TECHNICAL MEMORANDUM

To:	WRIME, Inc.	Date:	March 31, 2003
From:	Martin B. Feeney, RG 4634, CHG 145 Lewis I. Rosenberg, RG 5659, CEG 1777		
Subject:	Deep Aquifer Investigation—Hydrogeologic Data Inventory, Review, Interpretation and Implications		

INTRODUCTION

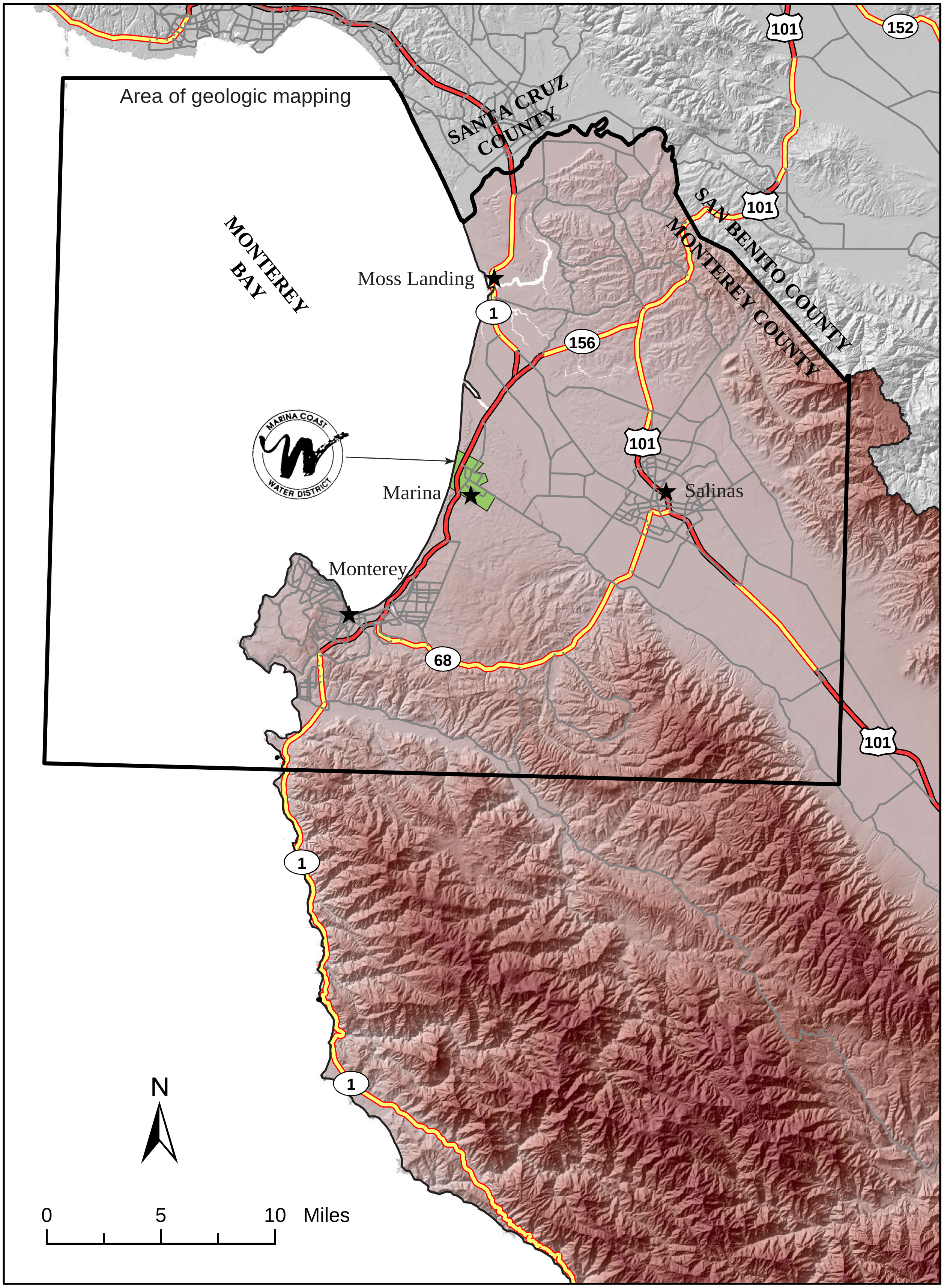
This technical memorandum tabulates and analyzes the available hydrogeologic data from the coastal portion of the so-called "deep aquifer" system of Monterey County. The "deep aquifer" designation derives from the history of water resource development in Monterey County. Advancing seawater intrusion, first, in the 180-foot aquifer, and subsequently in the 400-foot aquifer, forced ground water users to progressively driller deeper to find fresh water. The first "deep aquifer" water well was drilled in 1976. Since that time, approximately nine more water wells have been drilled into this aquifer system in the coastal area.

In order to develop an improved understanding of the regional ground water resource, this technical memorandum attempts to integrate all available data on the aquifer systems underlying the 180- and 400-foot aquifers of the Salinas Valley. We use this refined understanding to update the representation of the deep aquifer the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM). Several local-scale investigations into the hydrogeology of the deep zone have been performed over the last 20 years and provided useful insight into the understanding of the deep aquifer. 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the data that have been developed since the preparation of the Deep Aquifer Report prepared in 1976 by Richard Thorup (unpublished draft report).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 information in the present memorandum will be part of larger report (WRIME, Inc., Deep Aquifer Investigative Study, in preparation).

The available data set for the deep aquifer is scanty. These data are presented with preliminary conclusions based on the data available. Conclusions should be considered provisional and are subject to revision when more data are available. Much of the available data raises questions that cannot be adequately answered, or even speculated upon, within the existing framework of understanding. Much of the data and interpretations cannot be integrated within the existing framework of understanding. It is anticipated that through modeling, the various disparate interpretations can be better integrated into a cohesive understanding.

Study Area

As shown on figure 1, the study area is centered on the service area of the Marina Coast Water District (MCWD). Because of MCWD's geographical location relative to the advancing



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

Figure 1. Vicinity map showing Marina Coast Water District and area of geologic mapping

seawater in the 180- and 400-foot aquifers, MCWD was one of the first ground water users to be 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 the only significant user of the deep aquifer today.

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 ground water lexicon of the Salinas Valley for more than 25 years. Other alternative terms have included the "900-foot" and "1500-foot" aquifers. However, these terms have vague definitions and the "deep aquifer" is not necessarily 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 technical memorandum 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 "deeper aquifers" will be utilized in place of "deep aquifer", because data available strongly suggest a multiple aquifer system.

Previous Reports on the "deep aquifers"

The hydrogeology of the northern Salinas Valley has been the subject of many studies such as the landmark 1946 Salinas Basin Investigation (Dept. of Water Resources, 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 aquifer. Only several studies specifically focus on the "deep aquifer" and have provided significant insight into its hydrogeology. The most significant are summarized below:

<u>Thorup (1976, 1983)</u>—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 aquifer. 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 aquifer. Based on more refined data, Thorup calculated that the deep aquifer 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 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 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. The report provides valuable information on stratigraphy, water levels, and water chemistry on the deeper aquifers, in addition to the well construction. Of particular interest, is the documentation of Pliocene-age sediments from depth of 950 to 2000 feet.

DATA SOURCES AND AVAILABILITY

As discussed above, the available hydrogeologic data on the deep aquifers are limited in areal extent by the location of deeper water wells. Additional stratigraphic information is available from oil test wells drilled in the northern Salinas Valley during the 1930s and 40s. More recently, new gravity and aeromagnetic studies provide valuable information in areas lacking deep well control. These available data and their sources are summarized below.

Table 1. Data sources and availability

Data category	Period	Data type	Sources
Stratigraphic	1932–2003	Water well logs	1, 2, 3
		Oil well logs	3, 8
		Borehole data (paleontology, sidewall and core samples)	2, 3, 4, 6, 8
		Previous interpretations by others	3, 6
		Regional geologic maps	3, 4, 6, 9
		Geophysical data (gravity and aeromagnetic)	3, 4, 9, 11
Water-level	1980–2003	Castroville area wells	2
	1983–2003*	MCWD wells	5
	2000-2003	USGS/MCWRA/MCWD monitor wells	2
Extraction	1983–2003	MCWD wells	3, 5, 6
	1990–2003†	Castroville wells	2
Water quality	1983–2003	MCWD wells	7
	19??–2003	Castroville wells	2
Aquifer parameters		Aquifer tests at time of well construction	3, 4, 6
		Well interference data	10
		Tidal response	10

Notes:

* Intermittent
† Confidential
1. Calif. Department of Water Resources
2. Monterey Co. Water Resources Agency
3. Private files (Feeney and Rosenberg)
4. U.S. Geological Survey
5. MCWD
6. Unpublished consultant reports
7. Department of Health Services
8. Division of Oil and Gas
9. California Geologic Survey
10. This investigation
11. Al Malech

Well Inventory

There are numerous shallow water wells in the study area. However, there are only ten production wells in the deep aquifers. These production wells, supplemented by monitoring wells and oil test holes provide the only drill hole control on the stratigraphic interpretation. These wells, including their depths, construction, and the type of data available, are summarized below in Table 2. Data for some of the key wells used to constrain the geologic cross sections are discussed in the following part of this section.

Table 2. Well inventory

State well number	Well name	Year drilled	Well type	Surface elevation, in feet	Driller's log	Geophysical log	Geologic or paleontologic log	Depth, in feet	Bottom elevation in feet, datum is sea level	Seal	Depth to top of perforations, in feet	Depth to bottom of perforations, in feet	Producing formation
T13N/R1E-25R01	Mty Dunes Colony #3	1992	W	0	Y		Y	1,393	-1,393	1,250	1,255	1,400	QTp
T13N/R1E-36J01	Mty Dunes Colony #1	1977	W	10	Y	Y	Y	1,724	-1,713	1,080	1,298	1,448	QTp
T12S/R2E-02	Western Gulf Johnson 1	1932	O	181	Y	N	Y	3,198	-3,017	--	--	--	--
T13S/R2E-06	Elba Oil Co. Capurro	1937–1939	O	52	N	Y	Y	4,009	-3,957	--	--	--	--
T13S/R2E-07	Bayside Development Co. Vierra 1	1944–1946	O	15	Y	Y	Y	7,916	-7,901	--	--	--	--
T13N/R2E-17K	Fred Ash and Sons 2	1966	O	185	Y	Y	Y	1,959	-1,959	--	--	--	Tp
T13S/R2E-19	TEPI Pieri 1	1949	O	12	Y	Y	Y	3,291	-3,279	--	--	--	--
T13N/R2E-19Q03	PG&E Leonardini	1980	W	10	Y	Y	N	1,610	-1,600	1,190	1,280	1,550	QTp
T13N/R2E-31A02	Scattini	1985	W	10	Y	Y	N	1,635	-1,625	850	850	1,600	QTp
T13N/R2E-32E05	Sea Mist	1984	MN	10	Y	Y	Y	1,650	-1,640	755	775	1,585	QTp
T13N/R2E-32M02	Sea Mist	1984	W	10	Y	Y	N	1,630	-1,620	780	780	1,590	QTp
T13S/R2E-34	TEPI Davies 1	1949	O	69	Y	Y	Y	2,219	-2,150	--	--	--	--
T13N/R2E-34?	Castroville Water District well 3	?	W	220	N	Y	N	1,060	-840	--	--	--	--
T14N/R2E-06L01	Co. of Monterey	1976	W	10	Y	Y	Y	1,809	-1,799	800	880	1,540	QTp
T14N/R2E-22	Fontes	1976	TH	26	Y	Y	Y	1,718	-1,692	--	--	--	QTp
T14N/R2E-24L02	DMW-1	2000	MW	55	Y	Y	Y	2,030	-1,975	1,810	1,820	1,860	Tp
T14N/R2E-24L03	DMW-1	2000	MW	55	Y	Y	Y	2,030	-1,975	1,390	1,410	1,430	Tp
T14N/R2E-24L04	DMW-1	2000	MW	55	Y	Y	Y	2,030	-1,975	1,030	1,040	1,060	Tp
T14N/R2E-24L05	DMW-1	2000	MW	55	Y	Y	Y	2,030	-1,975	910	930	950	QTp
T14N/R2E-30G03	Marina No. 12	1989	W	107	Y	Y	Y	2,020	-1,912	1,250	1,390	1,940	Tp
T14N/R2E-31H01	Marina No. 10	1982	W	142	N	N	Y	1,515	-1,473	860	930	1,540	QTp/Tp
T14N/R2E-32D04	Marina No. 11	1985	W	142	Y	Y	Y	1,700	-1,558	880	970	1,650	QTp/Tp
T15N/R2E-03E01	Fort Ord Site D	1995	W	158	Y	Y	Y	1,212	-1,054	--	--	--	QTp
T15S/R2E-22Cb	Sand Bowl Group Metz 1	1948	O	30	Y	Y	N	2,151	-2,121	--	--	--	--
T15S/R4E-31	C.A. Luckey Marihart-Luckey 1	1958	O	70	Y	Y	Y	2,628	-2,558	--	--	--	--

Notes:
W Water well
O Oil test hole
TH Water test Hole
MN Monitoring well
QTp Paso Robles Formation
Tp Purisima Formation
Y Log Available
N Log Not Available

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

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.

