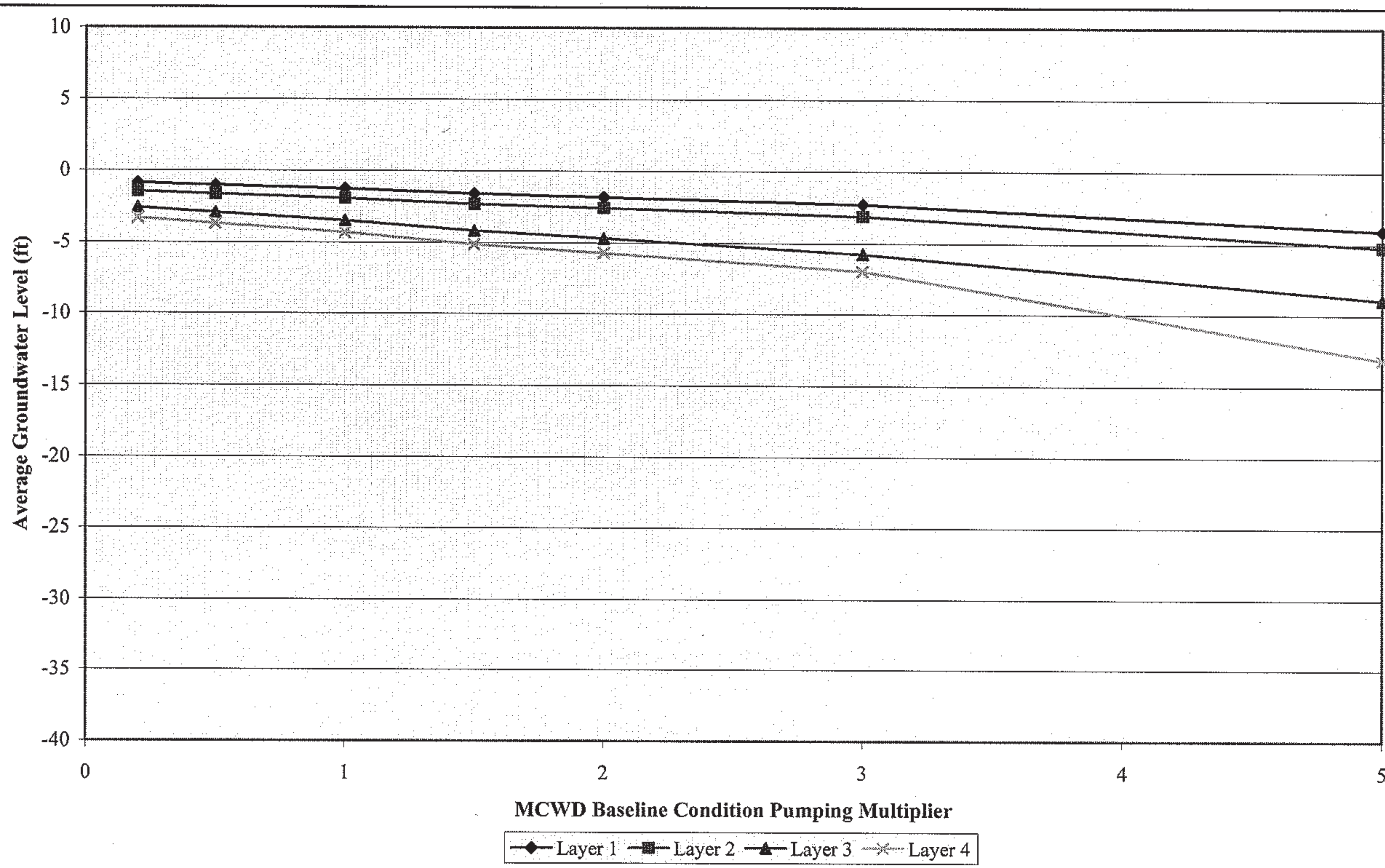
Baseline conditions occur when x-axis is equal to 1

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Response Curve of Pumping and Average Groundwater Levels for Coastal Hydrograph Locations per Aquifer

MAY 2003

FIGURE 4.2



Baseline conditions occur
when x-axis is equal to 1

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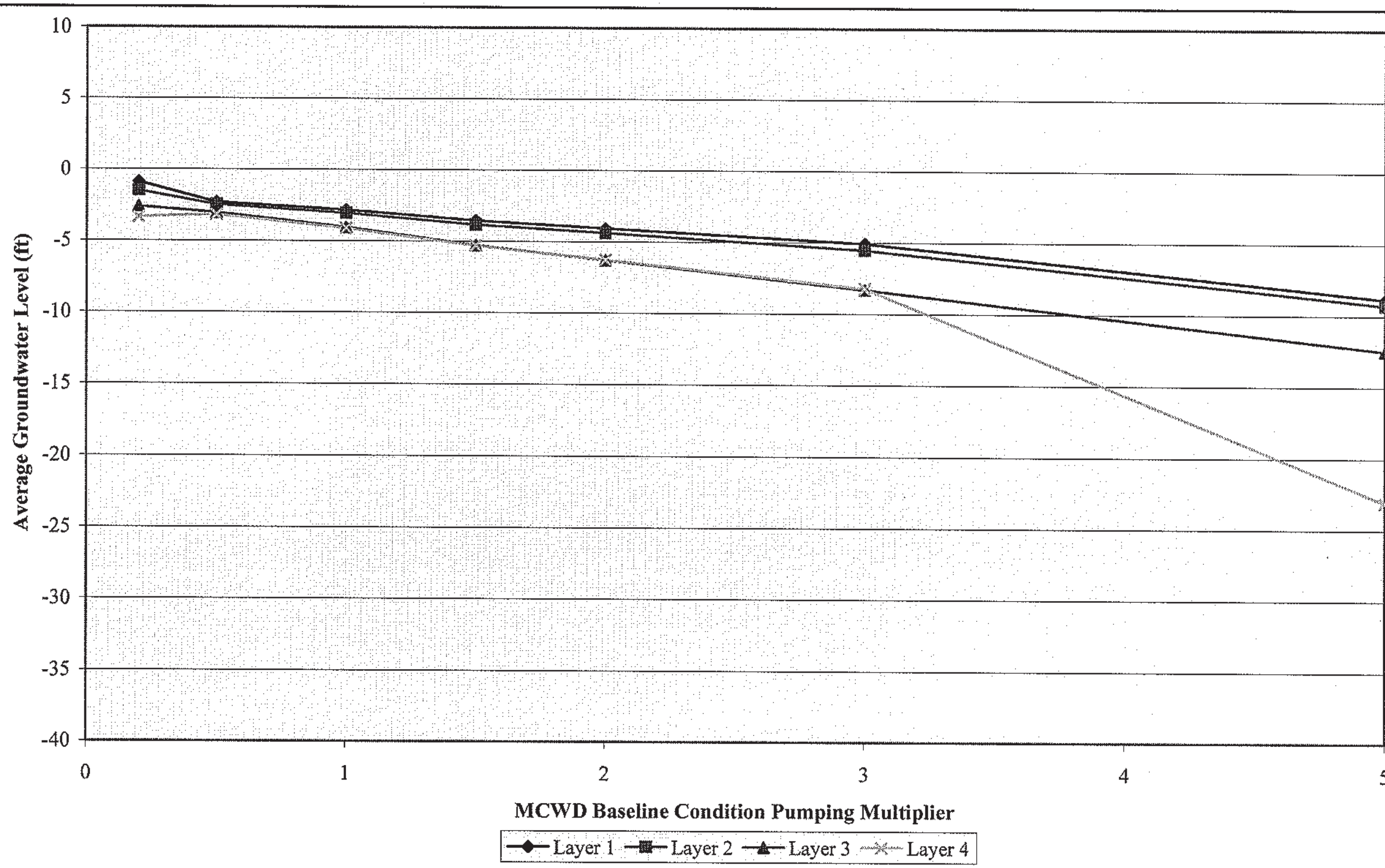
DEEP AQUIFER INVESTIGATIVE STUDY

Response Curve of Pumping and Average Annual (1959-94) Groundwater Levels for Coastal Hydrograph of Well 5

