CARPINTERIA GROUNDWATER BASIN

HYDROGEOLOGIC UPDATE
AND
GROUNDWATER MODEL PROJECT

FINAL REPORT

Prepared by:
PUEBLO WATER RESOURCES, INC.

with assistance from
HydroMetrics Water Resources, Inc.

Prepared for:

Carpinteria Valley Water District
Incorporated 1941

JUNE 2012

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PUEBLO
water resources

June 30, 2012
Project No. 06-0125

Carpinteria Valley Water District
1301 Santa Ynez Avenue
Carpinteria, California 93014

Attention: Mr. Robert McDonald, District Engineer

Subject: Carpinteria Groundwater Basin Hydrogeologic Update and Groundwater Model Project; Final Report

Dear Mr. McDonald:

We are transmitting the subject Final Report documenting the findings, conclusions and recommendations developed from the Carpinteria Groundwater Basin (CGB) Hydrogeologic Update and Groundwater Model Project. The project was implemented pursuant to a grant agreement between the District and the California Department of Water Resources (DWR) under the Local Groundwater Assistance (LGA) Grant Program for Fiscal Year 2007-08 (Grant Agreement No. 460000818). The overall purpose of the project was to develop a numerical groundwater model of the CGB with sufficient detail and features to support efficient and cost-effective analysis of various alternative management scenarios for the groundwater basin.

The updated hydrologic budget for the CGB indicates an average annual recharge volume of approximately 4,000 acre-feet per year (afy). Based on the ability of existing wells in the basin and their associated extraction patterns to capture recharge without inducing undesirable impacts (e.g., long-term declining water levels), an average annual operational yield of approximately 3,600 afy is recommended. The results of the hydrogeologic update were utilized to develop a well-calibrated numerical groundwater flow model of the CGB. The model simulates the occurrence and movement of groundwater in the basin and will be useful to the District as an ongoing basin management tool, such as in evaluating various basin management strategies to increase the basin operational yield through capture of additional recharge and/or through managed aquifer recharge.

We appreciate the opportunity to provide assistance to the District on this important project. Please contact us with any questions.

Sincerely,

PUEBLO WATER RESOURCES, INC.

Robert C. Marks, P.G., C.Hg.
Principal Hydrogeologist

Copies submitted: 1 digital (PDF)

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INTRODUCTION

GENERAL STATEMENT

This Final Report of the Carpinteria Groundwater Basin Hydrogeologic Update and Groundwater Model Project presents a summary of the findings, conclusions and recommendations developed from an update of hydrogeologic conditions and development of a numerical groundwater model of the Carpinteria Groundwater Basin (CGB). The project was performed by Pueblo Water Resources, Inc. (PWR) with assistance from HydroMetrics Water Resources, Inc. (HMWRI).

BACKGROUND

The Carpinteria Valley Water District (District) initiated the project in 2007 with the primary objective of developing a groundwater flow model of the CGB. The purpose of the groundwater model is to provide the District an ongoing groundwater basin management tool. In December 2007, PWR developed a work plan and the District submitted a grant proposal for the project to the California Department of Water Resources (DWR) under the Local Groundwater Assistance (LGA) Grant Program for Fiscal Year 07-08. The District and DWR entered into a grant agreement for the project in December 2008 (Grant Agreement 4600008188, amended December 2009 and January 2012).

The work plan for the project consists of two primary tasks: Task 1 consists of an update of the hydrogeologic conditions in the basin; Task 2 consists of the development of a calibrated three-dimensional numerical groundwater model of the basin. Detailed documentation of the findings, conclusions and recommendations associated with Task 1 and Task 2 were previously presented in two separate Technical Memoranda, dated February 2011 and February 2012, respectively. The Task 1 and Task 2 Technical Memoranda are presented as Appendices A and B of this report, respectively.

Previous Investigations

The hydrogeology of the CGB has been studied extensively over the last 60 years in previous investigations. The most significant reports include those prepared by Upson (1951), Evenson (1962), Slade (1975), Geotechnical Consultants, Inc. (1976 and 1985), Sullwold (1996), and Integrated Water Resources, Inc. (2003). These documents describe the stratigraphy, structure, hydraulic characteristics and hydrologic budget of the aquifer systems of the CGB. Taken together, they also document the evolution of the understanding of the hydrogeology of the CGB.

The earliest detailed study of the hydrogeology of the basin was by the United States Geological Survey (USGS) and J.E. Upson (1951). This USGS report also contained a section on surface water hydrology in the basin by Thomasson (1951). Based on the available data at the time, Upson defined the boundaries of the basin and divided it into two main aquifer bodies - a shallow and deep aquifer. Evenson (1962) later estimated the perennial yield of the CGB at approximately 3,400 acre-feet per year (afy) utilizing the so-called “practical rate of withdrawal” method for the base period of 1941 – 1958.

The current working conceptualization of CBG hydrostratigraphy (i.e., Aquifers A through D) was initially forwarded by Slade (1975). The most recent comprehensive report on the CGB was performed by Geotechnical Consultants, Inc. (GTC, 1976). The 1976 GTC report built upon Slade's work regarding the basin structure, hydrostratigraphy and hydraulic parameters. This GTC report included a detailed analysis of the hydrologic budget equation for the basin for a base period covering 1935 – 1973 and estimated the perennial yield of the basin at approximately 4,500 afy. GTC subsequently performed an update of their 1976 investigation in 1985, the focus of which was an update of the hydrologic budget for a base-period covering 1974 - 1984. Based on their analysis of this particular base period, GTC revised upward their previous estimate of the basin perennial yield to approximately 5,000 afy.

Sullwold (1996) refined the previous structural and hydrostratigraphic delineations of the CGB, taking into consideration water and oil wells drilled after 1975. Most recently, Integrated Water Resources, Inc. (IWR, 2003) performed a review of existing perennial yield (or safe yield) estimates for the CGB, including a review of the data utilized to develop the estimates. Based on their review of the previous estimates, IWR reasserted the perennial yield of the CGB to range between approximately 4,500 to 5,000 afy.

PURPOSE AND SCOPE

The overall purpose of this project was to develop a numerical groundwater model of the CGB with sufficient detail and features to support efficient and cost-effective analysis of various alternative management scenarios for the groundwater basin.

Task 1 of the project consisted of an update of the hydrogeologic conditions in the basin since the most recent comprehensive update of basin conditions was performed over 30 years ago by GTC (1976). Since that time, significant additional basin information has been developed. In particular, the District has constructed, tested, and operated several high-capacity municipal production wells, and has implemented a basin-wide water level, water quality, and production data collection program pursuant to the District's adopted Groundwater Management Plan. Task 1 also included an update of the water balance equation for the CGB since the last time it was updated (GTC, 1986), covering a base period of Water Years (WY) 1985 – 2008.

The hydrogeologic update performed as Task 1 of the project formed the basis for the Task 2 development of a calibrated three-dimensional numerical groundwater model of the CGB. The United States Geological Survey (USGS) MODFLOW model code (McDonald and Harbaugh, 1988) was used to construct a calibrated groundwater model that simulates the occurrence and movement of groundwater in the CGB. The model is intended to be used as an ongoing basin management tool. For example, the model allows the District to assess potential impacts of increases in groundwater pumping, evaluate how the basin would respond to long term drought conditions (and potential reductions in surface water deliveries), and simulate alternative basin management strategies such as redistributing pumping, implementation of an Aquifer Storage and Recovery (ASR) program, or other strategies to optimize the use of the groundwater basin.

The project work plan included specific subtasks for Task 1 and Task 2. The scope of work for Task 1 included the following:

- Compilation and review of existing and new data;
- Updating of basin cross-sections and structural contours;
- Characterization of aquifer hydraulic parameters;
- Updating of water-level hydrographs and groundwater surface contours;
- Performance of an updated hydrologic budget analysis, and;
- Preparation of a Task 1 summary Technical Memorandum

In addition to updating the hydrogeology of the basin where possible given the availability of new information, a project GIS database was developed as part of Task 1 that complied electronic geographic information from the District, Environmental Systems Research Institute (ESRI), and the USGS, and also includes all new digital geographic information developed as part of the work for this project.

The information developed in Task 1 formed the basis for Task 2. The scope of work for Task 2 included the following:

- Construction of a numerical flow model of the basin based on the conceptual model of the basin developed from the Task 1 results;
- Transient calibration of the numerical flow model over the base period established in Task 1;
- Development and execution of several initial model scenario simulations, and;
- Preparation of a Task 2 summary Technical Memorandum.

This Final Report presents a summary of the results of Task 1 and Task 2, an updated evaluation of the perennial yield of the basin, and recommendations for future efforts to optimize basin utilization, improve upon the current understanding of the basin, and enhance the numerical groundwater flow model. The technical details associated with Task 1 and Task 2 are presented in their respective Technical Memoranda and will not be repeated in this Final Report. The purpose of this Final Report is to present a summary of the findings, conclusions and recommendations developed from Task 1 and Task 2. The reader is directed to the Task 1 and Task 2 Technical Memoranda (Appendices A and B, respectively) for further details on the information presented in this Final Report.

FINDINGS

TASK 1 – HYDROGEOLOGIC UPDATE

Availability of Basic Data

The initial project task consisted of compiling and reviewing the available data for the hydrogeologic update of the CGB. The types of data and information collected and evaluated include the following:

- Previous Reports on Basin Conditions
- Drilling Logs
- Pumping Tests
- Water Levels
- Precipitation
- Stream Flow
- Municipal and Private Well Production
- Land Use and Soil Survey Information
- Imported Water

A detailed summary of the data obtained and an evaluation of the adequacy of the available data for the project was presented in a previous technical memorandum (Appendix A) and will not be repeated here. In summary, the overall data availability, quantity, and quality for drilling logs, precipitation, well production, land use and imported water were considered adequate for this hydrogeologic update. Although significant additional pumping test and water-level data were available for this update compared to that available for previous investigations, virtually all of the available data is from wells completed within multiple aquifer zones; therefore, the availability of these data for individual aquifer zones is generally deficient.

Based on the review of the previous studies and currently available data, a re-conceptualization of basin hydrostratigraphy and water balance components was not warranted (consistent with the work plan for the project). Rather, newly available subsurface data was used to refine geologic and hydrostratigraphic delineations, where appropriate. The water balance was updated for a more recent base-period (i.e., 1985 – 2008) utilizing methodologies similar to those used by GTC in 1976 and 1985. A significant focus of the Task 1 hydrogeologic update was the preparation of geologic structure, hydrostratigraphy and spatial distributions of the various water balance components into ArcGIS layers that served as the platform for developing the groundwater model in Task 2.

Hydrogeologic Setting

This section presents a general description of the hydrogeology of the CGB and water-bearing strata within the basin boundaries. The description is based largely on a compilation of information from previous investigations of the basin, supplemented and refined as appropriate based on new information and data developed as part of this project.

Basin Boundaries. The CGB is located on the south flank of the Santa Ynez Mountains, one of the east-west trending ridges of the Transverse Range Geomorphic Province. The basin represents the north limb of a structural syncline that has been filled with water-bearing sediments. In the CGB, water-bearing deposits include all unconsolidated and semi-consolidated sediments of Plio-Pleistocene and Holocene age, with older consolidated non-water bearing rocks forming the boundaries of the basin.

For this hydrogeologic update, the most recent published geologic maps (Minor, et al, [2009] and Tan, et al, [2004]) were utilized to refine the delineation of the basin boundaries. A geologic map showing the surficial geology from the recent geologic mapping and the corresponding refined basin boundaries is presented on Figure 1.

Within the CGB, the Rincon Creek Thrust Fault has created a barrier to subsurface groundwater movement within the basin, and the surface trace of the fault has been used to segregate the basin into two Storage Units: Storage Unit No. 1 (SU-1) is on the north side of the fault trace, and Storage Unit No. 2 (SU-2) is to the south. The southeastern portion of SU-1 is hydrogeologically separated from the ocean by the Rincon Creek Thrust Fault; however, west of El Estero basin deposits are in contact with the ocean. SU-1 contains all of the District's principal municipal supply wells, and is the primary focus of this project.

A map showing the boundaries of the two Storage Units is presented on Figure 2.

Hydrostratigraphy. In the CGB there are major aquifers that are correlatable throughout the central and eastern portion of SU-1, and occur primarily within unconsolidated marine sediments of the Pleistocene and upper Pliocene-aged Carpinteria and Casitas Formations. These major aquifers have been designated as so-called Aquifers A, B, C, and D. Aquifer A represents the shallowest major aquifer with Aquifer D being the deepest. Pliocene and older Tertiary sedimentary bedrock units are considered non water-bearing and constitute the boundaries of the groundwater basin. The top of bedrock in the deepest portion of the basin is as much as 4,000 feet below sea level in SU-1 and rises to approximately 500 feet above sea level along the northern boundary of the basin.

Lithologically, primary water bearing deposits in the basin consist of interbedded unconsolidated and semi-consolidated sand, gravel, silt and clay (and combinations thereof) deposits. The coarser grained sandy/gravelly strata in these deposits comprise the individual primary aquifer zones (i.e., Aquifers A - D). These primary aquifer zones are generally on the order of 50 to 100 feet thick each. Finer grained strata of silt and clay are generally thicker and form a series of aquitards between the primary aquifer zones. These aquitards are laterally extensive in the central alluvial plain portion of the basin and confine water held in the primary aquifers under artesian pressure. This area of the basin is referred to as the Confined Area.

Outside the Confined Area of the basin and extending to the bedrock boundaries, Aquifers A - D become laterally discontinuous and generally non-correlatable. The older alluvium and Casitas Formation in these areas contain laterally discontinuous layers of both permeable and impermeable materials, and water held in these areas is generally unconfined (although various degrees of local confinement occur). The source of recharge water to the basin is primarily by infiltration of precipitation, irrigation water and streamflow seepage (discussed later); however, in the Confined Area, downward percolation of water is limited due to the presence of fine-grained low-permeability materials overlying most of the area of the principal aquifers; therefore, recharge to the primary aquifers occurs in the areas between the Confined Area and the boundaries of consolidated bedrock. This area is referred to as the Recharge Area.

It is noted that no new information (i.e., correlatable aquitards from recently drilled wells) was developed for this project that indicated that the previous delineations of the Confined and Recharge Areas should be modified; therefore, the existing delineations of these areas of the basin have been adopted for this project. A map showing the Confined and Recharge Areas is presented on Figure 3.

Well logs obtained for the basin have been used to refine the previous interpretations of the geologic structure and hydrostratigraphy of the CGB and prepare geologic cross-sections through the basin. A summary comparison of previous investigators delineations of basin hydrostratigraphy and the delineations developed through this project is presented in Table B-1 in Appendix A. As shown, there is general agreement between the various investigators. The locations of water wells in the basin and cross-section lines are shown on Figure 4. The cross-sections are shown on Figures 5 through 8.

Using the available well log information, the depth to each of the principal aquifers was identified and structurally contoured to delineate the areal extent of each principal aquifer within the basin. Updated structural contours of the top and bottom elevations of Aquifers A, B and C are shown on Figures 9 through 11, respectively. Structural contours of the top of bedrock for SU-1 and SU-2 are shown on Figures 12 and 13, respectively.

Aquifer Parameters. The primary aquifer parameters necessary to characterize the hydraulics of groundwater movement and calculate basin storage include transmissivity, hydraulic conductivity, and storativity. Transmissivity and hydraulic conductivity are related (transmissivity is the product of hydraulic conductivity and aquifer thickness) and characterize the permeability of aquifer materials. Storativity is measure of the aquifer’s ability to store and release water. These aquifer parameters are used in the construction of the numerical groundwater flow model. Estimates of these parameters are ideally obtained from analysis of pumping test data; however, the number of controlled pumping tests conducted in the basin is relatively limited. Transmissivity can also be roughly estimated from specific capacity data (ratio of well yield to drawdown), which are a commonly measured parameter at pumping wells and are, therefore, more plentiful than pumping test data.

Data available to previous investigations was generally limited to specific capacity data. The District has since installed four high-capacity municipal production wells (Lyons, High School, El Carro, and Headquarters). Formal post-construction pumping tests conducted at the High School, El Carro, and Headquarters Wells were analyzed to determine aquifer parameters at those locations. In addition to pumping tests, transmissivities have also been estimated from specific capacity data for this project. For wells where only specific capacity data are available, the methods presented in Driscoll (1995, pg. 1021) to estimate transmissivity were utilized. Hydraulic conductivities were calculated by dividing transmissivity by total screen length of each well.

Detailed discussion of the aquifer parameters derived from available controlled pumping test and specific capacity data in the basin is presented in the Task 1 Technical Memorandum (Appendix A). Summaries of the aquifer parameters derived for the Confined and Recharge Areas are presented below:

Confined Area. Transmissivities derived from pumping test and specific capacity data in the Confined Area range between approximately 5,500 and 21,600 gallons per day per foot (gpd/ft) and average approximately 12,100 gpd/ft. Storage coefficients average approximately 6.5×10^{-4} (dimensionless), indicative of confined conditions. Estimated hydraulic conductivities for the primary aquifers in the Confined Area range between approximately 9 and 18 feet per day (ft/d), averaging approximately 14, 13 and 12 ft/d for Aquifers A, B and C, respectively.

Recharge Area. Transmissivities derived from pumping test and specific capacity data in the unconfined Recharge Area range between approximately 400 and 18,000 gpd/ft, averaging approximately 3,200 gpd/ft. Hydraulic conductivities range between 0.2 and 7 ft/d, averaging approximately 1.4 ft/d. Storage coefficients could not be calculated from the available pumping test data in the Recharge Area (calculation of storage coefficients requires a nearby monitoring well).

Water-Levels and Groundwater Movement. Hydrographs for water-level monitoring wells in the District database have been updated for this project. The hydrographs are essential elements of the hydrogeologic update and model. They are used to identify water-level trends, assess aquifer response to various hydrogeologic conditions, and assess changes in groundwater storage between various periods in time. They are also used as groundwater model calibration targets.

Water-level data in the basin have historically been collected and maintained by the USGS and the District. The USGS database contains water-level records for 75 wells in the CGB, dating back to as early as 1919 (State Well No. 4N/25W-28J1); however, most records begin in either the 1940s or 1970s. The USGS database does not extend beyond 2001. The District has historically made monthly measurements at over 40 wells in the basin, and until 2001, the District provided the USGS with these data to supplement the USGS database. After 2001 the District continued measuring water levels at these wells as part of their Groundwater Management Program and assumed the responsibility for maintaining the water-level records. Currently, there are records for 43 wells in the District database.

Hydrographs for 22 wells that have relatively complete records either dating back to the early 1940's or dating back significantly before the start of the model base period are presented in Appendix A as Plates C-1 through C-22. Hydrographs for 23 wells with relatively complete records through the project base period of 1985 - 2008 are presented as Plates C-23 through C-56 in Appendix A.

In general, the long-term hydrographs for SU-1 display seasonal and small amplitude annual fluctuations superimposed upon some larger, more prominent trends. Prior to the current base-period, the most notable trends occurred during the early 1940's through the mid-1950's when water levels in the basin declined substantially, and between approximately the early 1960's and about 1975 when water levels in the basin increased significantly.

There are notable trends within the 1985 – 2008 base-period as well. Water levels declined relatively sharply starting at the beginning of the base period through the fall of 1991, corresponding to the extended 6-yr drought of 1987 – 1992. This was followed by a relatively steep upward trend in water levels peaking in the spring of 1998, which was the wettest year on record (approximately 55.5 inches of rainfall). Since 1998, water levels throughout the basin have displayed a gradual declining trend. The *overall* trend for the 1985 – 2008 base period at most wells is also gradually declining. To illustrate these overall trends, best-fit linear trendlines were plotted for several key representative wells distributed at different locations throughout the basin (Figures 14 through 18). As shown, the overall declining trends range between approximately 5 to 10 feet for the 1985 – 2008 period. It is noted that during this period, annual pumping in the basin has averaged approximately 3,700 afy. The implications of the observed water-level trends with this level of pumping in the basin are discussed in a later section of the report regarding the basin perennial yield.

Analysis of the hydrographs led to the identification the basin high and the basin low periods within the 1985 - 2008 base period. Water-level contours were then prepared for the basin high and low periods, as well as for the periods coincident with the base period beginning and end. The four periods for which water-level contours were prepared include: Fall 1984 – beginning of base period; Fall 1991 – base period basin low; Spring 1998 – base period basin high; and Spring 2008 – end of base period. The purpose of the water-level contours was to help to identify general patterns in the flow regime within the basin, including those attributable to recharge sources and associated with discharge areas. The water-level contours are presented on Figure 19 – Water-Level Contours Storage Unit 1.

The water-level contours show that in SU-1, groundwater generally flows in a northeast to southwesterly direction in the eastern half of the basin, and north to south in the western half of the basin. The directions of groundwater flow generally reflect the movement of groundwater from the primary sources of recharge in the Recharge Area to the primary sources of extraction (groundwater pumping) in the Confined Area.

The water-level contours for the base-period historical low (Fall 1991) show the development of a water-level depression centered in the central portion of SU-1. In the center of the depression, water levels during this period declined to an elevation of more than 40 feet below mean sea level (msl). The water-level contours for Spring 2008 also show a limited depression in the same area, with water levels up to approximately 10 feet below msl. These water-level conditions result in a reversal of the natural seaward groundwater gradient, creating the potential for seawater intrusion in the northwestern portion of the basin (i.e., in the general area from Sand Point to Serena). It is noted that although seawater intrusion has not historically been detected in existing wells in the basin, there are no existing monitoring wells along the coast that penetrate into the deep Aquifers A – C that can serve as reliable seawater intrusion "sentinel" wells.

Changes in Storage. The water-level contours were also used to derive rough estimates of the changes the volume of groundwater storage between the contoured periods. The total difference in volume between the contoured surfaces for two periods was determined for both the Confined and Recharge Areas. The changes in groundwater storage for the two areas were then calculated by multiplying the total volume change by a specific yield or storage value; 0.08 (dimensionless) for the Recharge Area and 0.00065 (dimensionless) for the Confined Area. The results of the change in groundwater storage calculations are summarized below:

• Fall 1984 through fall 1991:	15,988 acre-feet of storage depletion.
• Fall 1991 through spring 1998:	17,661 acre-feet storage accretion.
• Spring 1998 through fall 2008:	5,879 acre-feet of storage depletion.
• Cumulative over base period:	4,206 acre-feet of storage depletion.

Hydrologic Budget

An updated hydrologic budget for the CGB was developed in order to quantify the primary sources of recharge to and discharges from the basin for the base period 1985 - 2008. A hydrologic budget for a groundwater basin can be expressed by the following equation:

Inflow = Outflow (+/-) Change in Storage

where Inflow equals:

- Subsurface Inflow
- Streambed Percolation
- Percolation of Precipitation, and
- Percolation of Irrigation Return Water (pumped and imported);

and Outflow equals:

- Subsurface Outflow
- Gross Groundwater Pumpage, and
- Extraction by Phreatophytes.

This accounting is generally conducted for as long a period as practicable, in order to evaluate variations in the budget and identify those components to which the basin is most sensitive. GTC performed an inventory of the various components of inflow and outflow to the CGB in its 1976 study for Water Years 1935 to 1973 (39-year base period). GTC subsequently updated the inventory in 1986 for Water Years 1974 to 1984 (11-year base period).

For this project, the inventory was updated for Water Years 1985 to 2008 (24-year base period). Some data are available via direct measurement (e.g., District metered pumpage), whereas others are more difficult to quantify and require estimation based on commonly used techniques. Detailed discussion of the various methods and calculations associated with each of the components of the updated hydrologic budget is presented in the Task 1 Technical Memorandum (Appendix A). In general, the methods used for the current update were similar to those used by GTC in their 1976 and 1986 inventories, but were modified/improved for this investigation where possible given the availability of new data and/or analytic tools. Utilizing similar methods for this updated base-period also allows for reasonable comparison and correlation with the previous estimates for the various base-periods.

A summary of the updated hydrologic budget for the 1985 – 2008 base-period is presented in Table 1 below. Summaries of each component of the hydrologic budget are presented below. For additional details on the calculations, the reader is referred to the Task 1 Technical Memorandum (Appendix A).

Rainfall. Rainfall is the primary source of inflow/recharge to the basin, whether it falls directly on the basin and percolates vertically downward through basin sediments or falls on adjacent watershed areas and flows into the basin via the surface or subsurface. The Santa Barbara County Flood Control District maintains precipitation data from the Carpinteria Fire Station with a period of record from 1949 to the present. Annual rainfall during the period of record is presented on Figure 21. As shown, the mean annual rainfall for this long-term period is 19.8 inches.

The cumulative departure of annual rainfall from the long-term mean is also plotted on Figure 21. The cumulative departure from mean graph is used to identify climatic trends over the period of record. As shown, the cumulative departure curve exhibits a series of cyclic dry and wet periods in the basin over the period of record.

It is noted that the base-period for the current update coincides with the beginning of a cumulatively dry period that occurred from about 1984 through 1992, followed by a wet period from 1993 through 1998, and ending with a dry period from 1999 through 2008. The mean annual rainfall for this period is 20.2 inches, which is within 2 percent of the long-term mean for the period of record (19.8 inches). These characteristics of the rainfall during the base-period for this update are important for the updated water balance, perennial yield estimates, and calibration of the groundwater model, as will be discussed later in the report.

Subsurface Inflow. Subsurface inflow is flow from consolidated rocks in the hill and mountain areas adjacent to the CGB. As discussed by Upson (1951) and Evenson (1962), underflow from the consolidated rocks must be considered as a source of recharge to the CGB. A direct relationship between subsurface inflow and precipitation was developed by GTC (1976), and seasonal subsurface inflow for the 1985 – 2008 base period was estimated using this same relationship. As shown in Table 1, for the 1985 - 2008 base period, a low of 405 afy and a high of 1,100 afy with an average of 896 afy were estimated. This compares favorably to averages of 890 and 939 afy estimated by GTC for the 1939 - 1973 and 1974 - 1984 base periods, respectively.

Table 1. Estimated Seasonal Deep Percolation, Extractions, and Change in Storage

Water Year	Rainfall (in)	INFLOW (acre-feet per year)							OUTFLOW (acre-feet per year)						Change in Storage	
		Subsurface Inflow	Streambed Percolation	Percolation of Precipitation	Percolation of Irrigation Water			Total Inflow	Subsurface Outflow	Groundwater Pumpage			Extraction by Phreatophytes	Total Outflow		
					Delivered	Pumped	Total			CVWD	Private	Total			Year	Cummulative
1985	15.26	869	57	391	58	190	248	**1,566**	16	1,836	949	2,785	100	**2,901**	-1,335	-1,335
1986	25.78	1,100	866	4,198	80	208	288	**6,451**	0	2,032	1,041	3,073	100	**3,173**	3,279	1,943
1987	11.99	683	91	30	90	186	276	**1,080**	0	2,363	932	3,295	100	**3,395**	-2,315	-372
1988	17.34	988	112	731	103	213	316	**2,147**	0	2,342	1,065	3,407	100	**3,507**	-1,359	-1,731
1989	10.27	585	26	0	116	304	420	**1,031**	0	2,984	1,520	4,504	100	**4,604**	-3,573	-5,304
1990	8.93	509	4	0	246	398	644	**1,157**	0	3,413	1,990	5,403	100	**5,503**	-4,346	-9,650
1991	20.11	1,100	758	1,634	166	452	618	**4,110**	0	3,014	2,261	5,275	100	**5,375**	-1,265	-10,915
1992	25.39	1,100	1,026	4,174	140	433	573	**6,873**	0	1,560	2,165	3,725	100	**3,825**	3,048	-7,867
1993	37.45	1,100	1,434	5,499	177	484	662	**8,695**	0	1,261	2,422	3,683	100	**3,783**	4,912	-2,954
1994	14.43	822	352	278	184	564	748	**2,200**	0	1,307	2,818	4,125	100	**4,225**	-2,025	-4,980
1995	41.59	1,100	1,746	5,487	162	478	640	**8,973**	231	1,291	2,389	3,680	100	**4,011**	4,961	-18
1996	19.55	1,100	894	1,401	162	502	664	**4,059**	239	1,557	2,510	4,067	100	**4,406**	-347	-365
1997	18.07	1,030	958	862	192	487	679	**3,529**	58	1,317	2,437	3,754	100	**3,912**	-383	-748
1998	51.48	1,100	1,744	5,467	149	486	634	**8,945**	418	575	2,428	3,003	100	**3,521**	5,424	4,675
1999	9.99	569	434	0	292	598	890	**1,893**	376	340	2,990	3,330	100	**3,806**	-1,913	2,763
2000	17.47	995	789	740	256	621	877	**3,401**	86	1,410	3,105	4,515	100	**4,702**	-1,301	1,462
2001	20.43	1,100	1,096	1,692	205	652	857	**4,745**	202	185	3,259	3,444	100	**3,746**	999	2,461
2002	7.66	436	7	0	257	621	877	**1,320**	196	558	3,103	3,661	100	**3,957**	-2,637	-175
2003	21.97	1,100	521	2,293	245	545	790	**4,704**	62	402	2,723	3,125	100	**3,287**	1,418	1,243
2004	9.57	545	2	0	277	561	838	**1,385**	4	999	2,803	3,801	100	**3,906**	-2,520	-1,278
2005	37.56	1,100	1,657	5,366	289	412	701	**8,825**	0	1,152	2,060	3,212	100	**3,312**	5,513	4,235
2006	18.58	1,059	927	930	316	417	733	**3,647**	0	1,120	2,083	3,202	100	**3,302**	345	4,580
2007	7.11	405	9	0	410	501	911	**1,325**	0	1,418	2,507	3,925	100	**4,025**	-2,700	1,880
2008	17.51	998	1,041	735	317	561	878	**3,652**	0	661	2,806	3,467	100	**3,567**	85	**1,966**
24-Year Avg.	20.23	896	690	1,746	204	453	657	**3,988**	79	1,462	2,265	3,728	100	**3,906**	**82**	
High	51.48	1,100	1,746	5,499	410	652	911	**8,973**	418	3,413	3,259	5,403	100	**5,503**	**5,513**	
Low	7.11	405	2	0	58	186	248	**1,031**	0	185	932	2,785	100	**2,901**	**-4,346**	
% of Total		22	17	44	5	11	16	**100**	2	37	58	95	3	**100**		

Streambed Percolation. There are five principal streams in the CGB; Carpinteria, Gobernador, Santa Monica, Arroyo Parida, and Rincon Creeks. Additional drainages include Toro and Franklin Creeks. Only two of these creeks have runoff records – Carpinteria Creek and Franklin Creek. Stream gages have historically been maintained and monitored by the USGS. The Carpinteria Creek gage is the only currently active gage, and has essentially continuous data since 1941 (there is a brief hiatus in the record for Water Year 1978). Records for Franklin Creek are limited to Water Years 1971 through 1978. Available data for the other drainages in the CGB are limited to miscellaneous measurements made by the USGS from 1941 to 1945.

Streambed percolation is assumed to occur only where the stream reaches cross the Recharge Area. Once streamflow reaches the Confined Area, the amount of deep percolation to the main groundwater system is assumed to be insignificant. The 1976 GTC study included an analysis of annual runoff and seepage losses for streams in the basin, and developed runoff vs. streambed percolation relationships for each individual stream. These same relationships were utilized for this update (refer to Appendix A for supporting data and calculations).

As shown in Table 1 above, the amount of estimated streambed percolation varies from less than approximately 5 afy during dry years (e.g., 1990, 2004) to as much as approximately 1,750 afy in wet years (e.g., 1995, 1998). It is also noted that Carpinteria and Gobernador Creeks combined contribute over 60 percent of the total streamed percolation, with Rincon Creek contributing approximately 20 percent. The average streambed percolation for the 1985 - 2008 base period was estimated at 690 afy, which is somewhat less than the 940 and 1,232 afy estimated by GTC for the 1935 - 1973 and 1974 - 1984 base periods, respectively.

It is noted that the reaches of both Santa Monica and Franklin Creek that cross the Recharge Area were channelized into concrete-lined box channels as part of the Carpinteria Valley Watershed Project in 1974; therefore, these two streams are considered to no longer recharge the CGB in a significant way. These two streams are estimated to have potentially contributed approximately 160 afy on average during the 1985 - 2008 base period, equivalent to approximately 20 percent of the total streambed percolation.

Percolation of Precipitation. Infiltration of precipitation is the most important source of recharge to the basin. Precipitation recharges the basin principally through deep percolation to the zone of saturation in the Recharge Area (see Figure 3). The amount of precipitation that percolates downward to a groundwater basin can vary considerably, depending mostly upon the type of soil, overlying land uses, density of vegetation, quantity, intensity and duration of rainfall, temporal distribution of rainfall, vertical permeability of the soil, and topography. Much of the infiltrating rainfall is held within the root zone because at the beginning of each rainy season there is an initial deficiency of soil moisture. During the summer months the capillary soil moisture is more or less completely depleted from the soil within the root zone by the processes of evaporation and transpiration. No deep percolation of rainfall can occur until the initial fall soil moisture deficiency is exceeded. As a result, many years may pass before any rainfall penetrates beyond the root zone of native vegetation. In irrigated soils, because of the artificial application of water, the initial fall moisture content is greater and less annual rainfall is required to meet the soil moisture deficiency. Once the soil moisture deficiency within the root zone has been satisfied, the excess precipitation will percolate downward until it eventually reaches the water table.

There are two primary considerations in calculating the volume of precipitation that percolates beyond the root zone and contributes to the CGB groundwater body: 1) the determination of the total area of the various land uses and vegetative covers in the Recharge Area for each year of the base period, and 2) the calculation of deep percolation of rainfall in inches for each of the various land uses / vegetative covers for each year of the base period. The total volume of percolation in acre-feet is then calculated (i.e., inches of percolation x acreage) for each year of the base period.

Land Use Acreage. Prior to 2002, District relied primarily on periodic aerial photography of the basin to update land use records in the basin. In 2002, the District undertook a comprehensive land use study utilizing a combination of digital imagery, GIS layers of land use and parcel boundaries, and statistical analysis to evaluate land use activities and estimate private well extractions. Since 2002, the land use studies have been GIS-based.