Elba Capurro—The Elba No. 1 well was drilled in 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., 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 commun, 2002). Of interest is a letter in the CDOGR files from the Deputy Supervisor of Division of Oil and Gas, dated November 22, 1938 that reports fresh water to a depth of 1,280 feet, below that is brackish to salt water. The well never reached basement to its drilled depth.

Bayside Development Vierra 1—According to CDOGR records, General Petroleum spudded this well in November 1944, drilled it to a depth of 5,739 feet. At that point Bayside Development took over the drilling, deepened the well to 7,916 feet, and 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.

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 drillers log and an e-log annotated by R.R. Thorup.

TEPI. Pieri 1—The Pieri well was drilled by the Texas Company and abandoned in August 1949 to a depth of 3,291 feet, where it reached basement. Picks are from CDOGR records and an e-log.

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

TEPI. Davies—Scout notes reveal that the Davies well was drilled as a play based on geophysical methods (E.E. Gribi, unpublished data). The Texas Company drilled and abandoned the Davies well 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. Sidewall and core sample data are from CDOGR files. Thorup’s e-log notes show “Purisima” extending from 1,320 to 1,680 feet depth. 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.

Castroville Water District 3—No driller’s 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.

County of Monterey 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).

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).

Marina Wells No. 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 is that Ingle interprets wells 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.

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.

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 reaching the Purisima Formation based on review of preliminary cross sections by the logging geologist, J.W. Oliver (MPWMD).

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 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).

Marihart-Luckey 1—The Marihart-Luckey well was drilled as a wildcat oil well to a depth of 2,628 feet in November 1958 by R.R. Thorup. No oil shows were noted according to CDOGR records and 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.

Geophysical Data

Recent published gravity mapping and unpublished aeromagnetic surveys by the USGS provide useful information in areas of sparse well control. These studies are at regional scale (1:250,000) and form a framework for visualizing structural elements such as faults and sedimentary basins.

Gravity data— 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 in a northwest-southeast direction beneath several deep water 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 and aligns with the projection of the Reliz fault.

Aeromagnetic data—In this same area, the Reliz fault also aligns with a high-definition magnetic boundary. The aeromagnetic locations are those of the fault trace at the basement surface. If the fault dips, or if the fault produces a flower structure in the sedimentary rocks overlying the basement, the location of the magnetically defined trace may not correspond precisely to the trace at the Earth's surface. This is important to remember in the case of the northernmost onshore location of the Reliz fault, because there the granitic basement rocks probably are covered by 2 km of sedimentary deposits (R.C. Jachens, USGS, written commun., 2002).

GEOLOGY

Stratigraphy

Granitic basement—As shown on figure 2, the oldest unit in the study area consist of mainly granitic rocks and lesser amount 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.

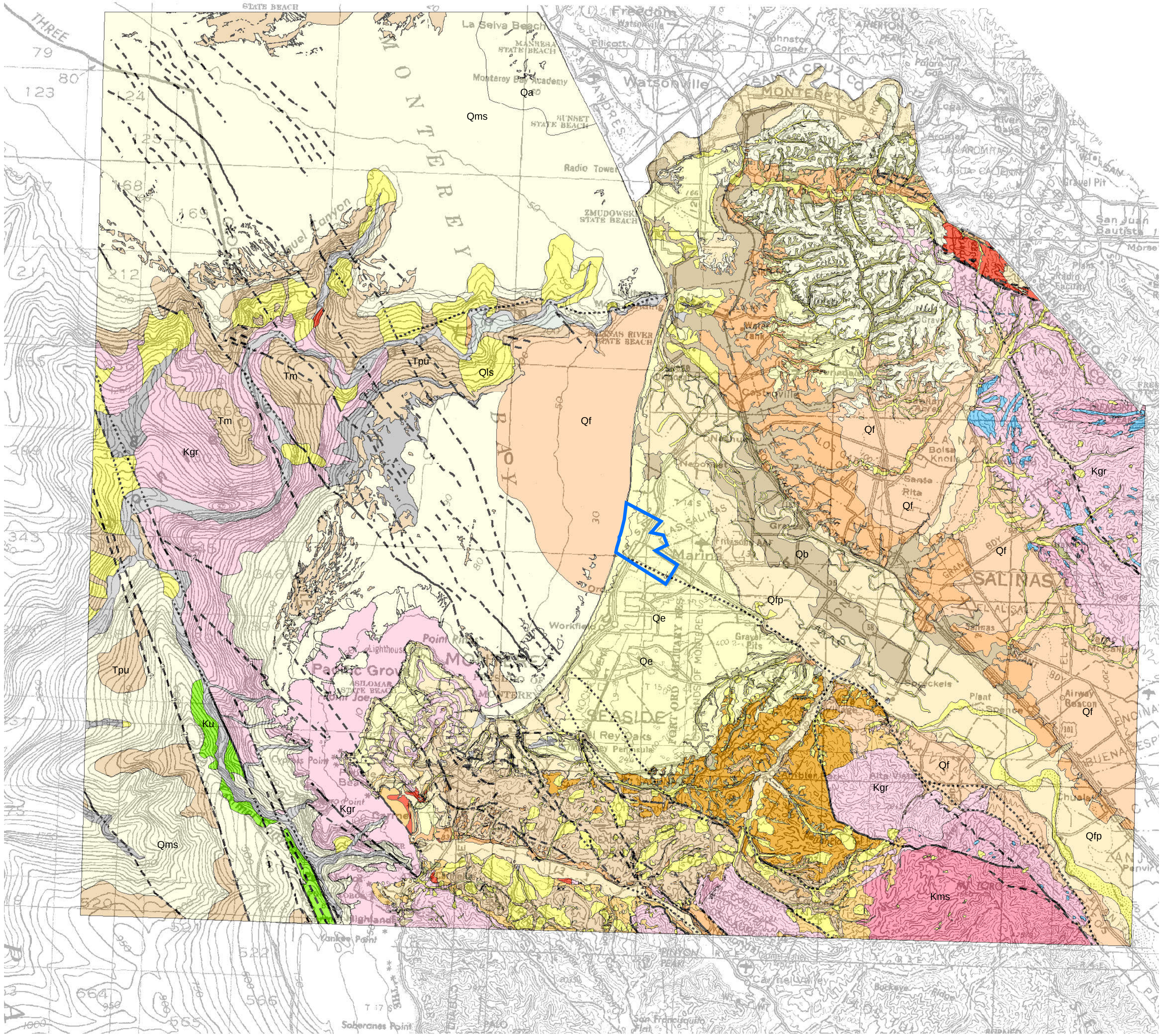
Lower to Middle Miocene sedimentary rocks—Overlying the granitic basement are a series of marine sedimentary rocks, which include an unnamed arkosic sandstone and the Monterey Formation. These rocks crop out in the hills near Monterey, Corral de Tierra, and Carmel Valley. Because these formations have 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 onland, 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 Purisima Formation range from 500 to 1,000 feet in the area of cross sections A, B, and 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 lithologically 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. 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. The surficial Quaternary sediments include floodplain deposits, alluvial fans, eolian deposits, fluvial and marine terraces, and basin deposits. Although aquifer recharge occurs through these sediments, they do not constitute a major water supply source.

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. The San Gregorio fault is the principal fault west of the San Andreas in central California and extends northward from Big Sur across Monterey Bay to join the San Andreas



EXPLANATION

- Qfl — Artificial fill (Historical)
- Qal — Alluvium, undifferentiated (Holocene)
- Qb — Basin deposits (Holocene)
- Qbs — Beach sand (Holocene)
- Qc — Colluvium (Holocene)
- Qd — Dune sand (Holocene)
- Qfp — Flood-plain deposits, undifferentiated (Holocene)
- Qcf — Canyon fill, offshore (Holocene)
- Qs — Sand, undifferentiated (Holocene)
- Qms — Marine sediments, offshore (Holocene-Pleistocene)
- Qls — Landslide deposits (Pleistocene-Holocene)
- Qa — Aromas Sand (Pleistocene)
- Qe — Eolian deposits (Pleistocene)
- Qf — Alluvial fan deposits (Pleistocene)
- Qt — Fluvial terrace deposits (Pleistocene)
- Qmt — Marine terrace deposits (Pleistocene)
- Qrb — Relict beach deposits, offshore (Pleistocene)
- Qocf — Older canyon fill, offshore (Pleistocene)
- Qct — Submarine canyon terrace (Pleistocene)
- QTc — Paso Robles Formation (Pliocene-Pleistocene?)
- Tpu — Purisma Formation (Pliocene-Late Miocene)
- Tsc — Santa Cruz Mudstone (Late Miocene)
- Tsm — Santa Margarita Sandstone (Late Miocene)
- Tm — Monterey Formation (Middle-Late Miocene)
- Tms — Unnamed marine sandstone (Late-Middle Miocene)
- Trb — Red beds (Miocene)
- Tts — Marine sandstone (Miocene)
- Tv — Volcanic rock (Miocene)
- Tvq — Vaqueros Formation (Oligocene)
- Tc — Carmelo Formation (Early Eocene)
- Ku — Unnamed sedimentary rocks (Late Cretaceous)
- Kms — Schist of Sierra de Salinas (Cretaceous)
- Kgr — Granitic rocks (Cretaceous)
- pKm — Marble (Pre-Cretaceous)
- pKms — Schist (Pre-Cretaceous)
- Fault, approx. located
- Fault, certain
- Fault, concealed
- Fault, concealed, queried
- Fault, inferred
- Fault, inferred, queried
- Thrust fault, certain
- Thrust fault, concealed
- Thrust fault, inferred
- Thrust fault, inferred, queried

Geology modified from Rosenberg (2001), Wagner and others (2002)
Base: USGS Monterey 1:250,000 topographic map, 1998, contour interval = 200 feet
Original projection: UTM Zone 10, 1927 North American Datum (NAD), meters
Current projection: State Plane, California Zone 4, 1983 NAD, feet

0 5 10 Miles

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REGIONAL GEOLOGY		
For: Marina Coast Water District		
DEEP AQUIFER INVESTIGATIVE REPORT		
March 2003	Lew Rosenberg, CEG 1777 Martin Feeney, CHG 145	Figure 2

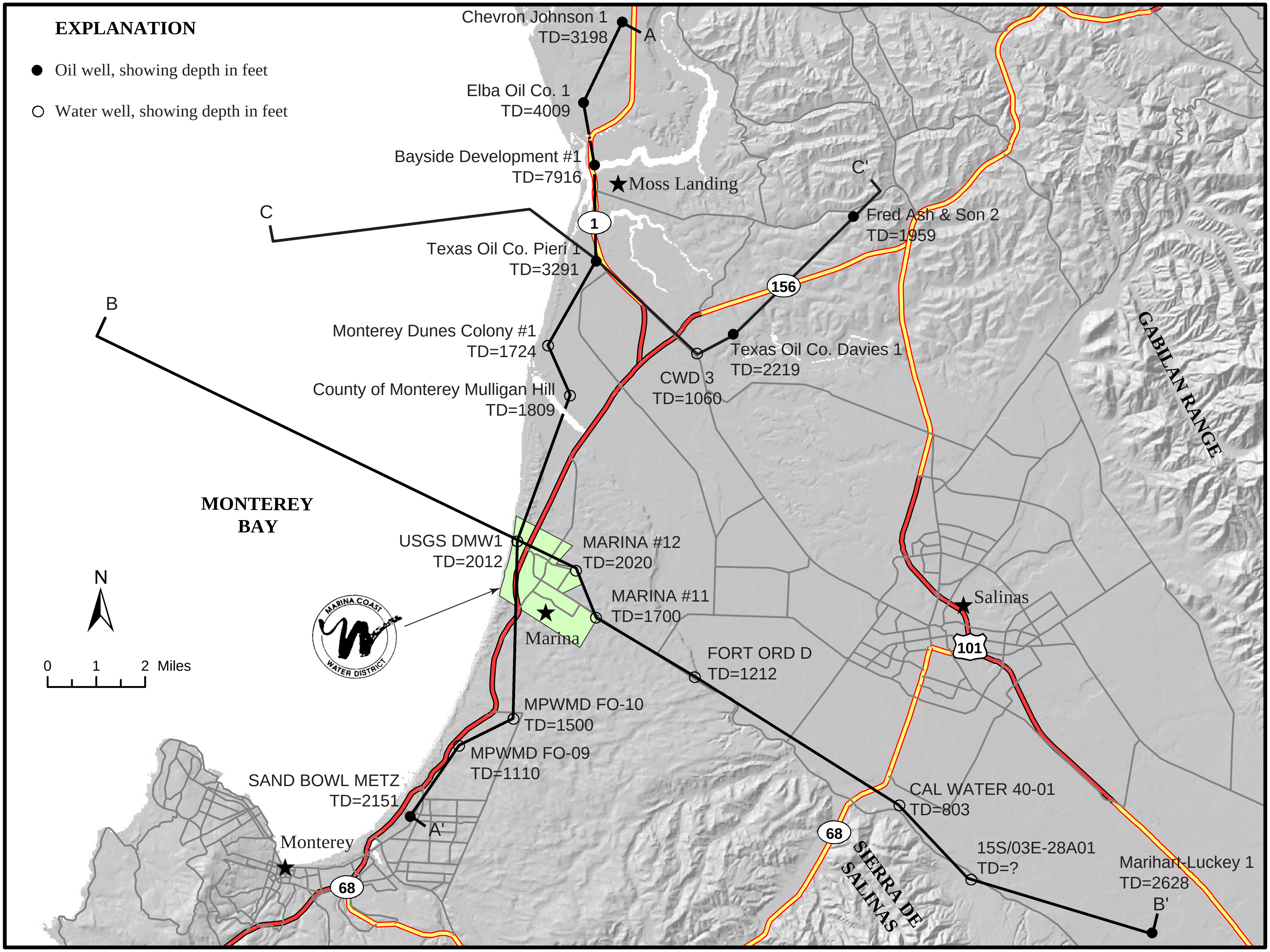
fault north of San Francisco. Some right-slip from the San Gregorio fault has been distributed eastward to intra-Salinian faults, including the Monterey Bay/Navy/Tularcitos fault zone. The Monterey Bay fault zone is a 6-to 9-mile-wide zone of short en echelon northwest-striking faults that are the offshore 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, where it joins the offshore Monterey Bay fault zone.