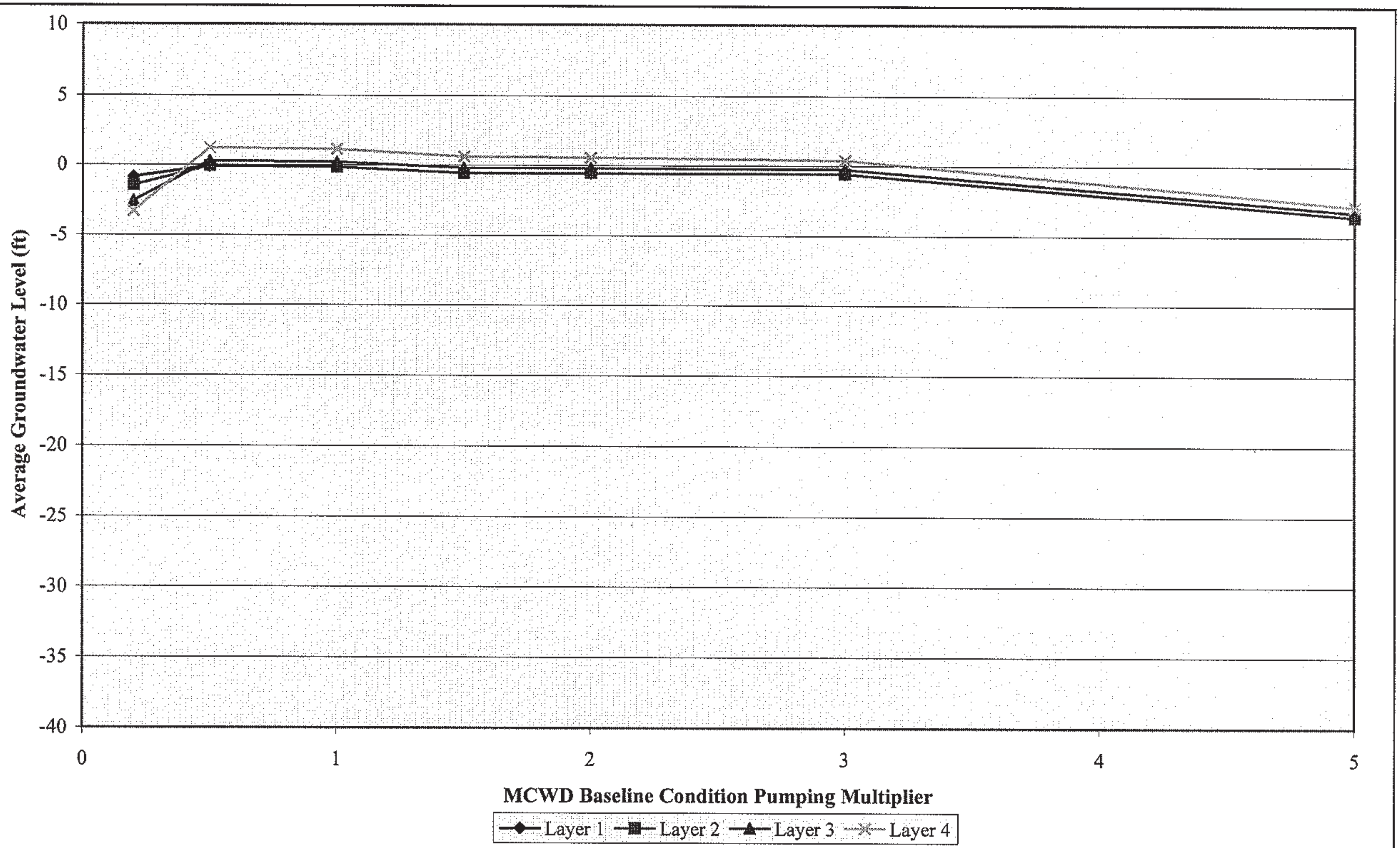
MAY 2003

FIGURE 4.3



Baseline conditions occur when x-axis is equal to 1

RIME	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **Response Curve of Pumping and Average Annual (1959-94) Groundwater Levels for Coastal Hydrograph of Well 12**	MAY 2003 FIGURE 4.4



Baseline conditions occur
when x-axis is equal to 1

RIME

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Response Curve of Pumping and Average Annual (1959-94) Groundwater Levels for Coastal Hydrograph Well 24

MAY 2003

FIGURE 4.5

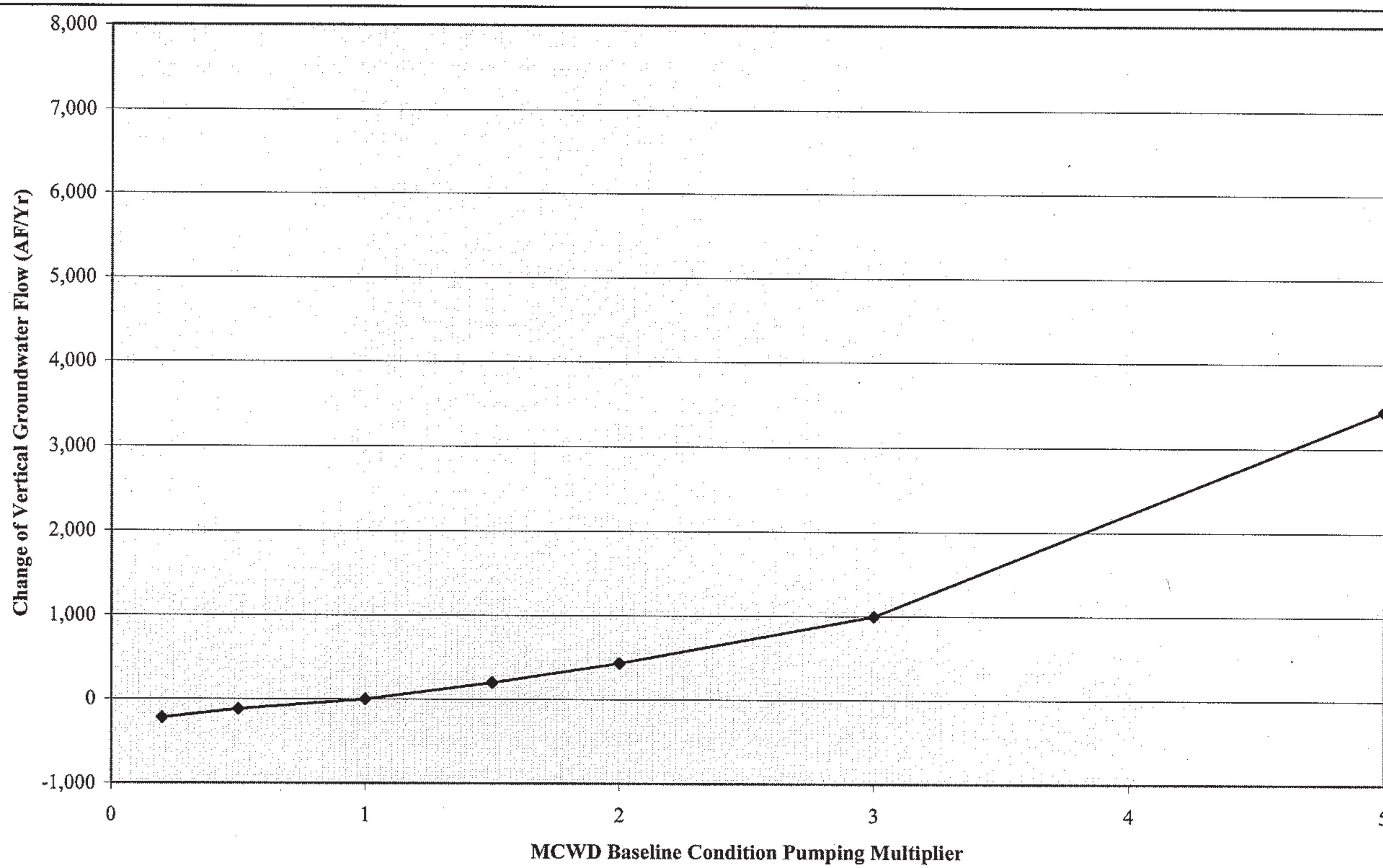
Figure 4.2 shows the response of the groundwater system as an average of all 25 hydrograph locations for each layer. Figures 4.3 through 4.5 show average groundwater levels, per layer, for three selected locations. All the figures indicate that groundwater heads will continue to decline in almost all aquifer layers if groundwater production from the deep aquifers is increased significantly from baseline levels.

Figure 4.6 shows the response of vertical groundwater flow to changes in baseline pumping. In general, as pumping increases there is an increase in vertical flow from Aquifer 1 to Aquifer 2.

Figure 4.7 shows the change in coastal groundwater flow from the baseline conditions because of changes in baseline groundwater pumping. In this case, the coastal subsurface flows are used as a surrogate for rate of seawater intrusion. In general, the inland groundwater flow towards the coast increases with groundwater pumping increases. It should be noted that increases in the coastal flows in the 180-foot aquifer and the deep aquifers are larger than those in the 400-foot aquifer. This may be due to the fact that increases in deep aquifers groundwater pumping induce more inland subsurface flux in the deep aquifers, as well as more downward flow of groundwater from the 400-foot aquifer. However, the 400-foot aquifer is also rapidly replenished by leakage from the 180-foot aquifer. Therefore, the net change in the 400-foot aquifer may not be as significant, even though the 180-foot aquifer appears to take a greater toll in seawater intrusion because of its substantially higher transmissivities.

POTENTIAL WATER SUPPLY ALTERNATIVES

In light of the varying range of safe or sustainable yield from the deep aquifers, and in order to analyze a set of realistic water supply options for the interim and/or long-term needs of MCWD, three alternative scenarios have been developed and analyzed. The focus of this analysis is to evaluate the impacts of these alternatives on the groundwater levels and inland subsurface flow across the coastline. Table 4.1 defines the three potential water supply scenarios that are analyzed. These scenarios are defined in coordination with the water supply master plan project, currently ongoing. These alternative groundwater supply options focus on maintaining the current groundwater production from MCWD Well Nos. 10, 11, and 12. Further, the additional supplies to meet the future needs of Marina and/or Fort Ord may come from a combination of the upper deep aquifer or 400-foot aquifer from a possible well further south along Reservation Road (in the vicinity of Well 32). Figure 4.8 shows the existing and proposed MCWD groundwater production wells. Increased pumping from Layer 4 is not considered a viable alternative given the lack of potential yield. These alternatives are presented to show the range of alternatives that can be evaluated using the updated SVIGSM. They do not necessarily represent the actual water supply scenarios that the MCWD may be considering in their water supply master plan.



Baseline conditions occur when x-axis is equal to 1

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Response Curve of Pumping for Change of Average Annual (1959-94) Vertical Groundwater Flow from Aquifer 1 to 2 in Pressure and Fort Ord Subregions