For this project, GIS was utilized to identify land use acreages for each year of the base period within the Recharge Area. For the period prior to 2002, annual changes in the acreages of each land use category within the Recharge Area were proportioned according to annual changes in the percentage of each land use category within the basin as whole. Estimated land use acreages in the Recharge Area for each year of the 1985 – 2008 base period are shown in Table E2 in Appendix A.

Deep Percolation. For this investigation, estimates of deep percolation were made using relationships developed by Blaney (1933). Blaney empirically tabulated the amounts of rain that percolated beyond the root zone, depending upon the land use, type of vegetation and amount of annual precipitation. Blaney's values of deep percolation versus annual rainfall were plotted for land covers similar to those in the CGB, and best-fit curves drawn trough these points. Values of percolation of rainfall corresponding to seasonal rainfall and vegetative cover types in the CGB were then calculated from these curves.

The total volume of deep percolation for each year of the base period is shown in Table 1. As shown, significant deep percolation only occurs in the wettest years (particularly on non-irrigated native lands), which is to be expected given the soil moisture discussion presented above. On irrigated lands, some additional deep percolation occurred in years when the average annual precipitation exceeded approximately 12 inches. In years when the average annual rainfall is less than approximately 12 inches, no deep percolation is estimated to occur. During wet years (e.g., 1993, 1995, 1998, and 2005) when average annual rainfall exceeds approximately 30 inches, over 5,000 af of deep percolation is estimated to occur.

The average annual recharge to the basin during the base period from deep percolation of rainfall is estimated to be approximately 1,750 afy. This represents a significant percentage (approximately 44 percent) of the overall water budget. These results are consistent with GTC's estimates of average annual deep percolation of rainfall of 1,560 and 1,960 afy for the 1935 - 1973 and 1974 - 1984 base periods, respectively.

Percolation of Irrigation Water. Percolation of irrigation return water in the CGB is dependent on a variety of factors, including climatic conditions, crop type, and irrigation practices. Studies by the U.S. Soil Conversation Service for Santa Barbara County indicate irrigation efficiencies range from 65 to 70 percent. For purposes of estimating deep percolation of irrigation return water in the CGB, a conservative estimate that 20 percent of applied water (both pumped and delivered) percolates into the basin is used. This conservative factor takes into account the relatively steeper slopes found in many portions of the Recharge Area, and hence greater amounts of runoff, as well as the relatively more efficient sprinkler-type irrigation commonly used in the basin.

The irrigation totals include both pumped and delivered water. In this context, pumped water is the District estimated private pumping (discussed later). Delivered water is metered water that District delivers to irrigators in the basin, and is a combination of both imported water and groundwater pumped by District wells. From a mass-balance standpoint, the volumes of delivered water to parcels in the Recharge Area accounts for water that is imported into the basin and contributes to basin recharge.

The estimated amount of water seasonally percolating into the basin from irrigation return water is shown in Table 1. The total amount of irrigation return water percolation was estimated to range annually between approximately 250 and 910 afy, averaging approximately 660 afy. For comparison, GTC estimated averages of approximately 830 and 740 afy of irrigation return flows for the 1935 - 1973 and 1974 - 1984 based periods, respectively.

Subsurface Outflow. Subsurface groundwater outflow from the CGB is difficult to estimate. Groundwater within the principal aquifers of SU-1 does not discharge directly to the ocean in the southeastern portion of the basin due to the presence of overlying confining layers and the barrier created by the Rincon Creek Thrust Fault. Groundwater is believed to be rising (surfacing) in and around El Estero along the fault boundary, and that subsurface water enters the alluvium through notches eroded in the fault by streams in the area. Subsurface outflow from SU-1 could occur, however, in the general area from Serene Park to Sand Point (a distance of approximately 9,000 ft.) where there is no fault barrier between basin sediments and the ocean. In SU-2, significant subsurface outflow is not believed to occur due to the onshore contact of unconsolidated water-bearing materials with consolidated bedrock, which effectively isolates SU-2 from the ocean.

The quantity of subsurface outflow from SU-1 was estimated using Darcy's Law, in which the rate of discharge through a given cross section of saturated material is proportional to the hydraulic gradient. The hydraulic gradient is driven by water-levels in the basin, and outflow occurs only when there is a seaward gradient (i.e., when water levels are generally above sea level). The results of the subsurface outflow calculations are shown in Table 1. Estimates of subsurface outflow varied from a maximum of approximately 420 af in 1998 (base-period historical high water levels in the basin) to zero outflow during periods of deficient recharge (e.g., the 1987 to 1991 drought period). The 24-year average subsurface outflow was estimated to be approximately 80 afy.

This outflow estimate is considerably less than GTC's estimates of 340 and 980 afy on average for the 1935 - 1973 and 1974 – 1984 base periods, respectively. As discussed above, groundwater outflow from the basin generally only occurs when water levels in the basin are above sea-level and there is a seaward groundwater gradient. The 1974 – 1984 base-period was a cumulatively wet period (refer to Figure 21) and water levels in the basin were relatively high throughout this period. The 1935 – 1973 based period is similarly skewed by high water-level conditions that occurred in the basin during the 1934 – 1941 period (i.e., prior to the period of extensive groundwater pumping in the basin) when subsurface outflow averaged approximately 1,000 afy. During the remaining portion of that base-period (i.e., 1942 – 1973) outflow averaged only 180 afy, which is more comparable to the average 80 afy estimated for the current base period.

Groundwater Pumpage. Groundwater extractions from the CGB occur from both District production wells and from approximately 50 to 170 private wells in any given year. District well production is metered, and monthly totals of production from each of the five District wells were compiled for the period of 1985 - 2008. Monthly totals were summarized by Water Year, and are shown in Table 1. As shown, District municipal pumping ranged between approximately 340 to 3,400 afy, averaging approximately 1,460 afy during the base period.

Private pumping in the basin is not metered and has been estimated on an annual basis by the District since 1984 utilizing land use survey and imported water delivery information. District supplies imported water and/or local groundwater to numerous agricultural parcels of known acreage and crop type (e.g., avocados, cherimoyas, open and covered nurseries, etc.). From these metered deliveries, unit use values (or water-duty factors, known by the District as “determining factors”) for various crop types have been estimated each year since 1984. These unit use values have been combined with land use acreage data to estimate aggregate annual private well production in the basin.

As shown in Table 1, aggregate private pumpage is estimated to have ranged between approximately 930 to 3,260 afy, averaging approximately 2,270 afy during the base period. Total combined municipal and private pumpage was estimated to average approximately 3,730 afy during the 1985 - 2008 base period. This compares to approximately 3,330 and 1,830 afy estimated by GTC for the 1935 - 1973 and 1974 - 1984 base periods, respectively.

Extraction by Phreatophytes. Phreatophytes are water loving plants (roots extend into the water table) that live in the vicinity of stream channels and in areas of high groundwater. Groundwater consumed by phreatophytes is dependent on many factors, including plant species, vegetative density, climate, soil types and conditions, and depth to groundwater. Direct measurements of consumptive use by phreatophytes in the CGB do not exist. GTC (1976) roughly estimated phreatophyte extractions for the CGB by applying results of a 5-year study in San Diego County utilizing the Blaney-Criddle formula (Blaney and Criddle, 1963). Extractions by phreatophytes were estimated to be approximately 120 to 130 afy from the 1930s through 1970, then reduced to approximately 100 afy as a result of removal of phreatophytes from the Santa Monica and Franklin Creek channels as part of the flood control channelization projects. It has been similarly assumed that extraction by phreatophytes is about 100 afy for this update. As shown in Table 1, phreatophytes consumption is a relatively insignificant (3 percent) portion of the outflow from the basin.

Changes in Storage. The difference between the groundwater volume from one year to the next is the annual change in groundwater storage. The change in the amount of groundwater in storage depends on the annual water supply surplus or deficiency, as expressed in the water balance equation. As shown in Table 1, using the water balance inventory method the total annual water demand (outflows) was slightly less than the total recharge (inflows) by approximately 82 afy on average during the 24-year base period. This resulted in a slight net accumulation of groundwater in storage of approximately 1,965 af for the 24-year period from 1985 to 2008.

As discussed previously, changes in the amount of groundwater in storage were also calculated by the water-level contour specific yield method. By this method, there was a net decrease in storage of approximately 4,200 af during the 24-year base period. A comparison of the net changes in groundwater storage for select periods during the 1985 – 2008 base period is presented in Table 2 below.

Table 2. Changes in Storage Calculation Comparison

Period	Description	Estimated Change in Storage (af)	
		Inventory Method	Specific Yield Method
1985 – 1991	Beginning of base period to basin low.	-10,915	-15,988
1991 – 1998	Basin low to basin high.	+15,590	+17,661
1998 – 2008	Basin high to end of base period.	-2,710	-5,879
1985 - 2008	Cumulative over 24-year base period.	+1,965	-4,206

As shown, there is general agreement between the two methods for the various periods, e.g., from the beginning of the base period (1985) to the basin low (1991) both methods result in significant storage depletion, and the period from the basin low (1991) to the basin high (1998) both methods result in significant storage accretion. The discrepancies between the absolute values of the two methods are a result of the inherent uncertainties associated with each method.

Hydrologic Budget Summary. Table 1 presents the annual amounts of each component of the water balance equation for the CGB as computed by the inventory method for the 1985 – 2008 base period. As shown, average annual inflow during the 24-year base period was estimated at approximately 3,990 afy and average annual outflow estimated at 3,910 afy, with a slight average annual net increase of groundwater in storage of approximately 80 afy.

GTC performed an inventory of the various components of inflow and outflow to the CGB in its 1976 study for Water Years 1935 to 1973. Total inflow to the basin was estimated to range from 1,450 to 9,940 acre feet per year (afy), and averaged 4,220 afy over that 39-year base period. Total outflows were estimated to range between 2,420 and 5,880 afy, and averaged 3,790 afy. GTC subsequently updated the inventory in 1986 for Water Years 1974 to 1984, and estimated total inflows and outflows to average 4,870 and 3,730 afy, respectively, over that 11-year base period. A comparison of the estimated amounts of average annual total inflow, outflow, and changes in storage for the three base periods is presented in Table 3 below.

Table 3. Hydrologic Budget Comparison

Base Period	Investigator	Total Inflow (afy)	Total Outflow (afy)	Change in Storage (afy)
1935 – 1973	GTC	4,194	3,777	+416
1974 – 1984	GTC	4,858	3,430	+1,428
1985 – 2008	PWR	3,988	3,906	+82

As shown in Table 3 above, there is general agreement between the inventories for the three base periods, with the average annual inflow to the basin ranging between approximately 4,000 to 4,900 afy, averaging approximately 4,350 afy, and annual outflow from the basin averaging approximately 3,700 afy. As noted previously, the methodologies utilized for the inventories of each base period were similar (but not identical). As such, the general agreement is not unexpected, and the differences in the total inflow and outflow values largely reflect differences in precipitation (and recharge) and land uses during each respective base period. These differences are important in determining estimates of the perennial yield of the basin, as discussed in the following section.

Since the methodologies utilized for each of the hydrologic budget inventories were similar, they can be reasonably compiled to yield a 74-yr inventory for the base period of 1935 – 2008. The combined hydrologic budget inventory for the 1935 – 2008 base period is shown on Table 4. As shown, the 74-yr average annual inflow is approximately 4,200 afy and the average annual outflow is approximately 3,800 afy, yielding an average annual net increase in storage of approximately 400 afy.

Table 4. Compiled 74-year Hydrologic Budget

			INFLOW (acre-feet per year)							OUTFLOW (acre-feet per year)							
						Percolation of Irrigation Water					Groundwater Pumpage					Change in Storage	
Water Year	**Investigator**	**Rainfall (in)**	**Subsurface Inflow**	**Streambed Percolation**	**Percolation of Precipitation**	**Delivered**	**Pumped**	**Total**	**Total Inflow**	**Subsurface Outflow**	**CVWD**	**Private**	**Total**	**Extraction by Phreatophytes**	**Total Outflow**	**Year**	**Cummulative**
1935	**GTC (1976)**	21.90	1,100	2,210	2,430		370	370	**6,110**	920			1,830	130	**2,880**	3,230	3,230
1936		19.30	1,100	1,420	1,500		570	570	**4,590**	770			2,860	130	**3,760**	830	4,060
1937		25.30	1,100	2,180	3,970		510	510	**7,760**	1,290			2,540	130	**3,960**	3,800	7,860
1938		26.70	1,100	2,180	4,870		520	520	**8,670**	1,370			2,590	130	**4,090**	4,580	12,440
1939		13.60	780	500	300		750	750	**2,330**	600			3,720	130	**4,450**	-2,120	10,320
1940		13.00	750	210	240		670	670	**1,870**	130			3,340	130	**3,600**	-1,730	8,590
1941		42.70	1,100	2,370	4,960		500	500	**8,930**	1,940			2,480	130	**4,550**	4,380	12,970
1942		15.40	880	380	550		640	640	**2,450**	480			3,170	130	**3,780**	-1,330	11,640
1943		20.40	1,100	2,150	1,890		740	740	**5,880**	890			3,690	130	**4,710**	1,170	12,810
1944		19.30	1,100	1,410	1,560		670	670	**4,740**	890			3,340	130	**4,360**	380	13,190
1945		17.40	1,000	910	920		770	770	**3,600**	640			3,820	120	**4,580**	-980	12,210
1946		13.20	760	490	270		790	790	**2,310**	370			3,920	120	**4,410**	-2,100	10,110
1947		13.90	810	640	340		1,150	1,150	**2,940**	0			5,760	120	**5,880**	-2,940	7,170
1948		7.80	450	20	0		980	980	**1,450**	0			4,900	120	**5,020**	-3,570	3,600
1949		9.19	510	60	0		970	970	**1,540**	0			4,830	120	**4,950**	-3,410	190
1950		13.80	770	230	290		900	900	**2,190**	0			4,470	120	**4,590**	-2,400	-2,210
1951		9.09	650	0	0		920	920	**1,570**	0			4,610	120	**4,730**	-3,160	-5,370
1952		30.01	1,100	2,110	4,970		830	830	**9,010**	0			4,150	120	**4,270**	4,740	-630
1953		13.89	830	150	430		900	900	**2,310**	0			4,520	120	**4,640**	-2,330	-2,960
1954		16.43	1,080	320	1,370	100	720	820	**3,590**	0			3,620	120	**3,740**	-150	-3,110
1955		14.70	820	70	420	140	650	790	**2,100**	0			3,240	120	**3,360**	-1,260	-4,370
1956		20.15	1,000	480	1,560	250	690	940	**3,980**	0			3,460	120	**3,580**	400	-3,970
1957		11.72	720	140	530	220	600	820	**2,210**	0			3,010	120	**3,130**	-920	-4,890
1958		31.86	1,100	2,210	4,930	230	560	790	**9,030**	0			2,800	120	**2,920**	6,110	1,220
1959		9.47	580	210	0	340	730	1,070	**1,860**	0			3,640	120	**3,760**	-1,900	-680
1960		11.67	680	90	120	240	710	950	**1,840**	0			3,530	120	**3,650**	-1,810	-2,490
1961		9.22	510	90	0	390	680	1,070	**1,670**	0			3,380	120	**3,500**	-1,830	-4,320
1962		27.39	1,100	2,100	4,950	310	650	960	**9,110**	0			3,250	120	**3,370**	5,740	1,420
1963		16.67	940	260	730	250	570	820	**2,750**	0			2,840	120	**2,960**	-210	1,210
1964		13.31	710	80	600	400	450	850	**2,240**	150			2,260	120	**2,530**	-290	920
1965		21.28	930	510	730	330	410	740	**2,910**	250			2,060	120	**2,430**	480	1,400
1966		18.86	990	1,240	1,020	330	470	800	**4,050**	390			2,360	120	**2,870**	1,180	2,580
1967		26.32	1,100	1,650	1,850	310	530	840	**5,440**	380			2,630	120	**3,130**	2,310	4,890
1968		16.27	720	240	720	410	510	920	**2,600**	120			2,530	120	**2,770**	-170	4,720
1969		36.15	1,100	2,470	5,370	360	640	1,000	**9,940**	680			3,200	120	**4,000**	5,940	10,660
1970		15.27	790	810	430	490	510	1,000	**3,030**	110			2,540	120	**2,770**	260	10,920
1971		18.69	940	60	940	500	570	1,070	**3,010**	130			2,820	100	**3,050**	-40	10,880
1972		9.59	470	1,770	0	400	430	830	**3,070**	80			3,980	100	**4,160**	-1,090	9,790
1973		29.07	1,100	1,830	5,210	330	400	730	**8,870**	310			2,010	100	**2,420**	6,450	16,240
39-Year Avg.		**18.46**	**881**	**929**	**1,563**	**317**	**657**	**819**	**4,194**	**331**			**3,326**	**121**	**3,777**	**416**	
1974	**GTC (1976)**	20.09	1,000	1,270	1,140	510	150	660	**4,070**	1,190	711	739	1,450	100	**2,740**	1,330	17,570
1975		20.43	1,000	1,290	1,580	500	220	720	**4,590**	1,190	465	1,104	1,569	100	**2,859**	1,731	19,301
1976		12.07	700	560	0	670	260	930	**2,190**	1,080	1,119	1,312	2,431	100	**3,611**	-1,421	17,880
1977		19.36	680	120	0	640	300	940	**1,740**	540	2,084	1,492	3,576	100	**4,216**	-2,476	15,404
1978		44.14	1,100	2,610	5,420	550	10	560	**9,690**	1,340	1,906	45	1,951	100	**3,391**	6,299	21,703
1979		24.23	1,100	1,290	2,860	550	200	750	**6,000**	1,210	0	998	998	100	**2,308**	3,692	25,395
1980		29.64	1,100	2,120	3,910	590	150	740	**7,870**	2,910	6	740	746	100	**3,756**	4,114	29,509
1981		13.96	850	450	0	680	80	760	**2,060**	1,210	1,360	389	1,749	100	**3,059**	-999	28,510
1982		17.26	1,100	490	1,180	510	120	630	**3,400**	1,210	641	585	1,226	100	**2,536**	864	29,374
1983		43.88	1,100	2,520	5,240	430	100	530	**9,390**	3,140	644	520	1,164	100	**4,404**	4,986	34,360
1984		14.79	700	840	0	660	240	900	**2,440**	1,430	2,096	1,222	3,318	100	**4,848**	-2,408	31,952
11-Year Avg.		**23.62**	**948**	**1,233**	**1,939**	**572**	**166**	**738**	**4,858**	**1,495**	**1,003**	**831**	**1,834**	**100**	**3,430**	**1,428**	
1985	**PWR (2012)**	15.26	869	57	391	58	190	248	**1,566**	16	1,836	949	2,785	100	**2,901**	-1,335	30,617
1986		25.78	1,100	866	4,198	80	208	288	**6,451**	0	2,032	1,041	3,073	100	**3,173**	3,279	33,895
1987		11.99	683	91	30	90	186	276	**1,080**	0	2,363	932	3,295	100	**3,395**	-2,315	31,580
1988		17.34	988	112	731	103	213	316	**2,147**	0	2,342	1,065	3,407	100	**3,507**	-1,359	30,221
1989		10.27	585	26	0	116	304	420	**1,031**	0	2,984	1,520	4,504	100	**4,604**	-3,573	26,648
1990		8.93	509	4	0	246	398	644	**1,157**	0	3,413	1,990	5,403	100	**5,503**	-4,346	22,302
1991		20.11	1,100	758	1,634	166	452	618	**4,110**	0	3,014	2,261	5,275	100	**5,375**	-1,265	21,037
1992		25.39	1,100	1,026	4,174	140	433	573	**6,873**	0	1,560	2,165	3,725	100	**3,825**	3,048	24,085
1993		37.45	1,100	1,434	5,499	177	484	662	**8,695**	0	1,261	2,422	3,683	100	**3,783**	4,912	28,998
1994		14.43	822	352	278	184	564	748	**2,200**	0	1,307	2,818	4,125	100	**4,225**	-2,025	26,972
1995		41.59	1,100	1,746	5,487	162	478	640	**8,973**	231	1,291	2,389	3,680	100	**4,011**	4,961	31,934
1996		19.55	1,100	894	1,401	162	502	664	**4,059**	239	1,557	2,510	4,067	100	**4,406**	-347	31,587
1997		18.07	1,030	958	862	192	487	679	**3,529**	58	1,317	2,437	3,754	100	**3,912**	-383	31,204
1998		51.48	1,100	1,744	5,467	149	486	634	**8,945**	418	575	2,428	3,003	100	**3,521**	5,424	36,627
1999		9.99	569	434	0	292	598	890	**1,893**	376	340	2,990	3,330	100	**3,806**	-1,913	34,715
2000		17.47	995	789	740	256	621	877	**3,401**	86	1,410	3,105	4,515	100	**4,702**	-1,301	33,414
2001		20.43	1,100	1,096	1,692	205	652	857	**4,745**	202	185	3,259	3,444	100	**3,746**	999	34,413
2002		7.66	436	7	0	257	621	877	**1,320**	196	558	3,103	3,661	100	**3,957**	-2,637	31,777
2003		21.97	1,100	521	2,293	245	545	790	**4,704**	62	402	2,723	3,125	100	**3,287**	1,418	33,195
2004		9.57	545	2	0	277	561	838	**1,385**	4	999	2,803	3,801	100	**3,906**	-2,520	30,674
2005		37.56	1,100	1,657	5,366	289	412	701	**8,825**	0	1,152	2,060	3,212	100	**3,312**	5,513	36,187
2006		18.58	1,059	927	930	316	417	733	**3,647**	0	1,120	2,083	3,202	100	**3,302**	345	36,532
2007		7.11	405	9	0	410	501	911	**1,325**	0	1,418	2,507	3,925	100	**4,025**	-2,700	33,832
2008		17.51	998	1,041	735	317	561	878	**3,652**	0	661	2,806	3,467	100	**3,567**	85	33,918
24-Year Avg.		**20.23**	**896**	**690**	**1,746**	**204**	**453**	**657**	**3,988**	**79**	**1,462**	**2,265**	**3,728**	**100**	**3,906**	**82**	
74-Year Avg.		**19.83**	**896**	**897**	**1,678**	**318**	**518**	**755**	**4,226**	**422**	**1,318**	**1,815**	**3,234**	**111**	**3,767**	**458**	
High		**51.48**	**1,100**	**2,610**	**5,499**	**680**	**1,150**	**1,150**	**9,940**	**3,140**	**3,413**	**3,259**	**5,760**	**130**	**5,880**	**6,450**	
Low		**7.11**	**405**	**0**	**0**	**58**	**10**	**248**	**1,031**	**0**	**0**	**45**	**746**	**100**	**2,308**	**-4,346**	
% of Total			**21**	**21**	**40**	**8**	**12**	**18**	**100**	**11**	**35**	**48**	**86**	**3**	**100**		

Perennial Yield

Perennial yield (or safe yield) is typically defined as the annual quantity of groundwater that on average can be extracted from a groundwater basin without creating adverse impacts, given existing land use conditions and existing wells in the basin. Adverse impacts include long-term declining water levels and depletion of groundwater storage. In a coastal basin such as the CGB, long-term declining water levels are of particular concern due to the potential for seawater intrusion (as discussed previously, the northwestern portion of SU-1 is in contact with the ocean) . The perennial yield estimate for any given basin is not an exact calculation, due to the inherent uncertainties in the estimates of the various components of inflow and outflow. Despite these limitations, there are several methods available to estimate perennial yield. These include preparing a hydrologic water budget for the basin that quantifies the various components of inflows and outflows of water to the groundwater basin (as discussed in the previous section) and variations of the so-called “practical rate of withdrawal” method. Each of these methods has been utilized to estimate the perennial yield of the CGB, as discussed below.

Base Period. The perennial yield calculation is based on a “base period”, which should represent long-term, average hydrologic conditions. Criteria for selection of a base period must include at least one period each of overall wet conditions and overall dry conditions (relative to average annual conditions) and have an average precipitation that is close to the average precipitation for the entire period of record. In addition, the beginning of the base period should be during a period of relatively dry conditions to eliminate the potential for any “in-transit” recharge water that might otherwise not be reflected in storage condition changes. Finally, the base period should begin and end at comparable points on the cumulative departure from the mean annual precipitation in order to represent average precipitation over the base period. The 1985 – 2008 base period for this hydrogeologic update satisfies these criteria reasonably well (refer to Figure 21).

The 1985 – 2008 base period also reasonably represents current cultural conditions in the CGB. In addition, this period benefits from water-level data collection and relatively sophisticated analysis and quantification of private groundwater pumping in the basin conducted by the District during this period pursuant to its Groundwater Management Plan.

Previous Estimates. Estimates of the perennial yield of the CGB have been advanced through previous investigations. The most notable include those advanced by Evenson (1962), GTC (1976 and 1986) and IWR (2003). Evenson utilized the practical rate of withdrawal method for the base period 1941 – 1958 and suggested a perennial yield of 3,400 afy. GTC (1976) utilized the water balance method for the base period 1935 - 1973 to establish an inventory of average seasonal amounts of supply and disposal under 1973 cultural conditions and advanced a yield of approximately 4,500 afy. GTC (1986) subsequently updated their previous estimate by assessing the 1974 – 1984 base period and suggested a yield of approximately 5,000 afy. IWR (2003) did not perform an independent analysis or calculation of basin yield, but rather performed a review of existing perennial yield estimates for the CGB, including a review of the data utilized to develop the estimates. Based on their review of the previous estimates, IWR reasserted that a basin yield value of 4,500 to 5,000 afy was appropriate. A summary of previous estimates of the yield of the CGB is presented in Table 5 below:

Table 5. Summary of Previous CGB Yield Estimates

Investigator	Base Period	Base Period Precipitation: Annual Avg. (in)	Base Period Precipitation: Percent of Long-Term Avg.[1]	Method	Yield Estimate (afy)	Comments
Evenson (1962)	1941-1958	17.8	-10.1	Practical Rate of Withdrawal	3,400	Based on past cultural conditions
GTC (1976)	1935–1973	18.5	-6.6	Hydrologic Budget	4,500	Based on past cultural conditions
GTC (1986)	1974–1984	23.6	+19.2	Hydrologic Budget	5,000	Based on wet hydrologic period
IWR (2003)	NA	NA	NA	Data Review	4,500-5,000	Review based. No actual calculations

Notes:
1 – Long-term average precipitation is 19.8 inches.
NA – Not applicable

As shown, previous estimates of the CGB basin yield have range between 3,400 and 5,000 afy. It is important to note that these previous estimates differ for identifiable reasons that need to be considered when compared to the estimate derived as part of this study (discussed in the following section). For example, the Evenson and 1976 GTC estimates were based on past cultural conditions (i.e., land uses and extraction patterns in the basin have since changed somewhat) and the availability of reliable data for those investigations was significantly less than is currently available (particularly estimates of private groundwater pumping). The 1976 GTC estimate also included recharge to the basin from streambed percolation in the Santa Monica and Franklin Creek channels. These creeks were concrete-lined in the mid-1970's and no longer contribute significant recharge to the basin.

The 1986 GTC estimate of 5,000 afy was based on relatively current cultural conditions and reliable data compared to the previous estimates; however, it was based on a relatively short base period (11 years) during which average precipitation was more than 20 percent greater than the long-term average. As discussed previously, precipitation is the single largest source of recharge to the basin (through both direct deep percolation and streambed seepage). As such, the volume of recharge during this 1974 – 1984 base period can be expected to be commensurately greater than the long-term average.

Current Estimate. The perennial yield of the CGB has been estimated for the 1985 – 2008 base period utilizing both hydrologic budget and practical rate of withdrawal methods.

Hydrologic Budget Approaches. As discussed in the previous section, an updated hydrologic budget for the CGB was prepared as part of this investigation to quantify the primary sources of recharge to and discharges from the basin for the base period 1985 – 2008. A summary of the updated hydrologic budget was presented as Table 1 (each component of the hydrologic budget was discussed in a previous section of this report and further details of the calculations are presented in the Task 1 Technical Memorandum [Appendix A]). Utilizing the results of the hydrologic budget, perennial yield can be estimated in several ways.

The first and most common approach is to assume that the perennial yield of the basin is equal to the rate of average annual recharge. From a mass-balance standpoint, this makes intuitive sense, i.e., pumping must not exceed recharge on a long-term average basis in order to be sustainable. Based on this approach, the perennial yield of the CGB can be estimated to range between approximately 4,000 to 4,200 afy (refer to Tables 1 and 4).

However, as addressed by Theis in 1940 (and reiterated by Bredehoeft in 1982 and again in 2002), the perennial yield of a basin is not necessarily equal to the rate of recharge, but rather is actually dependent on the *ability to capture recharge* without adverse impacts. The ability to capture recharge is based on current pumping patterns in the basin (i.e., existing well locations, capacities, etc.). Based on this concept, perennial yield can be taken to be equal to long-term average annual extractions plus or minus changes in basin storage. For the 1985 – 2008 base period (considered to represent existing land use and wells), the hydrologic budget data suggest a perennial yield for the CGB of approximately 3,800 afy (refer to Table 1).

Practical Rate of Withdrawal Approaches. The “practical rate of withdrawal” method involves statistical analysis to identify a groundwater extraction rate that corresponds to a period of stability in water levels and no changes in groundwater basin storage. The practical rate of withdrawal method was utilized to compare annual extractions with both *calculated* changes in storage and *observed* changes in water levels in the basin during the 1985 – 2008 base period. Annual changes in basin storage were calculated from the hydrologic budget equation (Table 1). Average annual water-level change (fall season to fall season) in the basin was calculated from water-level data for 15 key wells distributed throughout the basin.

As shown on Figure 22, the intercept of zero storage change (water balance inventory method) occurs at an annual pumping value of approximately 3,800 afy. The intercept of zero water-level change (water-level method) occurs at an annual pumping value of approximately 3,600 afy. A summary of the four methods for estimating the perennial of the CGB based on analysis of the 1985 – 2008 based period described above is presented in Table 6 below:

Table 6. Perennial Yield Estimate Summary for 1985 – 2008 Base Period

Method		Yield Estimate
Hydrologic Budget	Average Annual Recharge	4,000 afy
	Average Annual Pumping +/- Change in Storage	3,800 afy
Practical Rate of Withdrawal	Calculated Change in Storage	3,800 afy
	Observed Water-Level Changes	3,600 afy
Average		**3,800 afy**

As shown, the perennial estimates based on the 1985 – 2008 base period range between approximately 3,600 to 4,000 afy, averaging 3,800 afy. It is acknowledged that these perennial yield values are lower than the previous estimates of perennial yield (or safe yield) for the CGB. As discussed previously, however, there are identifiable reasons why the previous estimates differ from the current estimate. In particular, the 1986 GTC estimate (which forwarded an estimate of 5,000 afy) was based on a short 11-year base period that occurred during a cumulatively wet period when average rainfall and recharge was approximately 15 to 20 percent greater than the long-term average.

It is noted that the most conservative estimate of 3,600 afy is based upon statistical analysis of groundwater pumping data (which has relatively high degree of certainty) and observed water levels in the basin. In other words, it is based upon empirical observations for a period when long-term pumping has averaged only 3,700 afy and water-levels in most of the basin have displayed an overall slightly declining trend. The observed decline in water-levels and groundwater storage occurred during a 24-yr base period that included both wet and dry periods and the average annual rainfall was within 2 percent of the long-term average. As discussed previously, based on the water-level contour maps cumulative storage depletion has occurred during the 1985 - 2008 period. These trends have continued. As documented in the recent 2010 annual groundwater report for the basin (Fugro Consultants, Inc.), a water-level depression currently exists in the central portion of the basin with water-levels as much as 15 feet below sea level. If the perennial yield of the basin was greater than 3,700 afy, one would not expect to observe these trends in basin water-levels and storage conditions.

Based on the above, an average annual yield of approximately 3,600 afy should be considered an appropriate and conservative “operational value” for basin management planning purposes, given current basin conditions of land use and groundwater extraction patterns. It is important to understand that this operational yield represents a long-term *average* annual value. The basin can likely be pumped at levels up to approximately 5,000 afy for short-periods (e.g., as occurred in the early 1990’s), provided the basin is allowed to recover and that the long-term average does not exceed 3,600 afy. An upper yield limit of approximately 4,200 afy may be possible through additional capture of basin recharge, for example through optimized redistribution of basin pumping to more effectively capture recharge both spatially and temporally (the groundwater model can be used to evaluate basin optimization strategies).

TASK 2 – GROUNDWATER MODELING

The Task 1 hydrogeologic update formed the basis and conceptual model for the Task 2 development of a calibrated three-dimensional numerical groundwater flow model that simulates the occurrence and movement of groundwater in the CGB. The model is intended to be used as an ongoing basin management tool for the District by providing general guidance on predicted impacts of projected groundwater extractions and various alternative basin management scenarios. The Task 2 Technical Memorandum prepared by HMWRI describes in detail the model construction, calibration, and scenarios, and is presented as Appendix B of this report. A summary of these efforts is presented below.

Available Data

The previously-described Task 1 updated hydrologic budget coupled with the information about the physical characteristics of the basin formed the principal basis for constructing and calibrating the numerical groundwater model of the basin. Data developed from the Task 1 hydrogeologic update that was used to construct and calibrate the numerical model included:

- Outline of the basin boundary;
- Contours for the top and bottom of Aquifers A, B, and C, and top of bedrock;
- Locations of boundary conditions such as the ocean and Rincon Creek Fault;
- Water budget estimates including percolation of precipitation, percolation of irrigation water, streambed percolation, mountain front subsurface inflow, groundwater pumping, and extraction by phreatophytes;
- Watershed contact boundaries for mountain front subsurface inflow;
- Pumping well data for both District municipal and private wells, including annual production and screen intervals;
- Initial estimates for aquifer parameters of hydraulic conductivity and storativity, and;
- Groundwater level data for calibration.

Other data used for the model included the 10 meter digital elevation model (DEM) used to define surface elevations.

Numerical Flow Model Construction

Numerical flow model construction consists of selecting a model code, defining the structure of the model, and incorporating data from the conceptual model. Defining the model structure includes defining the model domain, constructing a model grid, and delineating model layers. Incorporating the conceptual model includes assigning boundary conditions, assigning hydrogeologic parameters, and incorporating components of the water balance. The recharge fluxes and discharge fluxes in the water balance are expressed in the model through areal recharge rates, well pumping rates, and flow rates across model boundaries.