<u>Monterey Formation subcrop</u>—We contoured the top of the Monterey Formation and the bottom of the Upper Miocene to Pliocene marine sequence, which consists of Purisima Formation near the coast and 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 Seca 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 that encompassed the region from the coast southeastward to King City. The density of well control is greatest near the coast and decreases farther southeastward. Likewise, the accuracy of the picks follows the same pattern.

The resulting structural contours were digitized and saved as ESRI shapefiles. 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.

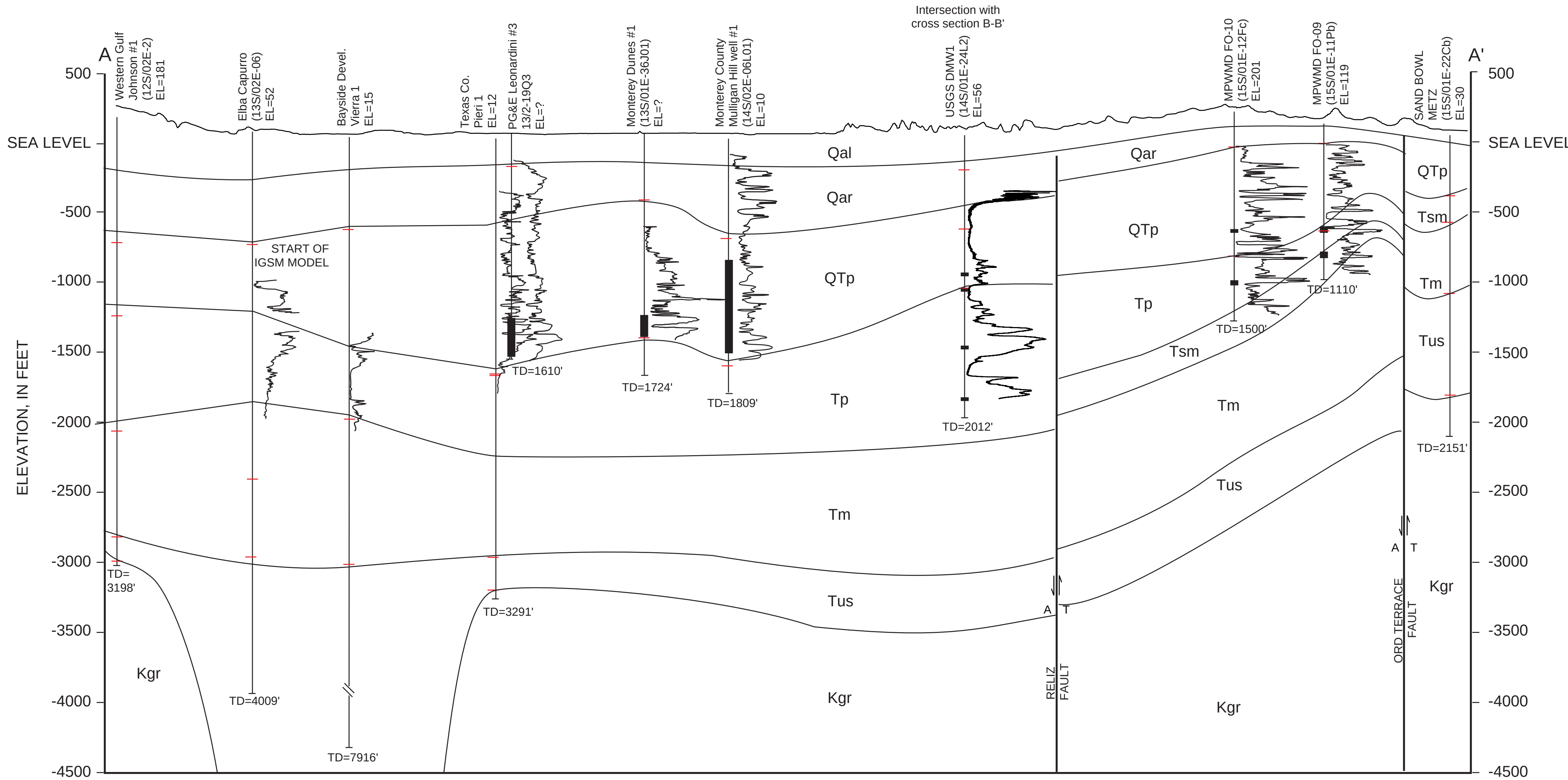
Cross Section Interpretations

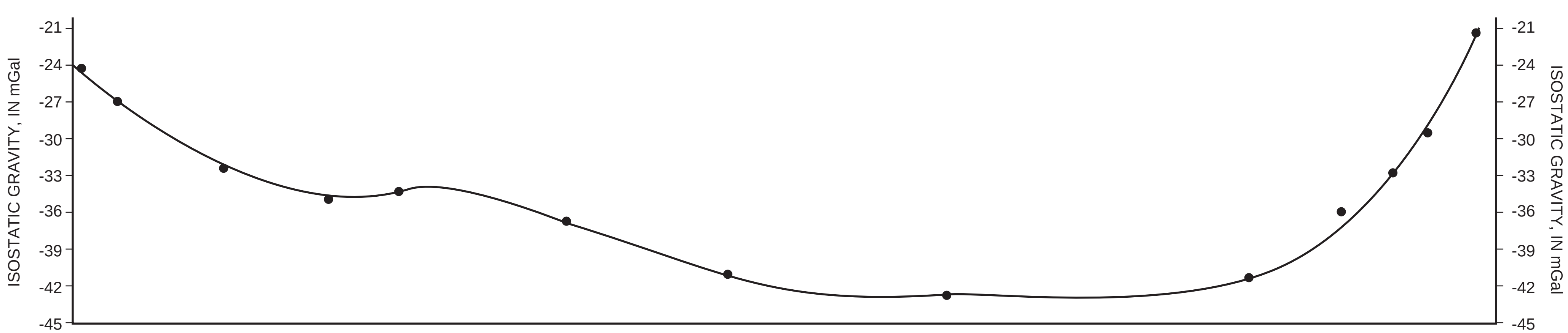
As part of modeling the deep aquifer, we developed three geologic cross sections. The location of the cross sections is shown on figure 3 and the cross sections are included as figures 4, 5, and 6. To construct the cross sections, a variety of sources were used. These include published geologic map compilations 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), unpublished water well records (on file at the Monterey County Water Resources Agency, the Marina Coast Water District, and the Monterey Peninsula Water Management District), and gravity data (Langenheim and others, 2002). Information from these sources were 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.



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

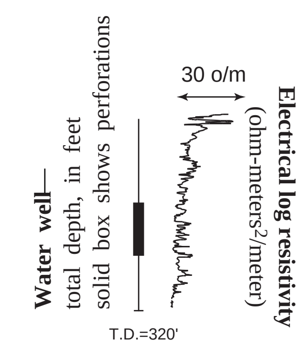
Figure 3. Cross section location map



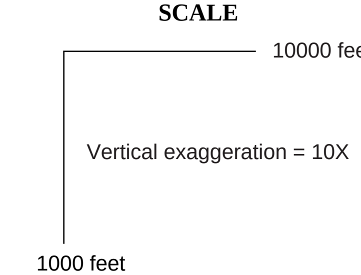


EXPLANATION

Qal	**Alluvium (Holocene)**
Qar	**Aromas Sand (Pleistocene)**
QTp	**Paso Robles Formation (Pleistocene-Pliocene?)**
Tp	**Purisima Formation (Pliocene)**
Tsm	**Santa Margarita Sandstone (late Miocene)**
Tm	**Monterey Formation (middle Miocene)**
Tus	**Unnamed sandstone (middle Miocene)**
Kgr	**Granitic rocks (late Cretaceous)**
	Fault
	Contact



SCALE



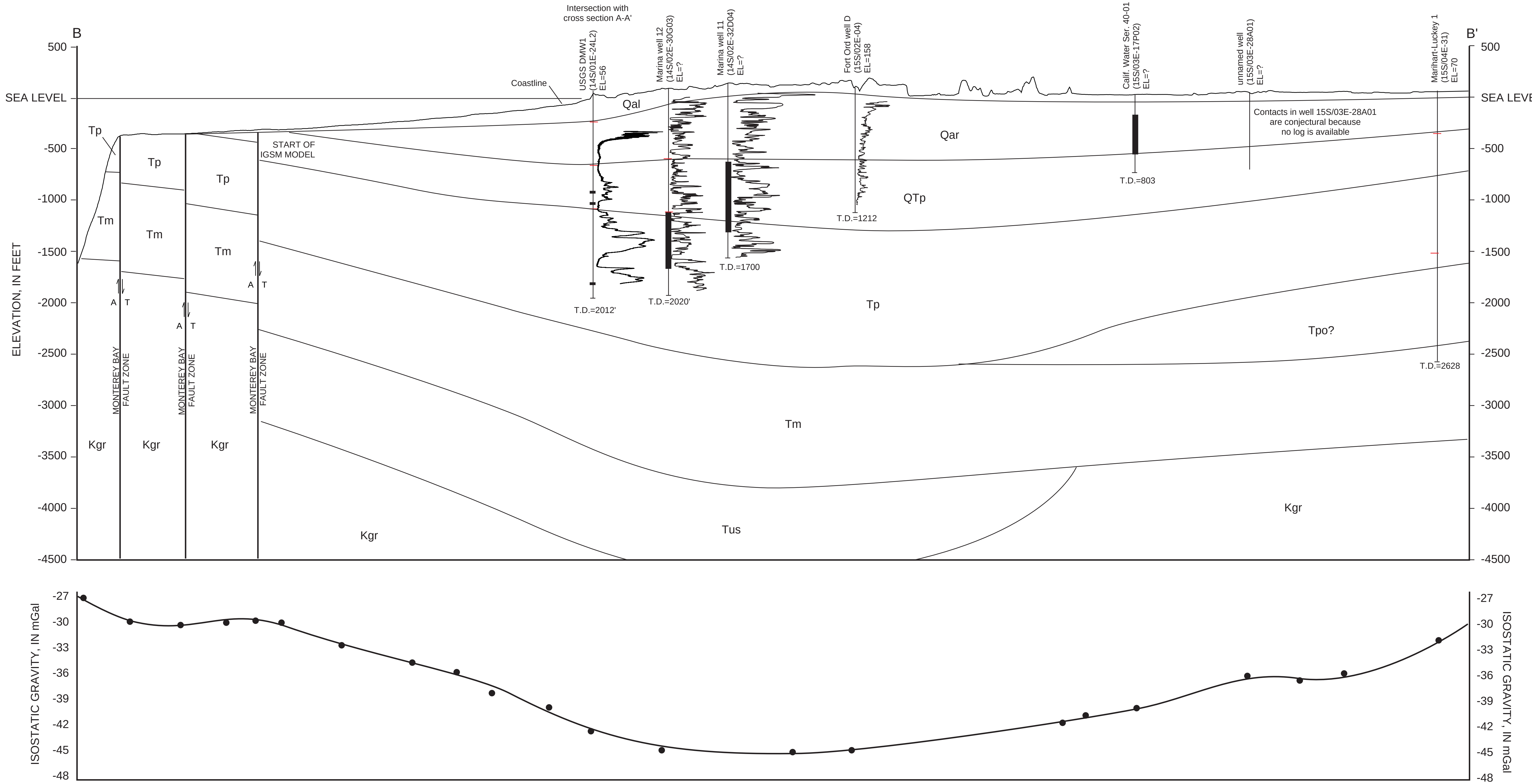
SOURCES OF DATA

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)