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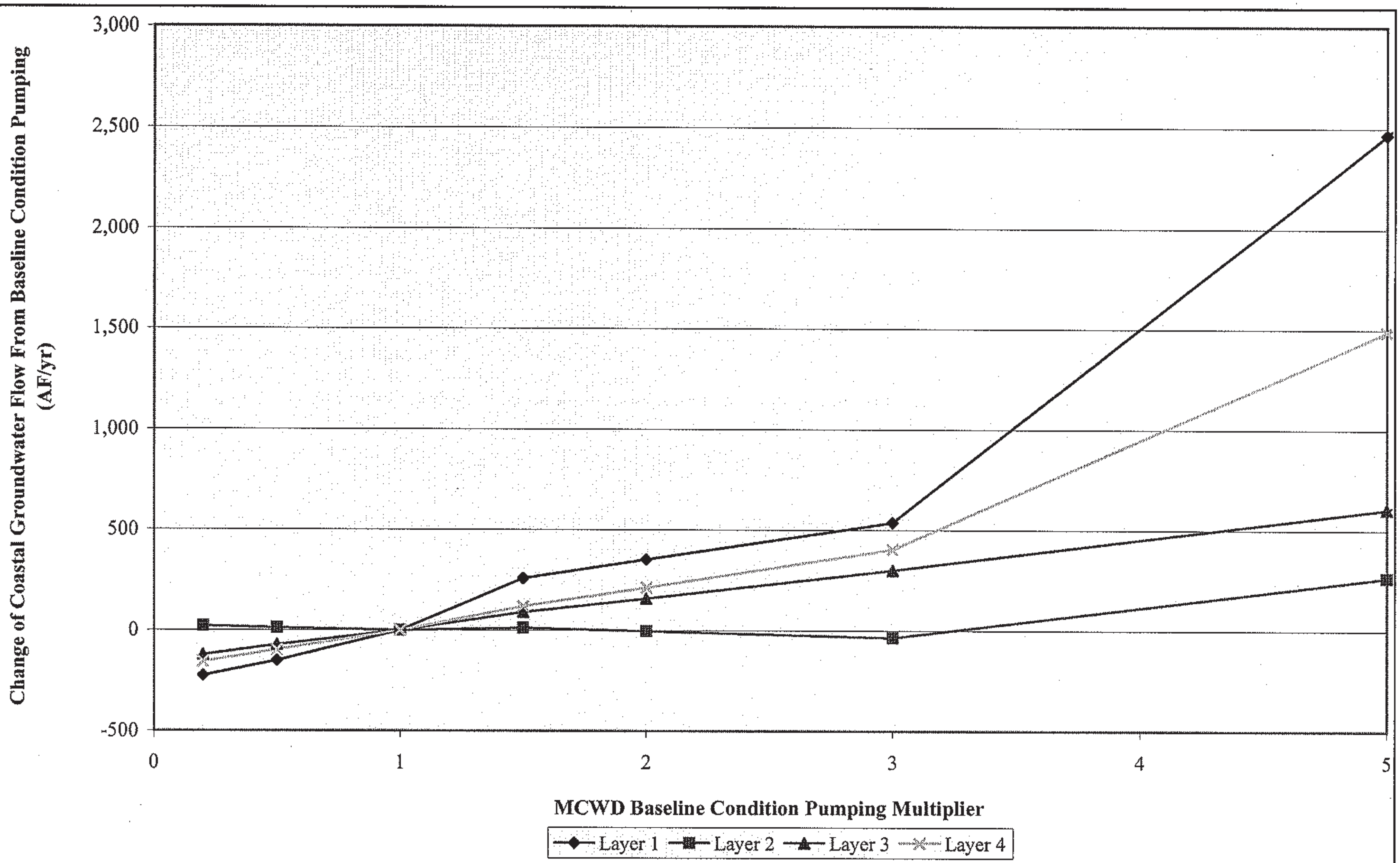
FIGURE 4.6



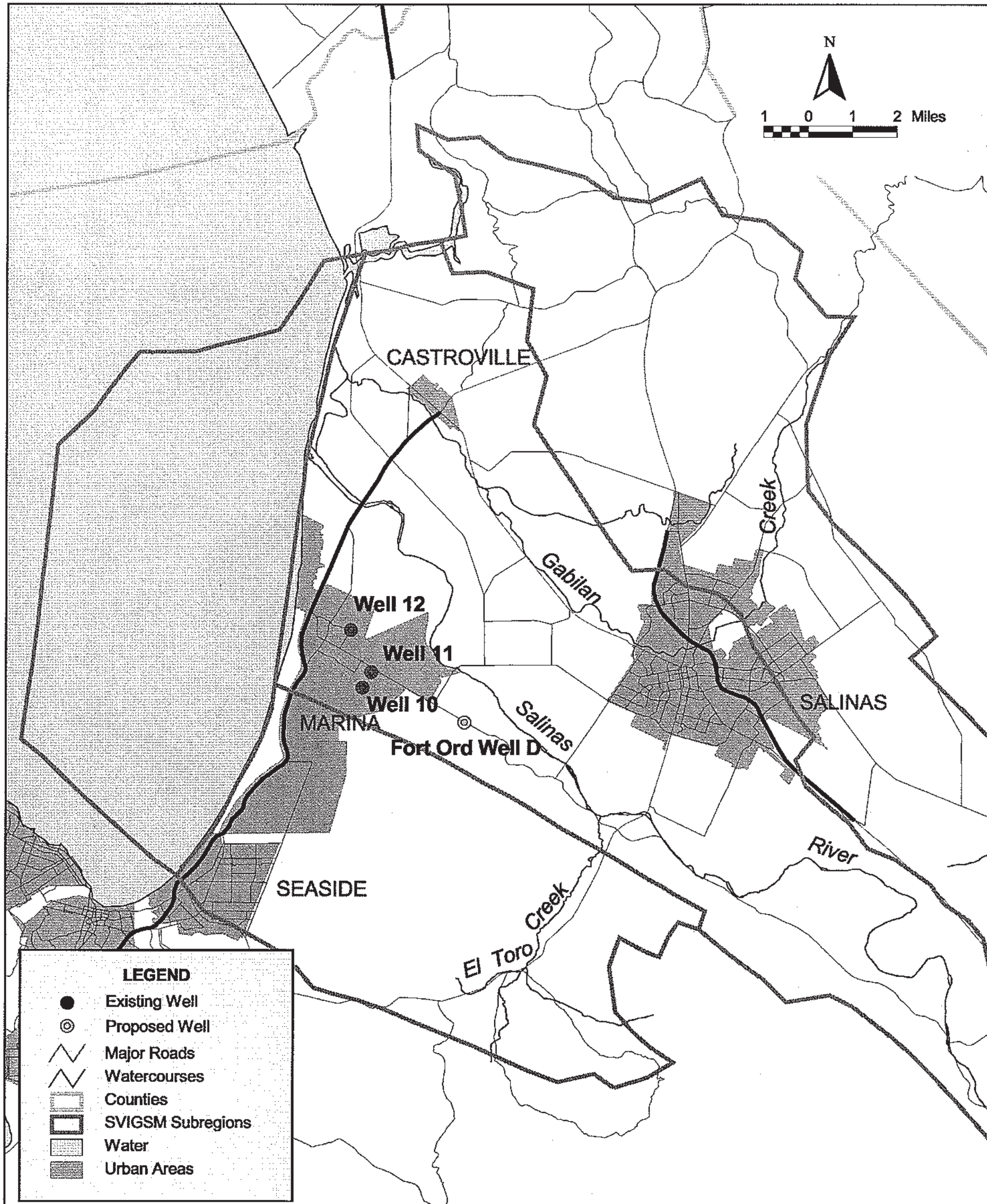
Baseline conditions occur when x-axis is equal to 1

MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Response Curve of Pumping to Change in Average Annual (1959-94) Coastal Groundwater Flow

MAY 2003

FIGURE 4.7



RIME Water Resources & Information Management Engineering, Inc.	MARINA COAST WATER DISTRICT DEEP AQUIFER INVESTIGATIVE STUDY **MCWD Existing and Proposed Groundwater Production Well Location Map**	MAY 2003 FIGURE 4.8

Table 4.1 Baseline Condition and Potential Water Supply Alternatives

Alternative	Description
Baseline	SVWP Baseline assumptions consisting of: 1995 land and water use; Castroville Seawater Intrusion Project is operational; 17,500 AFY of future deliveries to San Luis Obispo County from Nacimiento Reservoir; and MCWD present level of groundwater pumping (2,400 AFY) from existing wells
Alternative 1	MCWD Baseline condition pumping 2,400 AFY from deep aquifers + 1,400 AFY from MCWD upper deep aquifer wells (no change in lower deep well)
Alternative 2	2,400 AFY from deep aquifers + 1,400 AFY from MCWD upper deep aquifer wells (no change in lower deep well) 4,200 AFY from upper deep aquifer at Well 32
Alternative 3	2,400 AFY from deep aquifers + 1,400 AFY from MCWD upper deep aquifer wells (no change in lower deep well) 4,200 AFY from 400-foot aquifer at Well 32

Table 4.2 compares the average groundwater levels, per aquifer, for the 25 coastal monitoring locations.

Table 4.2 Comparison of Average Groundwater Levels (ft, MSL) per Aquifer for Coastal Monitoring Locations

	Aquifer 1	Aquifer 2	Aquifer 3	Aquifer 4
Baseline	-2.1	-4.5	-4.1	-3.9
Alternative 1	-2.5	-4.9	-4.9	-4.7
Alternative 2	-4.1	-6.7	-7.5	-7.1
Alternative 3	-4.2	-6.9	-6.8	-6.5

Table 4.3 compares the relative impact of the alternatives to the baseline conditions in terms of average annual coastal flux.

Table 4.3 Difference in Average Annual Coastal Groundwater Flow (AFY) Between Supply Alternative and Baseline Conditions for Each Aquifer

	Layer 1	Layer 2	Layer 3	Layer 4
Alternative 1	455	61	137	103
Alternative 2	1,663	273	367	390
Alternative 3	1,620	305	349	323

Table 4.4 shows a comparison of average annual vertical groundwater flow between Aquifers 1 and 2 in the Pressure and Fort Ord subareas.

Table 4.4 Comparison of Average Annual Vertical Groundwater Flow (AFY) between Aquifers 1 and 2 in the Pressure and Fort Ord Subareas

Scenario	Aquifers 1 and 2 (AF)	Aquifers 2 and 3 (AF)	Aquifers 3 and 4 (AF)	Difference in Vertical Flow Change from Baseline Condition		
				Aquifers 1 and 2 (AF)	Aquifers 2 and 3 (AF)	Aquifers 3 and 4 (AF)
Baseline	-60,114	167	2,601	0	0	0
Alternative 1	-61,044	-885	2,733	-929	-1,052	132
Alternative 2	-63,760	-3,984	3,216	-3,646	-4,152	614
Alternative 3	-64,558	-163	3,009	-4,443	-331	407