Model Code. The model code MODFLOW-NWT (Niswonger et al., 2011) was selected for the CGB flow model (model). MODFLOW-NWT was developed by the U.S. Geological

Survey as a standalone version of MODFLOW-2005 (Harbaugh, 2005) to better solve nonlinearities of the unconfined groundwater flow equation. The U.S. Geological Survey's (USGS) MODFLOW codes are an industry standard and well documented.

Model Domain. The model domain is based on the CGB basin boundaries delineated in the Task 1 hydrogeologic update and covers approximately 36 square miles. Figure 23 shows the finite difference model grid on which the numerical model is built. The grid comprises 72 rows and 156 columns with a uniform grid spacing of 300 feet.

Model Layers. The model consists of seven layers. All seven layers are active for SU-1 north of the Rincon Creek fault, while only three layers are active for SU-2 south of the Rincon Creek fault. The model layers are based on the structural contours for the top and bottom of Aquifers A, B, and C in SU-1, and the top of bedrock in both SU-1 and SU-2 developed in Task 1 (refer to Figures 9 through 13). As shown, the structural contours for Aquifers A, B and C do not cover the entire active portion of the model; therefore, the contours were extrapolated to create the model layers, ensuring that model layers did not intersect each other.

Cells that were outside of the bedrock boundary were made inactive. Bottom elevations of active cells overlying bedrock were made equivalent to bedrock elevations. All extrapolated geologic surfaces were adjusted so that they did not overlap, the model layer thickness was a minimum of 10 feet, and there was a smooth transition between the adjusted elevations and adjacent cells. The model bottom layer elevations are shown on Figure 24.

A west – east cross-section through the model layers is shown on Figure 25. This section is generally analogous to cross-section A-A' developed in Task 1 (refer to Figures 4, 5, and 22). The Rincon Creek Thrust Fault was simulated as dipping at approximately 50 degrees from horizontal. The dipping fault acts as the separator between SU-1 and SU-2, and allows SU-1 layers to occur at depth below SU-2. A south – north cross-section through the model layers is shown on Figure 26. This section is generally analogous to cross-section D-D' developed in Task 1 (refer to Figures 4, 8 and 22).

SU-2 was modeled with three model layers. The uppermost layer simulates the shallow sediments, most similar to Layer 1 in SU-1. The second layer simulates the Carpinteria Formation, most similar to Layer 2 in SU-1. The lowest model layer simulates the Santa Barbara Formation, and was assumed to be most similar to Layer 7 in SU-1. The lowest layer in SU-2 (Layer 3) was assigned bottom elevations from the top of bedrock contours developed in Task 1. The bottom elevations of Layer 1 and Layer 2 were assigned the bottom elevation of Layer 1 and Layer 2 just north of the Rincon Creek Fault in SU-1 and were maintained horizontally south from the Rincon Creek Fault along model columns. As discussed below, the layers are separated by flow barriers representing the fault.

Boundary Conditions. Model cells are made inactive by designating them as no-flow cells. The extent of no-flow cells in each layer is shown on Figure 27. No-flow cells are designated for one of three reasons:

1. The cell is outside the basin boundary;

2. The cell has an extrapolated top elevation below bedrock, i.e. the model layer is pinched out, and;
3. The cell is adjacent to no-flow cells such that the cell was isolated from the rest of the model so the cell was designated as no-flow.

The bottom boundary representing bedrock is also designated as a no-flow boundary.

Ocean General Head Boundary. Groundwater may flow into or out of the Pacific Ocean in the southwestern portion of the model. The ocean boundary is simulated using MODFLOW's General Head Boundary (GHB) package (Harbaugh, 2005). The GHB package assigns a known groundwater elevation to the model boundary at a specified distance from the model boundary. The general head boundary condition is assigned to the top active cells directly underlying the Pacific Ocean. These general head boundary cells occur in Layers 1 through 6 due to their projected outcrop at the seafloor surface. At the model's western boundary, the ocean boundary occurs in Layer 6 and the boundary moves to shallower layers to the east (Figure 27). All GHB cells are assigned a reference head of 0 feet msl, representing average sea level.

Mountain Front Subsurface Inflow. Subsurface inflow from the mountain front is represented as defined fluxes using MODFLOW's well (WEL) package (Harbaugh, 2005). The flux is added to cells adjacent to the northern bedrock from just east of El Toro Canyon to the eastern boundary of the model. The top of the flux cells are located in Layer 2 and extend into lower layers down to a depth of 500 feet (Figures 24 and 25). As discussed in the following section on the basin water budget, the subsurface inflow fluxes were apportioned during calibration along the northern bedrock boundary by watershed area above the boundary contact. The distribution of subsurface inflow cells by watershed contact is shown on Figure 28.

Rincon Creek Fault. The Rincon Creek Fault separates SU-1 and SU-2. The fault has an approximately 50 degrees from horizontal southward dip. As a result, both horizontal and vertical barriers to flow are implemented in the model. MODFLOW's horizontal flow barrier (HFB) package (Harbaugh, 2005) is used to add barriers to horizontal flow between SU-1 and SU-2. To represent the southward dip, the HFB barriers occur farther south for deeper layers. The barrier thickness is assumed to be 1 foot and the hydraulic conductivity of the HFB barrier was adjusted during calibration. The barrier to vertical flow between the underlying SU-1 and the overlying SU-2 was implemented using the quasi-3D confining bed option in MODFLOW's Layer-Property Flow (LPF) package (Harbaugh, 2005). The quasi-3D confining bed option implements a semi-confining layer underneath a layer. The thickness of the semi-confining layer is assigned as 1 foot and the vertical hydraulic conductivity was adjusted during calibration.

Model Water Budget. The updated hydrologic budget developed in Task 1 is implemented in the numerical groundwater model using MODFLOW recharge, well, and multi-node well packages with annual stress periods. The recharge (RCH) package is used to define percolation of precipitation, percolation of irrigation water, streambed percolation, and extraction by phreatophytes. The well (WEL) package is used to define the flux of subsurface inflow at the northern boundary. The multi-node well (MNW2) package is used to simulate extraction by groundwater pumping wells. Flows to and from the ocean boundary are calculated by the model.

The MODFLOW recharge package adds a specified amount of water to the model's top active layer. Twelve recharge zones are defined in the model, as shown on Figure 30. Each zone represents a combination of recharge components that occur in the cells making up the zone. For example, cells with streambed percolation also have extraction by phreatophytes from the stream, as well as percolation of precipitation and irrigation water because the stream does not cover the entire cell. Refer to the Task 2 Technical Memorandum (Appendix B) for details on the combinations of recharge components assigned to each zone. Individual components of the hydrologic budget implemented in the model are summarized in Table 7. A discussion of each component is presented below.

<u>Percolation of Precipitation.</u> Annual deep percolation of precipitation in the Recharge Area developed in the Task 1 hydrologic budget is used to calculate areal recharge based on the number of cells in the unconfined area with a uniform cell size of 90,000 square feet. The areal recharge from precipitation in feet per day is added to zone totals for the recharge package.

Although recharge from deep percolation of precipitation in the Confined Area precipitation was not included in the Task 1 conceptual model, it was important to add it into the numerical model. The original conceptual model balances for all groundwater in the basin regardless of location: the groundwater model must account for water at every unique location in the model. Therefore, even small amounts of recharge from precipitation in the Confined Area should be accurately modeled in order to avoid model numerical instability. As discussed in the model results section of this report, much of the precipitation that is infiltrated into the top layer of the Confined Area flows out to the ocean through shallow sediments rather than percolating into deeper aquifer layers.

<u>Percolation of Irrigation Water.</u> Percolation of irrigation return water occurs over the unconfined Recharge Area and does not occur in the Confined Area (Figure 30). The annual recharge values for pumped and delivered water are combined and used to calculate areal recharge based on the number of cells in the unconfined Recharge Area in SU-1 and SU-2 with a the uniform cell size of 90,000 square feet. The areal recharge from return flow in feet per day is added to zone totals for the recharge package.

<u>Streambed Percolation.</u> Recharge from streambed percolation occurs below portions of El Toro Canyon Creek, Arroyo Parida, Carpinteria Creek, Gobernador Creek, and Rincon Creek within the unconfined Recharge Area of the basin. Portions of all creeks occur in SU-1, while only Rincon Creek is in SU-2. As discussed previously, Santa Monica and Franklin Creeks are concrete-lined from the bedrock boundary to El Estero and do not currently contribute significant recharge to the basin. Annual streambed percolation for each creek system was developed in Task 1. Streambed percolation was added to the recharge package to ensure that the defined flux was added to the highest active layer. The annual percolation is divided by the number of cells in the portion of each creek system that crosses the Recharge Area and uniform cell area of 90,000 square feet to calculate the amount of stream percolation in feet per day to add to zone totals for the recharge package.

Table 7. Annual Water Budget Implemented in Model (acre-feet)

MODFLOW Package	Recharge					Well	Total Inflow	Recharge	Multi-Node Well		Total Outflow
	Unconfined Area				Confined Area						
	Deep Percolation from Precipitation	Deep Percolation from Irrigation Water		Streambed Percolation	Deep Percolation from Precipitation	Mountain-front Subsurface Inflow		Extraction by Phreato-phytes	Groundwater Pumpage		
Water Year		Delivered	Pumped						Distric	Private	
1985	391	58	190	57	121	869	1,687	100	1,836	949	2,901
1986	4,198	80	208	866	1,300	1,100	7,752	100	2,032	1,041	3,173
1987	30	90	186	91	9	683	1,089	100	2,363	932	3,395
1988	731	103	213	112	226	988	2,374	100	2,342	1,065	3,507
1989	0	116	304	26	0	585	1,031	100	2,984	1,520	4,604
1990	0	246	398	4	0	509	1,157	100	3,413	1,990	5,503
1991	1,634	166	452	758	506	1,100	4,616	100	3,014	2,261	5,375
1992	4,174	140	433	1,026	1,293	1,100	8,166	100	1,560	2,165	3,825
1993	5,499	177	484	1,434	1,703	1,100	10,398	100	1,261	2,422	3,783
1994	278	184	564	352	86	822	2,286	100	1,307	2,818	4,225
1995	5,487	162	478	1,746	1,699	1,100	10,672	100	1,291	2,389	3,793
1996	1,401	162	502	894	434	1,100	4,493	100	1,557	2,510	4,188
1997	862	192	487	958	267	1,030	3,796	100	1,317	2,437	3,873
1998	5,467	149	486	1,744	1,693	1,100	10,638	100	575	2,428	3,129
1999	0	292	598	434	0	569	1,893	100	340	2,990	3,446
2000	740	256	621	789	229	995	3,630	100	1,410	3,105	4,652
2001	1,692	205	652	1,096	524	1,100	5,269	100	185	3,259	3,560
2002	0	257	621	7	0	436	1,320	100	558	3,103	3,780
2003	2,293	245	545	521	710	1,100	5,415	100	402	2,723	3,235
2004	0	277	561	2	0	545	1,385	100	999	2,803	3,930
2005	5,366	289	412	1,657	1,662	1,100	10,487	100	1,152	2,060	3,312
2006	930	316	417	927	288	1,059	3,935	100	1,120	2,083	3,302
2007	0	410	501	9	0	405	1,325	100	1,418	2,507	4,025
2008	735	317	561	1,041	327	998	3,979	100	661	2,806	3,567

Subsurface Inflow. As discussed previously, mountain front subsurface inflow at the northern boundary is implemented using specified flux cells in the MODFLOW well (WEL) package. This package specifies the flux rate for specific cells for each stress period. The total annual mountain front subsurface inflow developed in Task 1 is areally distributed based on the area of the watersheds contributing inflow. Inflow from each watershed is distributed equally across the watershed contact (Figure 28). For each model row and column that receives mountain front recharge, the inflow is distributed vertically proportional to thickness of layers between Layer 2 and the deepest layer that is above a depth of 500 feet. The resulting inflow for each cell in cubic feet per day is added for each annual stress period to the well package file.

Extraction by Phreatophytes. This water budget component is applied to the model cells underlying El Toro Canyon Creek, Arroyo Parida, Carpinteria Creek, Gobernador Creek, and Rincon Creek. The annual extraction is divided by the number of these cells and uniform cell area of 90,000 square feet to calculate the amount of extraction by phreatophytes in feet per day and subtracted from the zone totals for the recharge package.

Groundwater Pumpage. The multi-node well package was used to simulate both District municipal and private well pumping. The annual groundwater pumping for District and private wells was developed in Task 1. Four of the five District wells have multiple screen intervals. The fifth District well (27F2, Smille Well) has a 346 foot long screen that spans Model Layers 4 to 7. Fourteen of the 174 private wells are known to have multiple screen intervals; and 44 of those wells are known to have a screen longer than 100 feet (Appendix B, Table A- 2). 113 of the private wells do not have known screen information. For most of these wells, screen intervals were estimated using known screen intervals from nearby pumping wells.

With MODFLOW's multi-node well package (MNW2), specific screen interval elevations for each pumping well are input to the groundwater model and the package calculates the layer flow distribution for each well based primarily on aquifer transmissivity at that location. The option to constrain pumping in any given well if groundwater levels fall below the bottom of the lowest screen is also implemented. Table A-3 in Appendix B shows the estimated screen intervals and basis for estimates for each pumping well in the basin/model.

Model Calibration

Calibrating the CGB groundwater flow model involved successive attempts to match model simulated groundwater elevations to measured data for the calibration period. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. Calibration was conducted by varying relatively uncertain and sensitive parameters over a reasonable range of values. The following parameters were varied during model calibration:

- Horizontal hydraulic conductivity;
- Vertical hydraulic conductivity using vertical anisotropy;
- Specific storages;

- Rincon Creek Fault conductance using horizontal flow barrier hydraulic characteristic and quasi-3D confining bed hydraulic conductivity;
- Spatial distribution of areal recharge, and;
- Spatial distribution of mountain front recharge.

The model calibration period corresponds to the 1985 – 2008 base period of the Task 1 hydrogeologic update. "Stress periods" define a time period in the groundwater model over which hydraulic stresses such as pumping and recharge are held constant. Consistent with the hydrologic budget data set, which is based on annual flow totals, annual stress periods are used for the model.

Pilot Point Method for Model Calibration. A pilot point approach, rather than a zoned conductivity approach, was used to distribute aquifer parameters during calibration. The pilot point approach results in smoothly varying hydraulic conductivity and specific storage fields. Using this method, the values of aquifer hydraulic properties are estimated at the locations of a number of points spread throughout the model domain. Hydraulic properties are then assigned to the model grid through spatial interpolation between those points. Spatial interpolation from pilot points to the finite difference grid defines a hydraulic property array on a cell-by-cell basis. Regularization, a geostatistical method that constrains heterogeneity, is also used. Using pilot points with regularization eliminates the need to guess where unmapped heterogeneity might exist: the calibration process informs where heterogeneity exists.

For the model, 20-50 pilot points were selected for each layer. The plotted pilot points were created for horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage. The locations of the pilot points for each layer are shown on Figure 31. The pilot points in SU-1 and SU-2 were treated as separate groups of pilot points to avoid spatial interpolation of hydrogeologic parameters across the Rincon Creek Fault. The use of pilot point methodology results in over 1,000 parameter values that can be varied in the calibration. PEST software and its Singular Value Decomposition (SVD)-assist functionality (Watermark Numerical Computing, 2004) was used to help update the full set of parameter values and improve the calibration.

Initial Hydrogeologic Parameters. Initial values for horizontal hydraulic conductivity were assigned based on pumping test data developed in Task 1. Based on these data, average horizontal hydraulic conductivities were estimated for Aquifers A, B, and C in the Confined Area, and the unconfined aquifer in the Recharge Area. For pilot points within the estimated extents of Aquifer A (Layer 2), B (Layer 4), and C (Layer 6), initial values were based on the average horizontal hydraulic conductivity of each aquifer developed in Task 1. For pilot points in aquitard layers or in the unconfined Recharge Area within SU-1, initial values were based on representative horizontal hydraulic conductivities estimated for those areas from pumping test data. Within SU-2, initial values were based on values used for geologically similar layers in SU-1. As discussed previously, Layers 1 and 2 are geologically similar across the fault, while SU-2's Layer 3 and SU-1's Layer 7 both represent the Santa Barbara Formation.

Initial values for vertical hydraulic conductivity were based on a vertical anisotropy of 10:1 for pilot points within the estimated extents of Aquifers A, B, and C, and the alluvial Layer 1 of SU-2. For pilot points in aquitard layers, areas outside the estimated Aquifer A, B and C extents, and Layers 2 and 3 of SU-2, vertical anisotropies of 20:1 to 250:1 were assigned with a minimum vertical hydraulic conductivity of 0.01 feet per day.

All pilot points were assigned an initial specific storage value of 1 x 10^{-5}. The specific yield was set to 0.12 for the model and not varied during calibration.

For the Rincon Creek Thrust Fault, a barrier thickness of 1 foot was assumed for both the horizontal flow barriers and the quasi-3D confining layers. The initial value for the Layer 1 horizontal flow barrier hydraulic conductivity was 1 foot per day. Initial values for the horizontal flow barrier hydraulic conductivity for Layers 2 and 3 were 10^{-4} feet per day. The vertical barriers to flow between Layers 1 and 2 and between Layers 2 and 3 represented by the quasi-3D confining layers were assumed to be equivalent to the horizontal barriers to flow in Layers 2 and 3, respectively. During calibration, the conductivities of the horizontal flow barriers in Layers 2 and 3 were maintained as equivalent to the conductivities of the overlying quasi-3D confining layers.

Calibration Results. Model parameters were adjusted during model calibration to improve the model's ability to simulate known conditions. Calibration of the model consisted of modifying the distribution and magnitude of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage values using the pilot point method discussed above. The final distributions of the aquifer parameter values are shown for each of the seven model layers in Figures 31 through 33.

It is noted that these parameter distributions do not necessarily match the mapped distribution of aquifers and aquitards because they are based on different data sets. The mapped aquifers and aquitards are based on geologic observations from scattered boreholes. The parameter distributions in Figures 32 through 34 are parameters necessary to simulate observed water level changes for each model layer. While empirical hydrogeologic data influences these parameters, they are not necessarily distributed similarly. For example, Figure 32 shows locations of relatively high hydraulic conductivity in Layers 4 and 6. These are *localized* conductivities that are greater than the average values reflected by the available hydrogeologic data (i.e., pumping test data) and were necessary for calibrating local groundwater elevations in the model.

Calibrating the Rincon Creek Thrust Fault consisted of modifying the equivalent hydraulic conductivity of the horizontal flow barrier and quasi-3D confining layers. Uniform values were used for each layer. The conductivities of the horizontal flow barrier in Layers 2 and 3 were kept equal to the overlying quasi-3D confining layers. Calibration resulted in the equivalent hydraulic conductivity for Layer 1 of 0.79 feet per day. Calibration resulted in the equivalent hydraulic conductivities for Layers 2 and 3 of 1 x 10^{-6} feet per day.

Groundwater Elevation Calibration. Flow model calibration is commonly evaluated by comparing simulated water elevations with observed groundwater elevations from monitoring and production wells. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Furthermore, the average errors between observed and simulated groundwater elevations should be relatively small and unbiased. The target well locations used for calibration of the regional groundwater flow model are shown in Figure 35. The target wells were selected based on data availability for both groundwater levels and screen intervals. For wells screened over multiple model layers, simulated groundwater levels in each of the layers are weighted by layer transmissivity and averaged before comparing with measured data.

Hydrographs showing both observed and simulated groundwater elevations are shown in Figures 36 through 43. These hydrographs were chosen to demonstrate the model's accuracy in various parts of the CGB. The hydrographs show that the model accurately simulates both the magnitude of groundwater fluctuations and trends observed in monitoring well data throughout most of SU-1. Figure 43, however, shows that calibration in SU-2 is not as good as calibration in SU-1. Additional refinement of the conceptual model (in particular aquifer hydraulic parameters and the water budget) will be required to improve calibration in SU-2 (if desired).

Model Calibration Accuracy and Bias. Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Figure 44 shows all simulated groundwater elevations plotted against observed annual averages for all wells and the entire calibration period. Results from an unbiased model will scatter around a 45 degree line on this graph. If the model has a bias such as exaggerating or underestimating groundwater level differences, the results will diverge from this 45 degree line. The line drawn on Figure 44 demonstrates that the results lie close to a 45 degree line, suggesting that the model results are not biased towards overestimating or underestimating average groundwater level differences.

Figure 44 also shows various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). The ME is the average error between measured and simulated groundwater elevations for all data on Figure 44. The MAE is the average of the absolute differences between measured and simulated groundwater elevations. The STD is one measure of the spread of the errors around the 45 degree line in Figure 44. The RMSE also measures the spread of the errors around the 45 degree line in Figure 44 and is calculated as the square root of the average squared errors.

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the STD should be less than 10 percent of the total head range in the model. The STD of 8.0 is approximately 2.6 percent of the total head range of 314 feet. A second general rule that is occasionally used is that the ME should be less than 5 percent of the total head range in the model. The ME of -1.7 is approximately 0.5 percent of the total head range. Therefore, on average, the model errors are well within acceptable ranges and indicate that the model is well calibrated.

Figure 45 is a graph of observed groundwater elevations versus model residual (simulated elevation minus observed elevation). Results from a non-biased simulation will appear as a cloud of data points clustered around the zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias. As shown on Figure 45, the calibrated model results are generally unbiased.

Simulated Water Budget. Figures 46 through Figure 49 show the model's water budget output compared to the hydrologic budget developed in Task 1. Figure 46 shows that simulated mountain front subsurface inflow and net storage changes closely match the totals developed in Task 1. Figure 46 also shows that simulated net model extraction by multi-node wells is slightly less (annual average of approximately 10 percent) than the groundwater pumping totals developed in Task 1. This is because pumping constraints are implemented in the multi-node well package such that if groundwater levels in a well node fall below the lowest well screen, extraction from the well node is reduced to maintain water levels above the bottom of the well screen.

The total of all Task 1 estimated recharge components are compared to the simulated recharge in Figures 47 through 49. The total net estimated recharge values combine both recharge inflows and extraction by phreatophytes. The simulated flows are shown with the yellow lines, and they match total estimated inputs for each recharge zone.

Outflow to the ocean general head boundary is not a model input but rather completely dependent on simulated heads in the model. Figure 46 shows that the model simulates an average of 410 afy of outflow to the ocean compared to approximately 80 afy estimated in Task 1 for the 24-year simulation period; therefore, the model simulates approximately 330 afy more outflow to the ocean on average than was estimated in Task 1. This difference in outflow to the ocean is due to the additional recharge from percolation of precipitation that was applied to the Confined Area of the model that was not included in the Task 1 conceptual model (discussed previously). The additional recharge that was applied to the Confined Area averaged approximately 545 afy; therefore, since approximately 330 afy year of the 545 afy of additional Confined Area recharge flows to the ocean, approximately 215 afy percolates into deeper aquifers and adds to the basin recharge.

This finding from the calibration of the numerical model suggests that the Confined Area is not entirely impermeable to recharge and that approximately 215 afy of average annual recharge should be added to the hydrologic budget for the CGB. Therefore, the average annual total inflow for the 1985 – 2008 based period (refer to Table 1) should theoretically be increased from approximately 4,000 to 4,200 afy.

Model Scenario Simulations

The calibrated transient numerical flow model of the CGB is intended to be used as an ongoing basin management tool for the District. For example, the model will allow the District to assess potential impacts of increases in groundwater pumping, to evaluate how the basin would respond to long term drought (and/or potential reductions in surface water deliveries), and to simulate alternative basin management scenarios, such as redistributing pumping, implementation of an Aquifer Storage and Recovery (ASR) program, or other strategies to maximize the efficient use of the groundwater basin. The work plan for this project included performing up to five (5) initial simulations to demonstrate the performance and capabilities of the model as a basin management tool. The five initial model scenario simulations that were performed as part of the project were developed in consultation with the District and include the following:

1. Extended Drought;
2. Increased Groundwater Demand;
3. Aquifer Storage and Recovery;
4. Supplemental Wells for Disinfection by-Products (DBPs) Blending, and;
5. Santa Monica and Franklin Creek “De-Lining”.

Each scenario is designed to provide general guidance on the groundwater impacts of the hypothetical strategy. These scenarios can be refined and perhaps combined in the future to develop different assessments of groundwater management strategies.

Results from each scenario are compared to results from the base simulation that represents the calibrated model. Groundwater elevation and groundwater storage data are analyzed to assess the relative effectiveness or impact of each scenario. These results assist in evaluating the model’s ability to represent the basin, as well as its predictive capabilities. A description of the scenarios, how they were implemented in the model, and their results are discussed below.

Scenario 1 - Extended Drought. This scenario was based on the District’s analysis of water supply and demand during a prolonged 8-yr drought (District Drought Water Model 6e). The Drought Water Model balances the District’s various sources of supply during a hypothetical extended drought to meet existing demands. The District projects that its annual allocation of Cachuma Project water would incrementally decline during a prolonged drought and that it would supplement this decline in surface water supplies with proportionally increased groundwater pumping. The purpose of this scenario was to simulate the basin’s response to the hypothetical drought and increase in groundwater pumping.

The base-period for the calibrated model consists of the 24-year period of WY 1985 – 2008. This period includes the 1987 – 1992 drought period (6 years). Implementation of the scenario in the calibrated groundwater flow model of the CGB involved the following:

1. Creation of Hypothetical 8-yr Drought Conditions: The hydrologic conditions and associated recharge components of the actual 1987 – 1992 6-yr drought were extended by 2 years to simulate the hypothetical 8-yr drought. Specifically, the hydrologic conditions and associated recharge components that occurred in WY 1990 (the last year of below normal precipitation during the 6-yr drought) were repeated an additional 2 years, creating a hypothetical 8-yr extended drought period. Hydrologic conditions following the drought period remained the same as utilized for the calibration period (i.e., WY 1993 - WY 2008).
2. Modification of District and Private Pumping: The pumping assigned to District and private wells during the hypothetical 8-yr drought was matched to the groundwater production developed for Drought Water Model 6e. Groundwater extractions following the drought period remained the same as utilized for the calibration period.

3. All other model parameters remained the same.

Figure 50 shows representative hydrographs comparing the results of the base simulation and results from the extended drought simulation. The hydrographs depict extremely low groundwater levels during the period of the extended drought, with water levels as much as 30 feet lower than during the actual 1987 – 1992 6-yr drought. Additionally, they depict a lack of complete recovery after the drought ends, with decreased groundwater levels persisting through the end of the simulation period.

Figure 51 shows the cumulative change in storage comparison between the base simulation and results from the extended drought simulation. As shown, the 8-year drought in Scenario 1 causes a substantial decrease in groundwater storage over the modeled period. Extended drought conditions deplete storage and the basin fails to recover, even years after conditions return to normal. The results of this simulation scenario reveal the basin's inability to quickly recover from the increased pumping and decreased recharge associated with extended multiple-year droughts.

Scenario 2 - Increased Groundwater Demand. This scenario would was based on the District's current projections of increases in its water demands by the year 2030. Based on anticipated growth in residential, commercial / industrial, and agricultural development within its service area, the District projects its total average annual demand will reach approximately 4,325 acre-feet per year (afy) by 2030. The District anticipates that its annual allocation of Cachuma Project Water will total 2,250 afy, leaving approximately 2,075 afy of average annual demand to be met from other sources.

Although the District has identified a variety of both demand and supply management measures to meet the projected increase in demands, groundwater is the least expensive supply option (e.g., groundwater currently costs approximately $140/af compared to purchased State Water cost of approximately $400/af). The purpose of this scenario was to simulate basin response to meeting the projected increase in District demands solely through increased groundwater production.

During the 1985 – 2008 base period, annual pumping by the District ranged between approximately 185 to 3,410 afy, averaging approximately 1,460 afy. In order to meet anticipated 2030 demand levels under this scenario, average annual District pumping would be increased by approximately 615 afy to total 2,075 afy (1,460 afy + 615 afy = 2,075 afy).

Implementation of the scenario in the groundwater flow model involved the following:

1. Proportionally adjusted District well pumping during each year of the 24-year base period to increase the average annual pumping by 615 afy to total 2,075 afy.
2. All other parameters remain the same.

Figure 52 shows representative hydrographs comparing the results of the base simulation and results from the increased demand simulation. As shown, the hydrographs for Scenario 2 depict a significant decrease in groundwater levels throughout the basin as a result of increased pumping demands. The decrease is especially significant during the height of the drought period (1990-1992).

Figure 53 shows the cumulative change in storage comparison between the base simulation and results from the extended drought simulation. As shown, Scenario 2 results in a decrease in groundwater storage due to increased pumping. The loss of groundwater storage is most significant during the six-year drought. After the drought, storage values remain consistently below the base simulation for the remainder of the simulation, with approximately 10,000 af of additional cumulative storage depletion.

It is noted that during the 1985 - 2008 base period, *total* annual groundwater pumping (i.e., District and private wells combined) from the basin ranged between approximately 2,800 to 5,400 afy, averaging approximately 3,700 afy. Increasing average annual groundwater production of the District by approximately 600 af would increase total average annual extractions from the basin to approximately 4,300 afy. As discussed previously, estimates of the long-term perennial yield of the CGB by previous investigators range between approximately 4,200 to 5,500 afy; however, the lack of actual pumping at levels exceeding 4,000 afy for extended periods has meant that the basin has not been stressed / tested at these extraction levels to observe basin response. The results of this scenario suggest that increasing average annual pumping from the basin to 4,300 afy would exceed the perennial yield (as defined previously) of the basin and result in long-term declining water-levels and storage depletion.

Scenario 3 – Aquifer Storage and Recovery. This scenario simulates the implementation of an Aquifer Storage and Recovery (ASR) program in the basin. The District has identified ASR as potential method to augment natural groundwater storage in the basin, thereby effectively increasing the perennial yield of the basin. As envisioned for this scenario, the District would inject excess Lake Cachuma “spill” water when available into the two recently drilled District wells that have been designed to be ASR-compatible, i.e., the Headquarters and El Carro #2 wells. The purpose of the scenario would be to simulate basin response to injection at these two wells during periods when Cachuma “spill” water is available. It is noted that no recovery of injected water was included in the simulation.

Implementation of this scenario in the groundwater flow model involved the following:

1. Determination of the timing and availability of excess “spill” water that occurred during the 1985 – 2008 base period.
2. Determination of reasonable injection rates for the Headquarters and El Carro #2 wells.
3. Assignment of injection / recharge rates and volumes to each of the two wells during the 1985 – 2008 base period based on 1 and 2 above.
4. All other parameters remain the same.

It noted that the Headquarters Well was field-tested and analyzed for ASR capabilities in 2003; however, the El Carro #2 well has not yet been tested for ASR (this testing is planned for the near future); therefore, for purposes of this scenario it was assumed the results of the Headquarters Well testing can be generally applicable to the El Carro #2 well, adjusted as necessary for the relative differences in their settings, aquifer completions, pumping performance, etc. Based on these assumptions, the two wells are assumed to be capable of maximum injection rates of 450 and 565 gallons per minute (gpm), respectively.

Based on the review of Cachuma spill records, there was no surplus Cachuma Lake water available for recharge in 16 of the 24 simulated years. During the eight years when surplus Cachuma Lake water was available, the amount of water recharged ranged between 275 afy and 815 afy.

The resulting hydrographs for the Headquarters and El Carro #2 Wells (29D7 and 28D2, respectively) are shown on Figure 54. The hydrographs show increased groundwater levels in some years, but the increase appears to be temporary, returning to normal after one to two years. However, there does seem to be a slight overall shift in all wells, depicting a subtle basin-wide groundwater level increase due to increased recharge.

Figure 55 shows the cumulative change in storage comparison between the base simulation and results from the ASR simulation. As shown, Scenario 3 results in a slight increase in total basin storage through time as expected. While this change does not become visible immediately, the second half of the model run reveals a clear increase, one that appears to persist through time. While the hydrographs for this scenario depict the groundwater level increases as temporary; the storage graph shows that most of the ASR water remains in storage in the basin. Some of the recharged water is lost due to outflow to the ocean, however approximately 70 percent remains in the basin at the end of the simulation. .

It is noted that this simulation represents an injection only scenario, without seasonal recovery periods following injection. As such, the amount of outflow predicted in this simulation likely overstates the amount that would be associated with an ASR program that implemented an active seasonal recovery schedule. In order to simulate a true seasonal ASR program, however, the model's current annual stress periods would need to be re-discretized to quarterly (or monthly) stress periods.

Scenario 4 – Supplemental Wells for DBP Blending. The District has identified certain locations within the distribution system that at times contain elevated levels of disinfection by-products (DBPs). This scenario simulates the redistribution of a portion of District well pumping to hypothetical supplemental wells for purposes of providing a source of non-DBP blend water to reduce DBP concentrations at specific locations in the District's distribution system. The concept is to install new supplemental well(s) that are sited at strategic locations within the distribution system to provide a source of blend water into the distribution system. The purpose of the scenario would be to simulate the basin response to such a redistribution of District pumping.

Implementation of the scenario in the groundwater flow model involved the following:

1. Identification of parcels/locations for supplemental wells.
2. Determination of reasonable pumping rates for potential supplemental wells based on their location in the basin.
3. For each year of the base period, proportionally redistribute a portion of the historical District pumping from existing District wells to the hypothetical supplemental wells such that the net annual District pumping does not change.
4. All other parameters remain the same.

The District identified two parcels in the basin as potential well locations for purposes of DBP blending: one was located in the northwestern portion of the basin in Section 23 near Toro Canyon (APN 155-140-047, a private parcel) and the other located in the east-central portion of the basin in Section 27 (APN 155-200-008, the Carpinteria Reservoir site). Unfortunately, the parcel in Section 23 was adjacent to the bedrock boundary of the basin and had little to no saturated basin sediments underlying and is, therefore, not a viable well location site for this scenario.

For the hypothetical well located near the Carpinteria Reservoir, based on available well performance and aquifer parameter data, a well capacity of 750 gpm is considered feasible at this site. The 750 gpm pumping capacity of this new well was proportionally redistributed from existing District wells, with total pumping remaining the same.