GEOLOGIC CROSS SECTION A—A'		
For: Marina Coast Water District		
DEEP AQUIFER INVESTIGATIVE REPORT		
March 2003	Lew Rosenberg, CEG 1777 Martin Feeney, CHG 145	Figure 4



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)

EXPLANATION

Qal	**Alluvium (Holocene)**
Qar	**Aromas Sand (Pleistocene)**
QTp	**Paso Robles Formation (Pleistocene-Pliocene?)**
Tp	**Purisima Formation (Pliocene)**
Tpo	**Pancho Rico Formation (Pliocene)**
Tm	**Monterey Formation (middle Miocene)**
Tus	**Unnamed sandstone (middle Miocene)**
Kgr	**Granitic rocks (late Cretaceous)**
———	**Fault**
———	**Contact**

Water well—total depth, in feet solid box shows perforations

T.D.=320'

30 o/m

Electrical log resistivity (ohm-meters^2/meter)

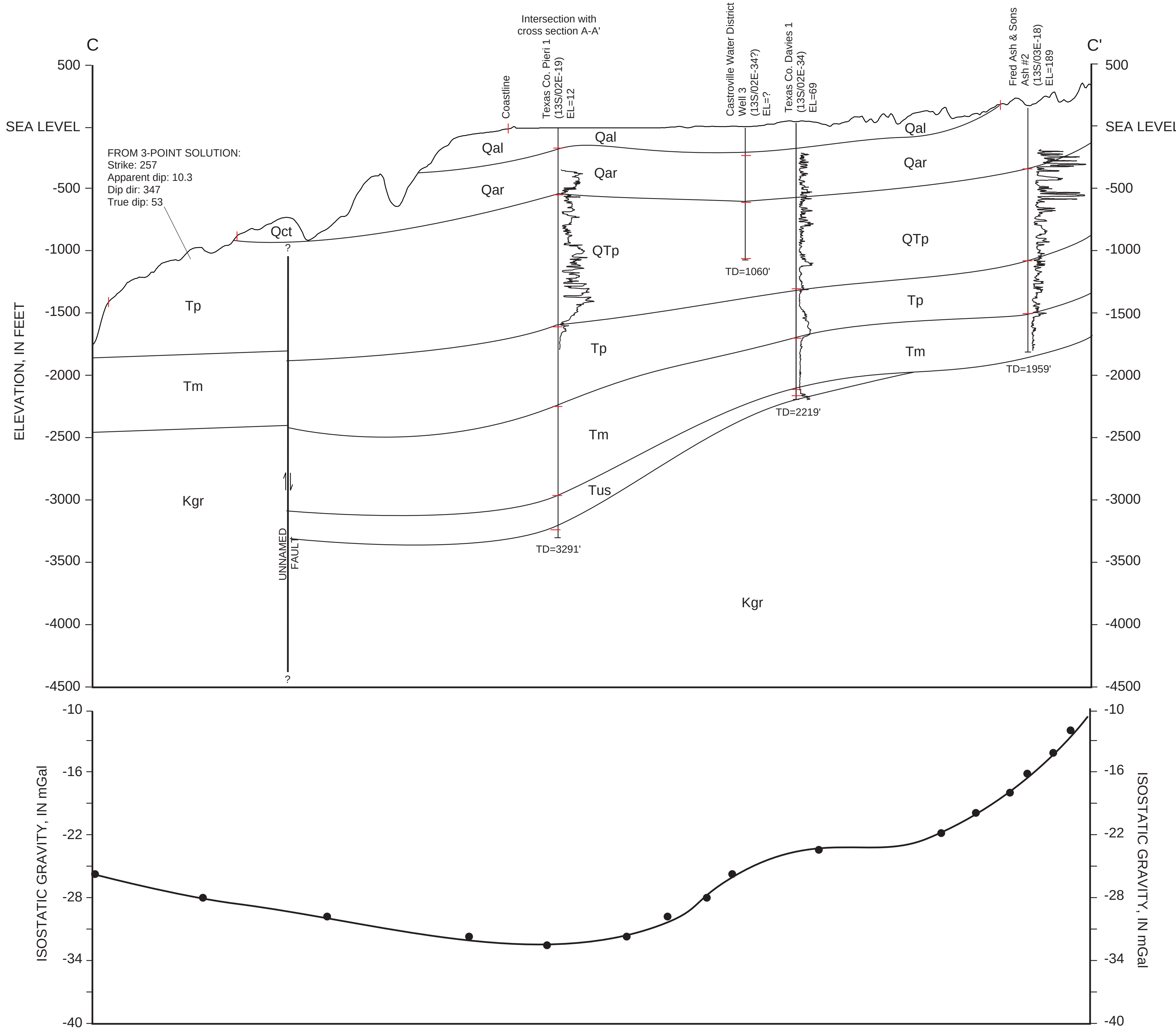
SCALE

10000 feet

Vertical exaggeration = 10X

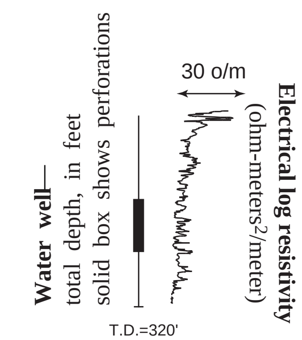
1000 feet

GEOLOGIC CROSS SECTION B—B'		
For: Marina Coast Water District		
DEEP AQUIFER INVESTIGATIVE REPORT		
March 2003	Lew Rosenberg, CEG 1777 Martin Feeney, CHG 145	Figure 5



EXPLANATION

Qal Alluvium (Holocene)
Qct Submarine canyon terrace (Pleistocene)
Qar Aromas Sand (Pleistocene)
QTp Paso Robles Formation (Pleistocene-Pliocene?)
Tp Purisima Formation (Pliocene)
Tsm Santa Margarita Sandstone (late Miocene)
Tm Monterey Formation (middle Miocene)
Tus Unnamed sandstone (middle Miocene)
Kgr Granitic rocks (late Cretaceous)
Fault--inferred and queried
Contact



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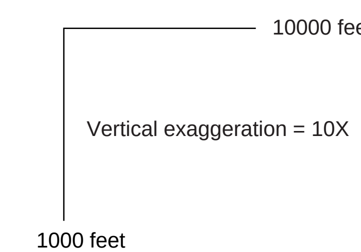


SOURCES OF DATA

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)

GEOLOGIC CROSS SECTION C—C'

For: Marina Coast Water District

DEEP AQUIFER INVESTIGATIVE REPORT

March 2003	Lew Rosenberg, CEG 1777 Martin Feeney, CHG 145	Figure 6

Cross section A-A'—This cross section is parallel to the coast and extends from Seaside northward to the Elkhorn area. A significant feature shown on this section is a postulated possible buried canyon beneath the Elba Capurro and Bayside Development Vierra wells (Starke and Howard, 1968). Gravity contours show closure and thus suggest a structural basin, rather than a fault origin for the unusually thick accumulation of middle Miocene sandstone in this area. Also of note is the contrast in thickness of Pliocene age strata across the Reliz fault. Cross section A-A' shows approximately 100 feet of vertical displacement (southwest side up) of the Purisima Formation, which is approximately 980 feet thick on the northeastern side of the fault. Interestingly, in the lower 260 feet of the Pliocene section on the southwestern side of the fault, the lower part of the Purisima Formation is replaced by the late Miocene age Santa Margarita Sandstone

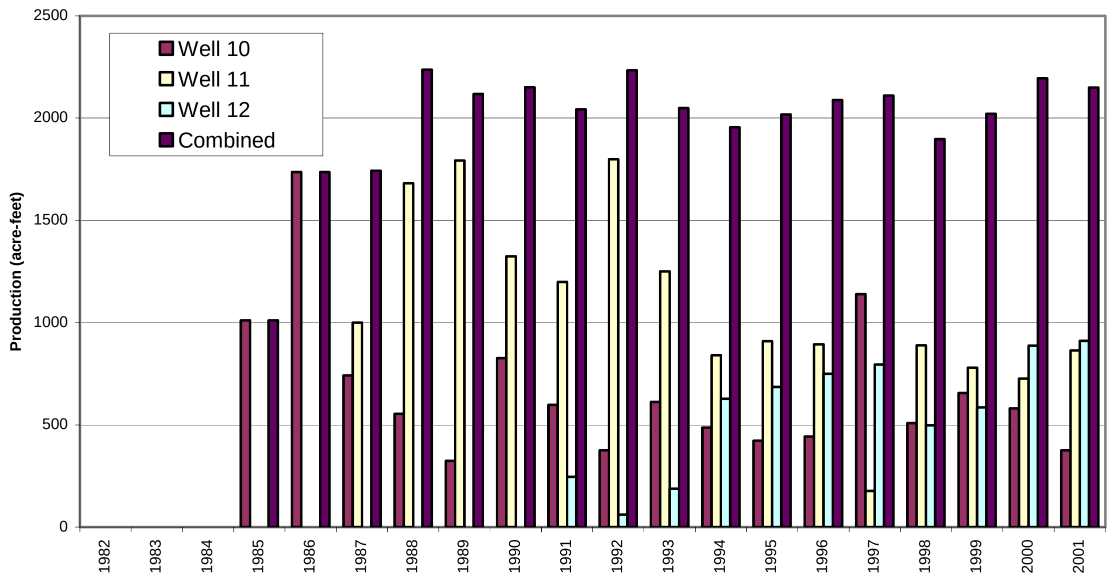
Cross section B-B'—This B-B' is perpendicular to the coast and extends from approximately 9 miles offshore southeastward to near Spreckels. Wagner and others (2002) mapped several northwest-striking strands of the Monterey Bay fault zone offshore. These faults are included on cross section B-B'. Although the Wagner and others (2002) map does not indicate the sense of fault displacement, Greene (1977) reported mainly high-angle faulting (southwest side up) with an unknown component of strike-slip displacement along the southern Monterey Bay fault zone. This formed the basis for showing the high-angle en echelon faults on cross section B-B'. Although the vertical displacement is indicated by high-resolution seismic profiling by Greene (1977), the amount of displacement is conjectural.

Cross section C-C'—Cross section C-C' is a modified version of a cross section by Geoconsultants (1996), with the cross section line extended approximately 7 miles offshore and 4 miles northeastward to include the Fred Ash No. 2 wildcat oil well. Similar to cross section B-B', the amount of displacement of strata across the fault is speculative. The thickness of the Purisima Formation differs across the fault in cross section C-C'—it ranges from 400 to 600 feet on the northeastern side on the fault, whereas it is about 900 feet on the southwestern side of the fault as suggested by outcrop pattern (Wagner and others, 2002) and three-point calculation.

PRODUCTION

Ten water wells have been installed in Monterey County to produce from the deeper aquifers. MCWD operates three wells—MCWD wells 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. Data reported to MCWRA are confidential and are 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 7.

Annual Production by Well



Monthly Total Production

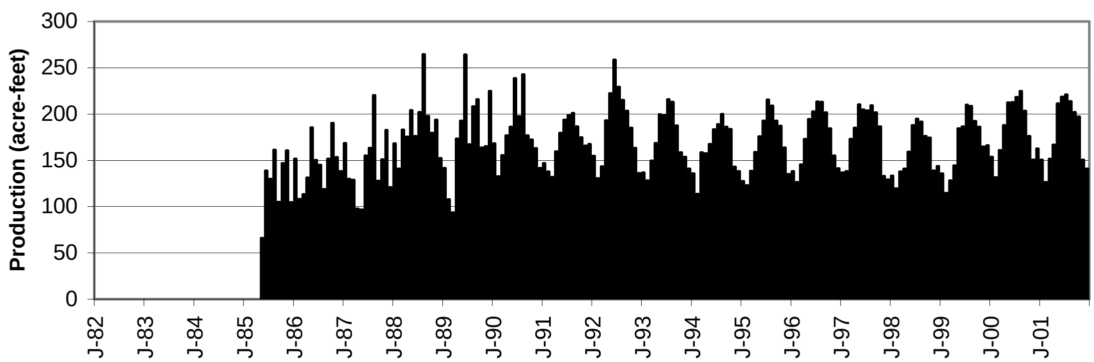


Figure 7. MCWD deep aquifers production

Figure 7 reveals annual production from the deeper aquifers to have been relatively constant since the completion of well 12 in 1990. Total production has averaged approximately 2000 acre-feet/year over this period. Figure 7 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.

WATER LEVEL DATA

Water level data are available for wells in the deeper aquifers in the Castroville area from the MCWRA. Intermittent water level data are also available from MCWD for their three production wells. Continuous water level data are available for the USGS Monitoring well cluster since June 2001.

Marina Coast Water District Wells

A water level history of MCWD Wells can be assembled from various sources. MCWD has collected water level data from these wells on an irregular schedule, with 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 where no data are available. Since beginning of investigation, water level data have been collected on almost a continuous basis. The available water level data are presented on figures 8 and 15.