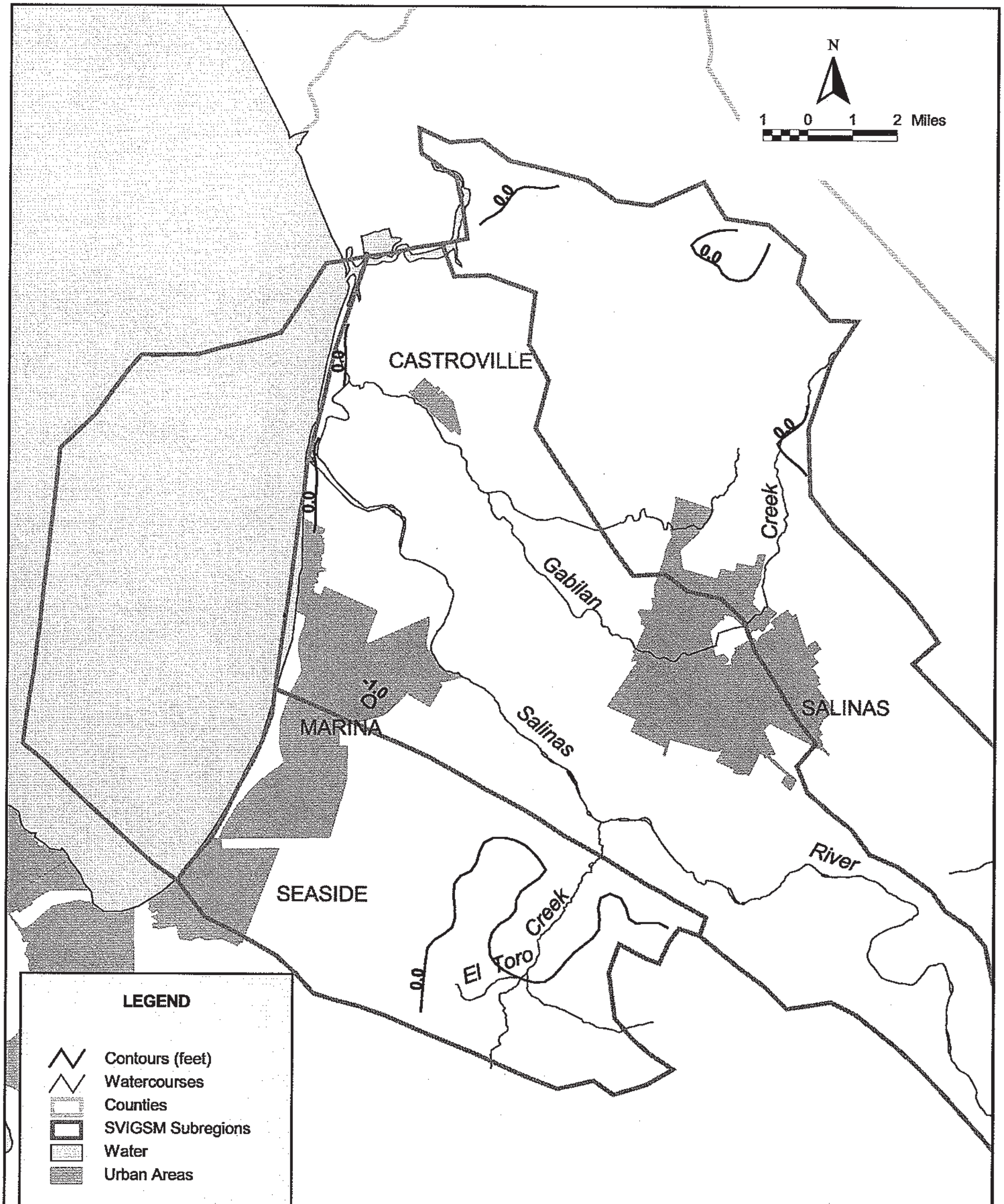
*Positive Values Indicate Upward Flow

Figures 4.9 through 4.20 show September 1994 drawdowns in groundwater heads in various aquifer layers as a result of each alternative groundwater pumping scenario.

Figures 4.9 through 4.12 show the results of long-term pumping under Alternative 1. These figures indicate that the increased long-term MCWD pumping rate in the deep aquifers would cause approximately a 2-feet drawdown in the upper deep aquifer, with much lesser impacts on the other aquifers

Figures 4.13 through 4.16 show the results of long-term pumping under Alternative 2. This alternative is designed to evaluate the effects of additional groundwater production in the upper deep aquifer from the existing MCWD wells, as well as a potential new well further inland, drilled in the upper deep aquifer along Reservation Road. The figures indicate that the additional MCWD pumping from existing wells plus the new well cause approximately 9 feet of decline in the upper deep aquifer groundwater head levels with up to 4 feet and 2 feet of additional decline in groundwater heads in the 400-foot and 180-foot aquifers, respectively.

Figures 4.17 through 4.20 show the results of long-term pumping under Alternative 3. This alternative is designed to evaluate the effects of additional groundwater production in the upper deep aquifer from the existing MCWD wells, as well as a potential new well further inland, drilled in the 400-foot aquifer along Reservation Road. The figures indicate that the additional MCWD pumping from existing wells plus the new well cause approximately 4 feet of decline in the upper deep aquifer groundwater head levels with up to 6 feet and 5 feet of additional decline in groundwater heads in the 400-foot and 180-foot aquifers, respectively.



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Alternative 1 Groundwater Level Difference for Layer 1, September 1994

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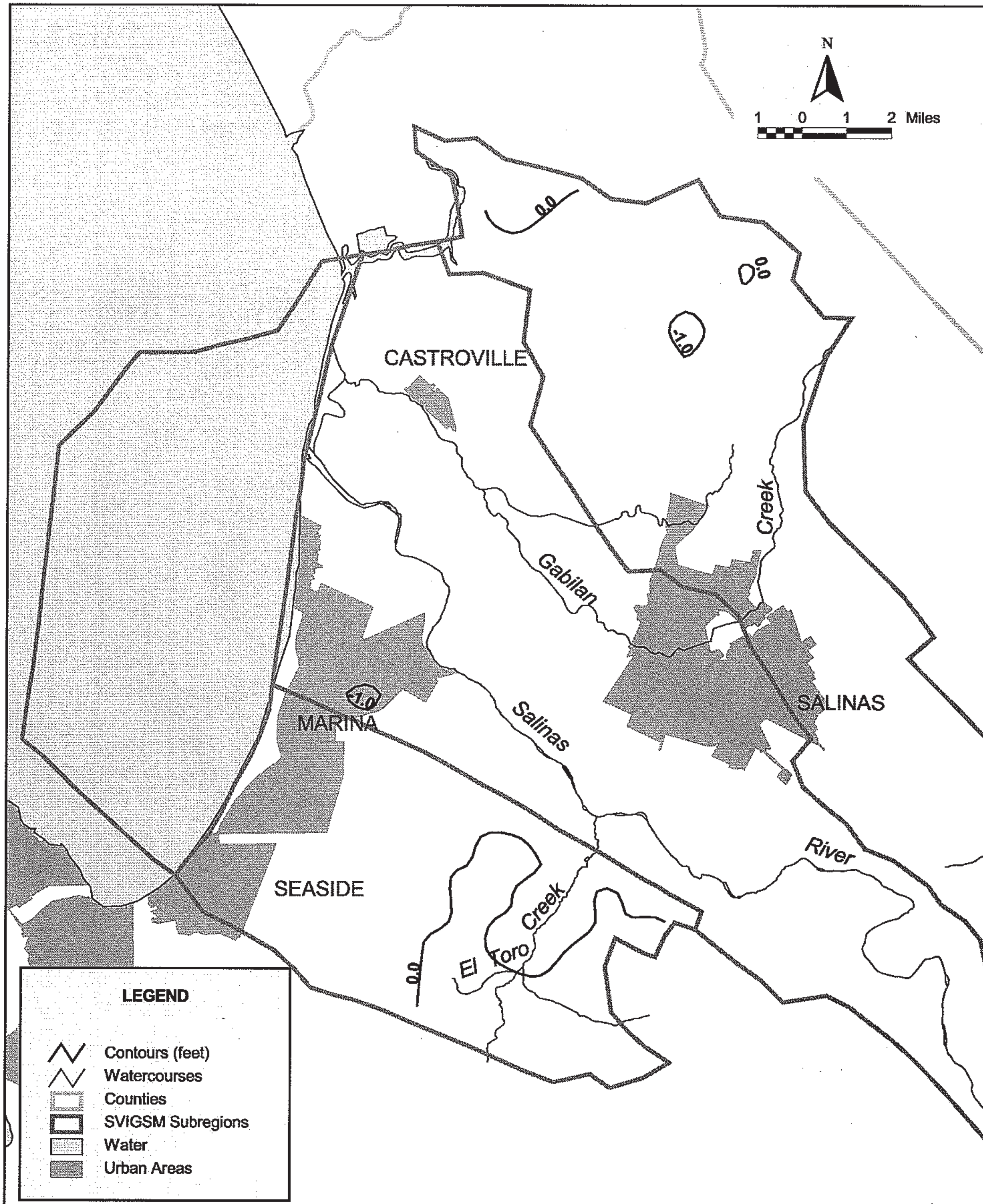
FIGURE 4.9