The resulting hydrographs are shown on Figures 56 through 58. These hydrographs show that the redistributed pumping does not appear to have a significant effect on the District wells, despite the fact that their pumping rates have decreased. The only noticeable difference in groundwater level of well 29D7-D8, 27F2, and 28F7 occurs during the drought years, where the redistributed pumping scheme appears to alleviate the effects of drought conditions.

Figure 59 shows the cumulative change in storage comparison between the base simulation and results from the supplemental wells simulation. As shown, Scenario 4 storage data are identical to the calibration storage data throughout the course of the simulation and does not result in any net change in basin storage. This is expected because the simulation involves no net loss or gain in pumping, only a shift in pumping from one area of the basin to another.

Scenario 5 – Santa Monica and Franklin Creeks "De-Lining". Santa Monica and Franklin Creeks were channelized into concrete-lined box channels as part of the Carpinteria Valley Watershed Project in 1974. As a result, these two creeks no longer recharge the basin to a measurable extent. The purpose of this scenario was to simulate basin response if the creeks had not been channelized into concrete-lined channels and allowed to naturally contribute recharge to the basin.

Implementation of the scenario in the groundwater flow model involved the following:

1. Addition of Santa Monica and Franklin Creek channels to the model domain.
2. Quantification and assignment of annual streambed percolation for each of the two creeks for each year of the base period.
3. All other parameters remain the same.

Based on analysis of reconstructed streamflow records and percolation losses for these two creeks during the 1985 – 2008 base period, the annual increase in recharge due to de-lining Santa Monica Creek and Franklin Creek was estimated to range between 0.4 acre-feet in the driest year, to 520 acre-feet in the wettest year. The average annual increase in recharge is 165 afy, roughly equivalent to 20 percent of the total streambed percolation in the basin.

The resulting hydrographs are shown on Figure 60. These hydrographs show that the scenario results are similar to the calibrated model hydrographs during drought times. However, the added recharge affects groundwater levels more significantly during periods of normal rainfall and recharge.

As shown on Figure 61, this scenario results in the most significant increase in basin storage of all the modeled scenarios. In addition, the recharge added by de-lining of creeks has basin-wide storage effects, not just local ones. Approximately 3,940 acre-feet of water are recharged through Santa Monica and Franklin Creeks during the 24-year simulation. Of this amount, approximately 2,930 acre-feet, or 74 percent, remain in the basin at the end of the simulation.

CONCLUSIONS

The Carpinteria Groundwater Basin Hydrogeologic Update and Groundwater Model Project consisted of two primary tasks. Task 1 consisted of a hydrogeologic update of groundwater conditions in the Carpinteria Groundwater Basin (CGB). The results of the Task 1 hydrogeologic update formed the basis for the development and calibration of a numerical groundwater flow model of the CGB performed as Task 2. Specific conclusions regarding the results of Task 1 include the following:

- The well log collection obtained for the basin update was used to refine the previous interpretations of the geologic structure and hydrostratigraphy of the CGB. In general, the refined interpretations are consistent with the previous interpretations. The updated aquifer geometry and structural contours of the principal aquifer aquifers and bedrock in the CGB were developed into ArcGIS shape files, and were used for direct import into the model development environment.
- The development of aquifer hydraulic parameters from recent controlled pumping tests at District wells represents a significant advancement in the hydrogeologic framework of the CGB, and was of significant importance to the construction and reliable calibration of the numerical model.
- The development of individually assigned groundwater pumpage to wells in the basin, combined with available well construction information, is also of significance to the development of the numerical model. This information allowed for the reliable input of both spatial (laterally and vertically) and temporal well extractions from the basin.
- The base-period of this update (1985 – 2008) represents an appropriate base-period for estimating the hydrologic budget of the basin and for model development and calibration. The base-period begins and ends at similar points on the cumulative departure from the mean graph and has an average rainfall that is within 2 percent to the average rainfall for the entire period of record. The period includes two periods of dry conditions and one period of overall wet conditions (relative to the mean annual conditions). It also closely represents current cultural conditions in the basin.
- The overall water-level trend for the 1985 – 2008 base period is slightly declining. Basin water-level contours and storage coefficients used to derive rough estimates of the changes the volume of groundwater storage suggest that approximately 4,000 af of cumulative storage depletion occurred over the 24-yr base period.
- Water levels declined relatively sharply starting at the beginning of the base period through the fall of 1991, corresponding to the extended 6-yr drought of 1987 – 1992. During this period, water levels were as much as 40 feet below sea level in the basin, conditions that can lead to seawater intrusion. This was followed by a relatively steep upward trend in water levels peaking in the spring

of 1998, which was the wettest year on record. Since 1998, water levels throughout the basin have displayed a gradual declining trend.

- Although seawater intrusion has not historically been detected in the basin, there are no existing wells at the coast that penetrate into the deeper Aquifers A – C that could serve as early warning "sentinel" wells. There is likely some volume of fresh water in groundwater storage offshore; however, the current location of the seawater/fresh water interface is unknown.
- There is general agreement between this hydrogeologic update and previous investigations on estimates of the water balance equation for the basin. For example, total average annual inflow to the basin was estimated at approximately 4,000 afy for this update, compared to approximately 4,200 afy estimated by GTC in their 1976 study of the basin. The difference is essentially attributable to the loss of Santa Monica and Franklin Creeks streambed percolation in the mid-1970s.
- Based on analysis of the updated hydrologic budget and the amount of average annual recharge to the basin, the perennial yield of the CGB is estimated to be approximately 4,000 afy. Based on analysis of groundwater pumpage, water-level and groundwater storage changes, the ability of existing wells and their associated extraction patterns in the basin to capture recharge without inducing undesirable results (i.e., long-term declining water levels) indicates a long-term average annual operational yield of approximately 3,600 afy.

Task 2 resulted in the development of a well-calibrated numerical groundwater flow model of the CGB. The model will be useful to the District as an ongoing basin management tool. In addition, the development of the model has provided substantial new information about how groundwater flows in the CGB. Particular lessons learned from the groundwater model include:

- Recharge from precipitation in the Confined Area adds approximately 545 acre-feet per year to the basin. Approximately 330 acre-feet per year of the 545 acre feet of recharge (60 percent) flows to the ocean, and 215 acre-feet per year (40 percent) adds to the basin recharge.
- Basin recharge is not equally distributed areally. In particular, the rate of areal recharge in Storage Unit 2 is less than the rate of areal recharge in Storage Unit 1.
- Mountain front recharge is not equally distributed across the northern basin boundary. Distributing mountain front recharge in proportion to upslope drainage area provided better calibration.
- Supplemental wells have a beneficial effect on basin by distributing extractions, which lessens the degree of water-level depressions in the Confined Area.
- Approximately 70 percent of water injected through ASR wells can be expected to remain in the basin over long time periods, assuming no active seasonal

recovery occurs to limit losses. It is considered likely that seasonal recovery of injected water would significantly reduce or eliminate the predicted losses; however, the model will need to be rediscretized into quarterly or monthly stress periods in order to simulate such a program.

- Approximately 75 percent of additional stream percolation derived from de-lining Santa Monica and Franklin creeks can be expected to remain in the basin over long time periods.

It is noted that the primary purpose of this project was to develop a calibrated groundwater flow model of the CGB that can be used as an ongoing management tool for the District upon completion of the project. Additional basin management strategies to the initial scenarios simulated for this project are likely to emerge in the future that can also be simulated with the model (e.g., a seasonal ASR program). The initial scenarios performed for this project are not intended to encompass all possible basin management scenarios, but rather to provide a basis for demonstrating a range of capabilities (and limitations) of the groundwater model while also providing the District with useful basin management information.

RECOMENDATIONS

Based on the results of the CGB Hydrogeologic Update and Groundwater Model Project, and our experience with similar projects, we offer the following recommendations:

- For conservative basin planning purposes and given existing well locations and extraction patterns in the basin, an operational yield of approximately 3,600 afy is recommended. This is a long-term average annual value. Historical records suggest that during periods of deficient surface water supplies, the basin can support levels of extraction up to approximately 5,000 afy for short periods (up to four years), provided the basin is allowed to sufficiently recover during periods of surplus supplies.
- The groundwater model should be used to evaluate various basin management strategies to optimize basin pumping to capture additional recharge and increase the operational yield (up to approximately 4,000 afy). Such strategies include various spatial and temporal redistributions of pumping in the basin to optimize capture of additional recharge without adverse impacts.
- Given that water levels have historically at times been (and are currently) below sea level, the conditions for potential seawater intrusion in the northwestern portion of the basin exist. The District should install at least one coastal sentinel monitoring well in the northwest portion of SU-1 of the basin that has dedicated monitoring wells completed in Aquifers A, B and C (and possibly Aquifer D). These wells should be monitored for both water-levels and water-quality as part of the District's ongoing Groundwater Management Plan.
- The District should proceed with installing a supplemental well or wells (at the Carpinteria Reservoir and/or other hydrogeologically suitable areas) to serve as a source of water for blending DBPs in the distribution system.

- The District should consider measures to increase recharge and the perennial yield of basin, including:
  - Implement an ASR program in the CGB utilizing excess Cachuma "spill" water and/or State Project water when available.
  - Further investigate the potential to induce additional basin recharge from Santa Monica and Franklin Creek flows. Potential strategies include "de-lining" of the channel bottoms to allow recharge (and possibly natural habitat), or possibly offstream spreading basin recharge facilities.

The current level of development of the CGB model is appropriate to provide general guidance of impacts from various groundwater scenarios such as those performed for this project. If more accurate assessments of groundwater scenarios or evaluation of different scenarios are required, the following model enhancements should be considered.

- Implement quarterly stress periods to represent seasonal variations. The model uses annual stress periods and does not reflect seasonal changes in groundwater levels. If the evaluation of groundwater scenarios requires predictions of seasonal changes, shorter stress periods will be required. For example, quarterly stress periods could more accurately reflect seasonal extraction and injection periods associated with a managed seasonal ASR program in the basin.
- Refine the conceptual model and water budget for Storage Unit 2. If groundwater scenarios involve activity in Storage Unit 2, the model should be refined in this area. The calibration for Storage Unit 2 is not as good as the calibration in Storage Unit 1.
- Implement the MODFLOW river or stream routing package for stream percolation from creeks. The current model uses the recharge package to implement the defined flux of stream percolation. If local impacts from stream percolation need to be evaluated more accurately, a river or stream routing package will simulate the percolation flux based on river stage or streamflow and groundwater levels as opposed to evenly distributing flux along creek length as currently implemented. This could be important in a more detailed evaluation of recharge from creek "de-lining" or offstream storage projects.
- Evaluate effect of pumping constraints in model-node well package on simulation results. If simulated groundwater levels fall below the lowest well screens, the model currently limits well extraction. As a result, simulations may not result in the full extraction required by different scenarios. A more accurate assessment may require modifying pumping inputs and/or assumed well screen intervals to result in desired extraction levels.
- Perform uncertainty analysis on the calibrated model. The uncertainty of model predictions can be evaluated by varying model parameters that results in an acceptable level of calibration. This analysis could be useful to assess the probability groundwater scenarios will meet management objectives.

CLOSURE

This report has been prepared exclusively for the Carpinteria Valley Water District for the specific application to the Carpinteria Groundwater Basin Hydrogeologic Update and Groundwater Model Project. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

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FIGURES

June 2012
Project No. 06-0125

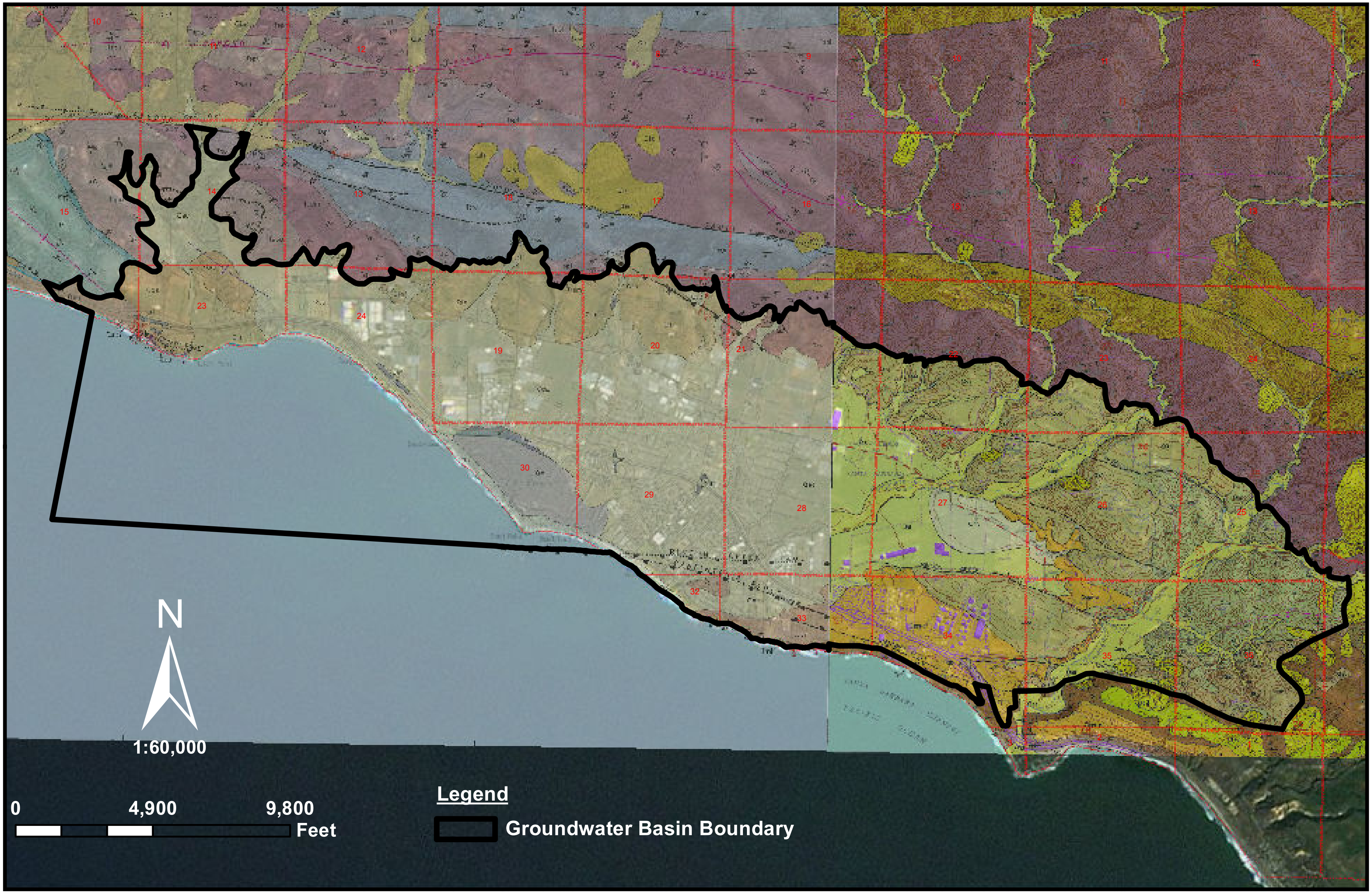

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FIGURE 1. GEOLOGIC MAP AND BASIN BOUNDARIES
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

June 2012
Project No. 06-0125

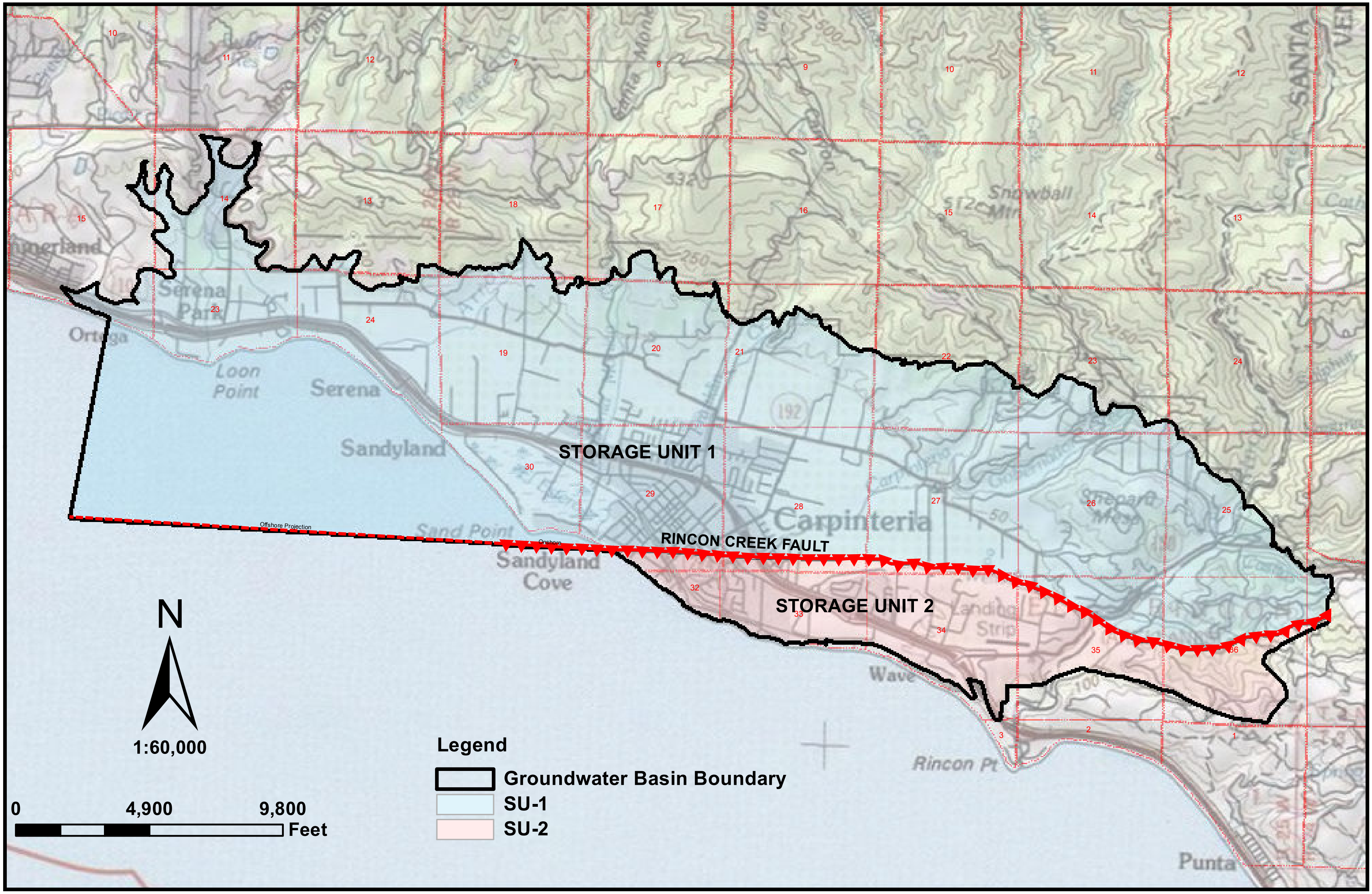

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FIGURE 2. STORAGE UNITS 1 AND 2
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

June 2012
Project No. 06-0125

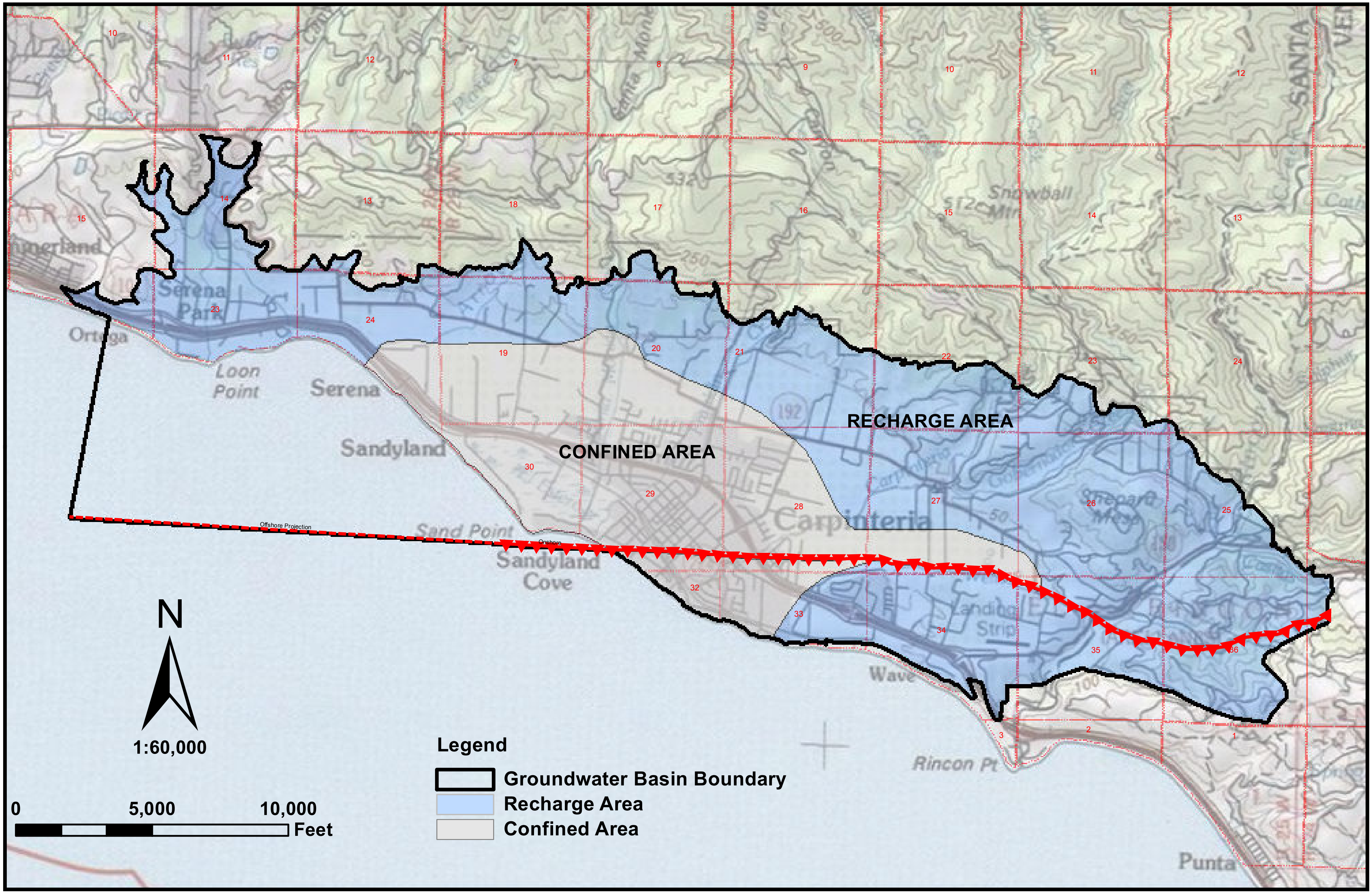

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FIGURE 3. CONFINED AND RECHARGE AREAS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

June 2012
Project No. 06-0125

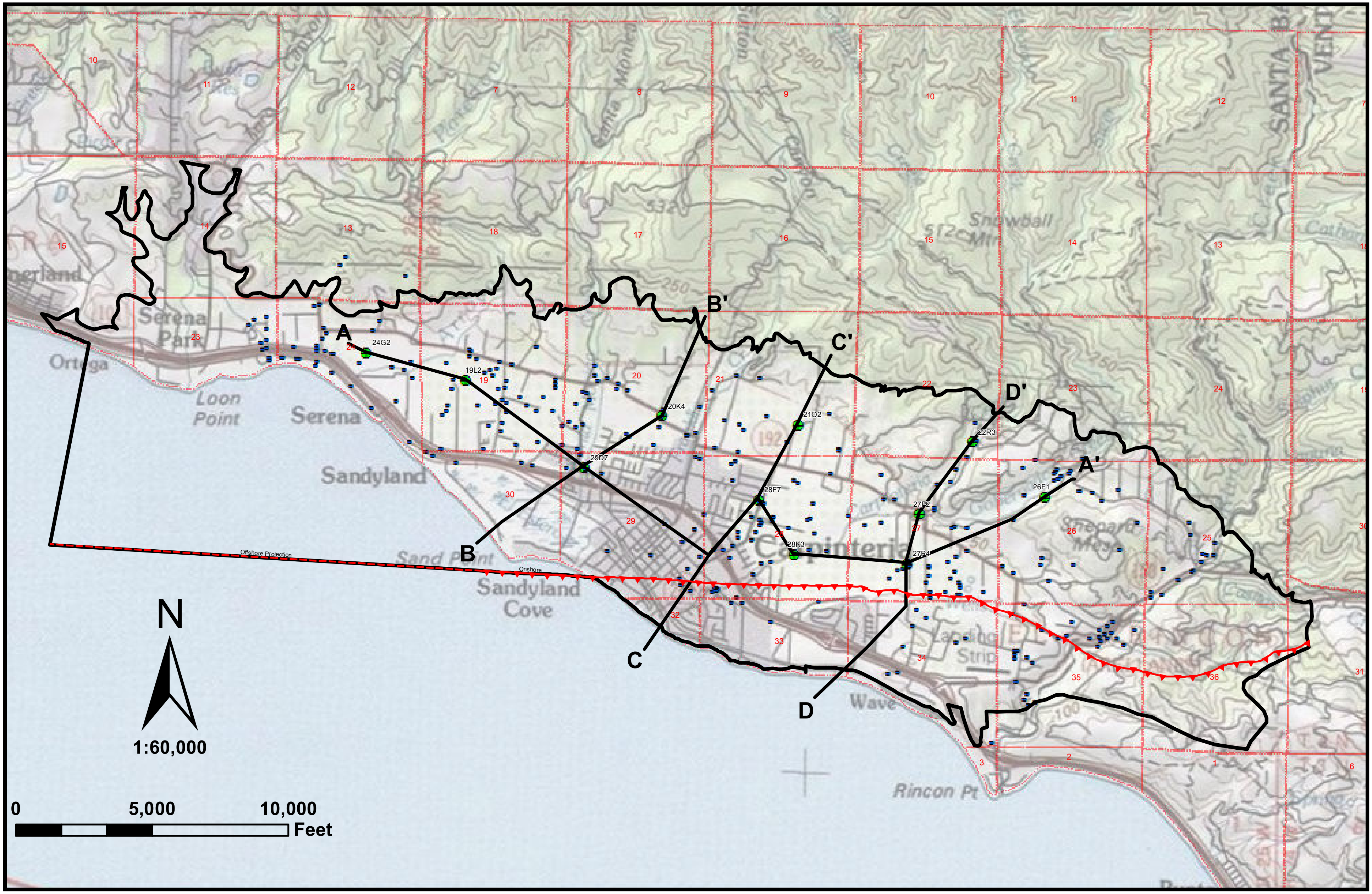

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FIGURE 4. WELL AND CROSS-SECTION LOCATION MAP
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

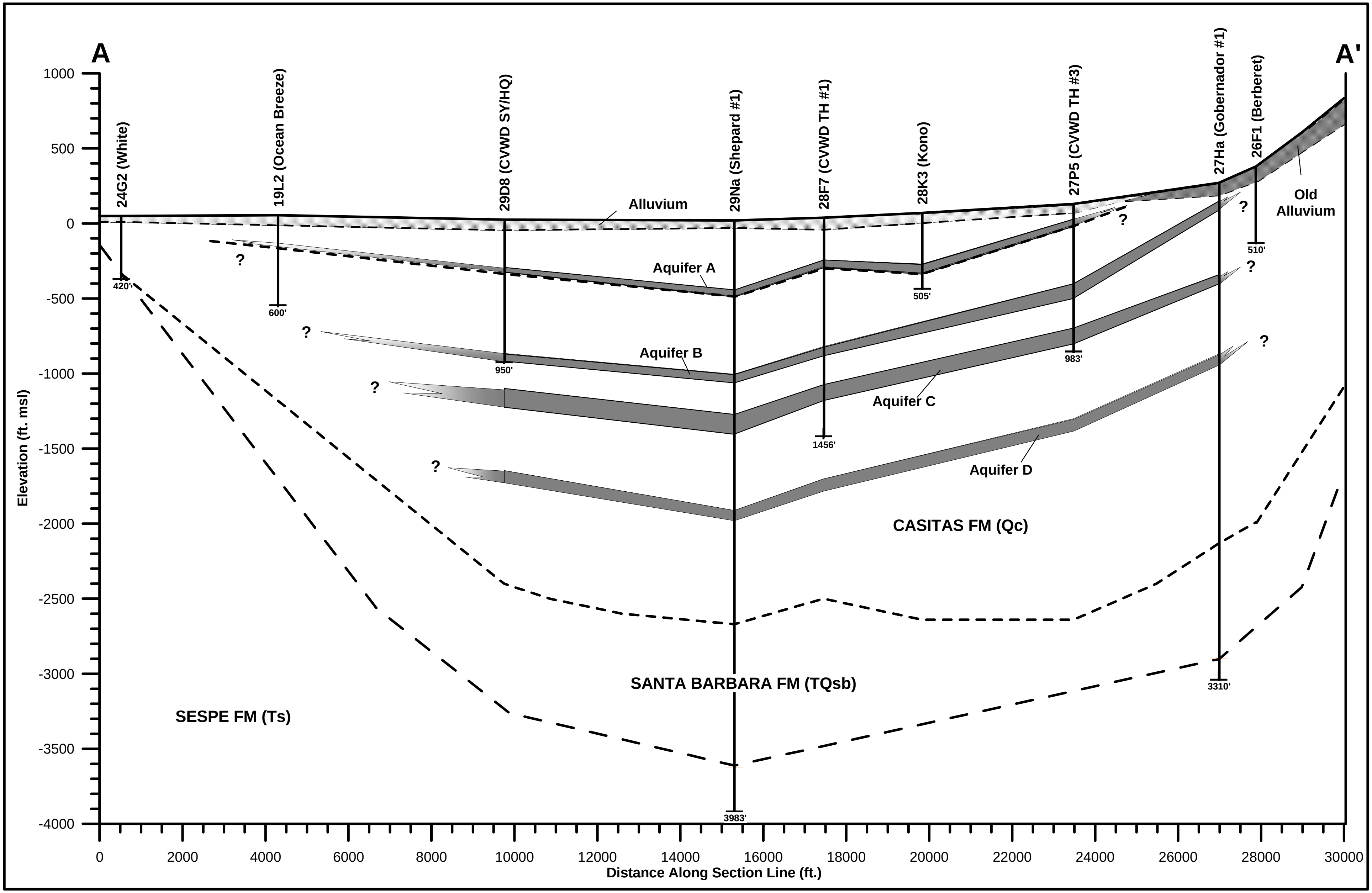

FIGURE 5. HYDROGEOLOGIC CROSS SECTION A-A'
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

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Project No. 06-0125

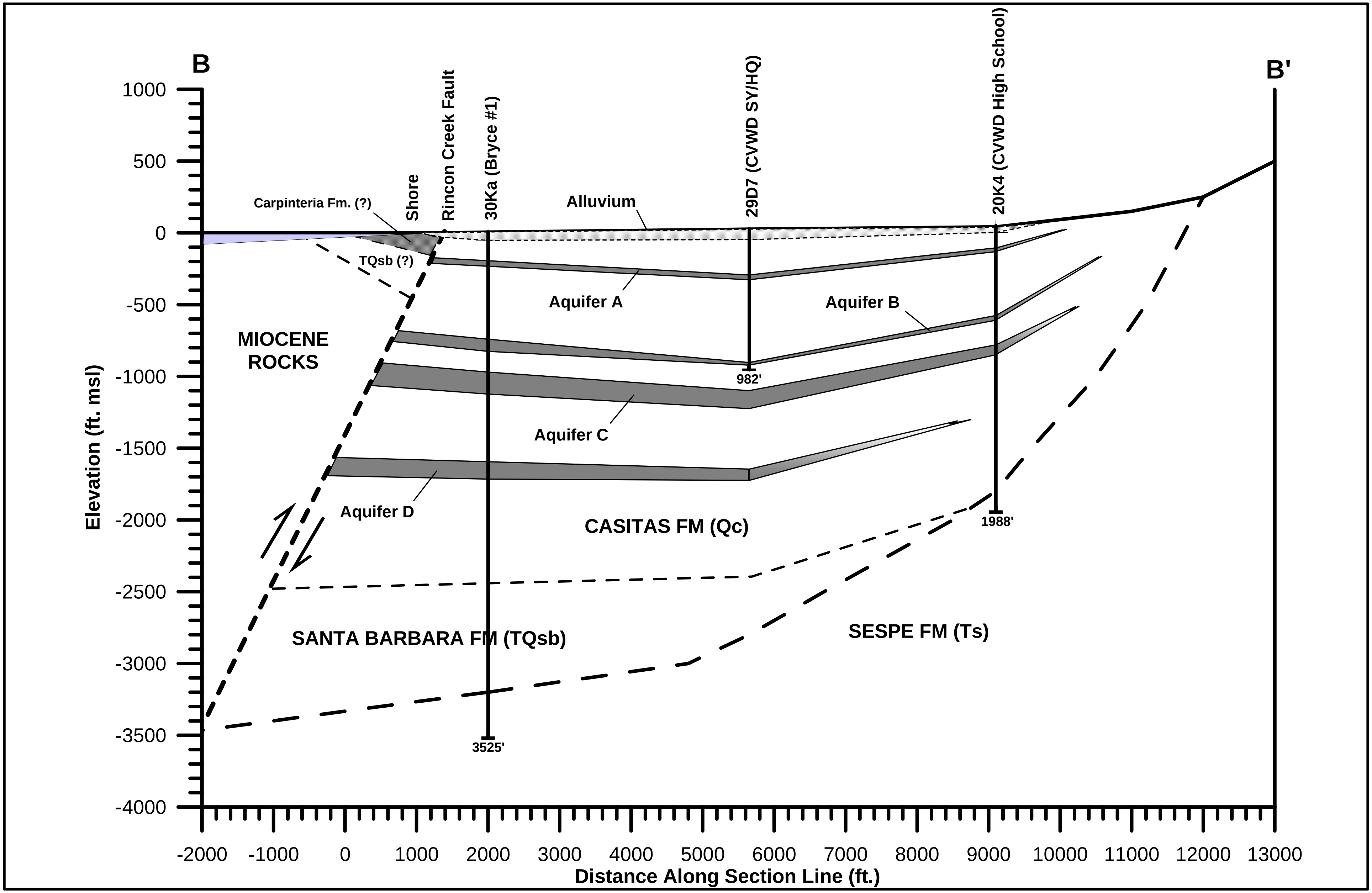

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FIGURE 6. HYDROGEOLOGIC CROSS SECTION B-B'
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Carpinteria Valley Water District