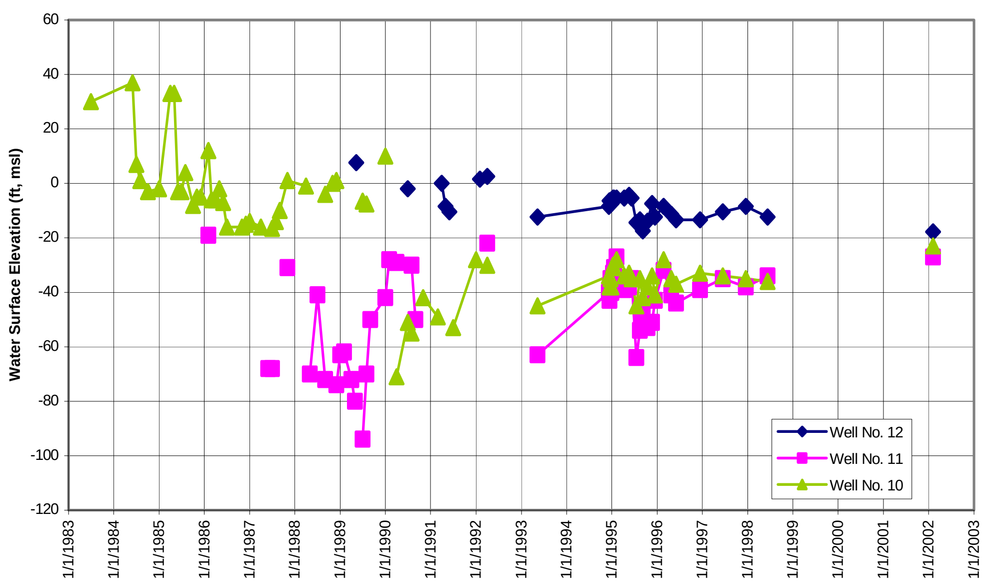
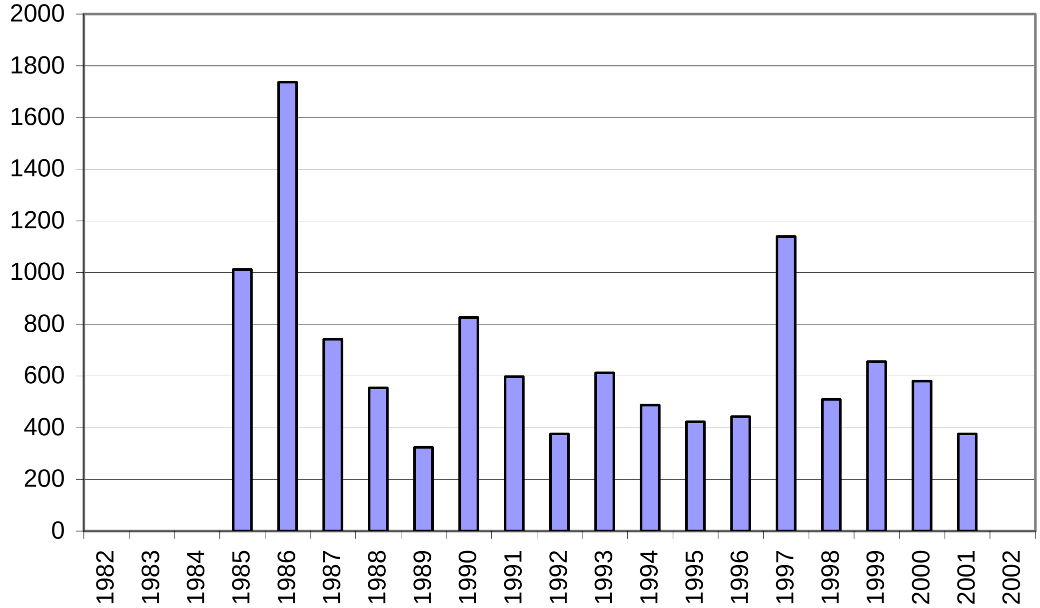


Figure 8. MCWD deep aquifer wells water level data

Although the record in figure 8 is incomplete, the 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 maintaining a narrow range of fluctuation. All three of MCWD's wells have maintained water levels significantly below sea level since initiation of extractions. Wells 10 and 11 display water levels averaging below elevation -40 feet. Well 12 displays average water surface elevation of approximately -15 feet. Of interest are the strong vertical gradients maintained between these wells and the increasing head with increasing well depths.

Figures 9 through 11 present annual production and water level history for each of MCWD's wells. Water level data are generally too sparse to discern a strong linkage between extractions



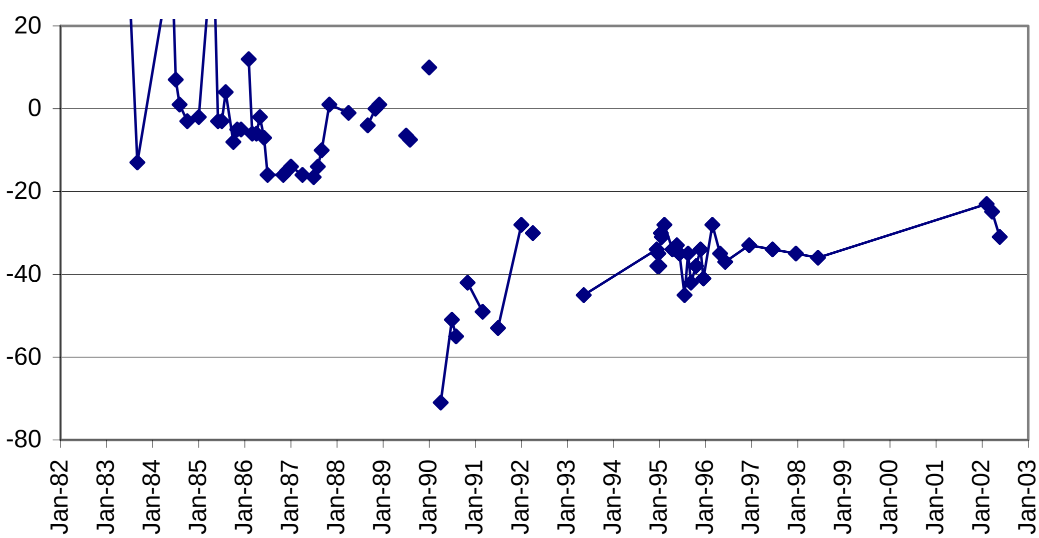


Figure 9. MCWD well 10, yearly production vs. water level

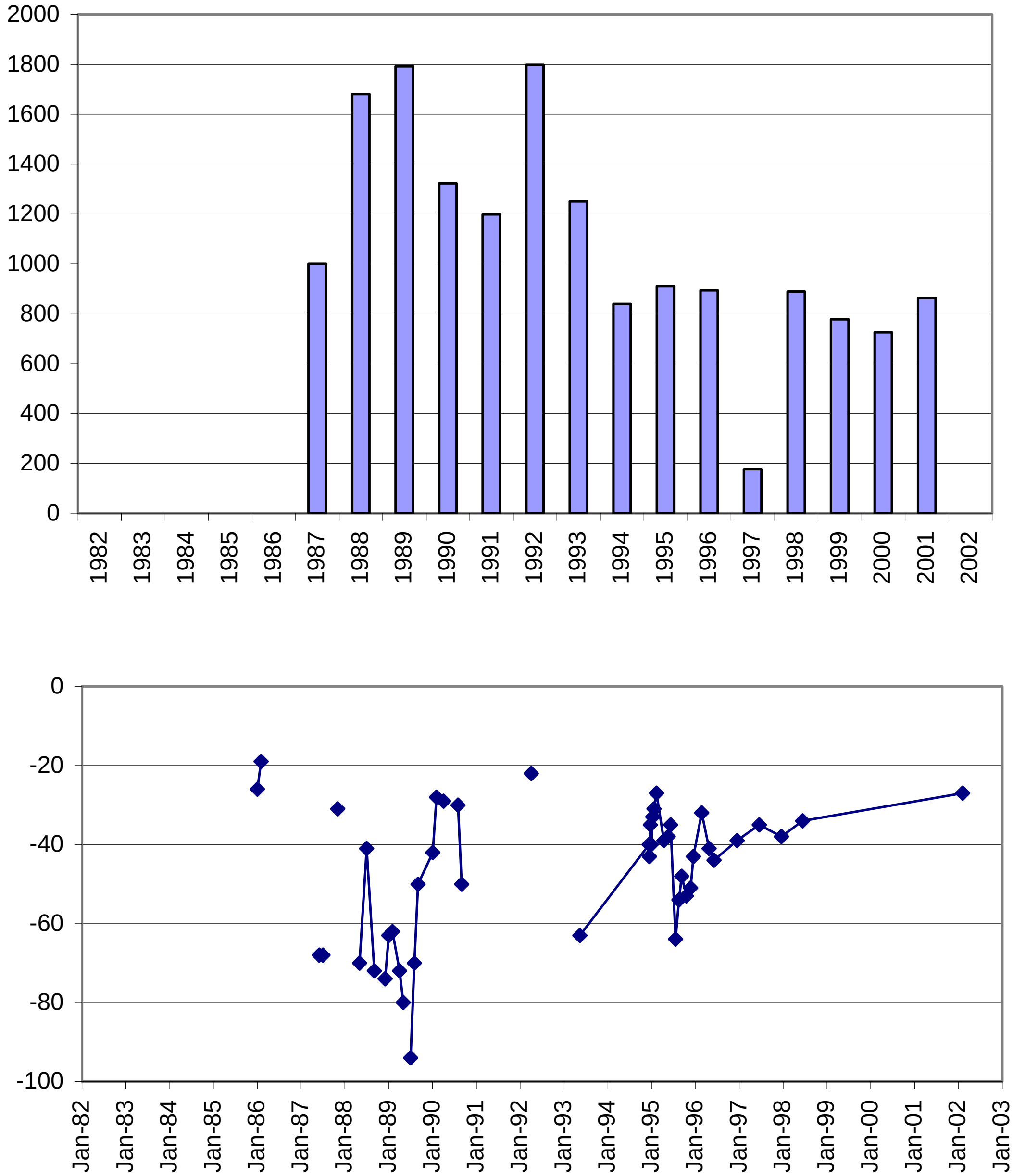
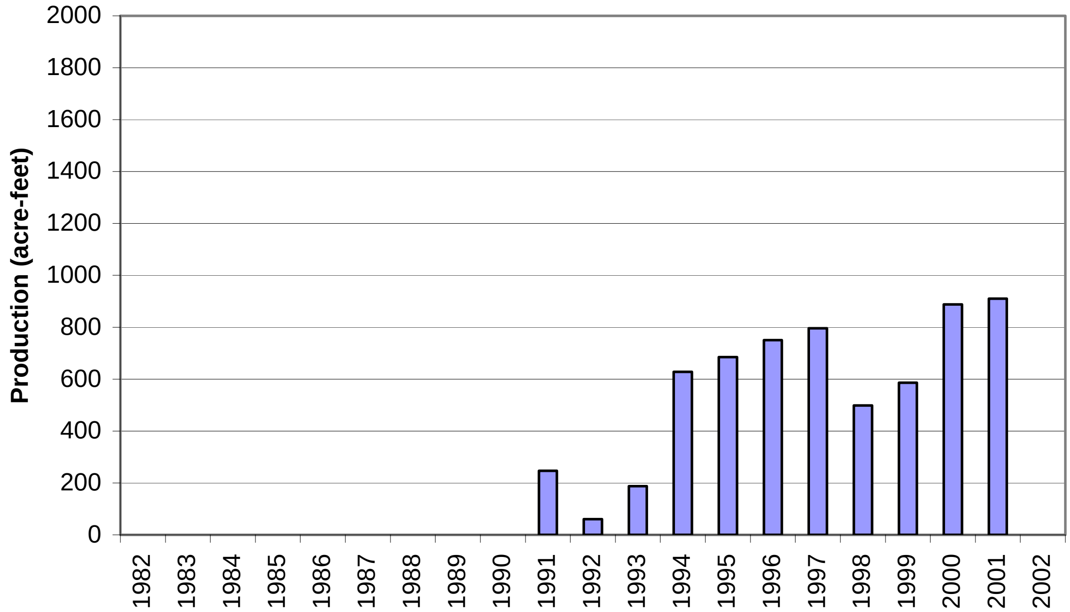


Figure 10. MCWD well 11, yearly production vs. water level



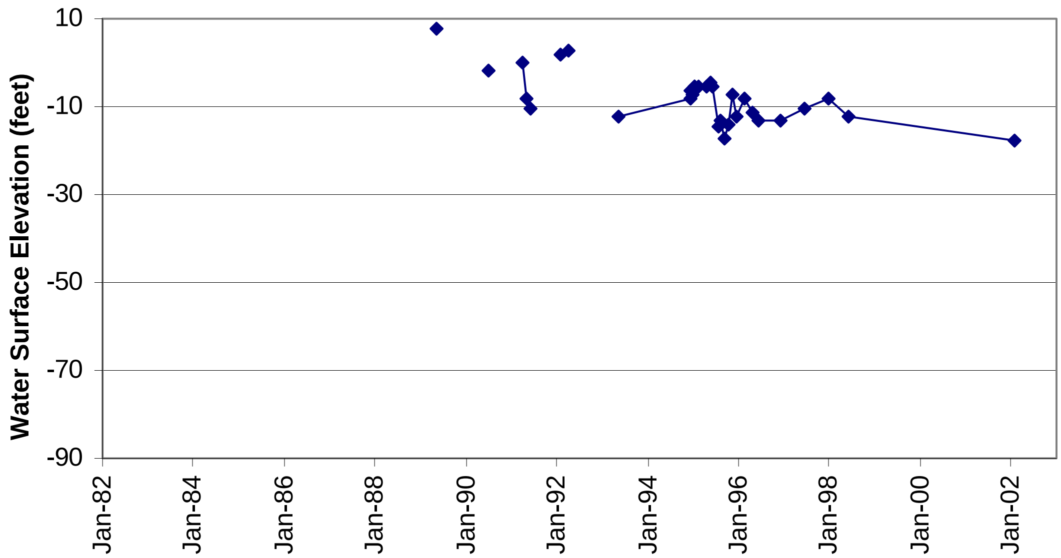


Figure 11. MCWD well 12, yearly production vs. water level

at well 10 and 11. The record for Well 12 is clearer showing 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 10 shows a large shift in average water level in approximately 1989. This is the period when production from Well 11 was coming on-line. As is discussed below, Well 10 and 11 display significant mutual interference effects. Beginning in 1987, water level records in wells 10 and 11 reflect the aggregate pumping from these wells. Water levels in well 12 are impacted by pumping from wells 10 and 11 only in that fewer extractions from wells 10 and 11 results in increased extractions from well 12. As discussed below, the hydraulic linkage between wells 10 and 11 and well 12 is poor.