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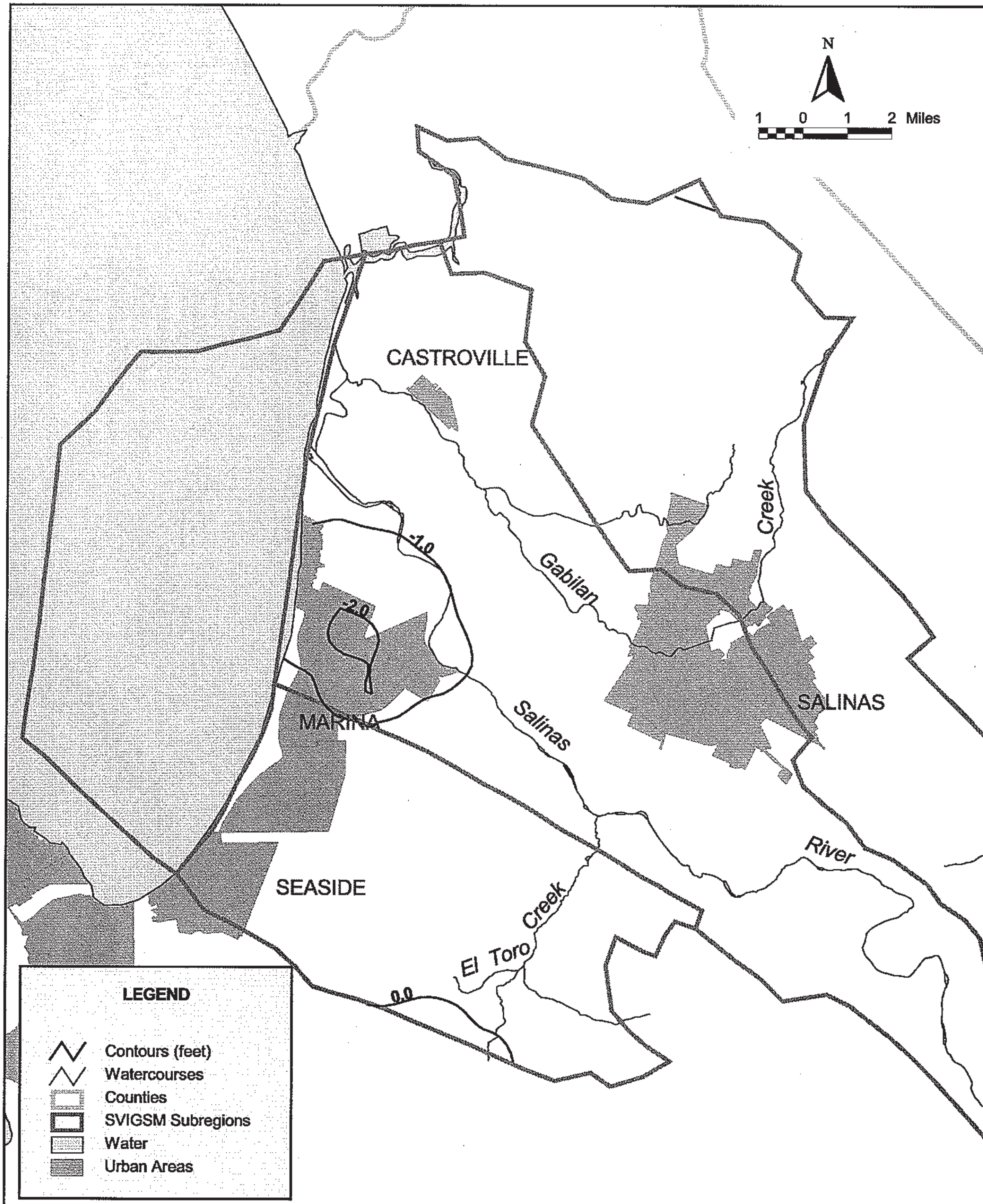
Alternative 1 Groundwater Level Difference for Layer 2, September 1994

MAY 2003

FIGURE 4.10



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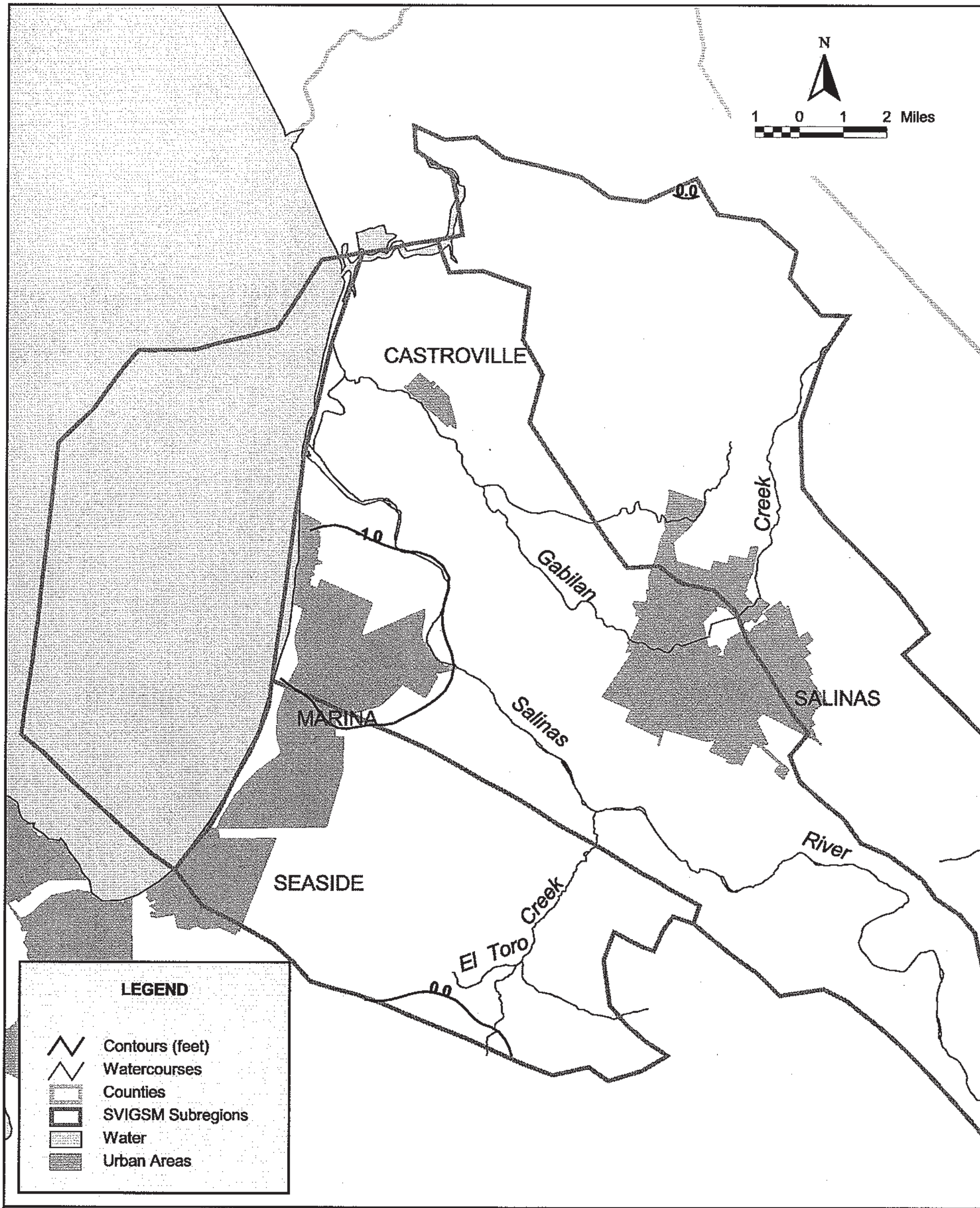
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 1 Groundwater Level Difference for Layer 3, September 1994

MAY 2003

FIGURE 4.11



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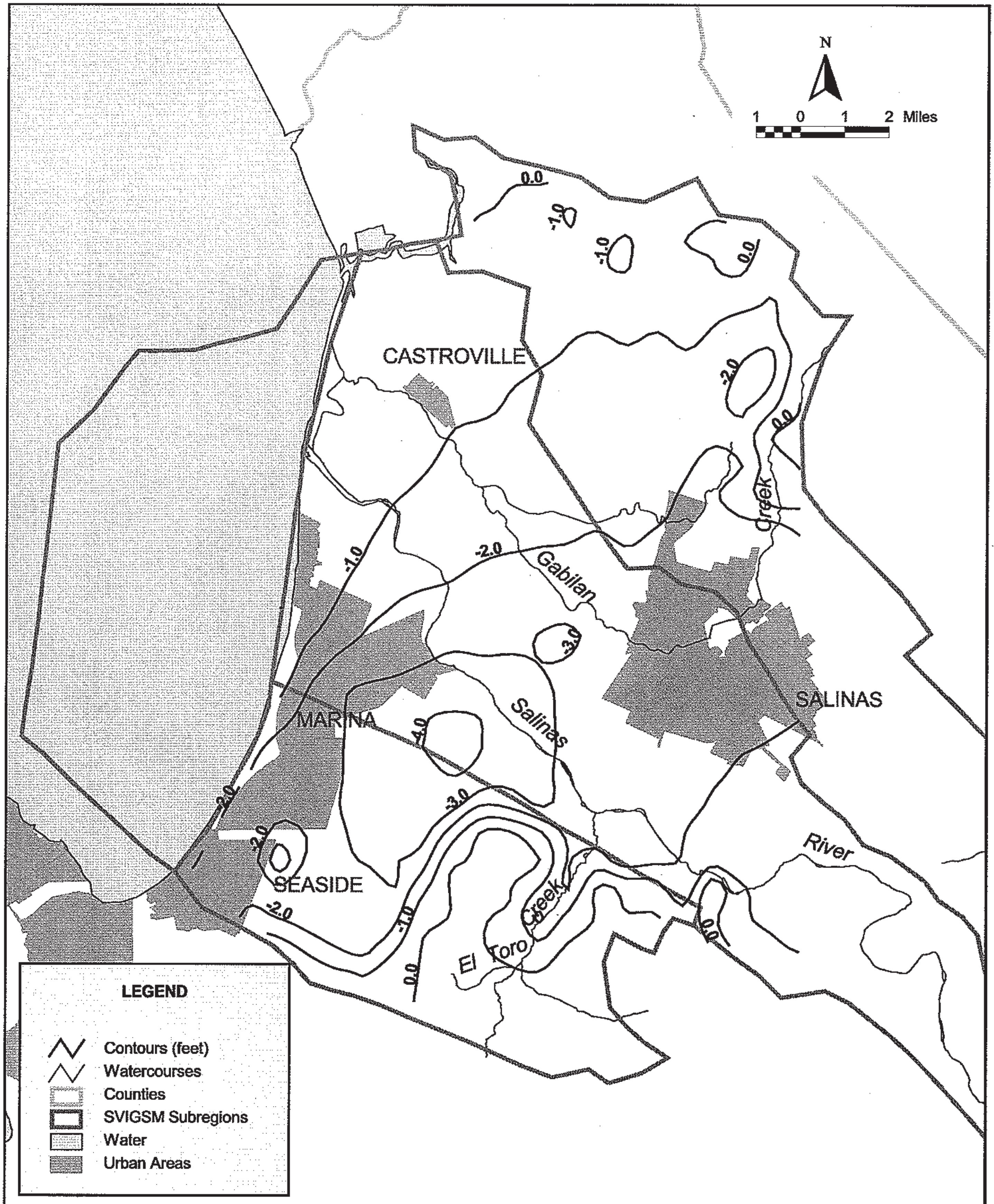
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 1 Groundwater Level Difference for Layer 4, September 1994