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Project No. 06-0125

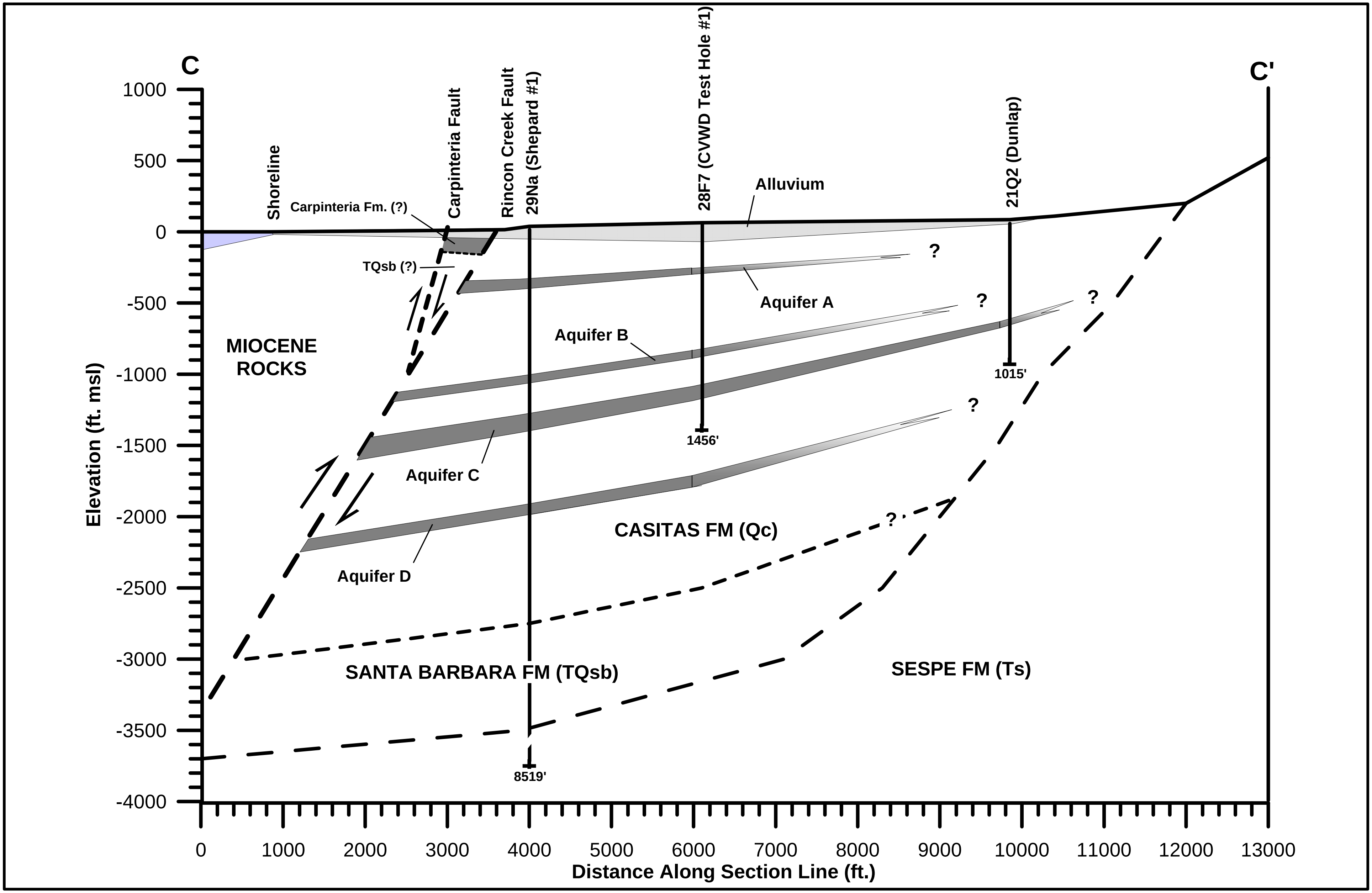

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FIGURE 7. HYDROGEOLOGIC CROSS SECTION C-C'
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

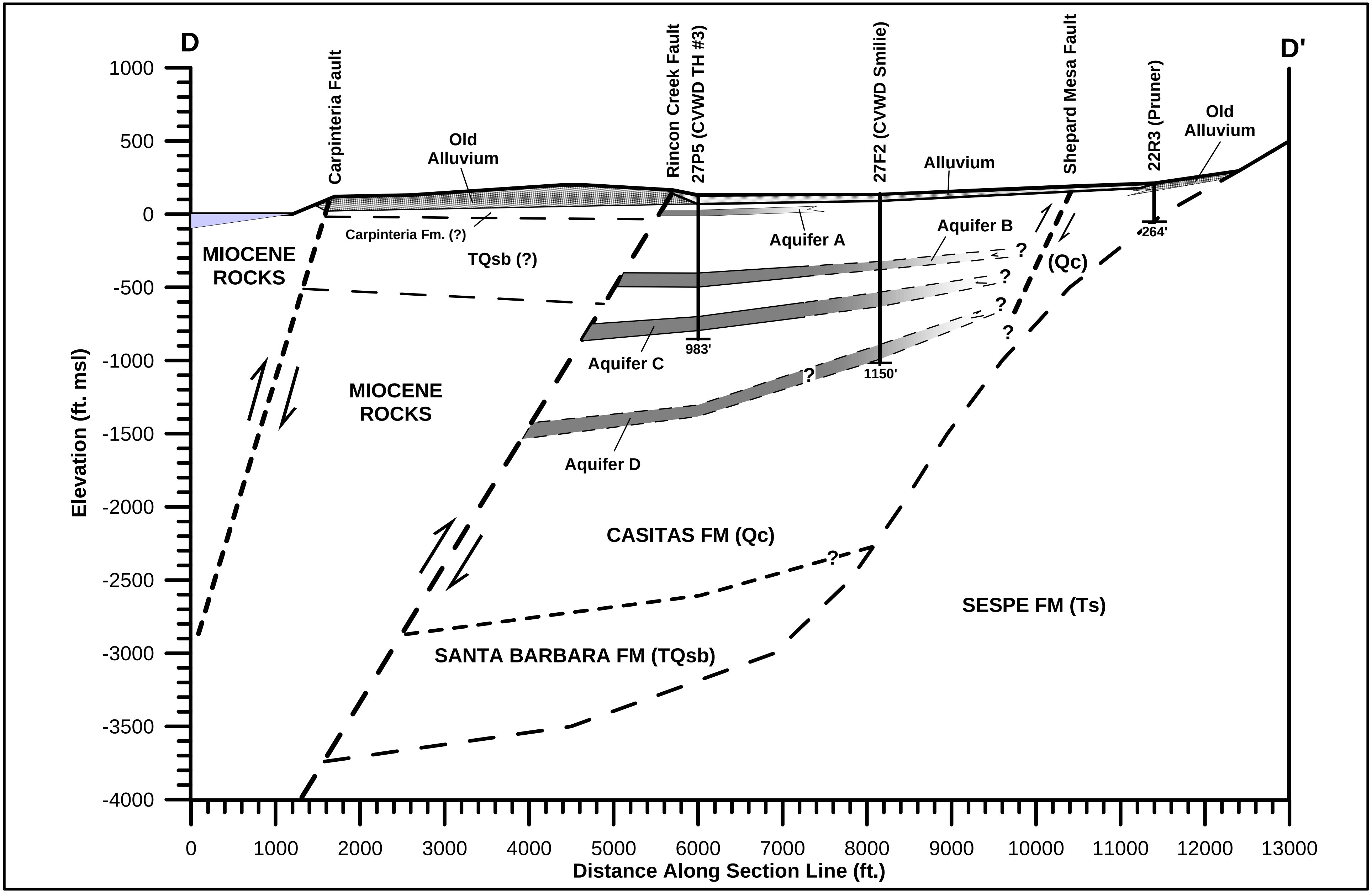

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FIGURE 8. HYDROGEOLOGIC CROSS SECTION D-D'
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Carpinteria Valley Water District

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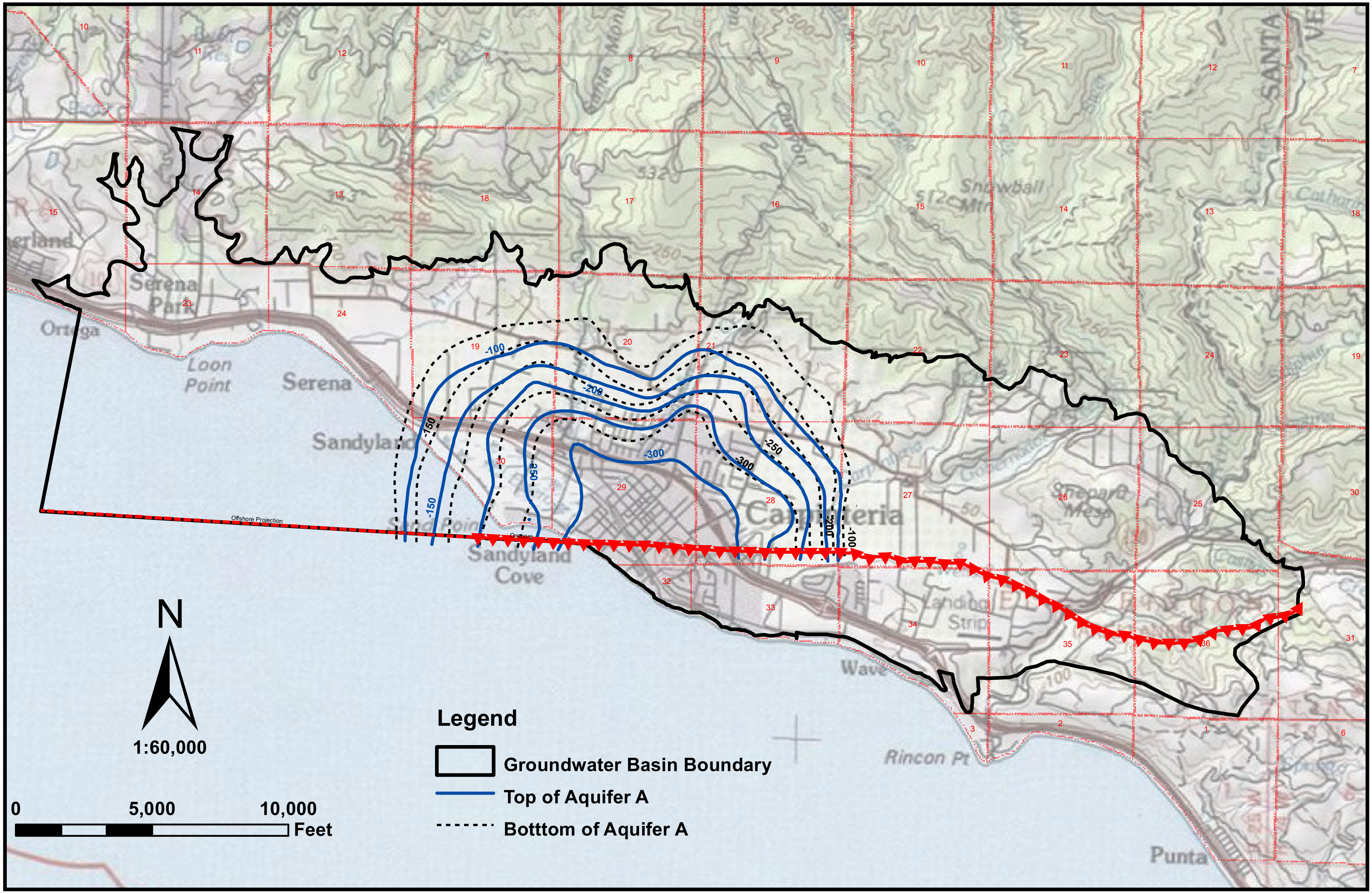

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FIGURE 9. STRUCTURAL CONTOURS - AQUIFER A
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

June 2012
Project No. 06-0125

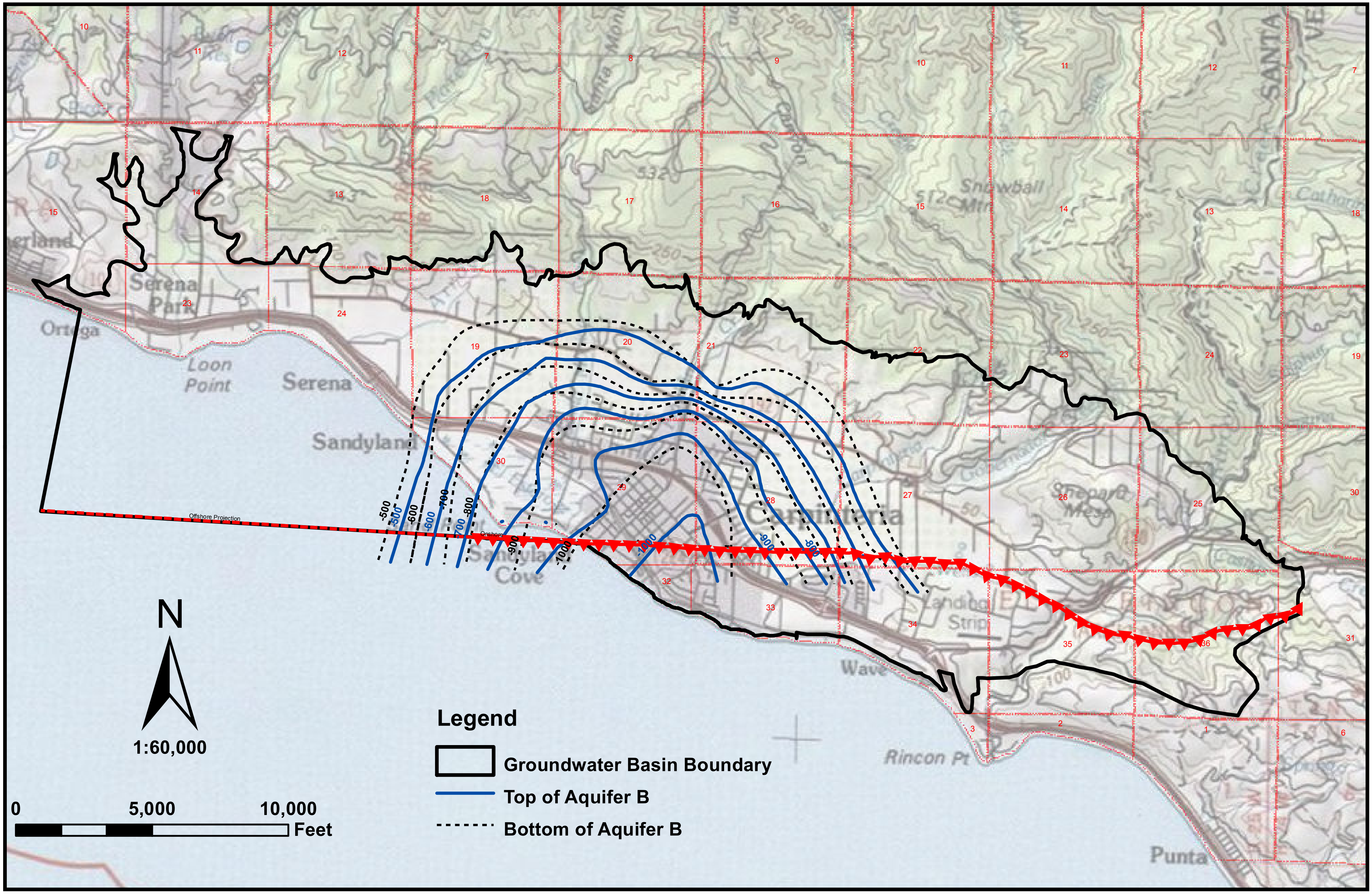

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FIGURE 10. STRUCTURAL CONTOURS - AQUIFER B
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Carpinteria Valley Water District

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Project No. 06-0125

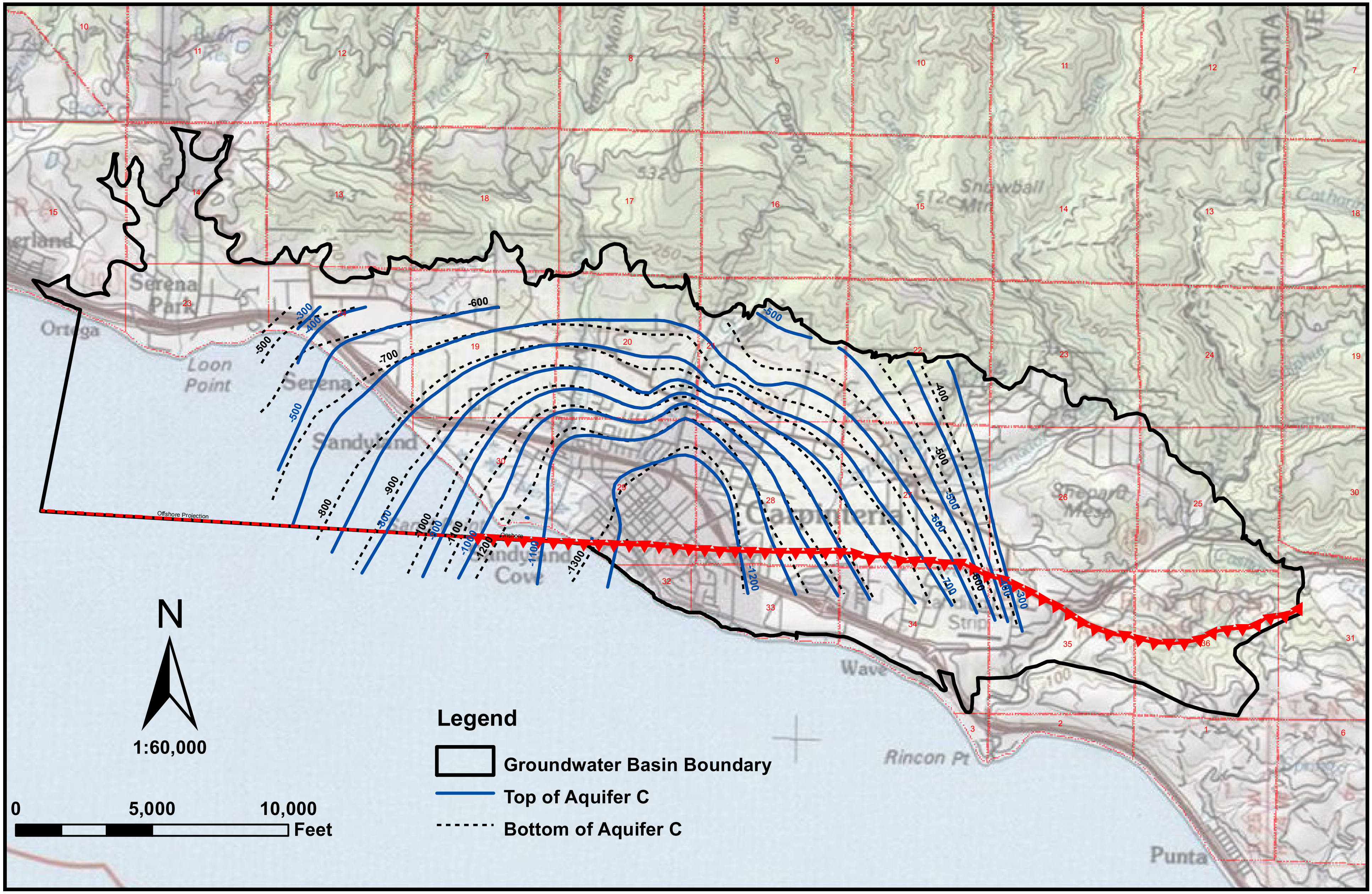

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FIGURE 11. STRUCTURAL CONTOURS - AQUIFER C
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

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Project No. 06-0125

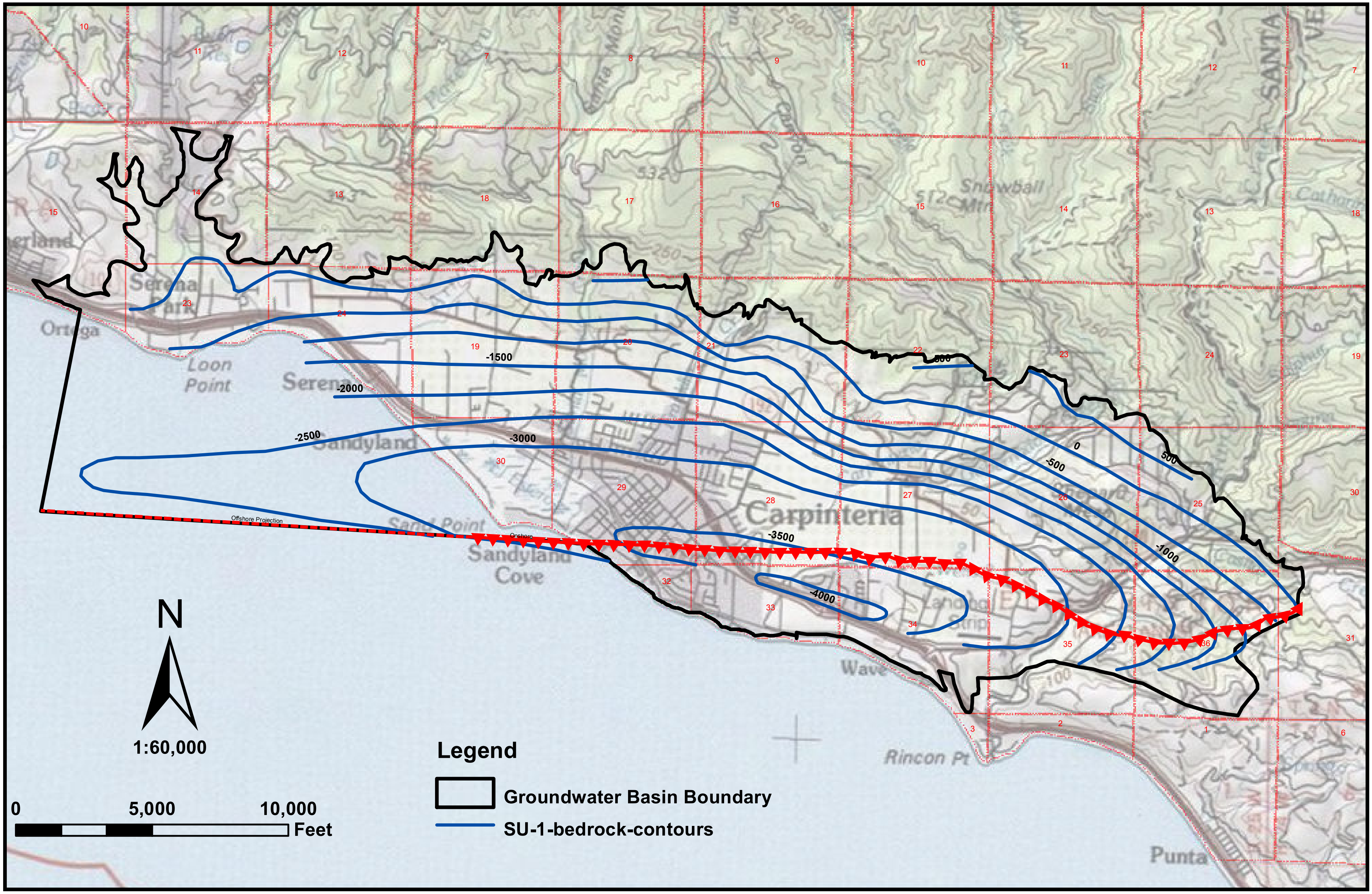

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FIGURE 12. STRUCTURAL CONTOURS - BEDROCK STORAGE UNIT 1
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

June 2012
Project No. 06-0125

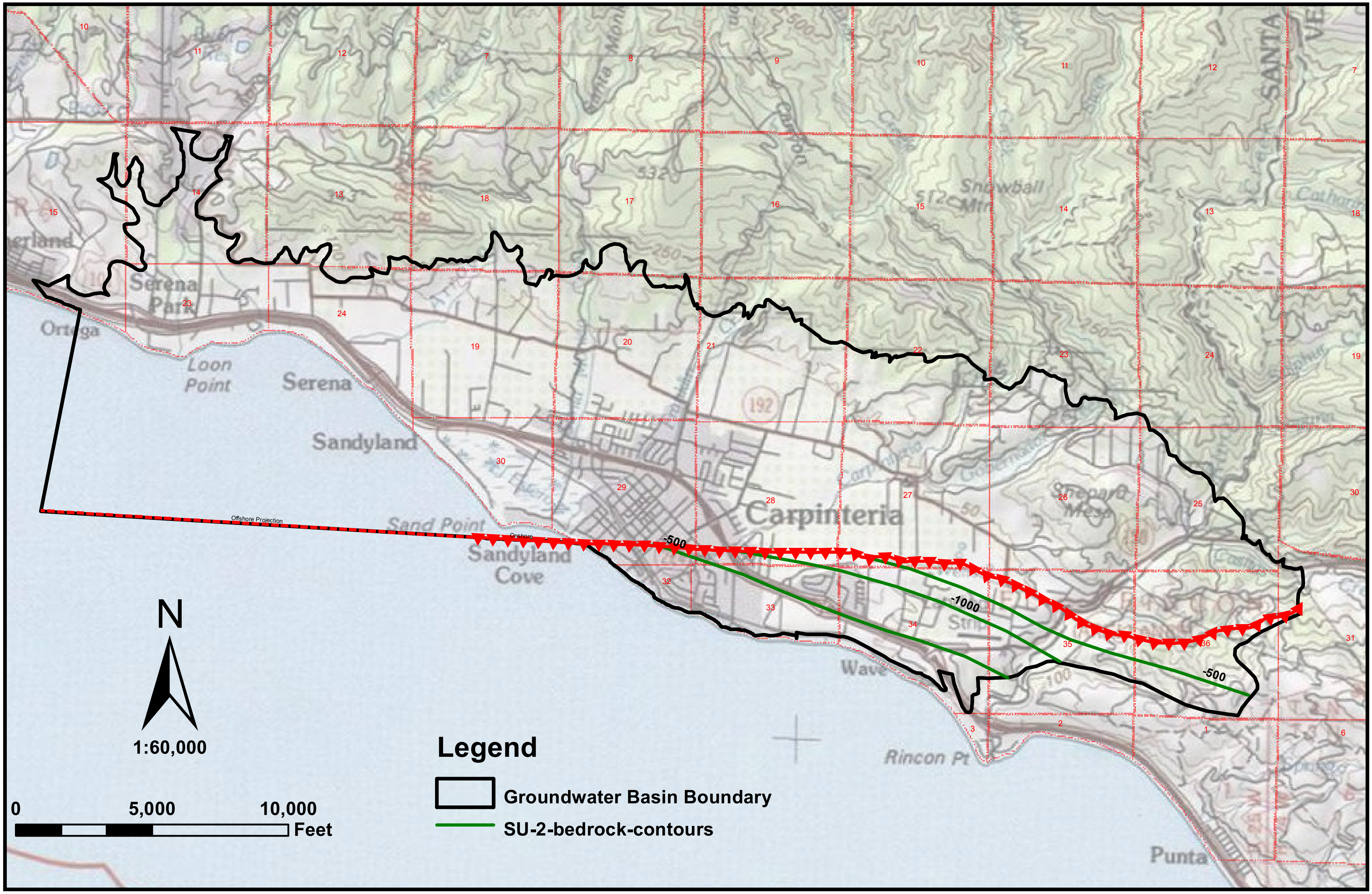

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FIGURE 13. STRUCTURAL CONTOURS - BEDROCK STORAGE UNIT 2
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

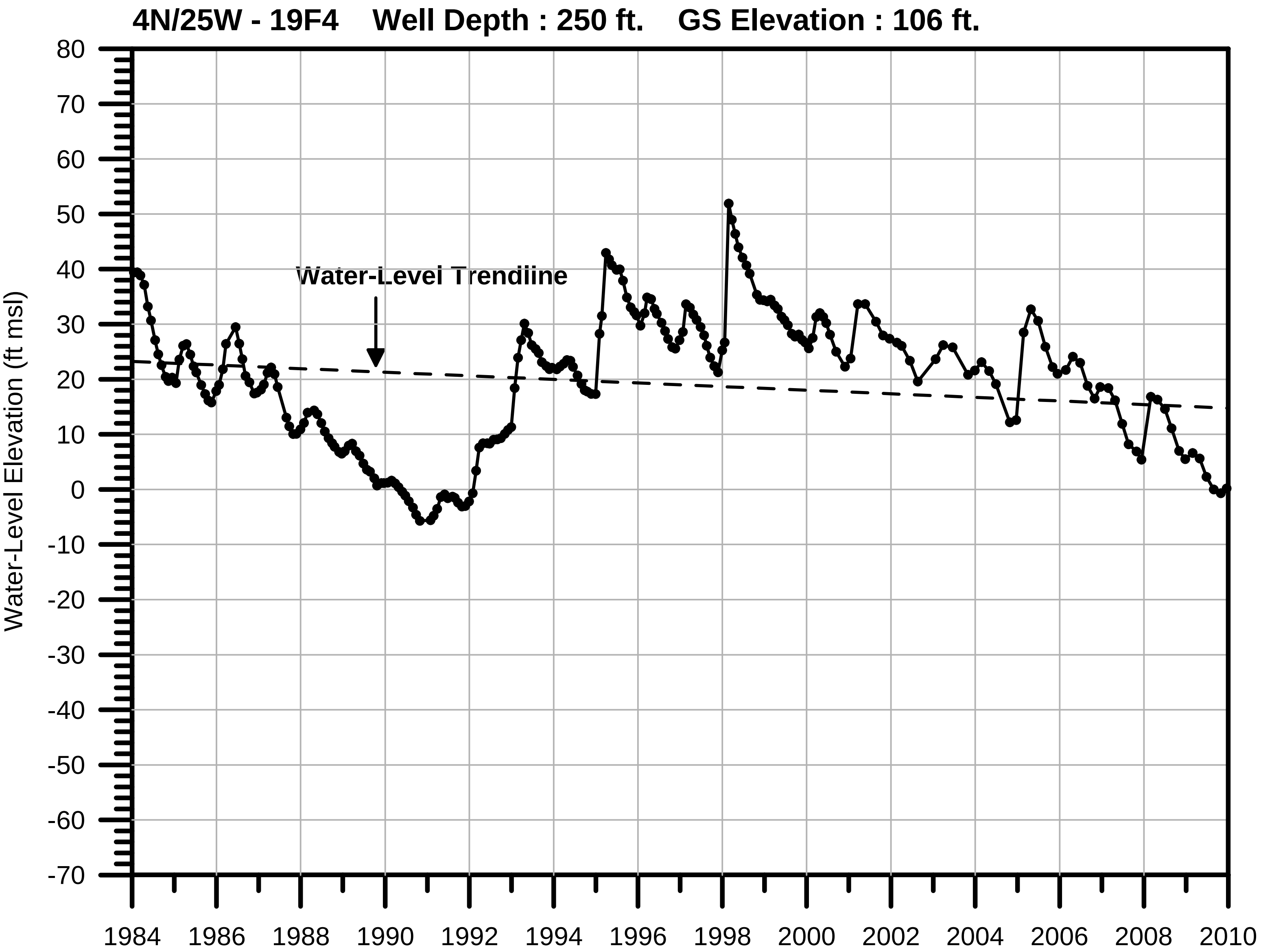

FIGURE 14. CARPINTERIA BASIN HYDROGRAPH (19F4)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

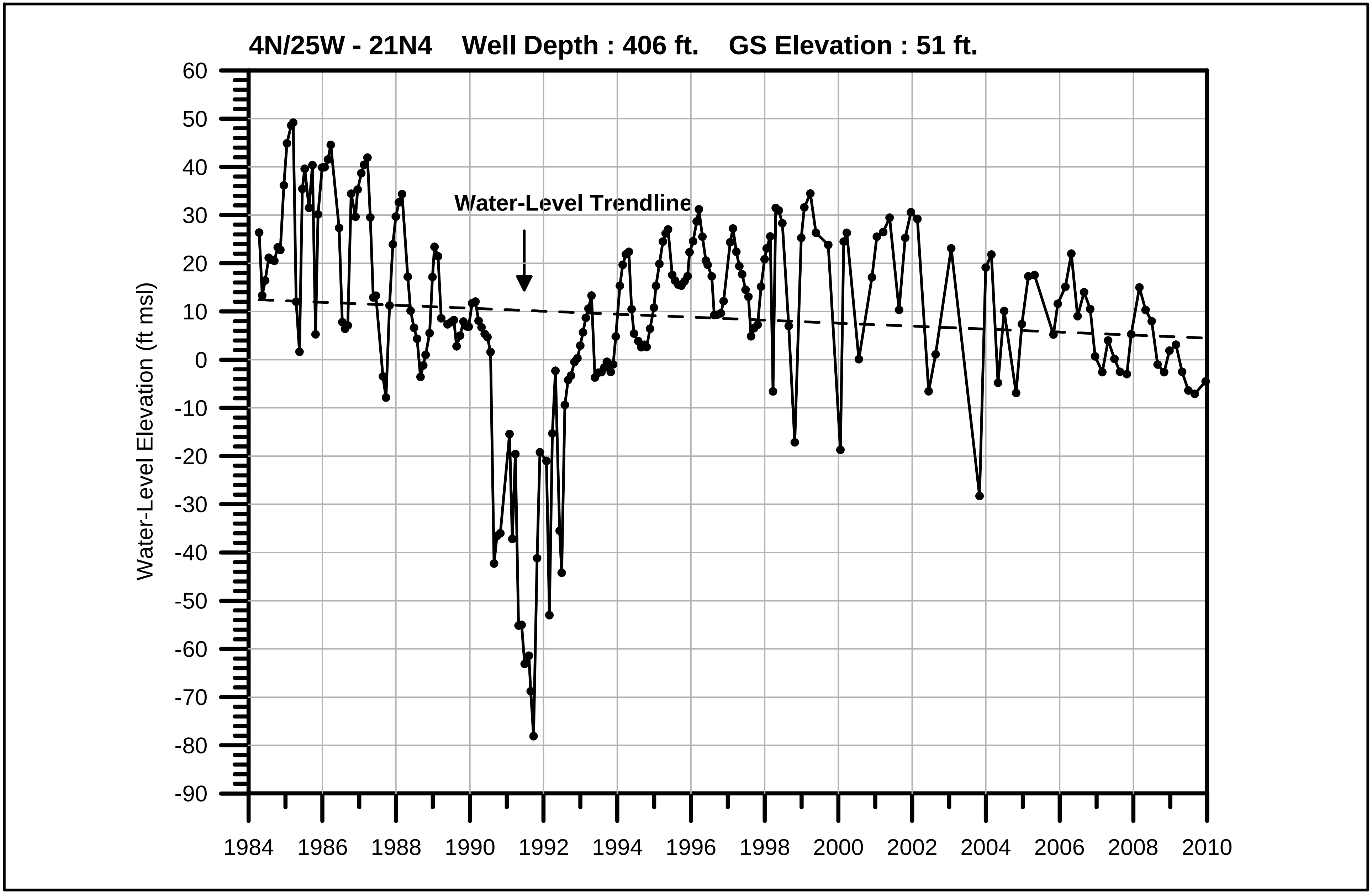

FIGURE 15. CARPINTERIA BASIN HYDROGRAPH (21N4)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