Figure 12 presents monthly production and water levels from MCWD wells over the period from January 1995 to December 1997 – a period with the most water level data. Figure 12 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.

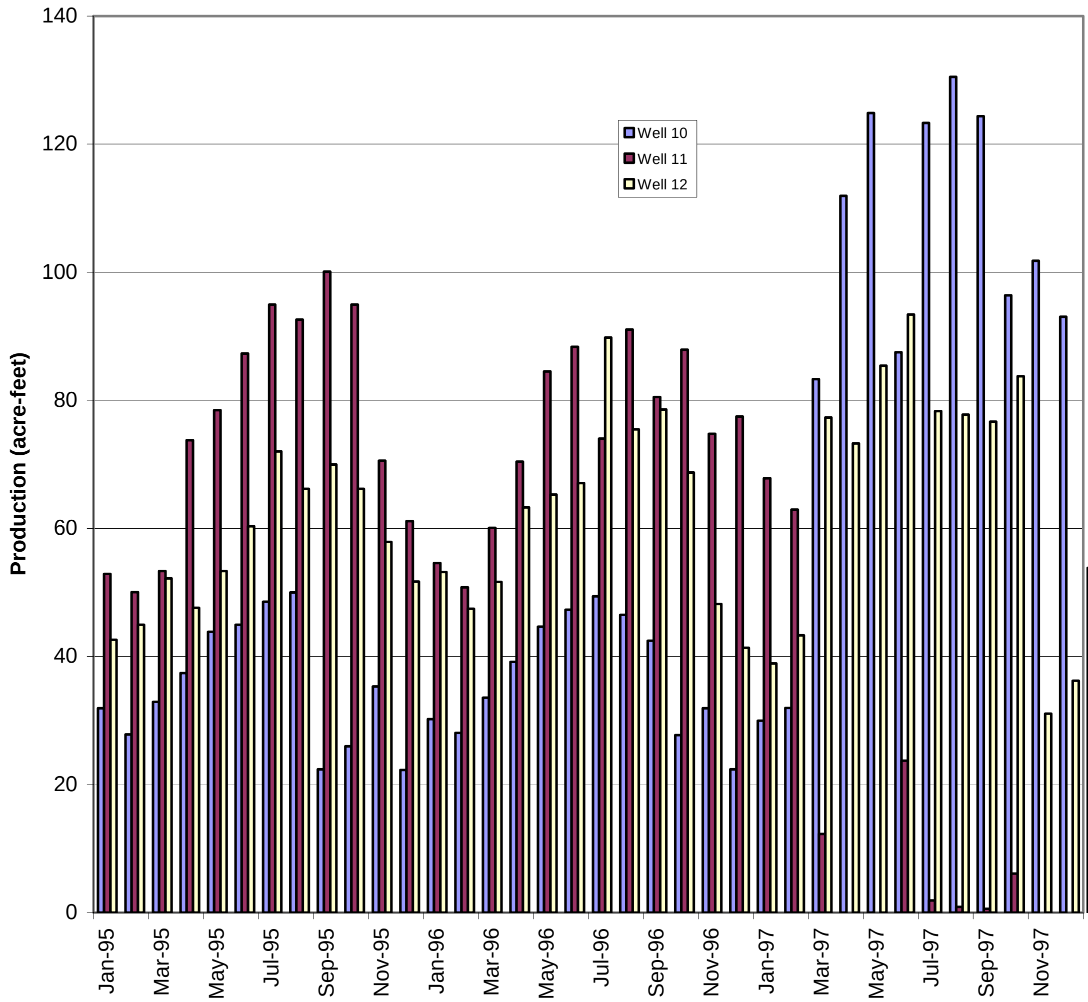
Castroville Area Wells

The MCWRA collects monthly data from five of the wells completed in the deeper aquifers in the Castroville area. Monthly water level data extends back to approximately October 1986. These data are presented in figure 13. 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 13N/2E-32E05, which is 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 recover to above sea level elevations by 2000, again indicative of a connected, confined aquifer system.

Figure 14 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.