MAY 2003

FIGURE 4.12



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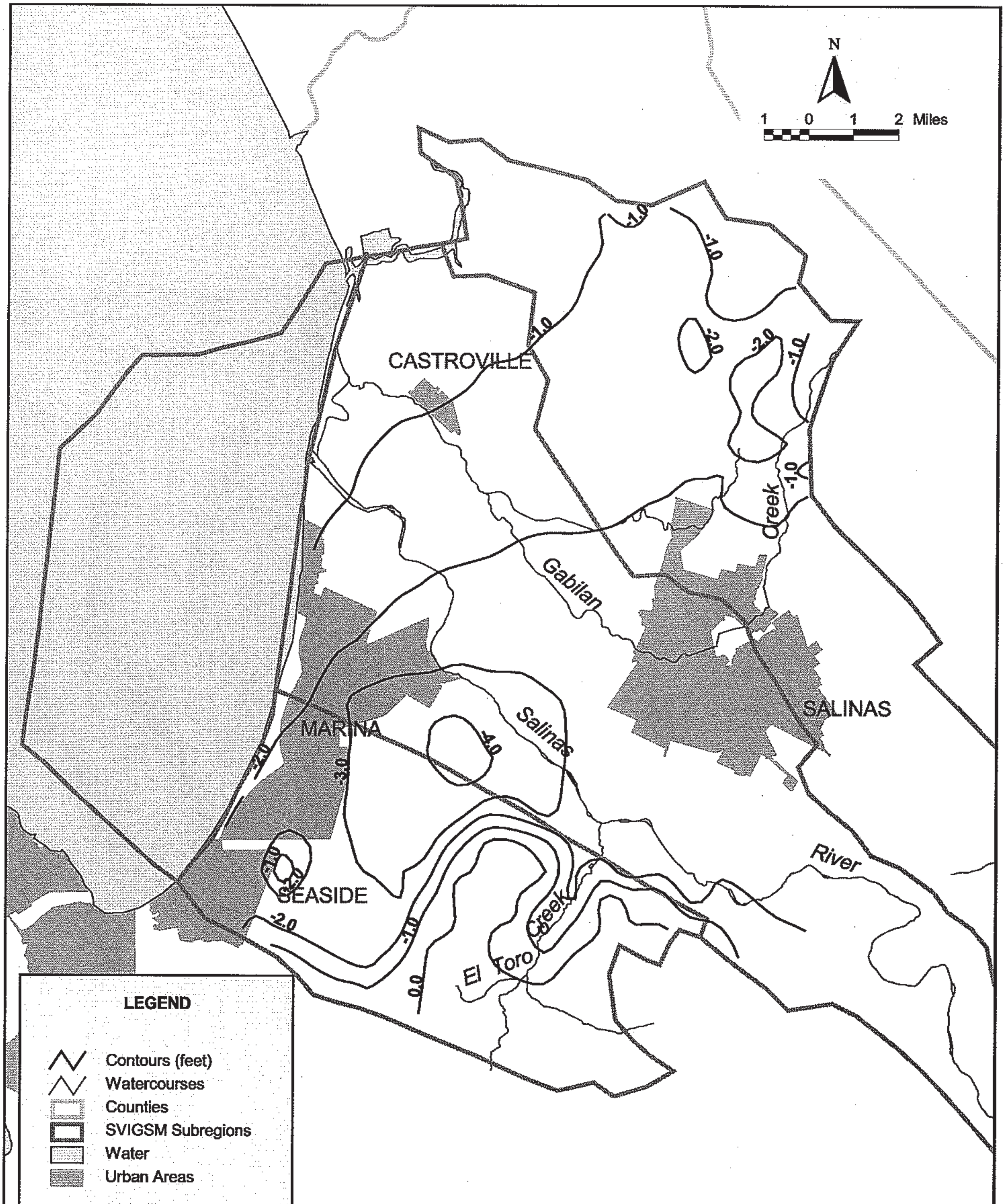
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 2 Groundwater Level Difference for Layer 1, September 1994

MAY 2003

FIGURE 4.13



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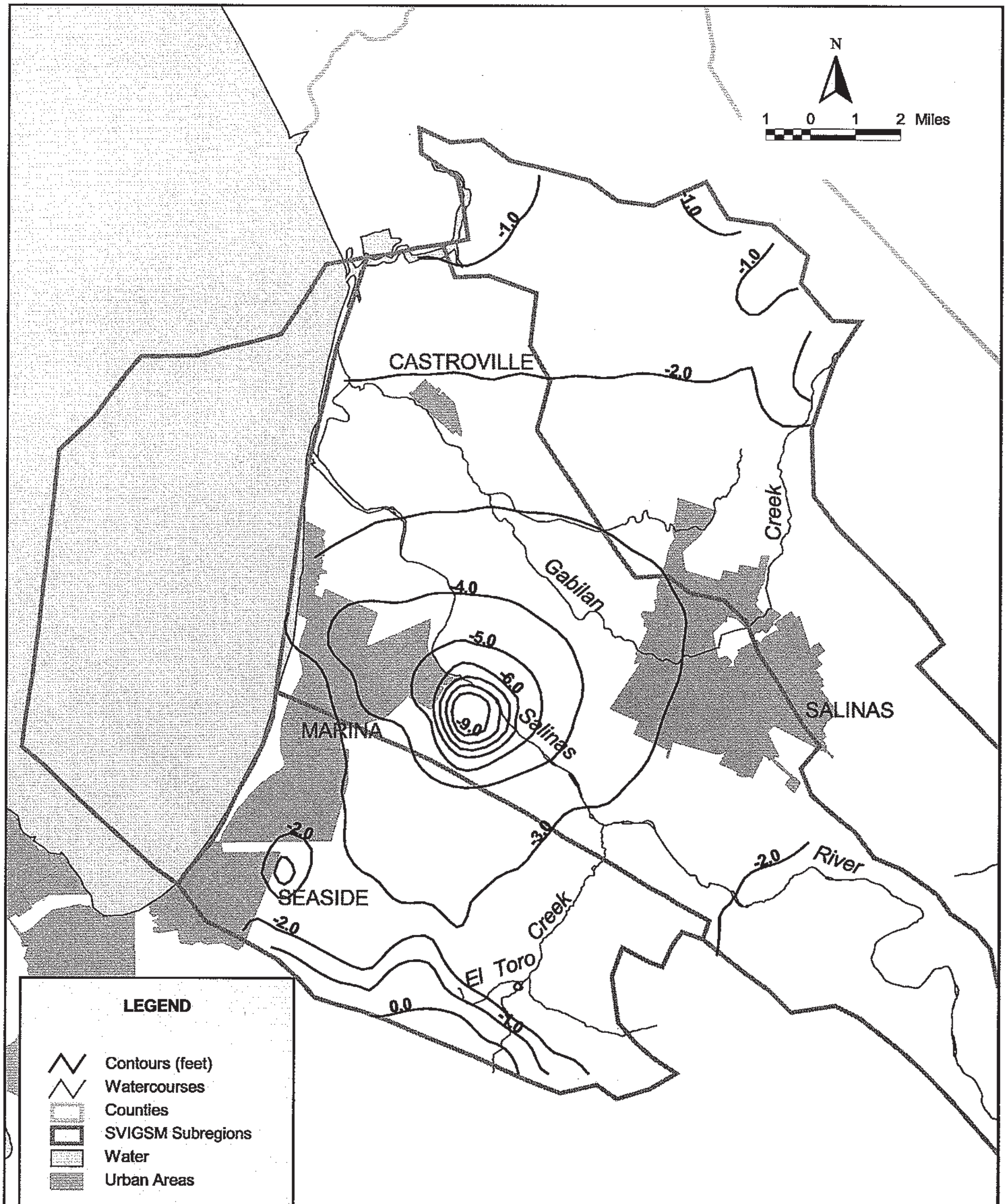
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 2 Groundwater Level Difference for Layer 2, September 1994

MAY 2003

FIGURE 4.14



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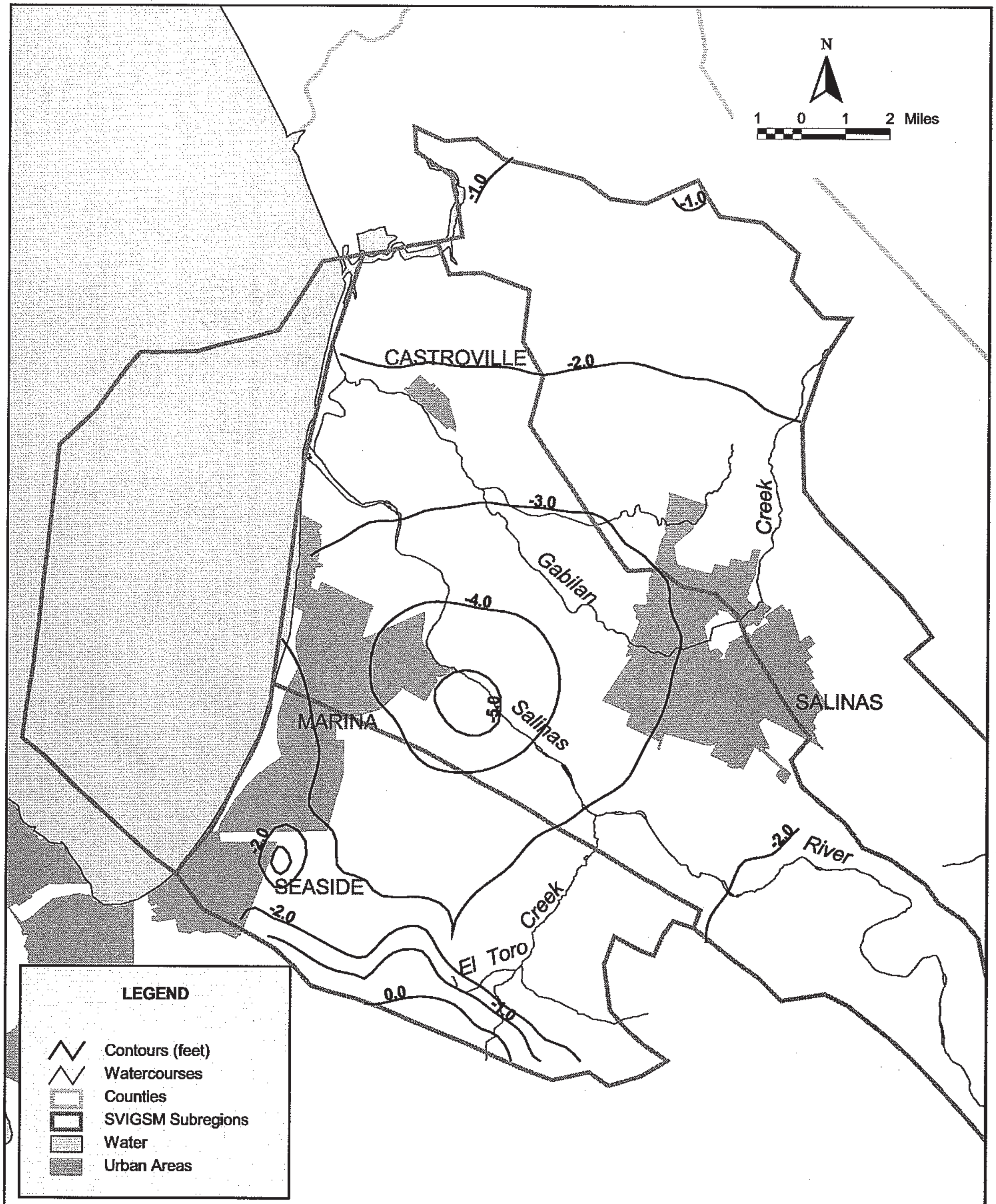
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 2 Groundwater Level Difference for Layer 3, September 1994