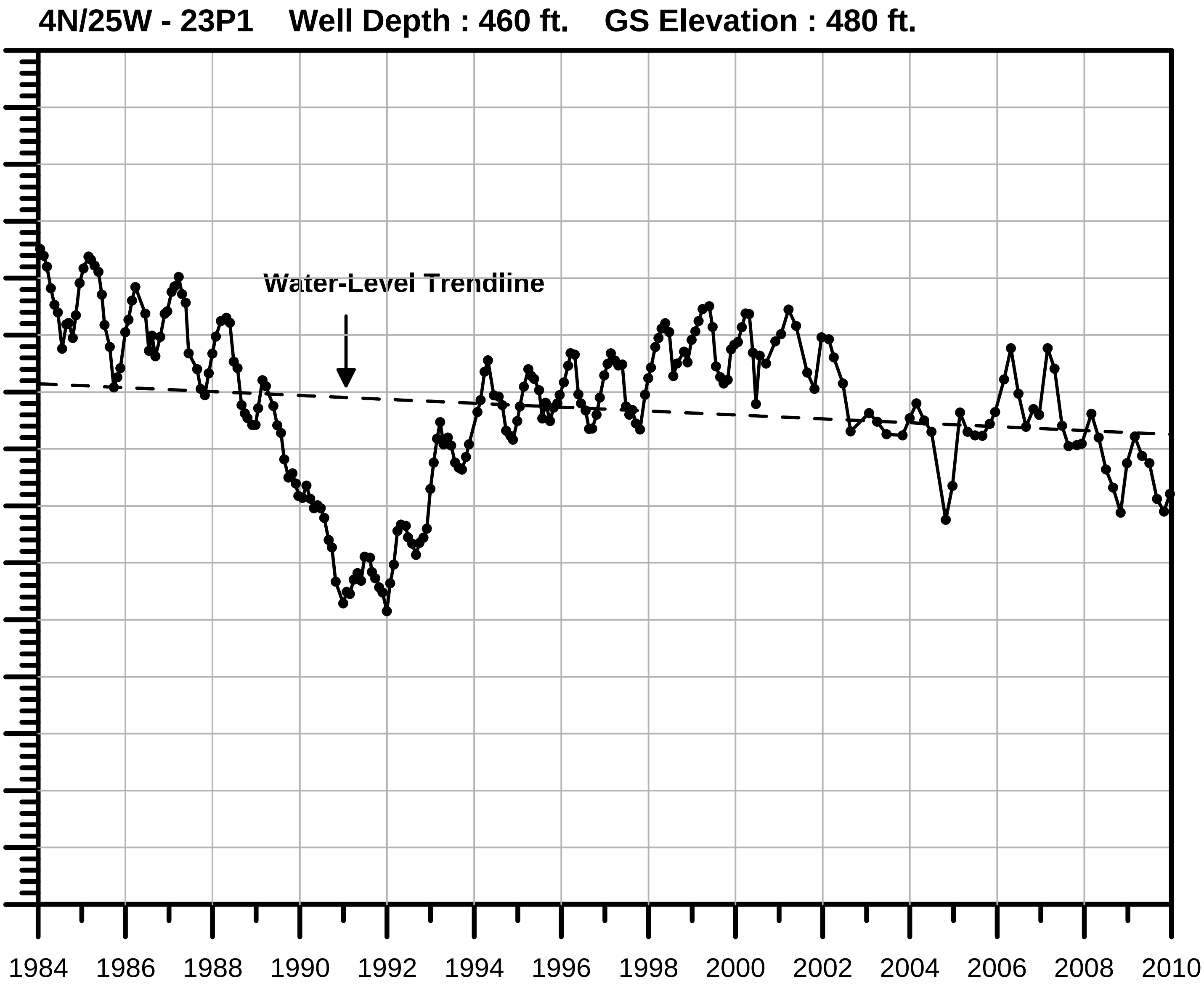

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FIGURE 16. CARPINTERIA BASIN HYDROGRAPH (23P1)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

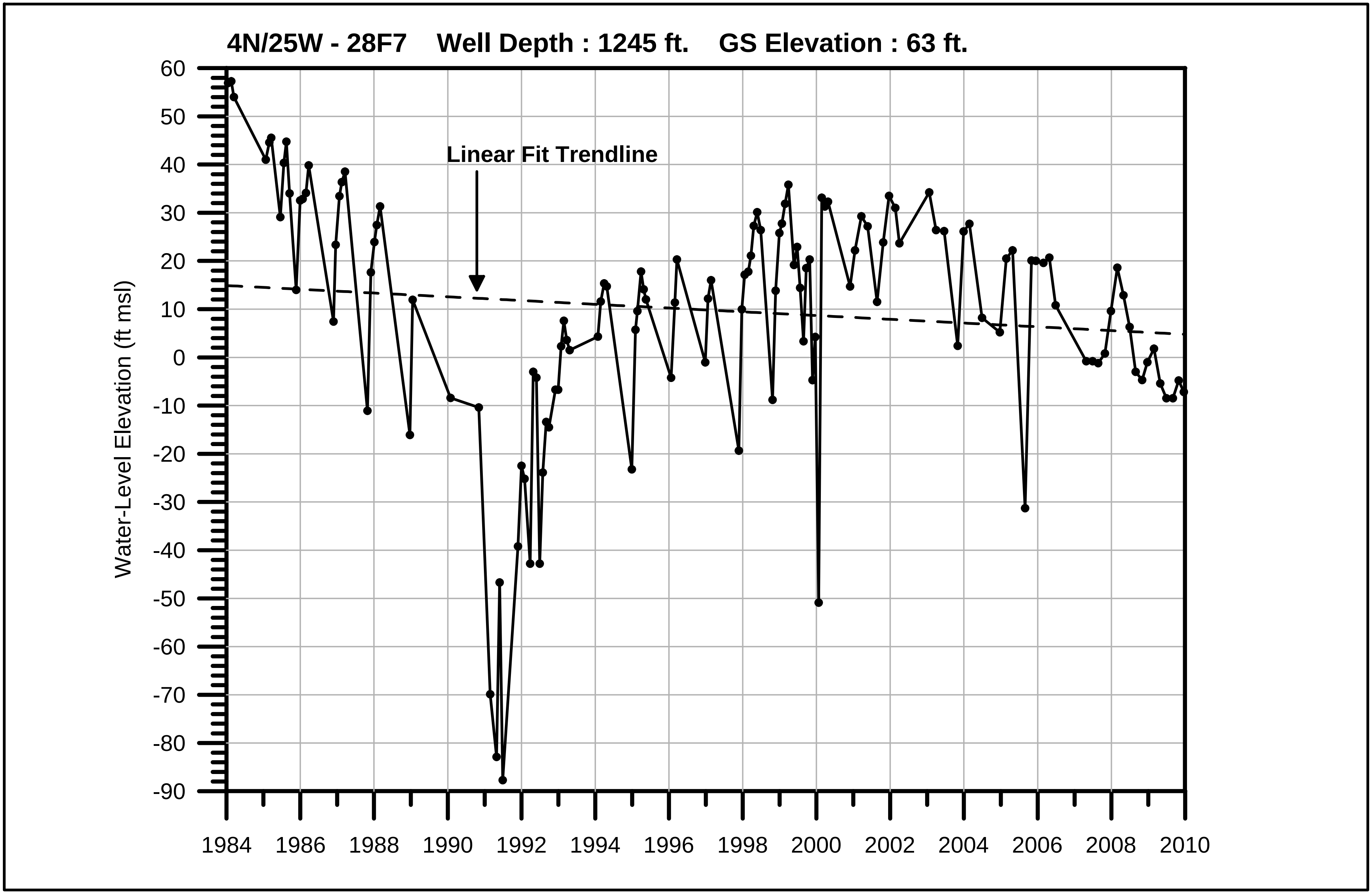

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FIGURE 17. CARPINTERIA BASIN HYDROGRAPH (28F7 - LYONS)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

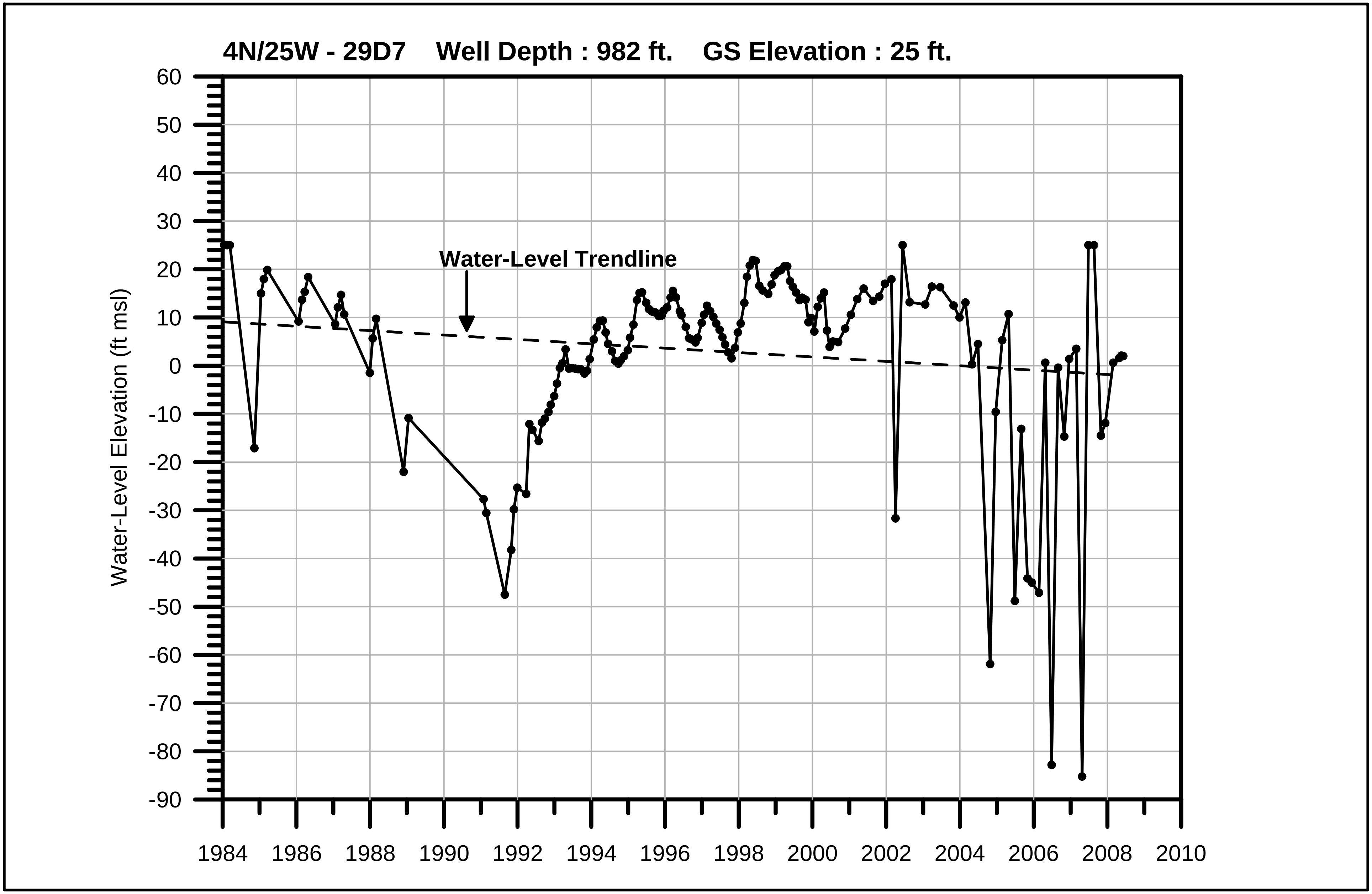

FIGURE 18. CARPINTERIA BASIN HYDROGRAPH (29D7 - SANTA YNEZ/HEADQUARTERS)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

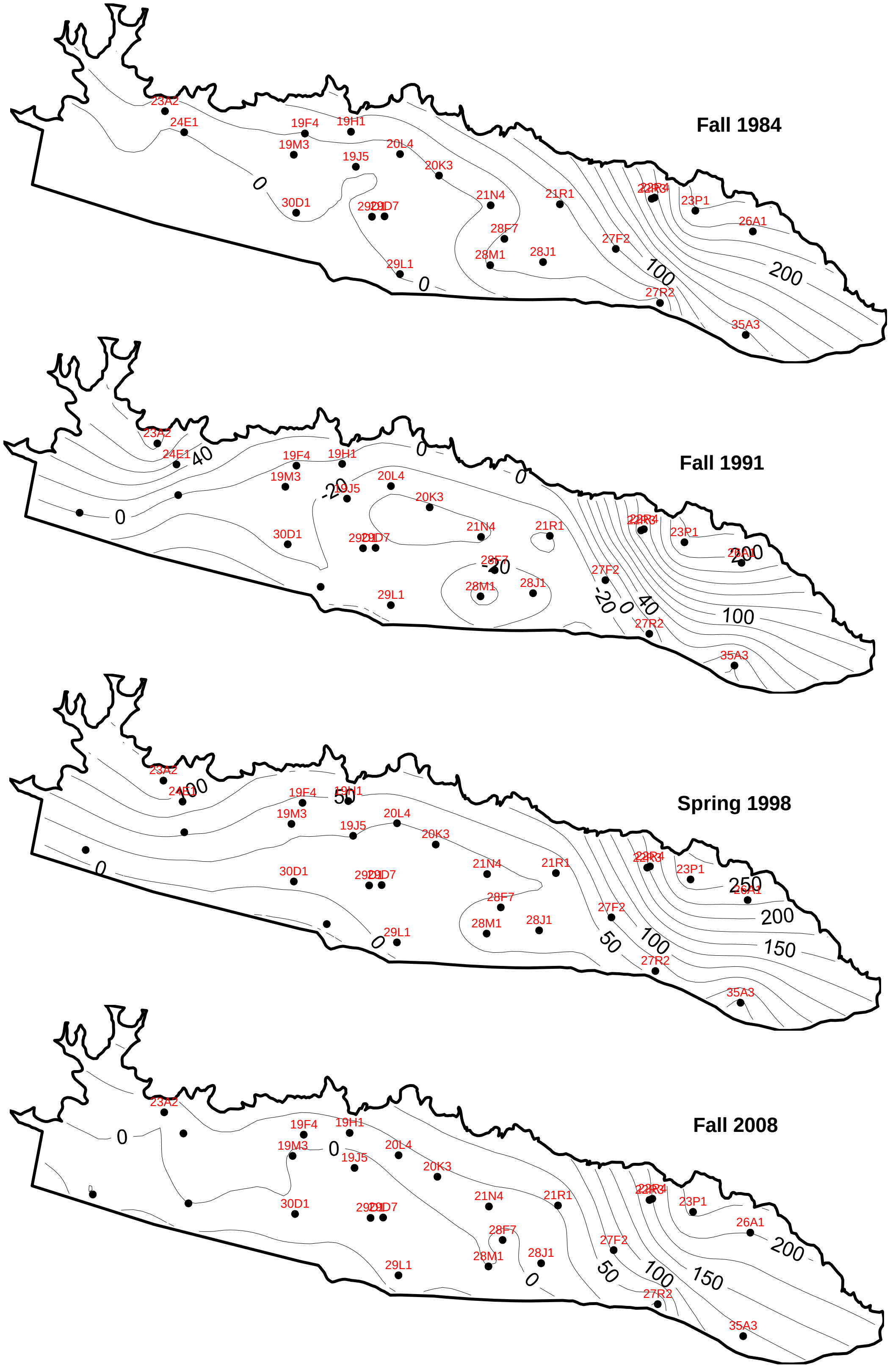

FIGURE 19. WATER LEVEL CONTOURS - STORAGE UNIT 1
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

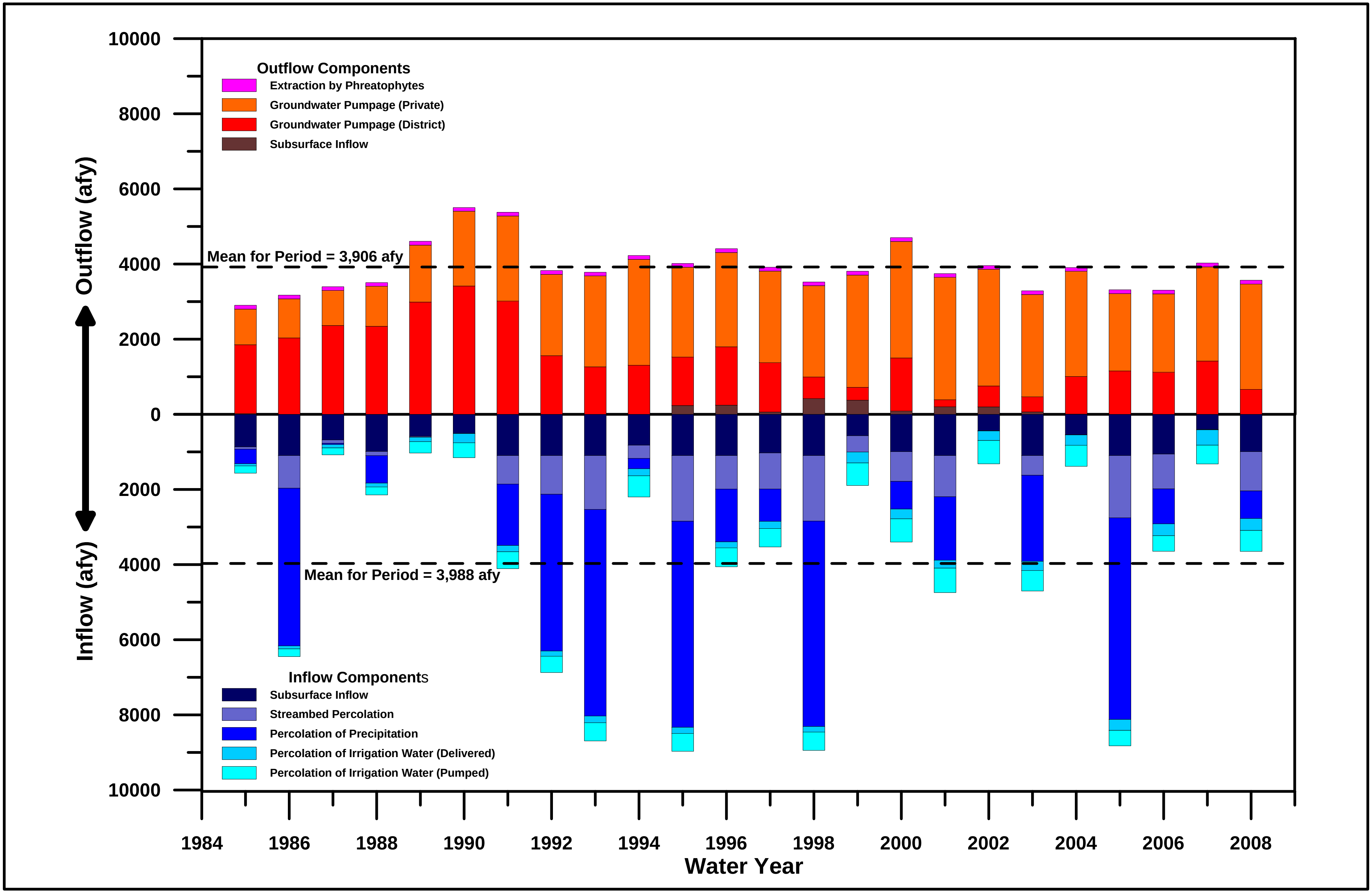

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FIGURE 20. HYDROLOGIC BUDGET SUMMARY FOR 1985 - 2008 BASE PERIOD
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

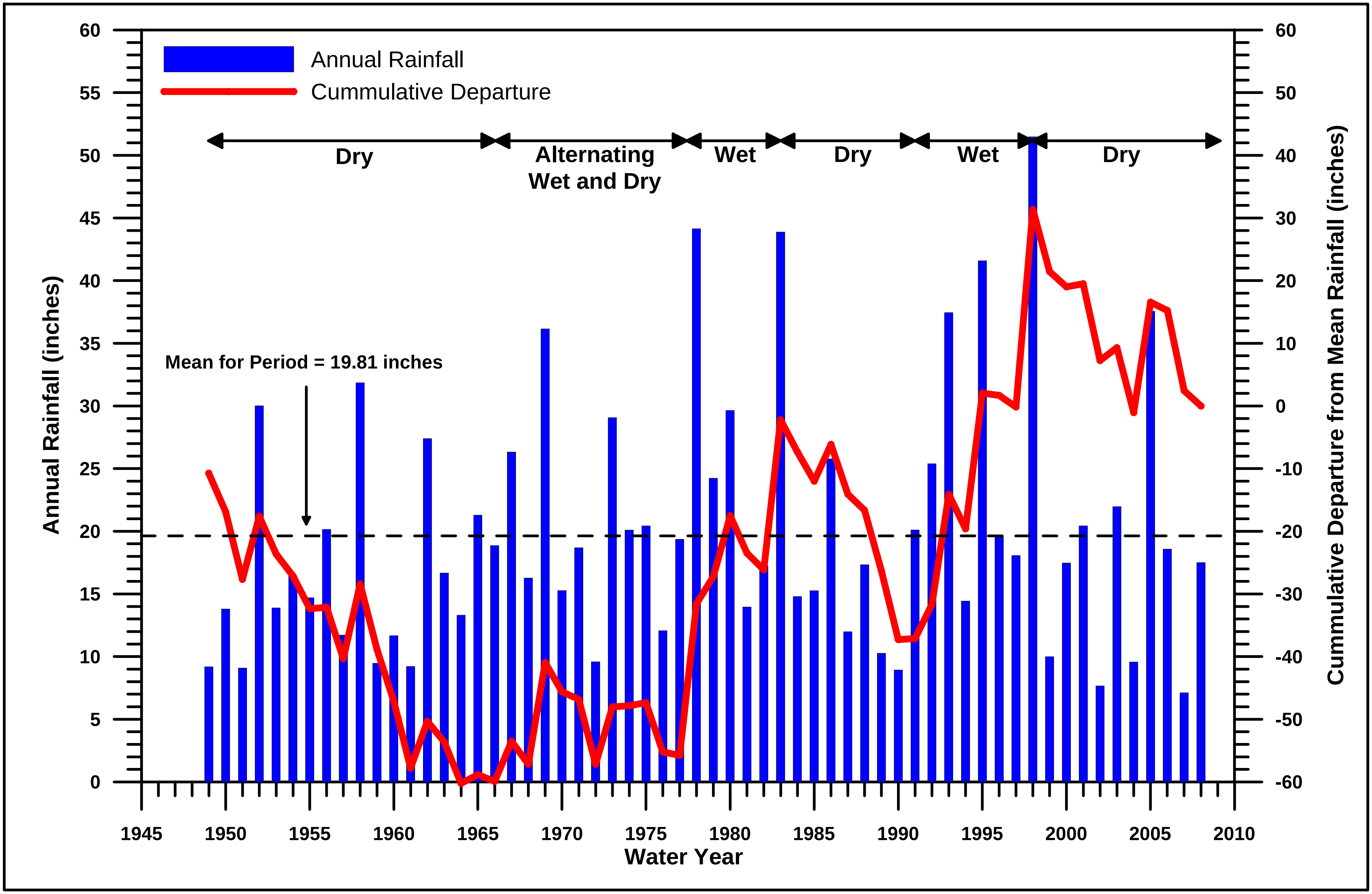

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FIGURE 21. CUMULATIVE DEPARTURE OF ANNUAL RAINFALL - CARPINTERIA FIRE STATION (208)
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