USGS Monitoring Well

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



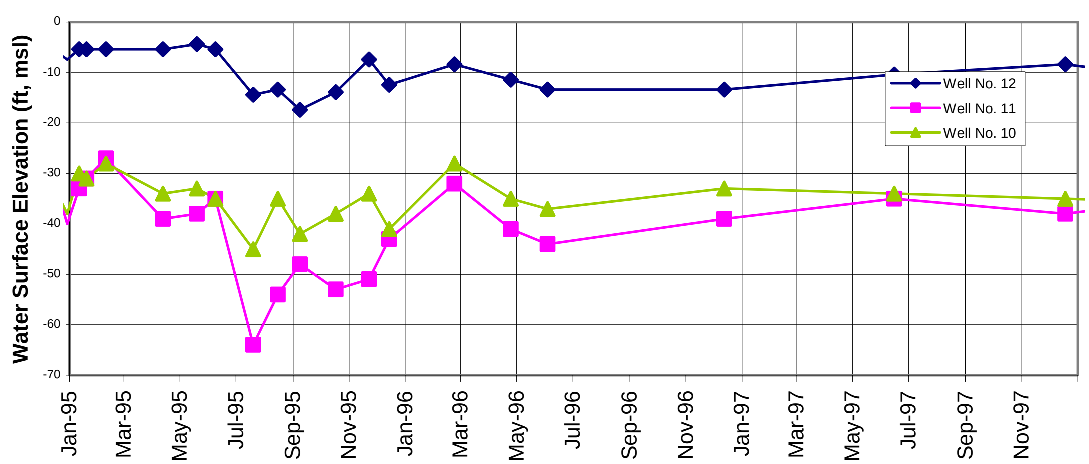


Figure 12. MCWD water level vs. production

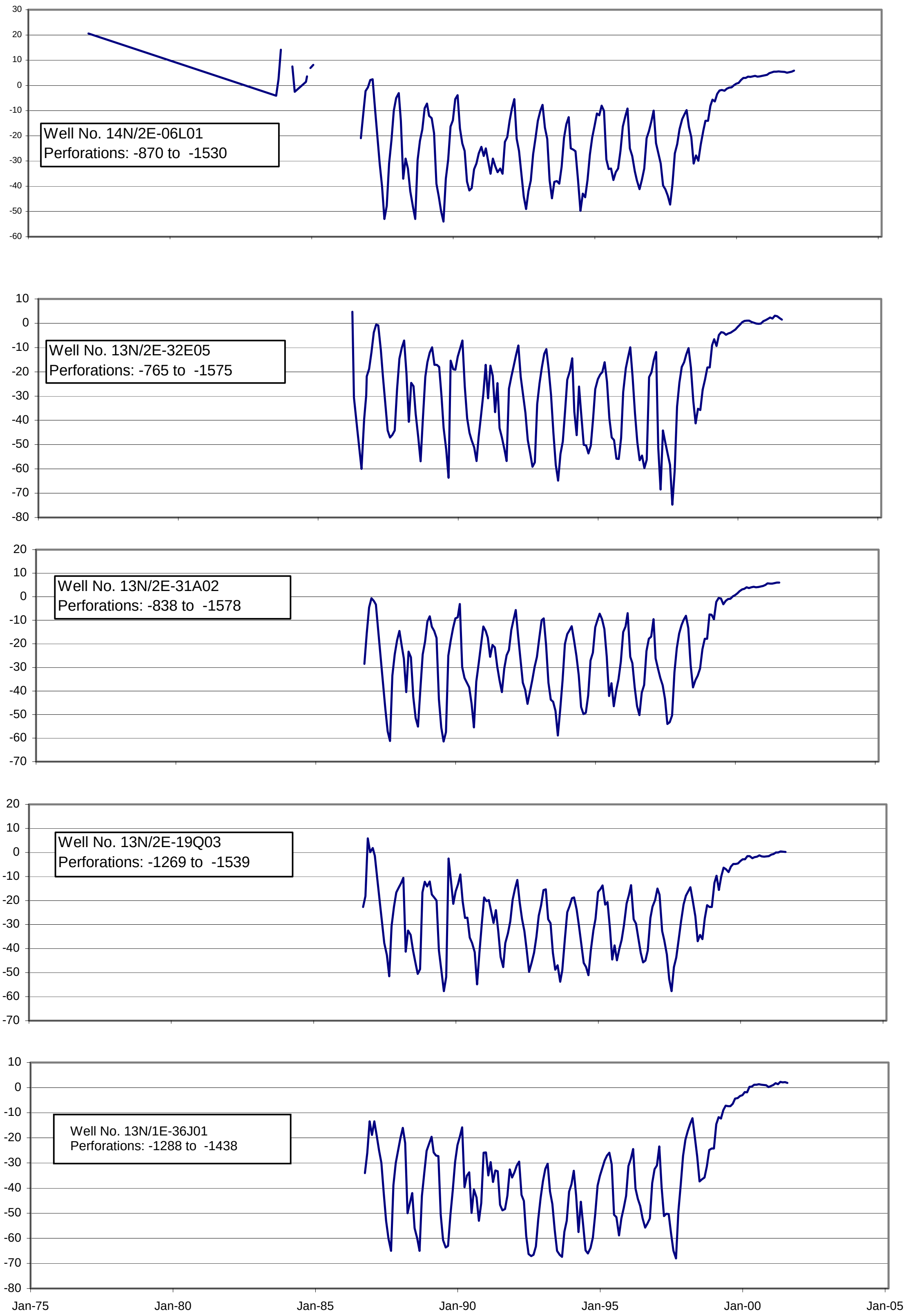


Figure 13. Water level history, Castroville area deep zone wells

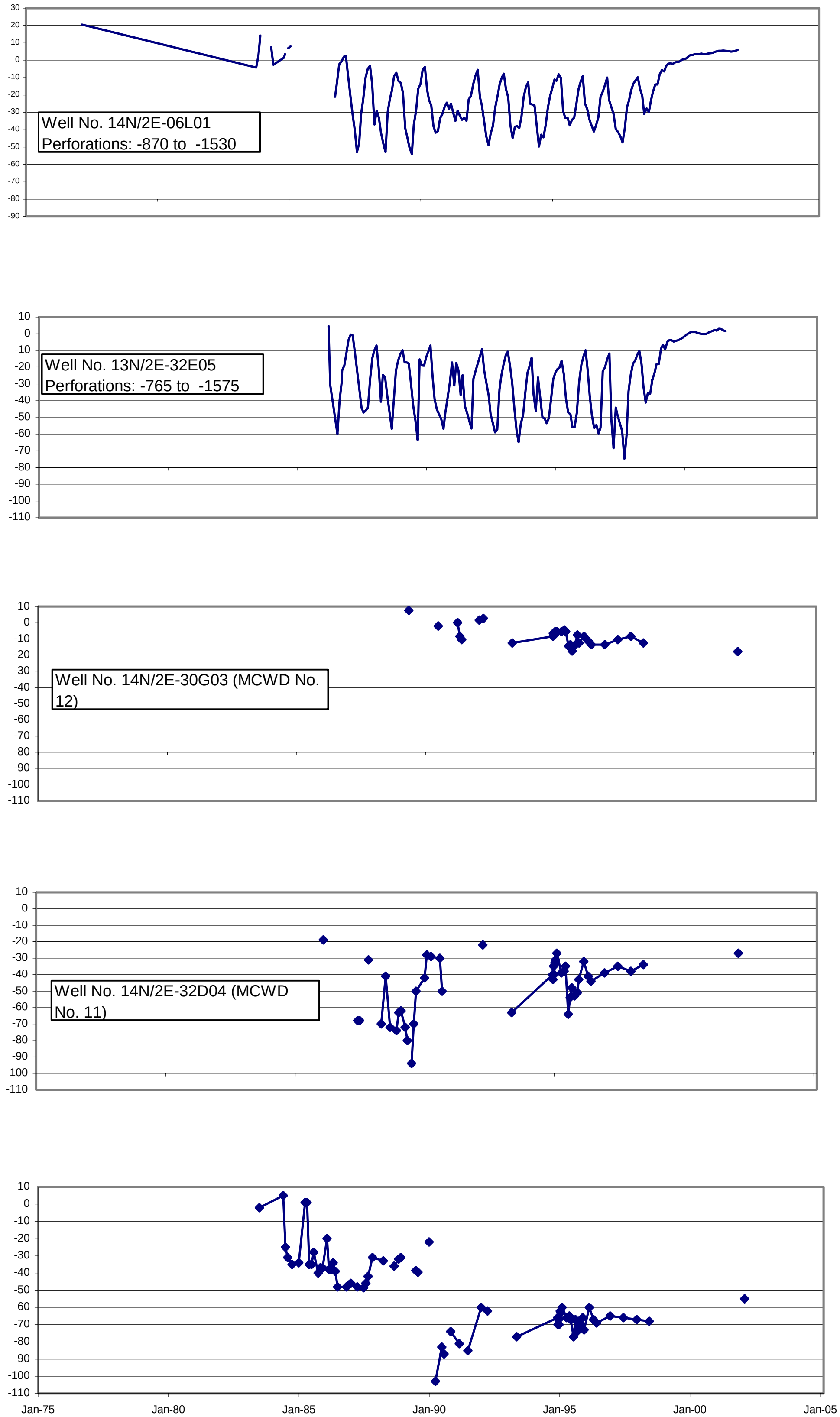


Figure 14. Water level history, Castroville and Marina area deep zone wells

Table 3. Water levels, USGS DMW well and MCWD production wells

Well	Elevation of perforations in feet	Average water surface elevation in 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 ground water elevations in the USGS well with ground water elevation data from the production wells is difficult. The USGS wells are completed in thin discrete zones, whereas the production wells are completed across multiple zones. For example, well 12's perforated interval includes the intervals in which DMW-1 and DMW-1-2 are completed. The water surface in DMW-1-2 is substantially above that of well 12 while DMW-1-1 is below. The water level in well 12 is likely a composite head of several smaller zones of differing heads from which it produces.

AQUIFER PARAMETERS/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 4.

Table 4. 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

Notes:
SC—Logan approximation
Slug—Slug test
Pumping—Pumping test
Lab—sidewall sample in laboratory

Well Interference Tests

MCWD Wells 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 15.

Well 12 was shut down for the first week followed by well 10 for the second week and well 11 for the third week. During week one, well 12 water level record displays a conventional recovery response. The recovery curve is undisturbed by interference with other wells although the operational cycles of wells 10 and 11 during this period are obvious in the records of these wells. Well 10 was off for week 2. Well 10 also shows a recovery curve; however, this curve is disturbed with a classic interference signature, corresponding to the operations of well 11. The third week and part of the fourth, well No. 11 was off. Again, the recovery curve of this well is disturbed with the interference signature from well 10, demonstrating the mutual interference between wells 10 and 11.

The interference between wells 10 and 11 is relatively consistent with the expected theoretical response utilizing the available aquifer parameters. The lack of measurable response in well 12 suggests that this well is not in hydraulic communication with wells 10 and 11. The observed and predicted responses are presented in table 5.

Table 5. Observed and theoretical response—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: Transmissivity 31,000 gpd/ft, Storativity 0.0001, 0.25 days

The difference between observed and theoretical responses likely derive from the fact that the aquifers from which these wells produce are more accurately an aggregation of smaller aquifers, making some of the assumptions required for theoretical prediction invalid. Still, the magnitude of the observed interference in wells 10 and 11 is consistent with predicted responses. The lack of any interference response to the combined pumping of wells 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 12 in the Purisima Formation, whereas wells 10 and 11 are largely in the Paso Robles Formation.

Close inspection of the recovery record of well 12 shows minor variations in water levels superimposed on the recovery curve. Closer inspection of these data (figure 16) shows the variations are a tidal signature that correlates directly with the tides in Monterey Bay.

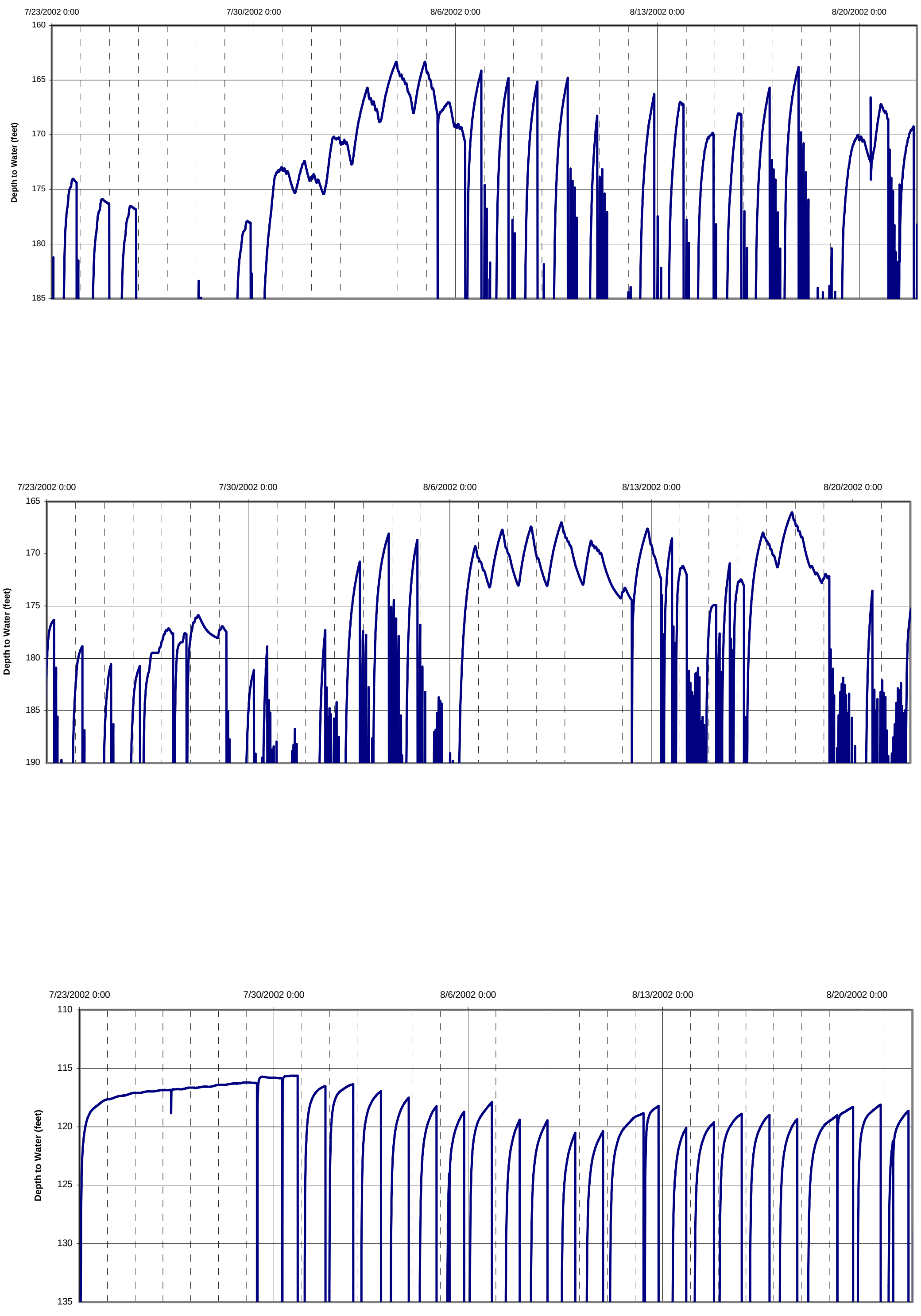


Figure 15. Well interference testing, MCWD wells 10, 11, and 12

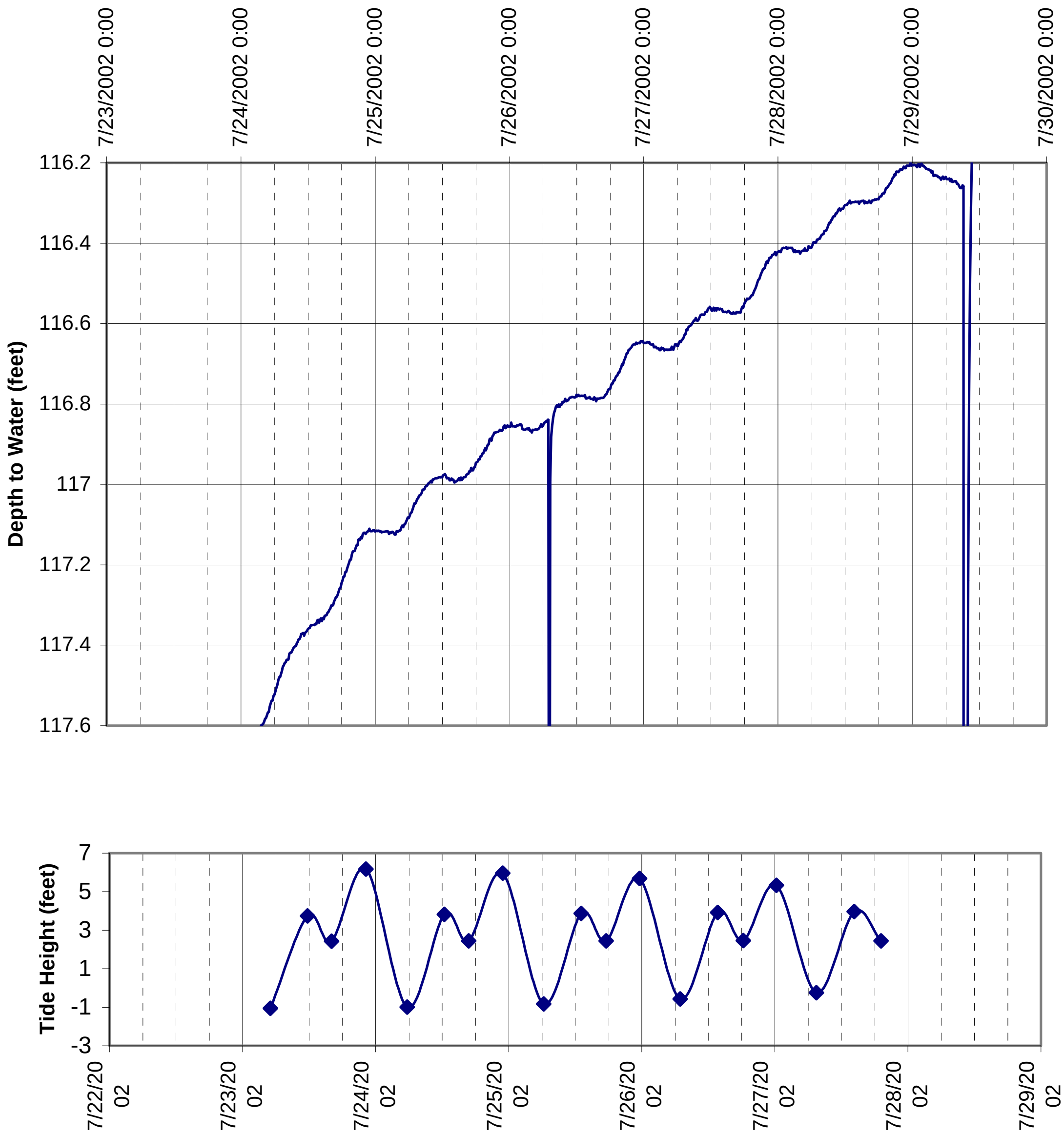


Figure 16. MCWD well 12—idle period record

<u>USGS Monitoring Well versus MCWD Well 12</u>—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 12 is also completed in the Purisima Formation. Figure 17 compares water level data collected at the four USGS monitoring wells with data collected from MCWD well 12 during the Well Interference exercise described above. Most evident in figure 17 is 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 MCWD well 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 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 MCWD well 12. Well 12 is perforated between elevations -1283 to -1833 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 x 10^{-6} in^2/lb
	TE = tidal efficiency	= 0.33

Utilizing these values, a specific storage coefficient of 0.000013 (dimensionless) can be calculated. A value considered very appropriate for confined conditions. This value is lower than the value 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.