MAY 2003

FIGURE 4.15



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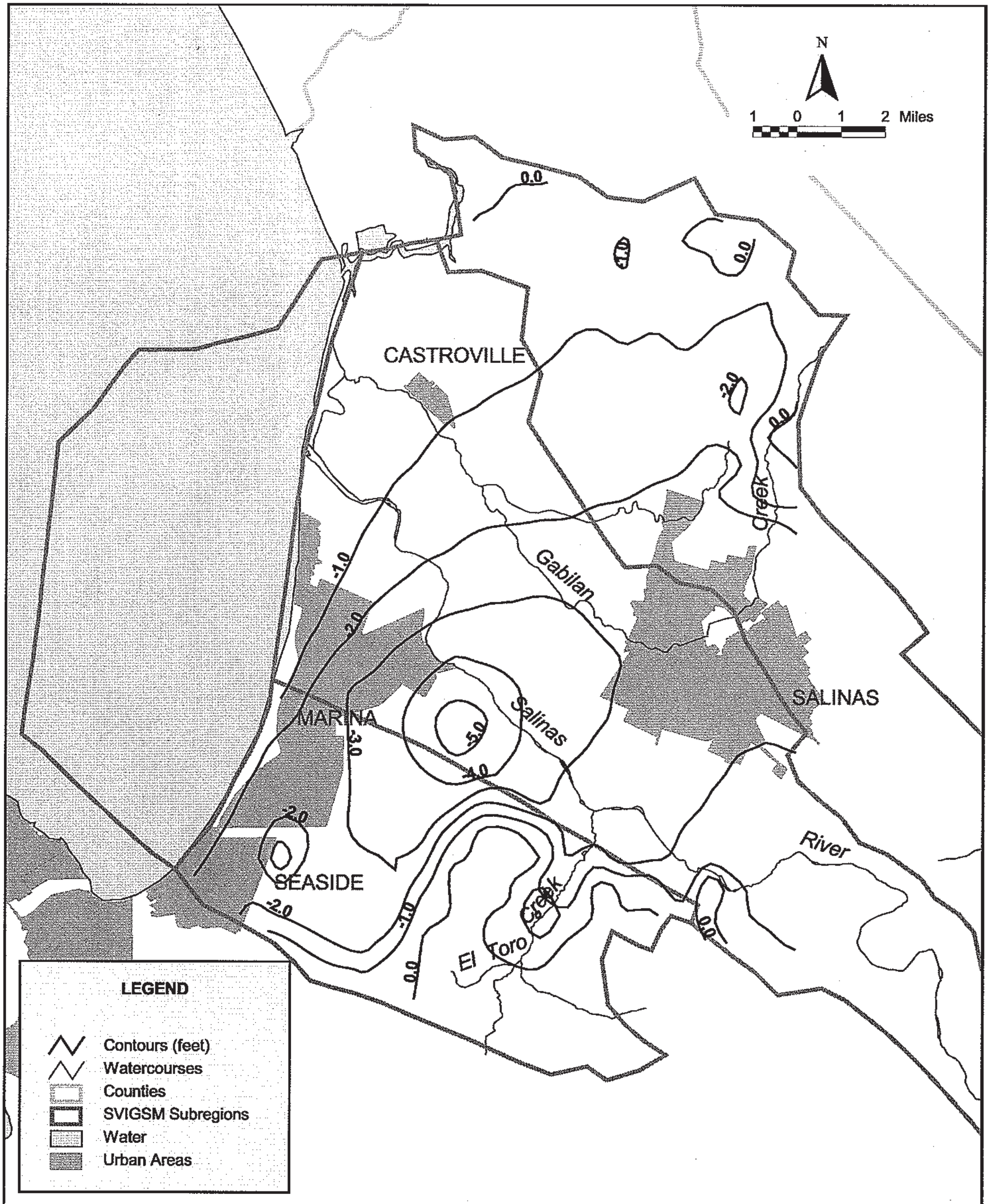
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 2 Groundwater Level Difference for Layer 4, September 1994

MAY 2003

FIGURE 4.16



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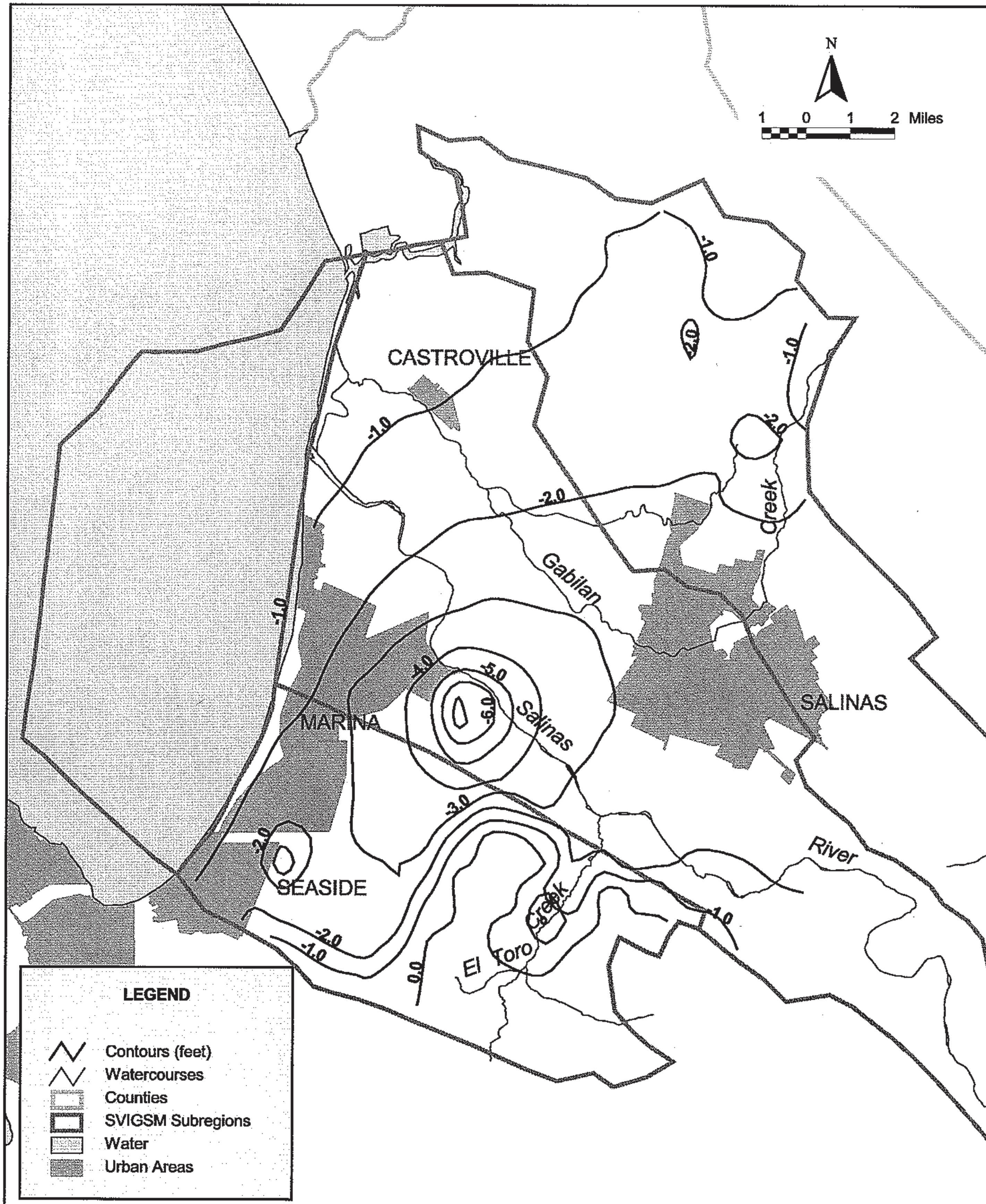
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 3 Groundwater Level Difference for Layer 1, September 1994

MAY 2003

FIGURE 4.17



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DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 3 Groundwater Level Difference for Layer 2, September 1994