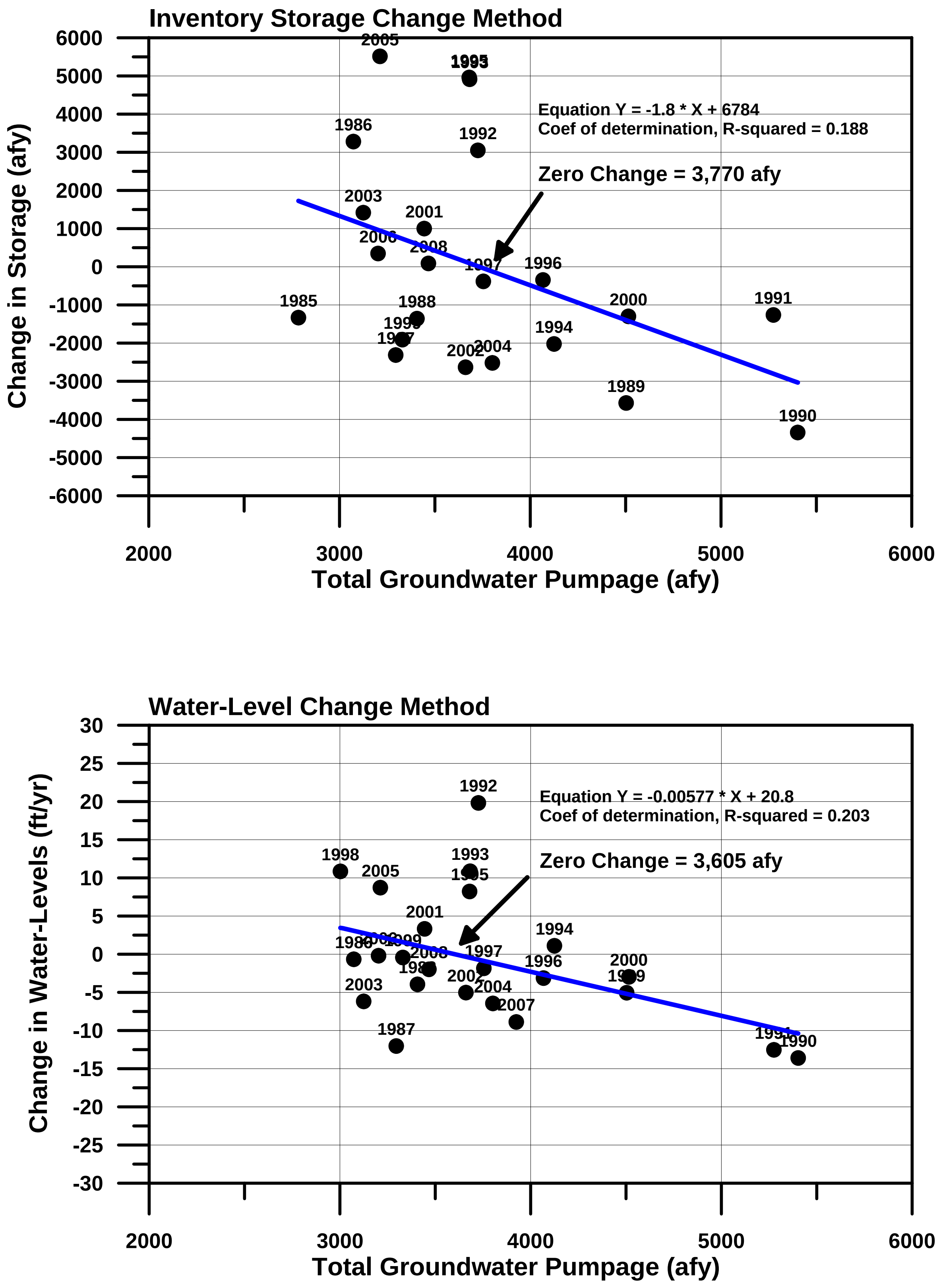

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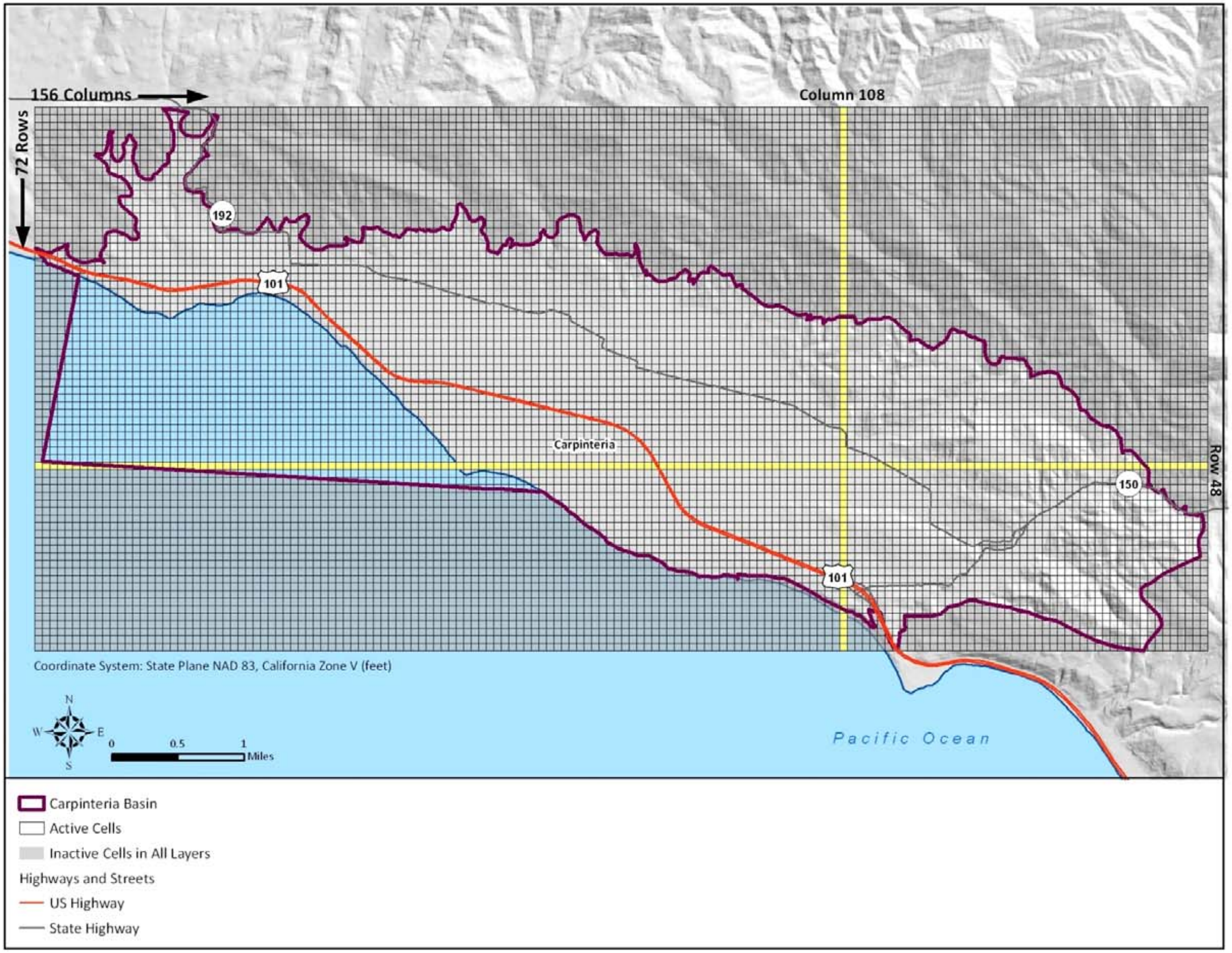
FIGURE 22. PRACTICAL RATE OF WITHDRAWL ANALYSIS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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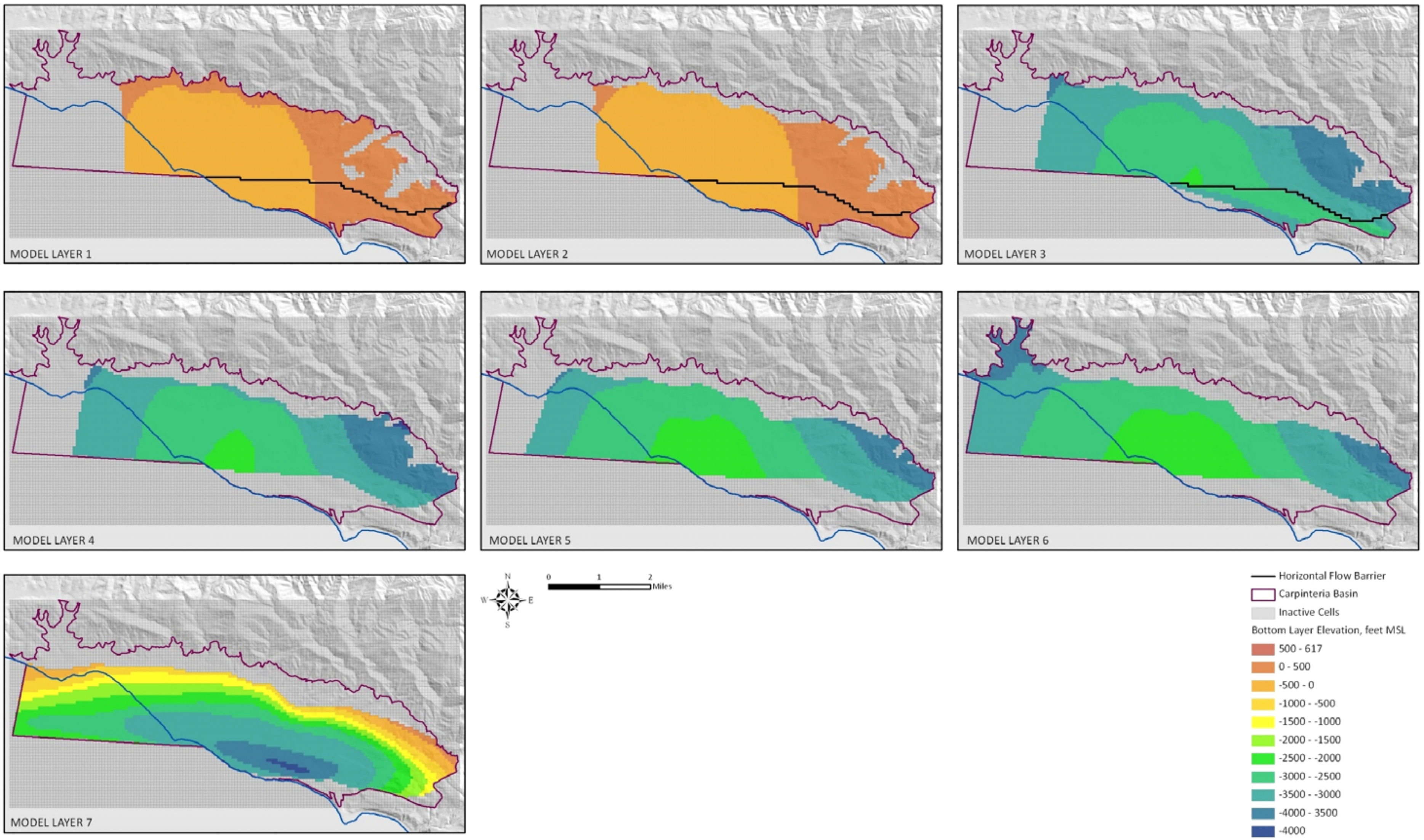
FIGURE 23. FINITE DIFFERENCE MODEL GRID
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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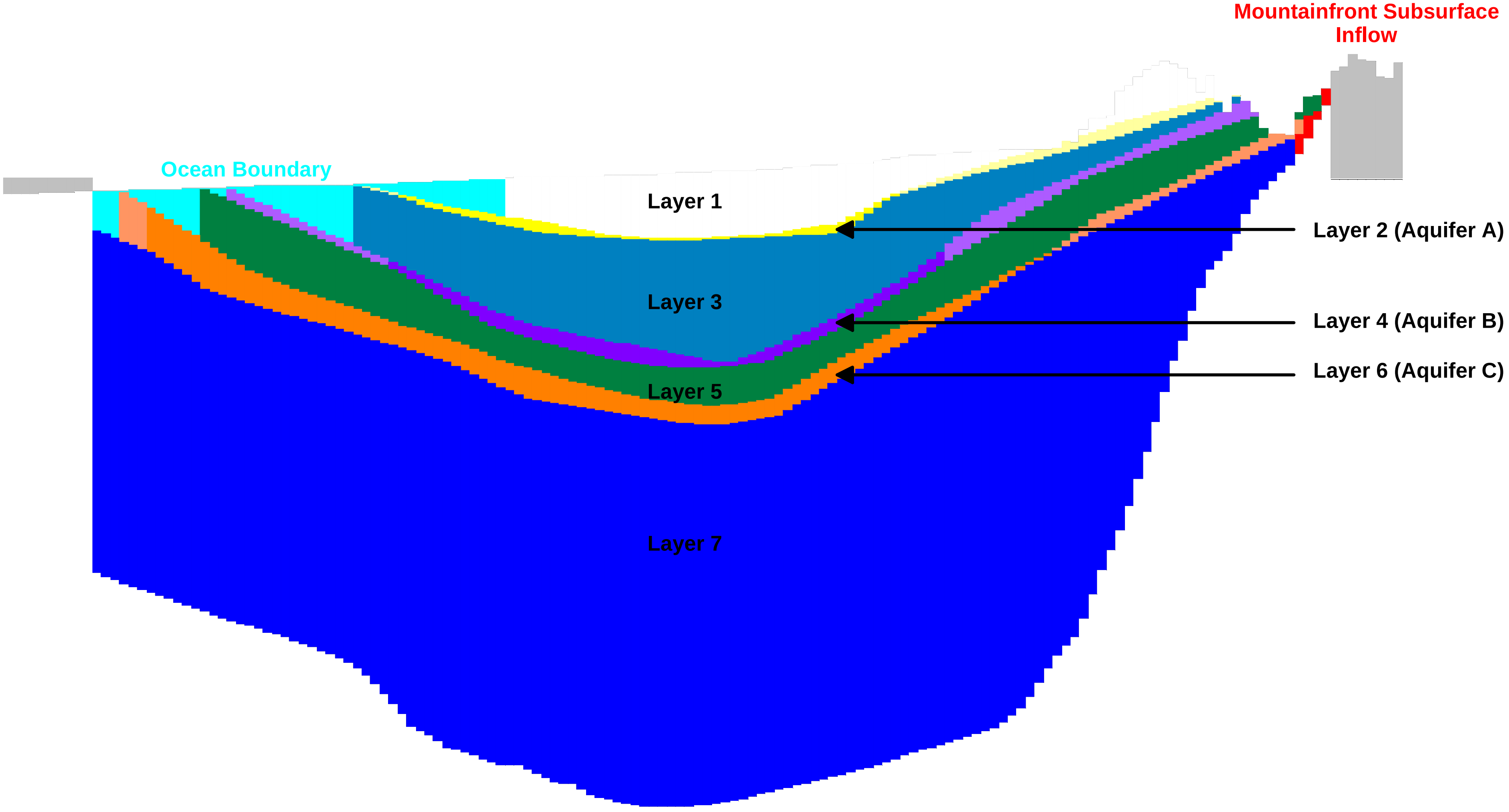
FIGURE 24. MODEL BOTTOM LAYER ELEVATIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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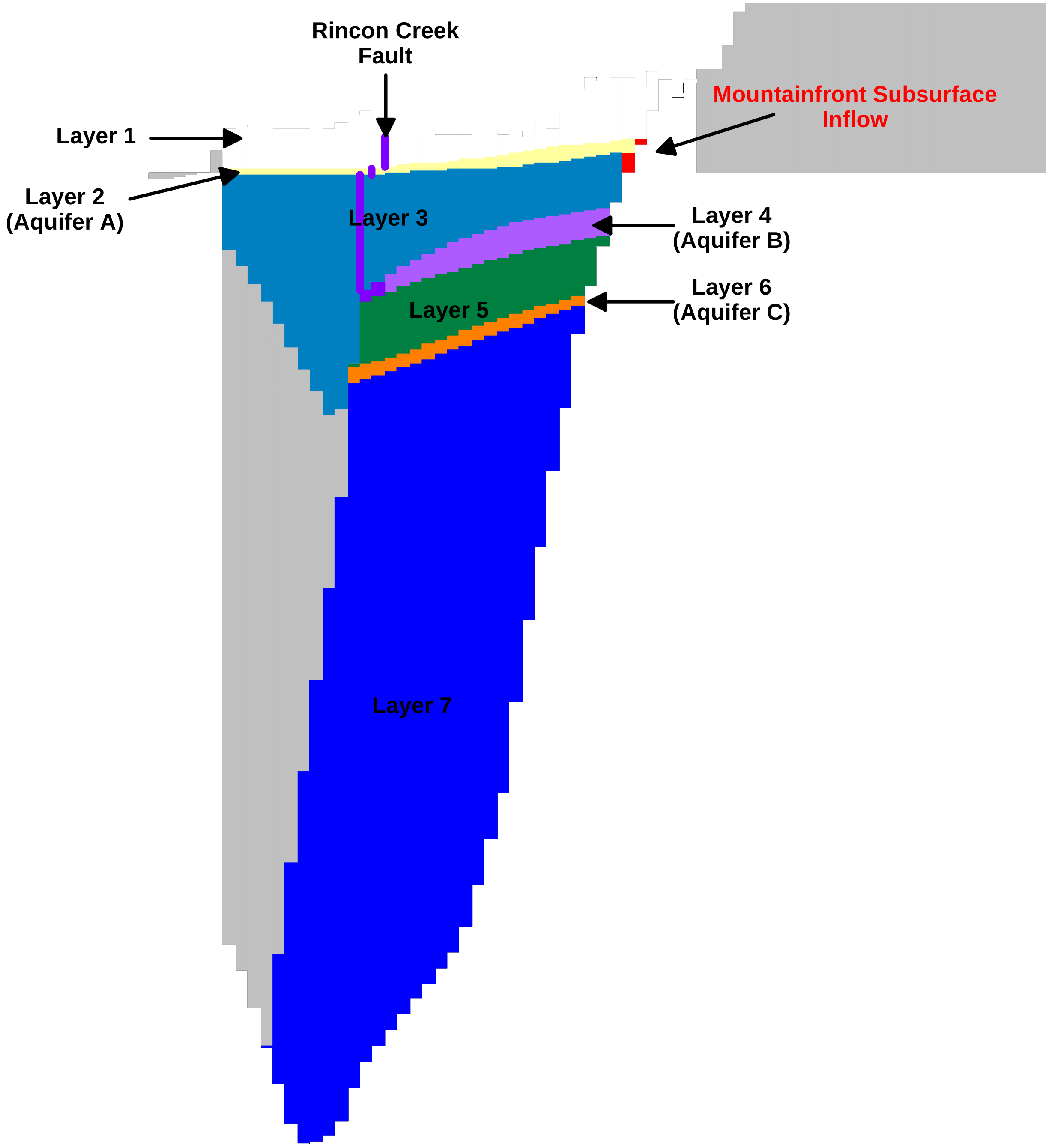
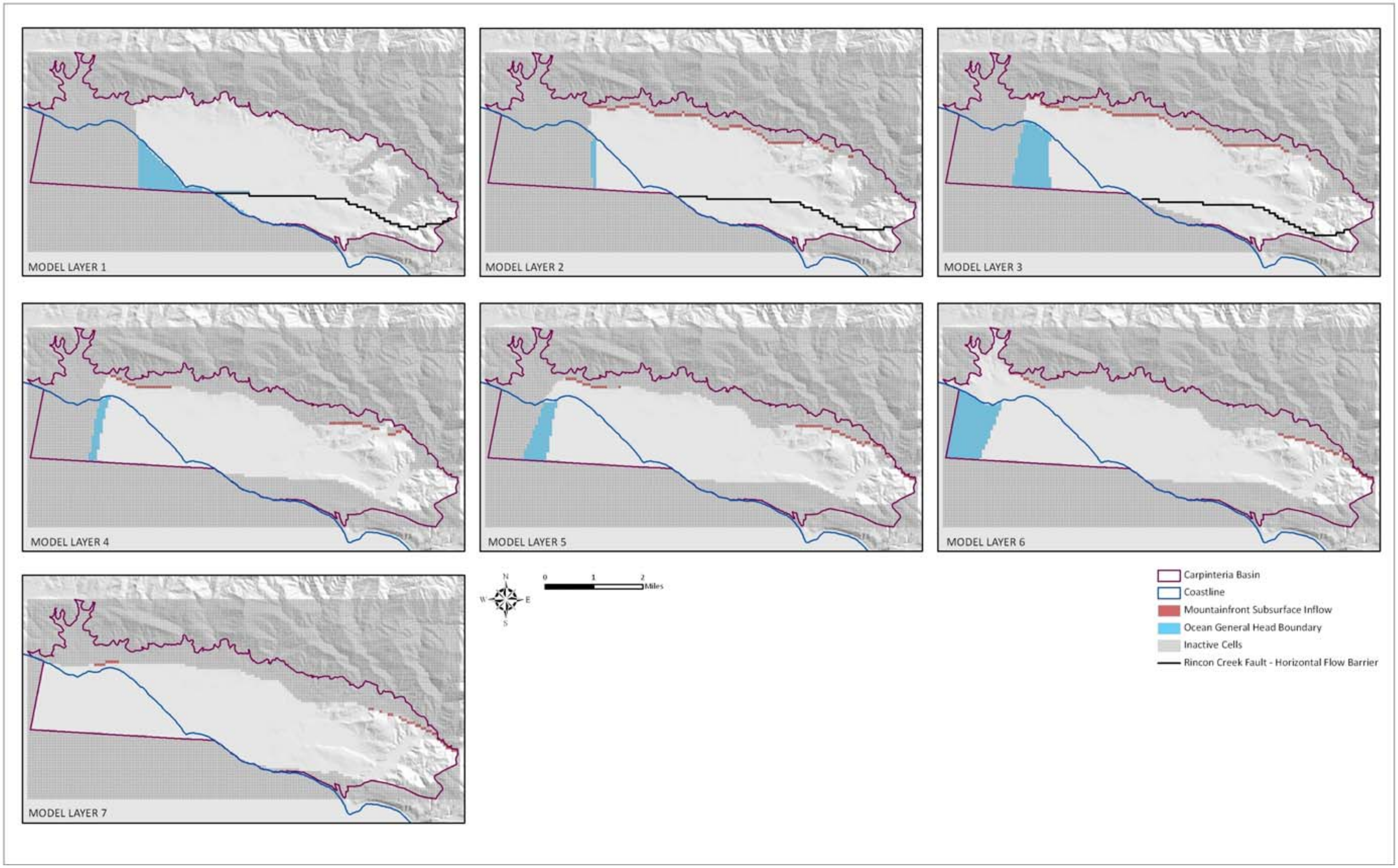
FIGURE 25. MODEL LAYER WEST - EAST CROSS SECTION
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Vertical Exageration = 6x

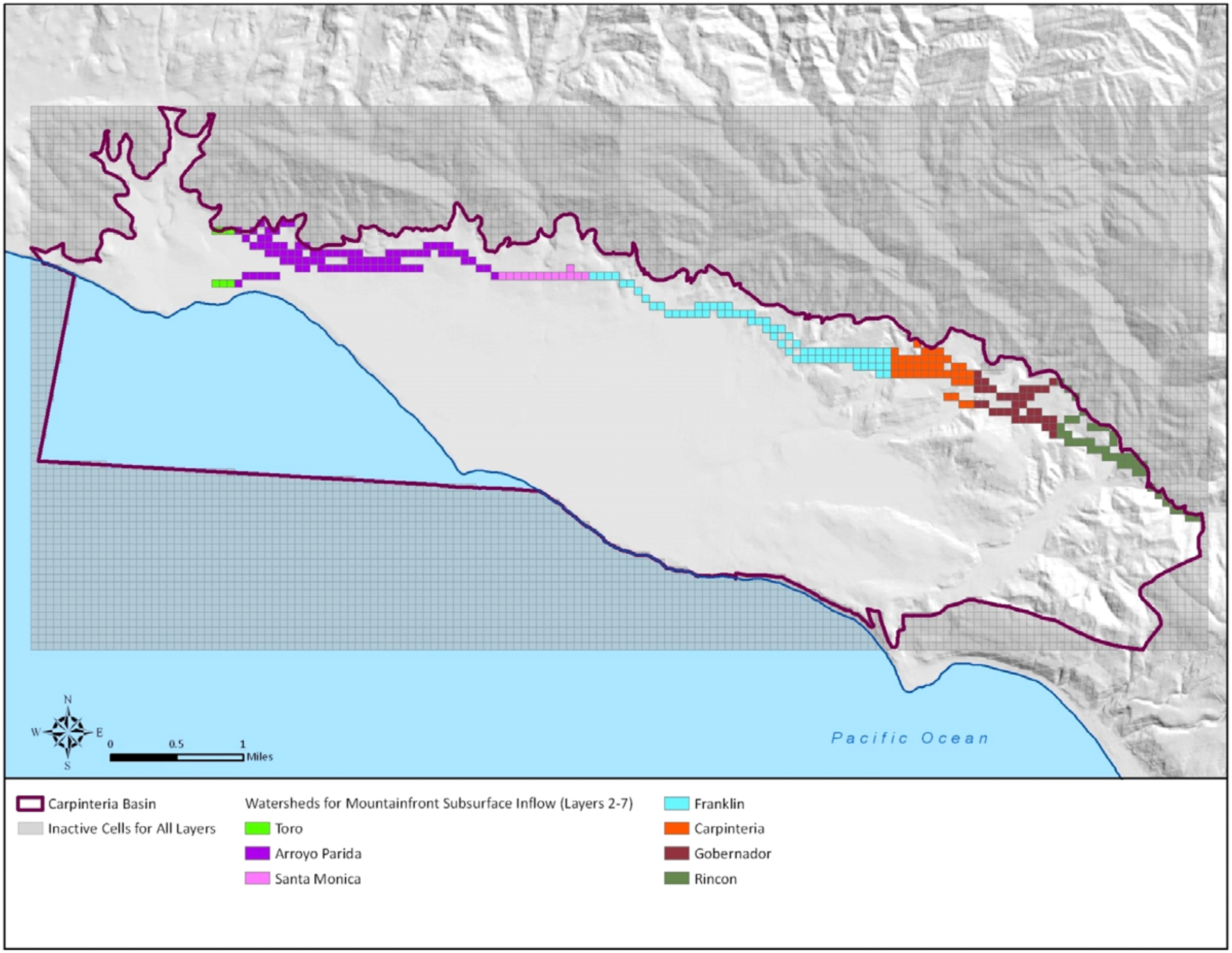
Source: HMWRI (2012)

FIGURE 26. MODEL LAYER SOUTH - NORTH CROSS SECTION
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



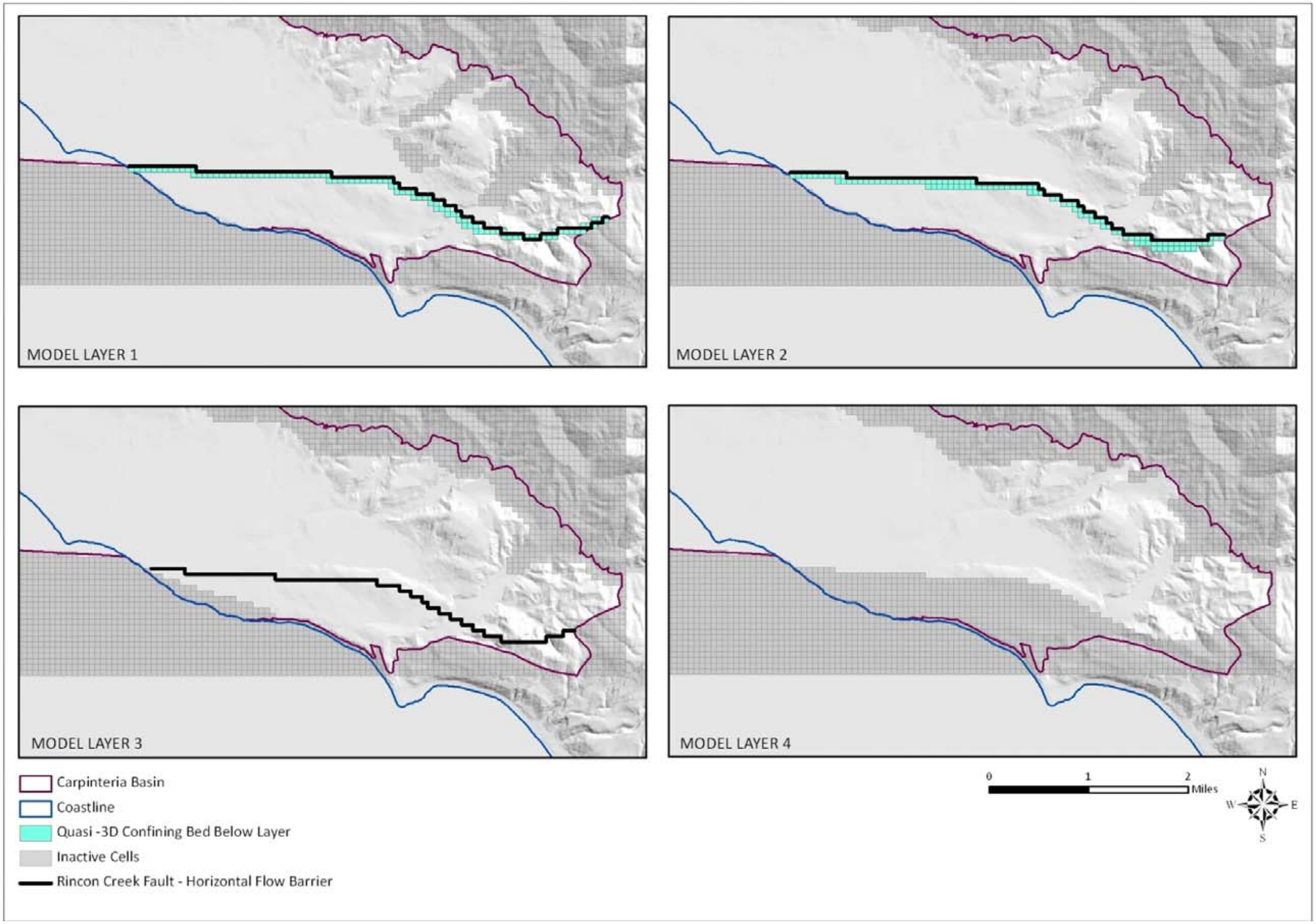
Source: HMWRI (2012)

FIGURE 27. MODEL BOUNDARY CONDITIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 28. MOUNTAIN FRONT SUBSURFACE INFLOW WATERSHEDS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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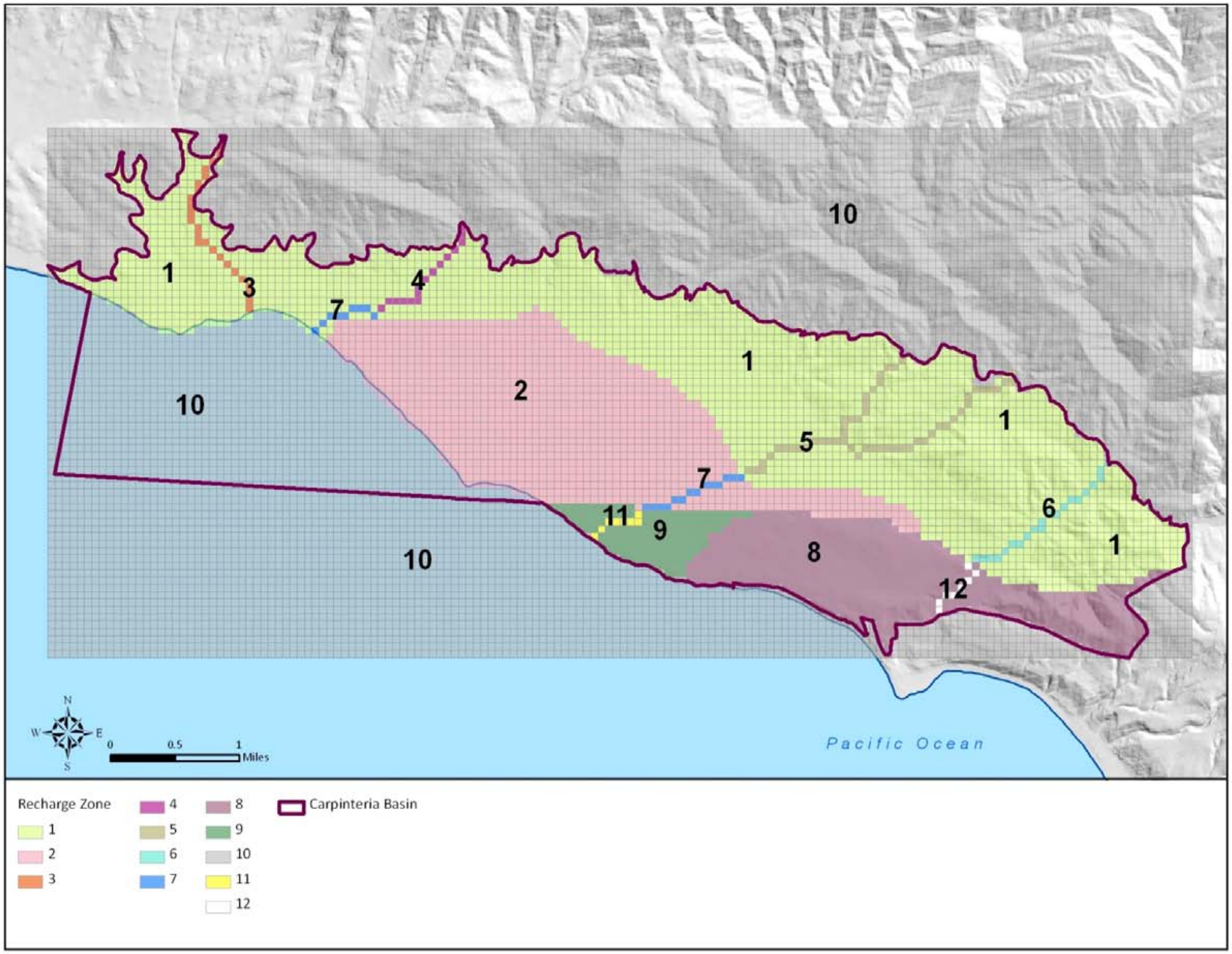
FIGURE 29. FLOW BARRIERS REPRESENTING RINCON CREEK FAULT
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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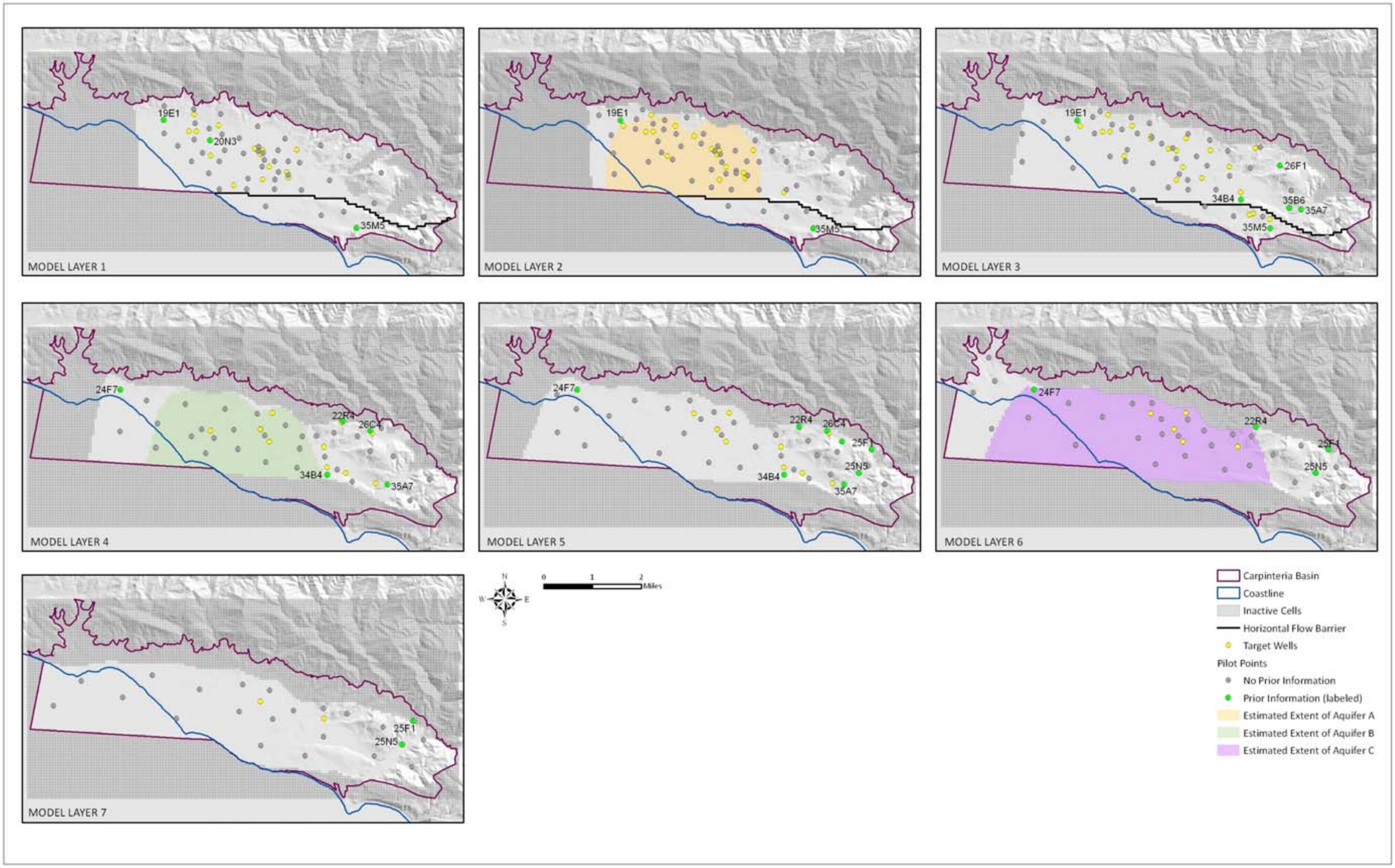
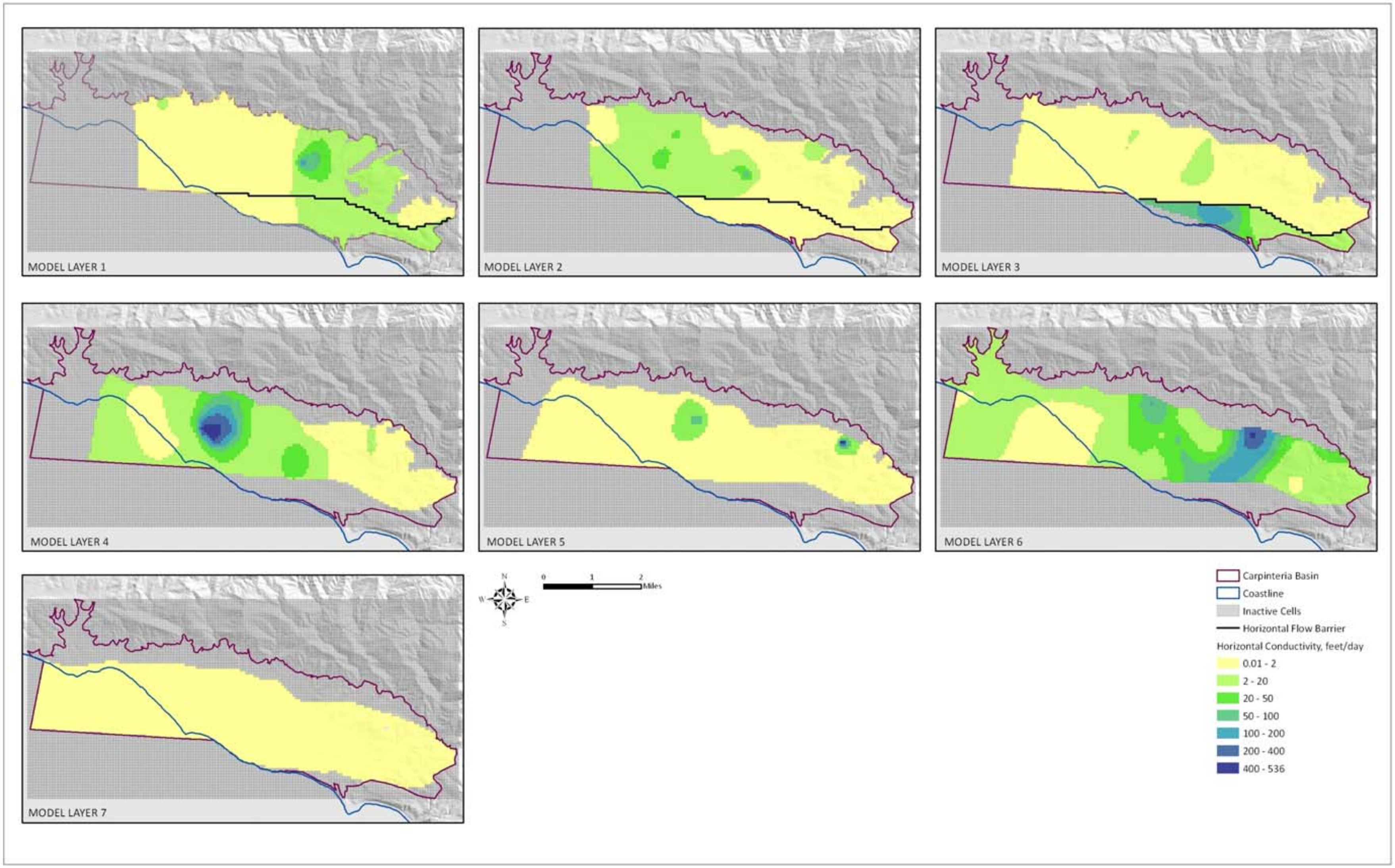
FIGURE 30. MODEL RECHARGE ZONES
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