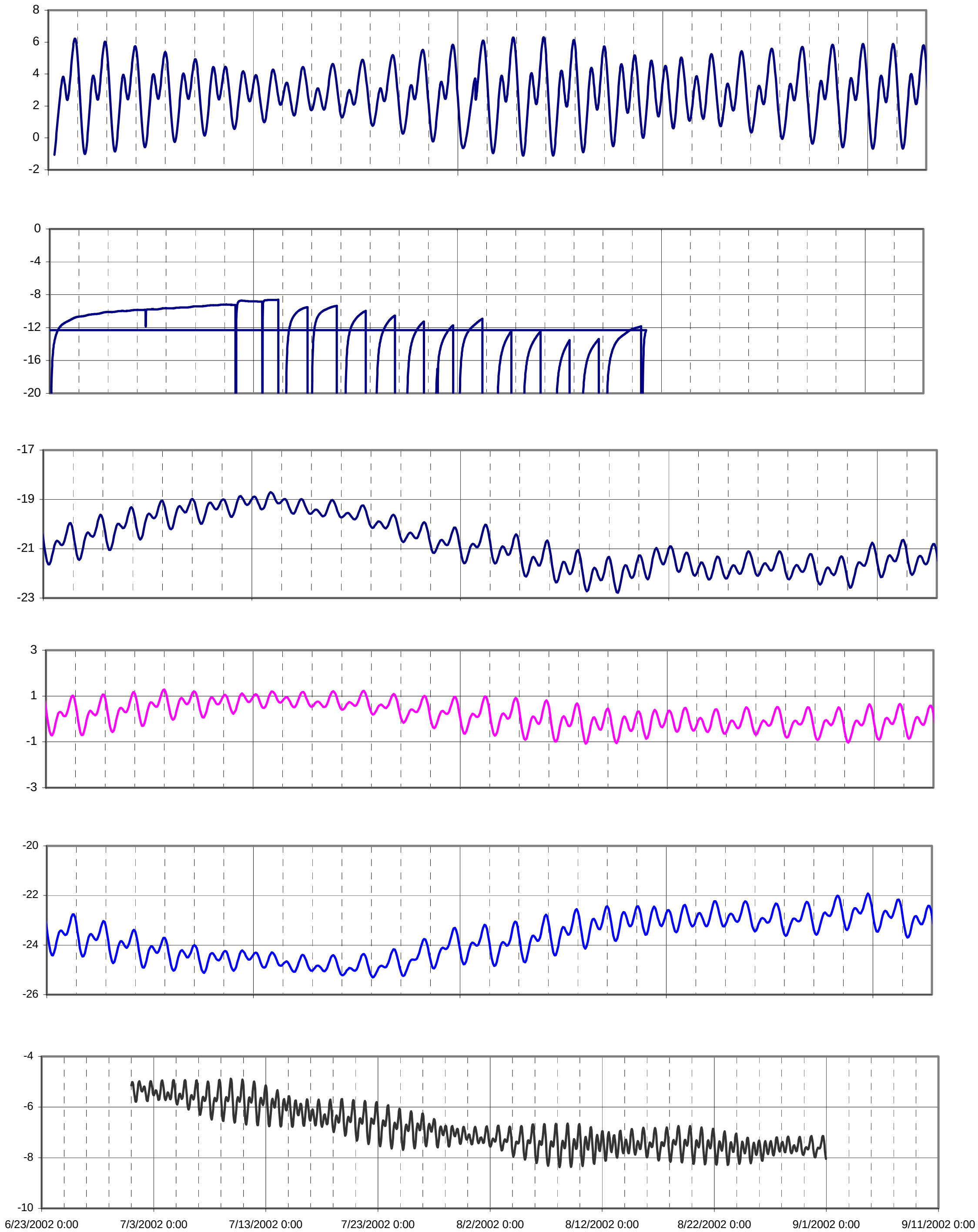


Figure 17. MCWD well. 12—USGS monitoring well vs. MCWD well 12

WATER QUALITY

Water quality data from MCWD's wells are available from DHS since the time of their completion. Figures 18–20 present water quality history (i.e., selected constituents) for the three wells completed in the deeper aquifers. As can be seen, water quality parameters presented (i.e., TDS and chloride ion) have been generally stable over the period of record. wells 10 and 11 generally show more fluctuation in quality than well 12, but no trend towards water quality degradation is evident.

Water quality generally decreases with depth of well. The average total dissolved solid concentrations are 300, 389, and 463 mg/l for wells 10, 11 and 12, respectively. Chloride ion concentrations display the same pattern with average concentrations of 63, 78 and 119 mg/l for wells 10, 11 and 12, respectively. This trend toward increasing concentration with depth also corresponds with a change in chemical character as can be seen in the geochemical diagram below. Water from well 10 has a sodium-bicarbonate chemical character. Well 11 has a transitional sodium-chloride-bicarbonate chemical character, whereas well 12 has a sodium-chloride chemical character. Of note is the distinctive low concentration of magnesium ion in the water from well 12.

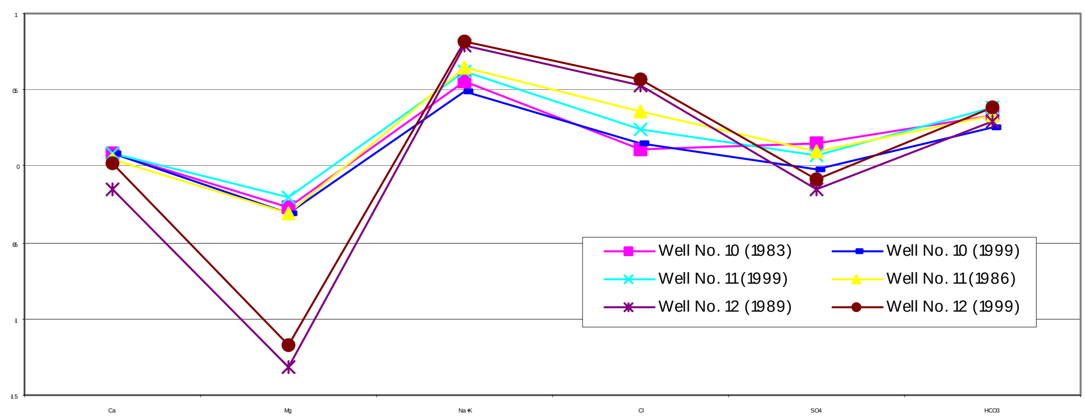


Figure 18. Marina deep aquifer wells

The Castroville wells all display a similar water quality. These wells display a sodium-chloride chemical character. The water quality differs from MCWD's wells 10 and 11 in that it displays more elevated concentrations of chloride and lower concentrations of sulfate. The Castroville wells are similar to MCWD well 12 with the exception of higher concentrations of magnesium. The geochemical signatures of the Castroville and MCWD wells are compared in the chart below.

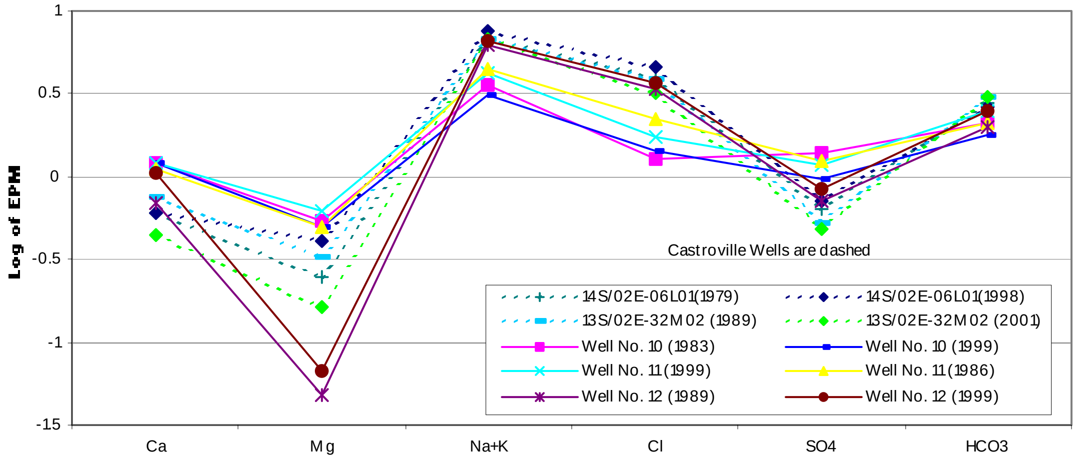


Figure 19. Marina Deep Aquifers Wells Comparison to Castroville Well

The geochemical diagram below compares the water chemistry of the MCWD wells with that of the four USGS wells. Apparent in the diagram is the relatively good match of the deepest monitoring wells (DMW–1-1) with the deepest MCWD well (well 12), and the transition in water chemistry as the monitoring wells become shallower. The shallowest USGS monitoring well compares positively with MCWD well 10. This is interpreted to reflect a transition from the Paso Robles Formation to the Purisima Formation as well completion depths become shallower.

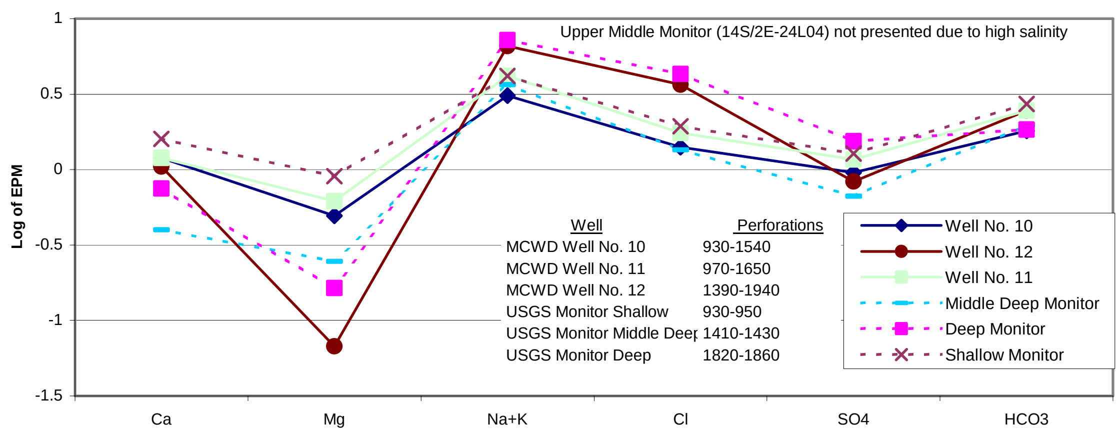


Figure 20. Marina deep aquifer wells comparison to USGS monitor well

IMPLICATIONS OF FINDINGS

Taken together, the overall conclusion that can be derived from the collected data and the preliminary analysis is that the “deep aquifer” from which MCWD extracts its water supply is actually two separate aquifer systems. Existing geologic and water chemistry data suggest that MCWD wells 10 and 11 produce primarily from the Paso Robles Formation, whereas MCWD well 12 produces from the Purisima Formation. In contrast, the “deep aquifer” wells in the Castroville area are interpreted to produce from the Paso Robles Formation. Aquifer response data suggest these two aquifer systems are hydraulically isolated from each other.

Recharge Considerations

The hydrogeologic interpretation of the deeper aquifers raises questions regarding the nature and magnitude of recharge to these aquifers. Well 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 (Santa Cruz County) where the Purisima Formation is the primary source of water for the Soquel Creek Water District. Recharge for the Purisima Formation (MCWD well 12) is therefore primarily leakage from overlying aquifers. Some portions of extractions may be supported by depletion of ground water storage. However, the low estimates for storage coefficients for this aquifer system suggest that the volume of ground water 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 Paso Robles Formation underlies the Salinas Valley alluvium and Aromas Sands that comprise the 180- and upper portion of the 400-foot aquifers. 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, 12,400 acres, or 33 percent, of Paso Robles Formation are exposed in the El Toro-Laguna Seca Area where it 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 falling 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 and then a stabilization as extractions equilibrate with leakage. This interpretation is best evaluated by modeling.

Modeling Implications

The revised interpretation of the Salinas Valley Basin, including deeper aquifers results in a four-layer hydrogeologic model—the 180-foot, the 400-foot, the Paso Robles and the Purisima Formation. The current version of the Salinas Valley Integrated Ground and Surface Water Model (SVIGSM) is a 3-layer model—two layers corresponding to the 180- and 400-foot aquifers and a third representing the deeper aquifers. Because Marina's deep aquifer water supply is derived from wells completed in both the Purisima and the Paso Robles Formations, SVIGSM, as currently configured, does not accurately reflect the hydrogeology of the MCWD's Wells.

SUMMARY OF RELEVANT FINDINGS AND CONCLUSIONS

- Geologic, hydraulic, and geochemical data all suggest the "deep aquifer" is 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.

- Marina Coast Water District's wells10 and 11 produce from the Paso Robles Formation, whereas well 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 deeper aquifers in the Marina area have been substantially below 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. This conclusion is supported by water level records from MCWD's wells. 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 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 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 sea level. However, storage coefficients suggest that the volume of ground water in storage in the lower aquifers is small. Increased production would likely come from increased leakage.

- The Purisima Formation is relatively hydraulically isolated from 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. The model could possibly be improved by adding a fourth layer and incorporating the current understanding.

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