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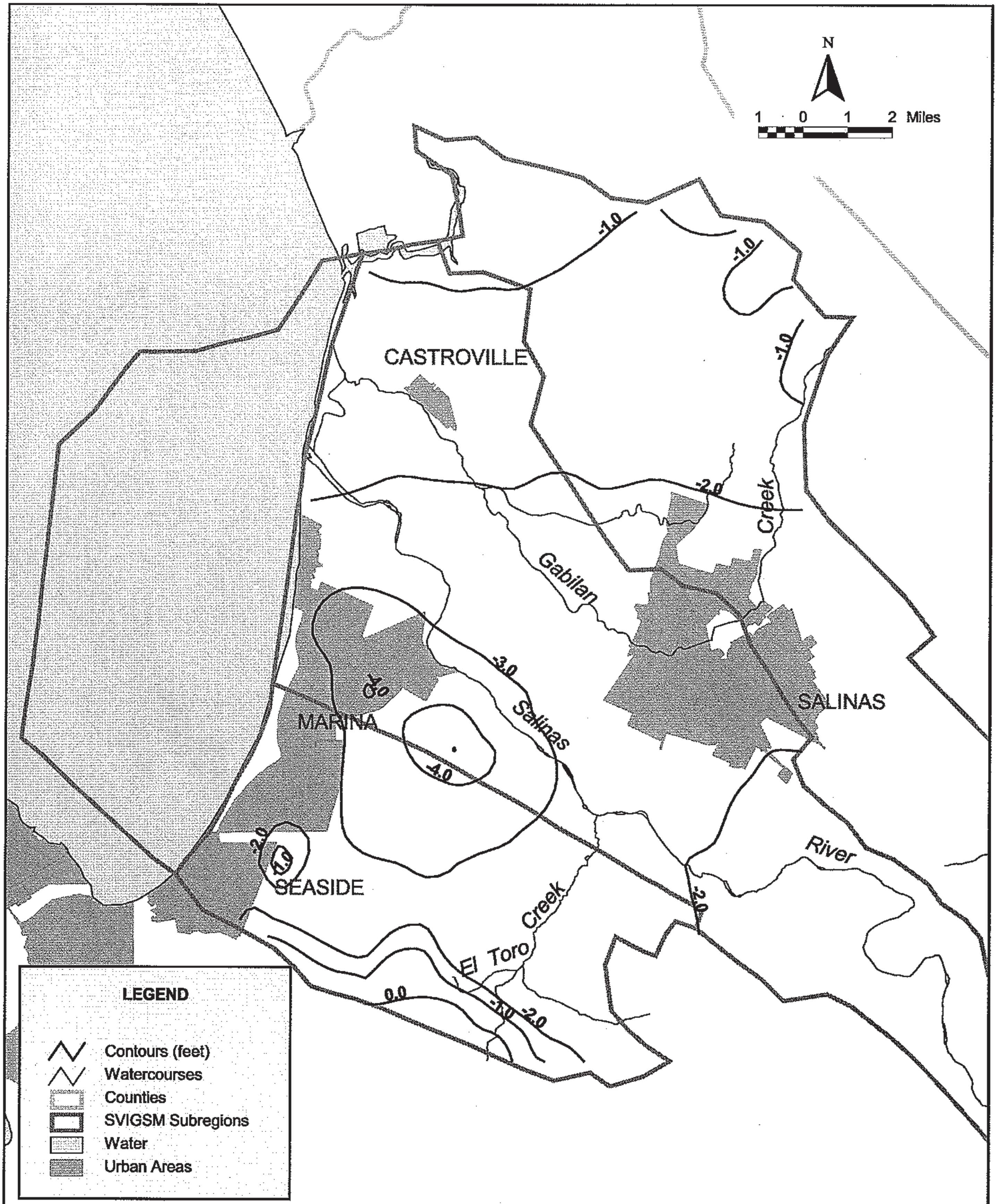
FIGURE 4.18



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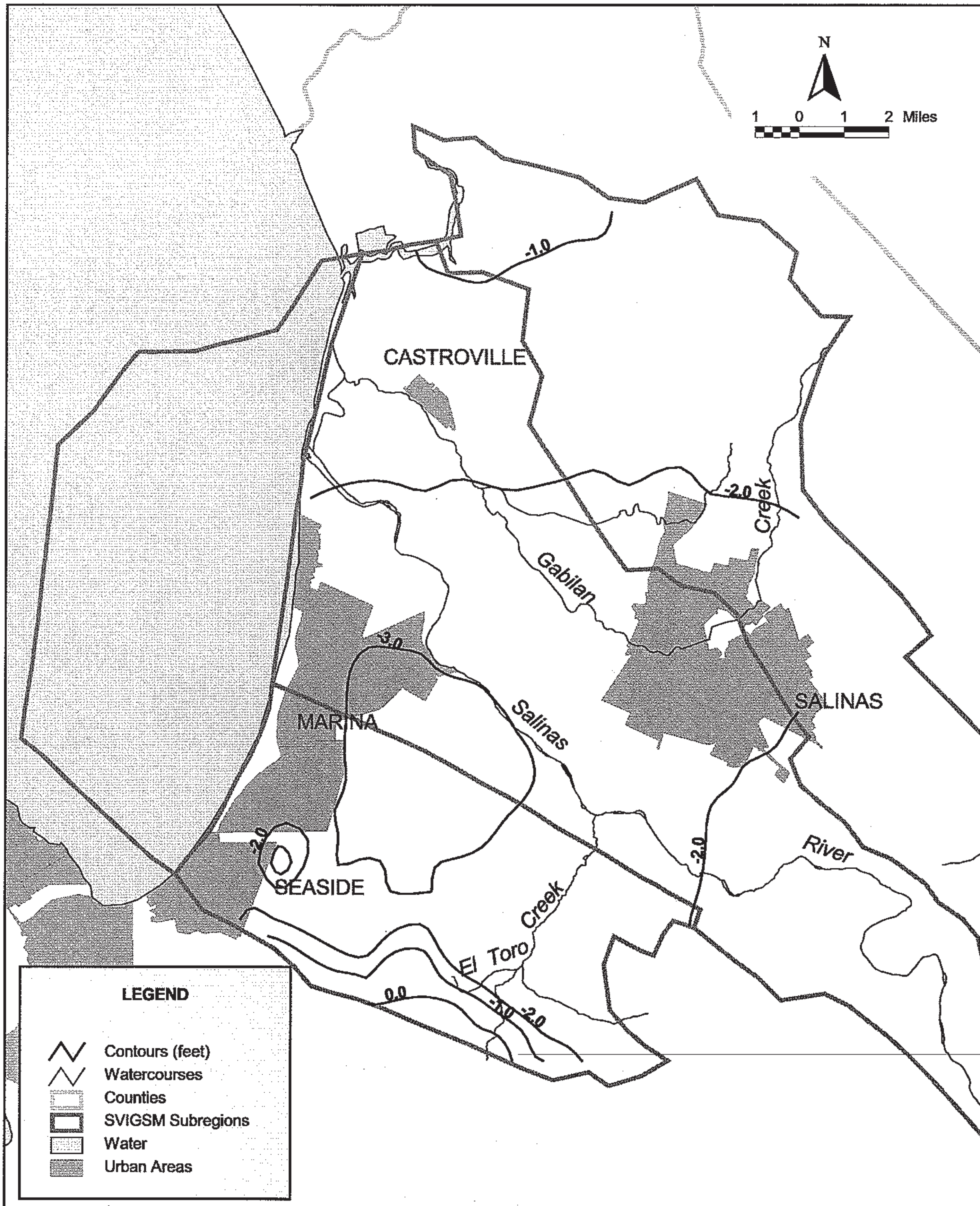
MARINA COAST WATER DISTRICT
DEEP AQUIFER INVESTIGATIVE STUDY

Alternative 3 Groundwater Level Difference for Layer 3, September 1994

MAY 2003

FIGURE 4.19



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Alternative 3 Groundwater Level Difference for Layer 4, September 1994

MAY 2003

FIGURE 4.20

The findings of this study can be divided in to three categories:

- Data assessment and analysis,
- Hydrologic modeling and analysis, and
- Water supply reliability.

DATA ASSESSMENT AND ANALYSIS

- Geologic, hydraulic, and geochemical data all suggest the "deep aquifer" to be two distinct aquifers.
- The uppermost aquifer of the "deep aquifer" is comprised of continental deposits assigned to the Paso Robles Formation. The lowermost aquifer is assigned to the marine Purisima Formation.
- MCWD's Well Nos. 10 and 11 produce from the Paso Robles Formation while Well No. 12 produces from the Purisima Formation. The "deep aquifer" wells in the Castroville area are completed in the Paso Robles Formation.
- Water levels in the Marina area deep aquifers have been substantially below mean sea level since the initiation of extractions.
- The areal distribution and stratigraphic location of the Paso Robles and Purisima Formations limit recharge to leakage from overlying aquifers. Water level records from MCWD's wells support this conclusion. Static water level curves from all of the MCWD wells appear to be stabilized, suggestive of equilibrium with recharge.
- Piezometric head in the Purisima Formation is higher than in the overlying Paso Robles Formation. Extractions from Paso Robles may be supported by leakage from both overlying and underlying sediments.
- Although water levels are chronically below mean sea level, there is no evidence of water quality degradation.
- The geologic setting may provide a buffer against seawater intrusion, allowing for the maintenance of water levels below mean sea level. However, storage coefficients suggest that the volume of groundwater in storage in the lower aquifers is small. Increased production would likely come from increased leakage.

- The Purisima Formation is relatively isolated hydraulically from the overlying Paso Robles Formation near the coast.
- As currently configured, the hydrogeologic model incorporated into SVIGSM is not consistent with a two-layer deep aquifer system. Adding a fourth layer and incorporating the current understanding could possibly improve the model.

HYDROLOGIC MODELING AND ANALYSIS

- The SVIGSM was updated to IGSM version 5.0.
- The SVIGSM deep aquifers system is divided into two distinct aquifers, an upper deep aquifer representing the Paso Robles formation, and the lower deep aquifer representing the Purisima formation. The revised SVIGSM, therefore, has four hydrostratigraphic units, among them the 180-foot and the 400-foot aquifer systems.
- The SVIGSM groundwater pumping data in the Marina Coast area is revised to represent the historical groundwater production records of the MCWD at their well sites.
- The SVIGSM is recalibrated so that the aquifer hydraulic conductivities in the deep aquifers, as well as the single aquifer layer in the Upper Valley area, represent an equivalent hydraulic conductivity with similar transmissivity values as in the original SVIGSM 4.18.
- The revised model depicts the observed groundwater levels equal to or better than the original model, and produces water budget estimates similar to the original model.

WATER SUPPLY RELIABILITY

- The updated SVIGSM was used to develop response curves on the sensitivity of groundwater heads and subsurface flows across the coastline to changes in MCWD groundwater pumping.
- The response curves indicate that additional increases in the deep aquifers groundwater pumping in the coastal areas may induce additional reduction in the groundwater heads, and subsequently additional landward subsurface flows across the coastline. The results also indicate that the increase in coastal subsurface flows occurs at a much more rapid pace in the 180-foot aquifer than in the 400-foot aquifer, due to substantially higher transmissivities.
- The results of alternative potential groundwater supply alternatives indicate that the increase in inland groundwater pumping (in the vicinity of Reservation

Road) has a much lesser impact on the groundwater level declines, as well as a lesser effect on the coastal subsurface flows.

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