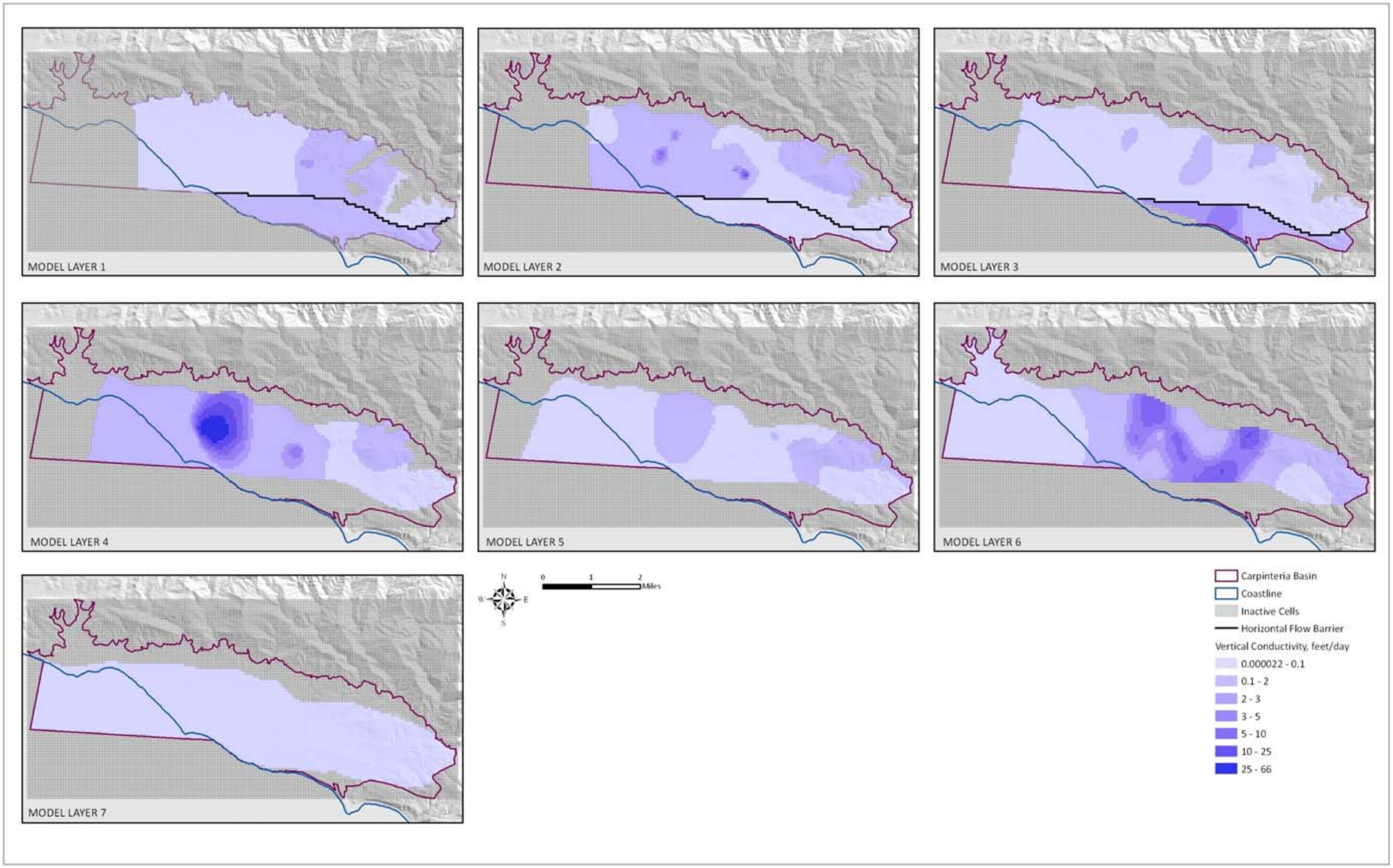
Source: HMWRI (2012)

FIGURE 31. PILOT POINT AND TARGET OBSERVATION WELL LOCATIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



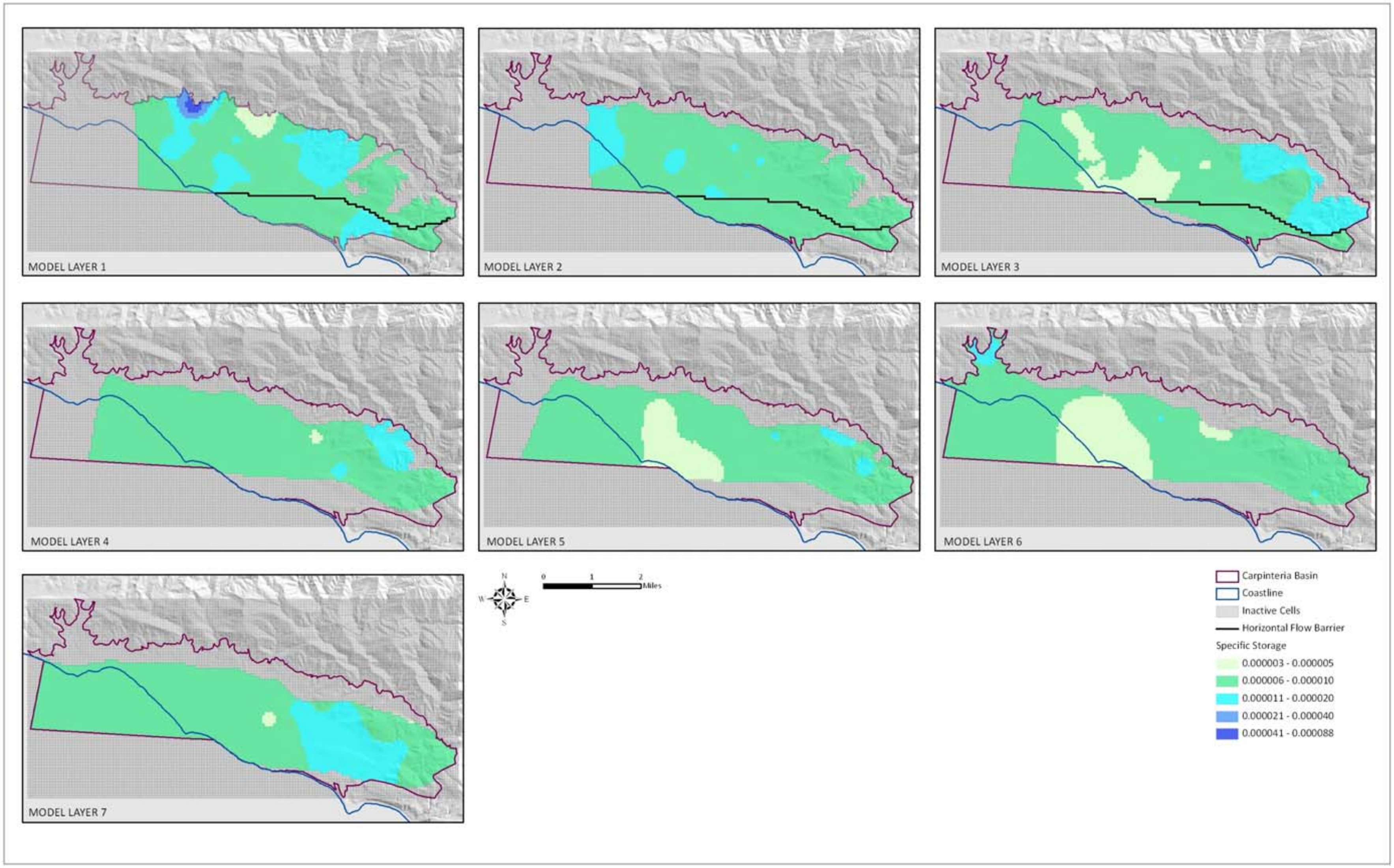
Source: HMWRI (2012)

FIGURE 32. FINAL DISTRIBUTION OF HORIZONTAL HYDRAULIC CONDUCTIVITY
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



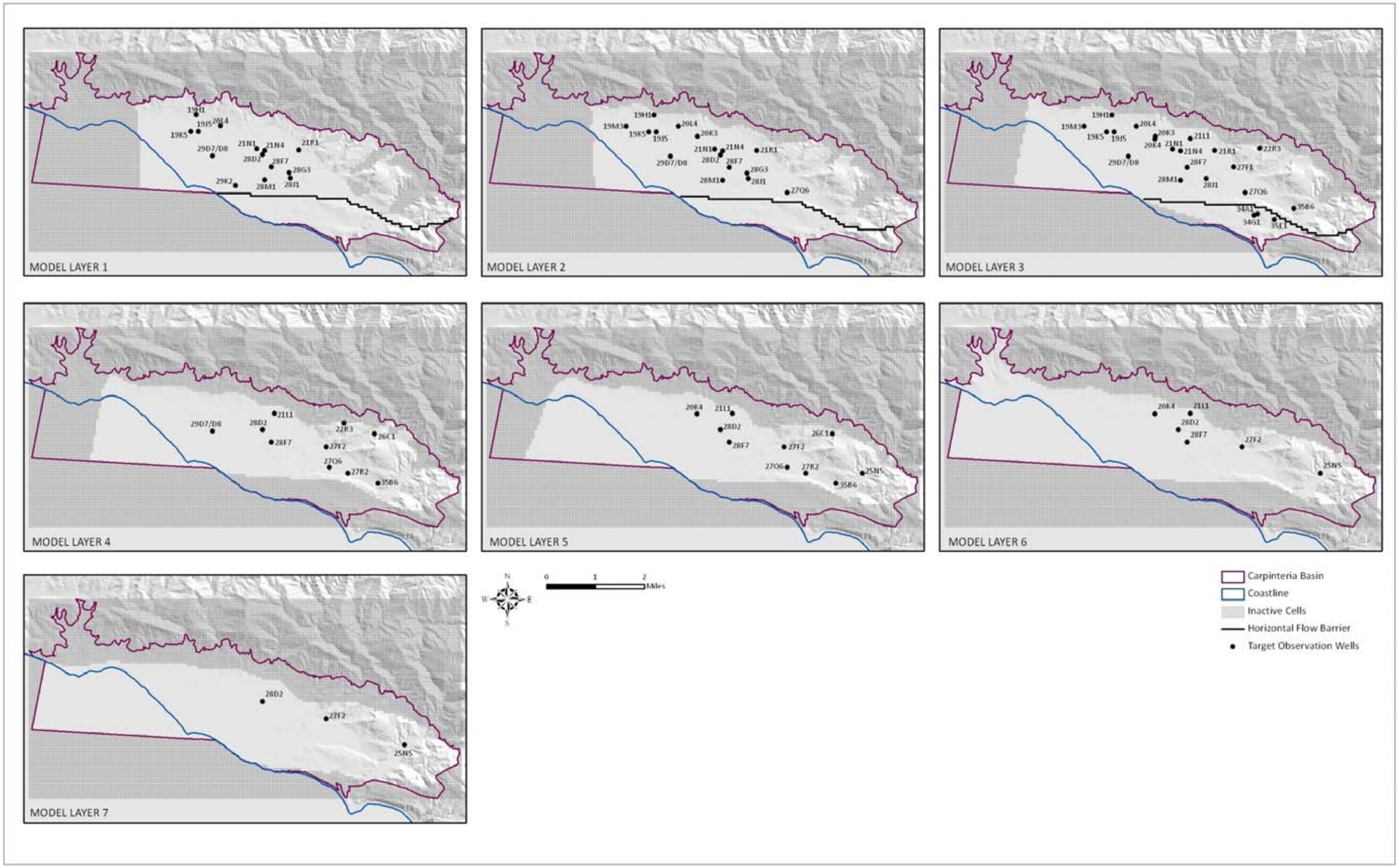
Source: HMWRI (2012)

FIGURE 33. FINAL DISTRIBUTION OF VERTICAL HYDRAULIC CONDUCTIVITY
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



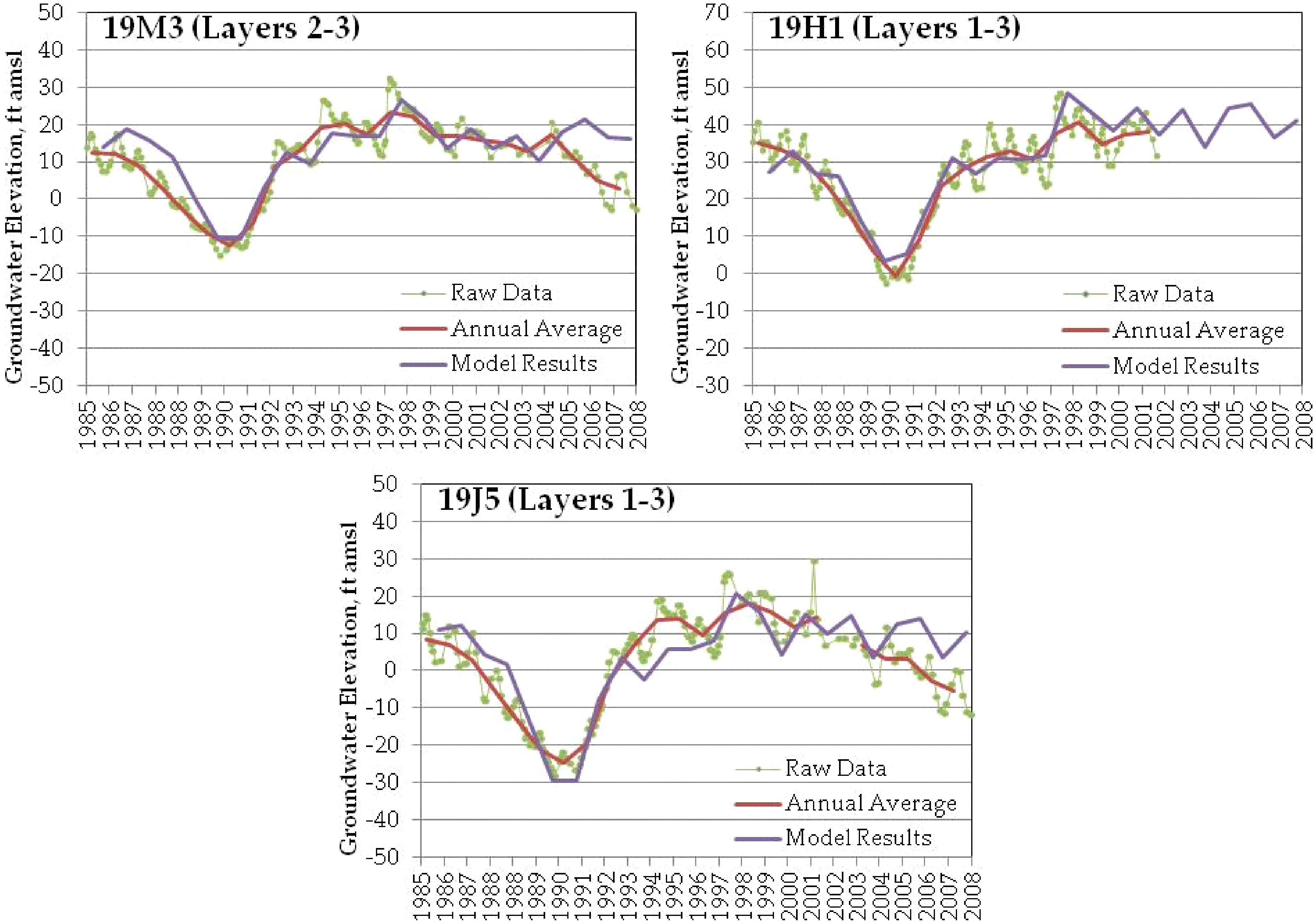
Source: HMWRI (2012)

FIGURE 34. FINAL DISTRIBUTION OF SPECIFIC STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 35. CALIBRATION OBSERVATION WELL LOCATIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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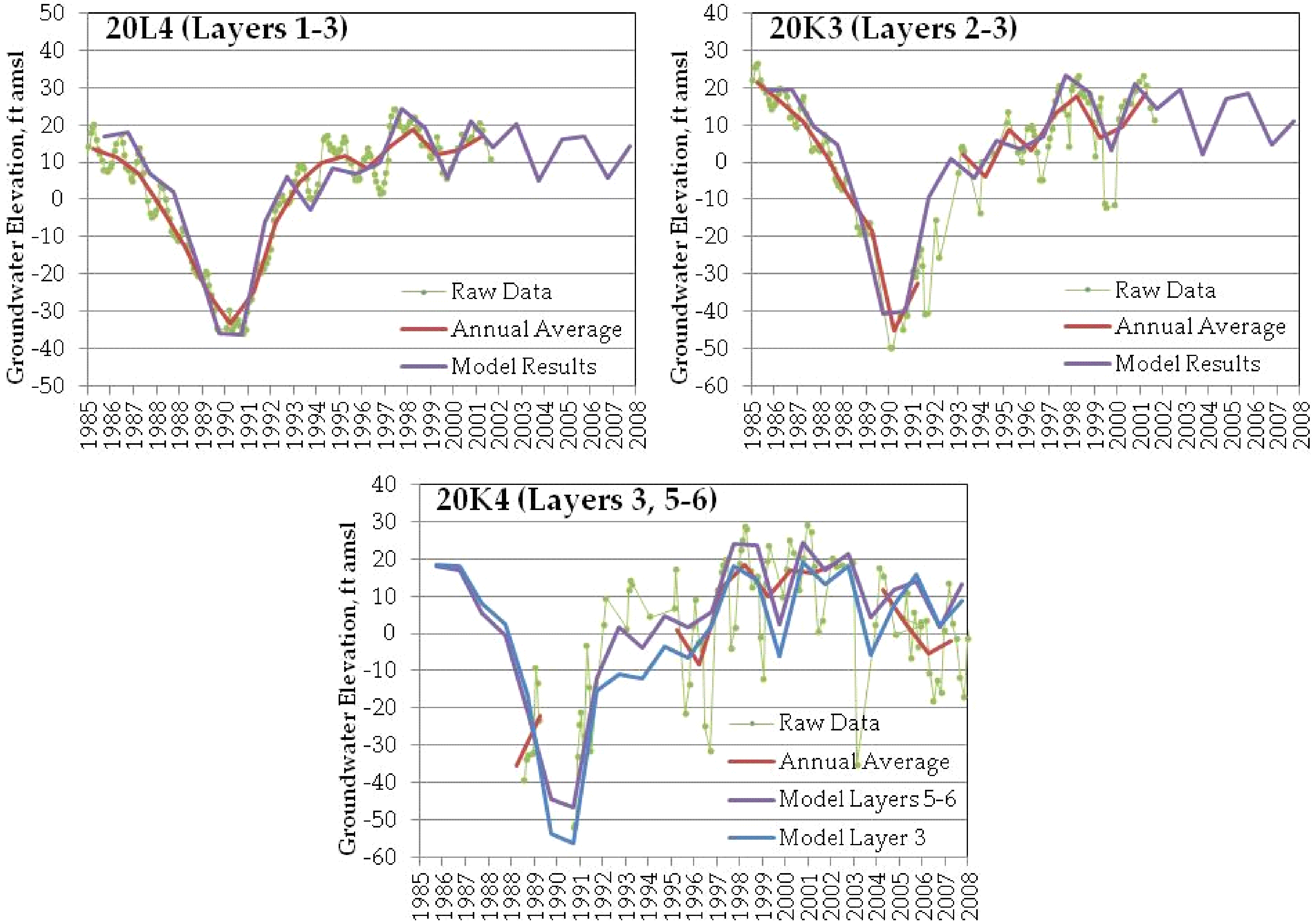
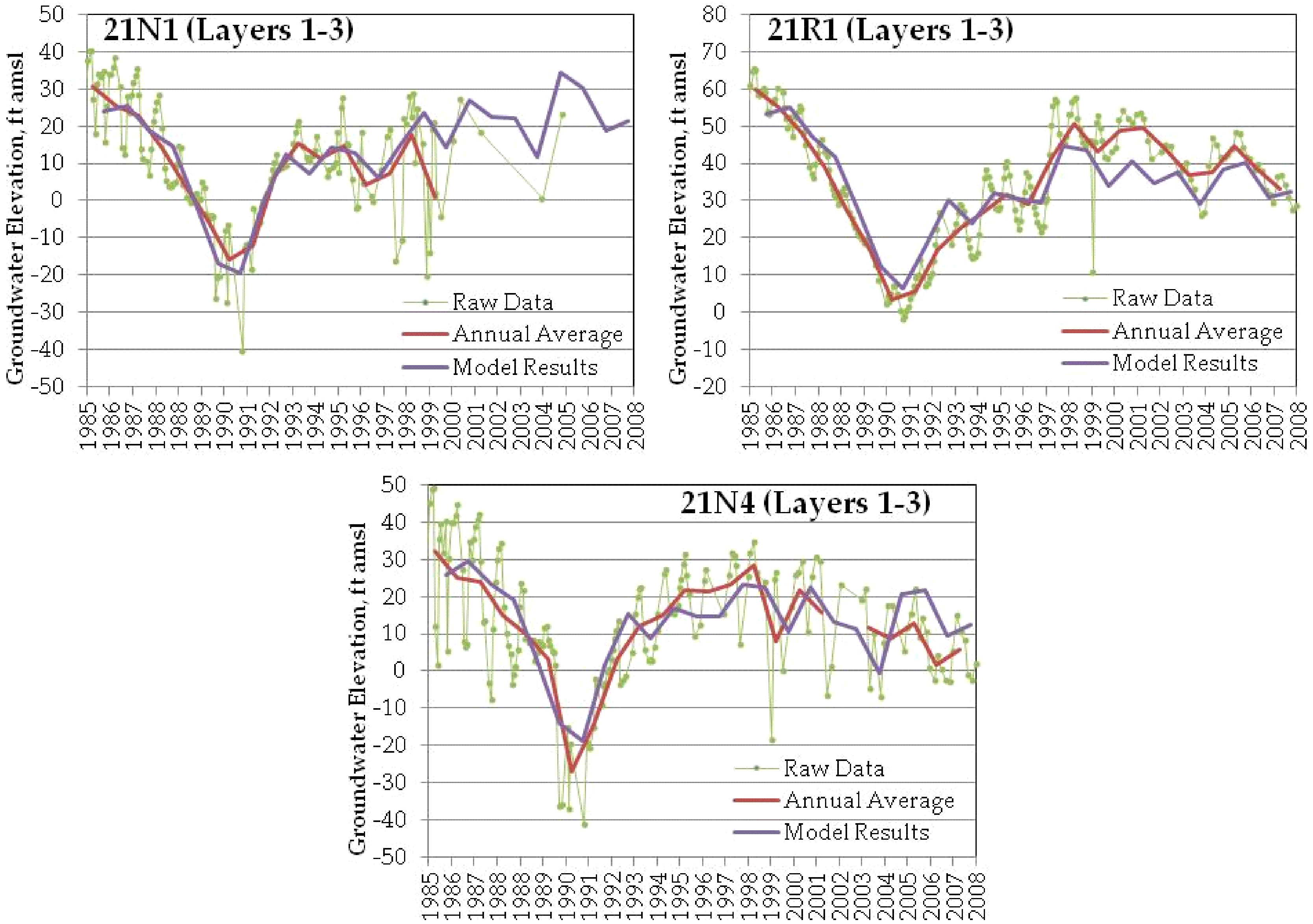
FIGURE 36. CALIBRATION HYDROGRAPHS - SECTION 19
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



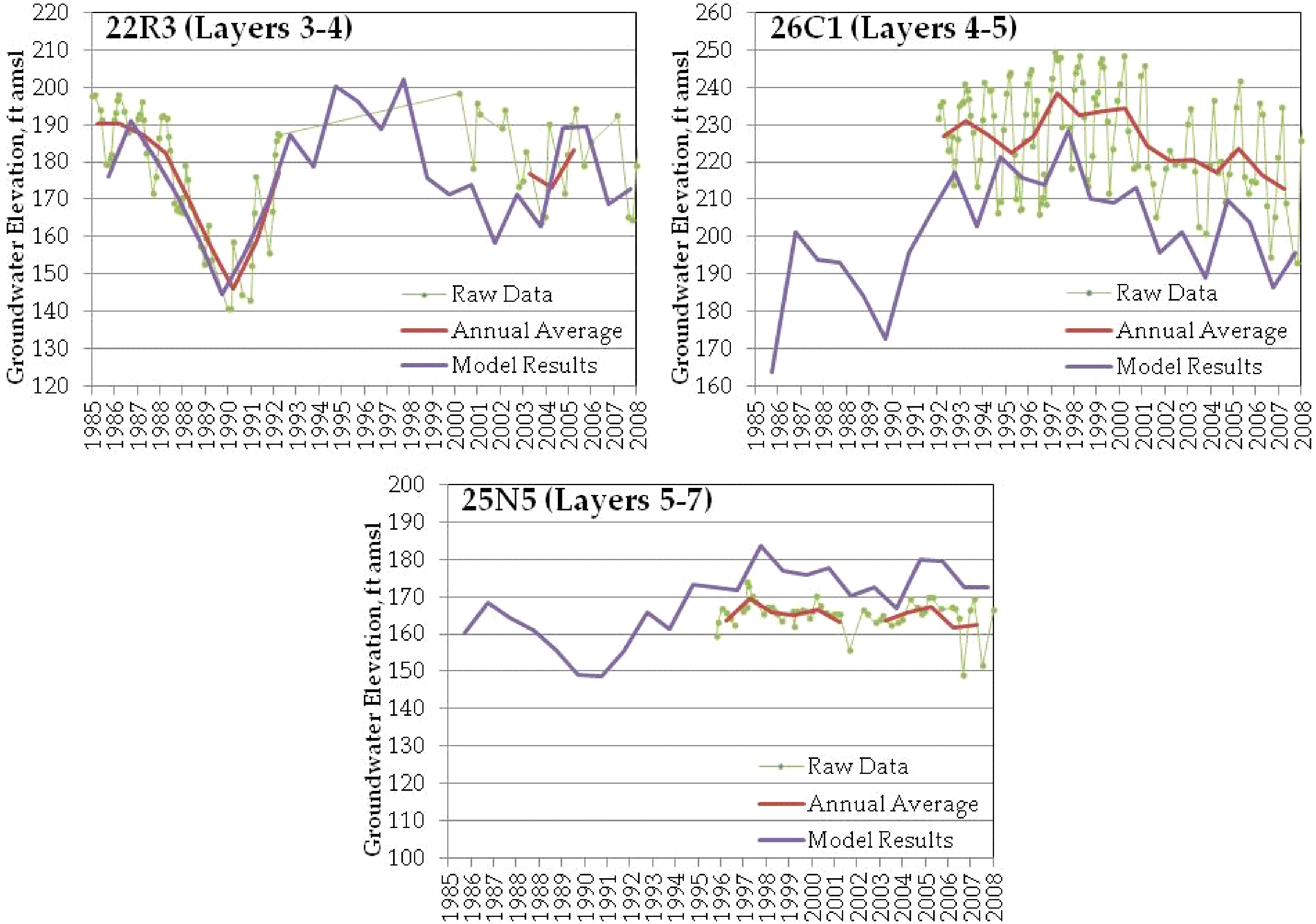
Source: HMWRI (2012)

FIGURE 37. CALIBRATION HYDROGRAPHS - SECTION 20
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



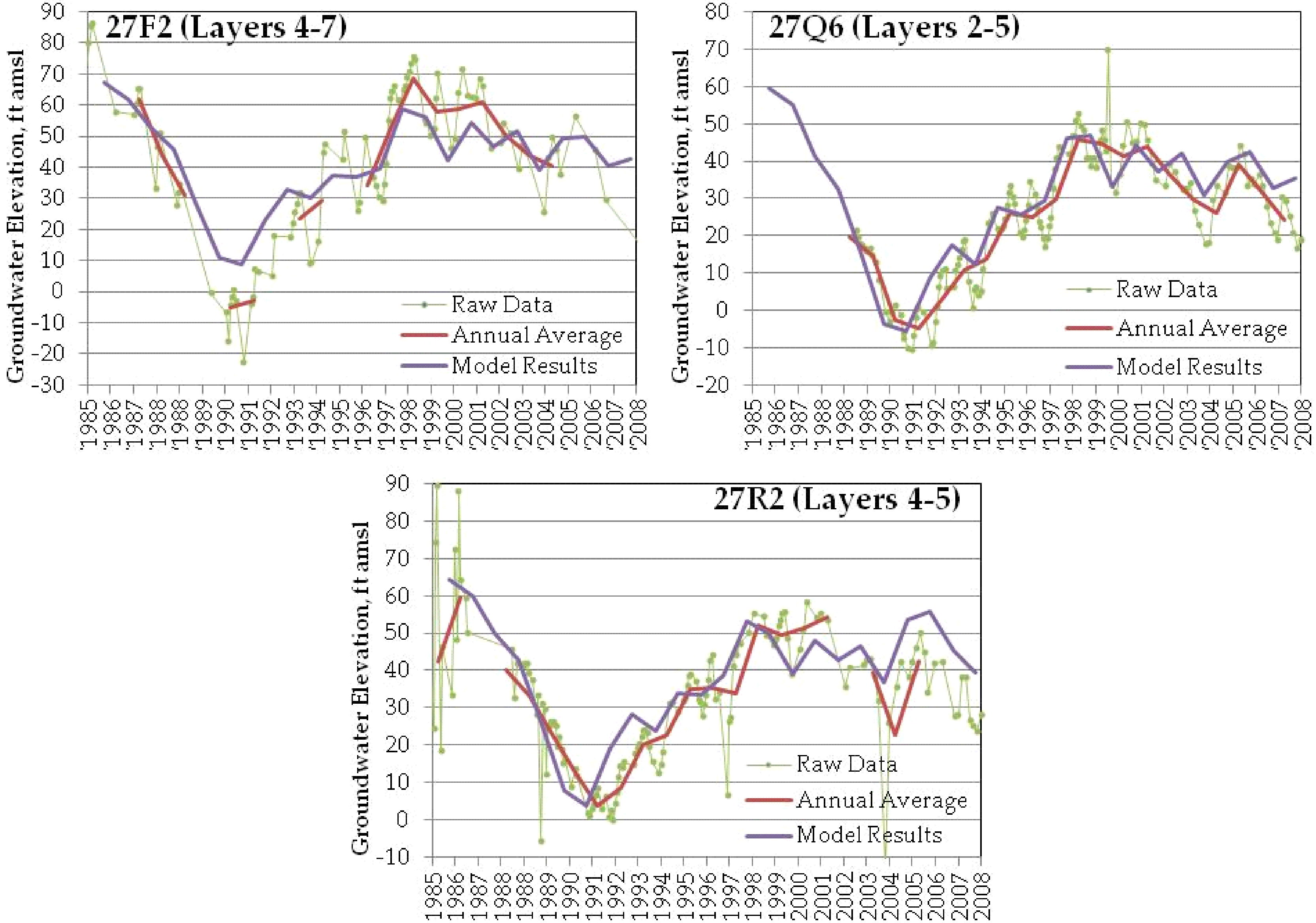
Source: HMWRI (2012)

FIGURE 38. CALIBRATION HYDROGRAPHS - SECTION 21
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



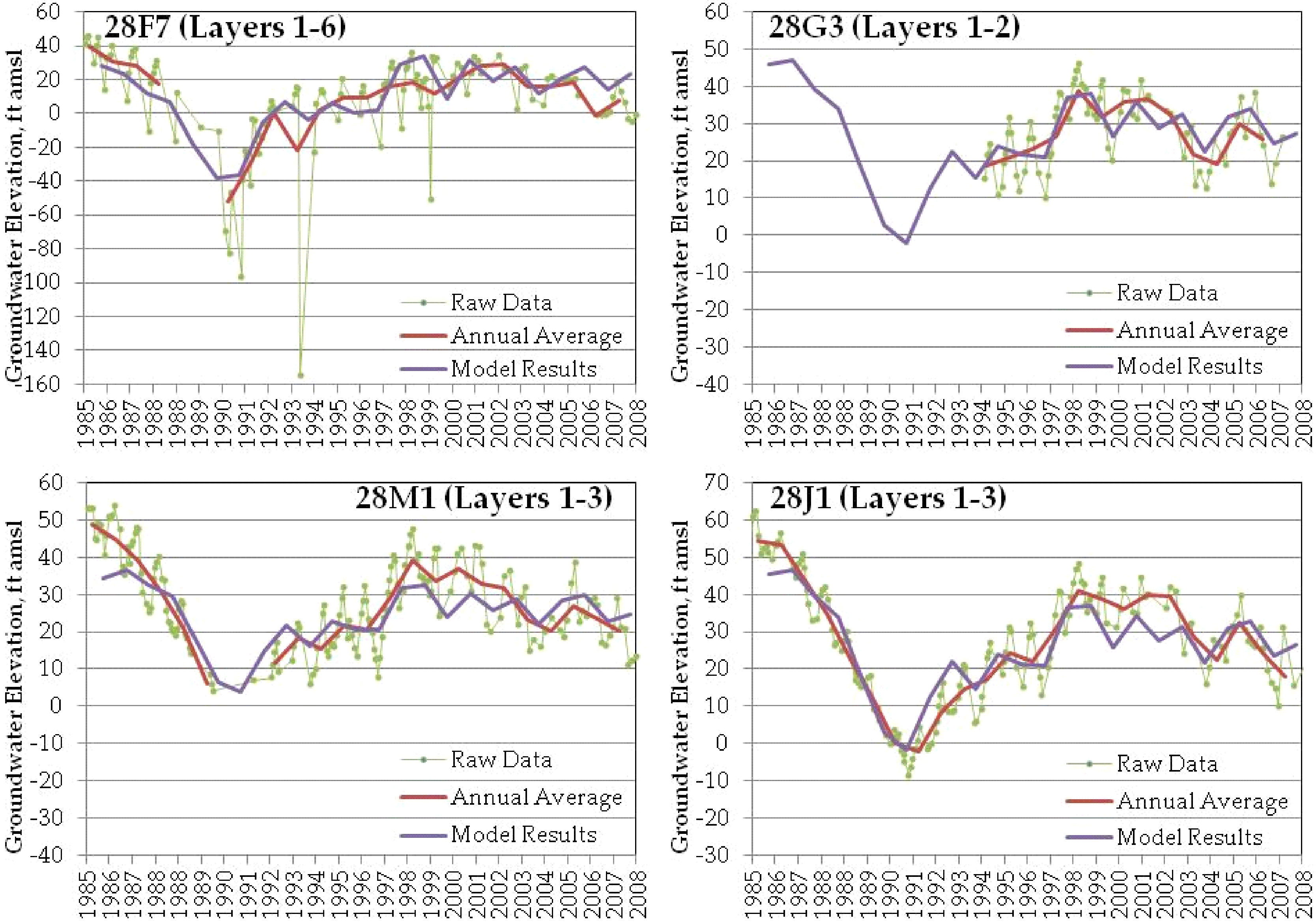
Source: HMWRI (2012)

FIGURE 39. CALIBRATION HYDROGRAPHS - SECTIONS 22, 25 AND 26
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



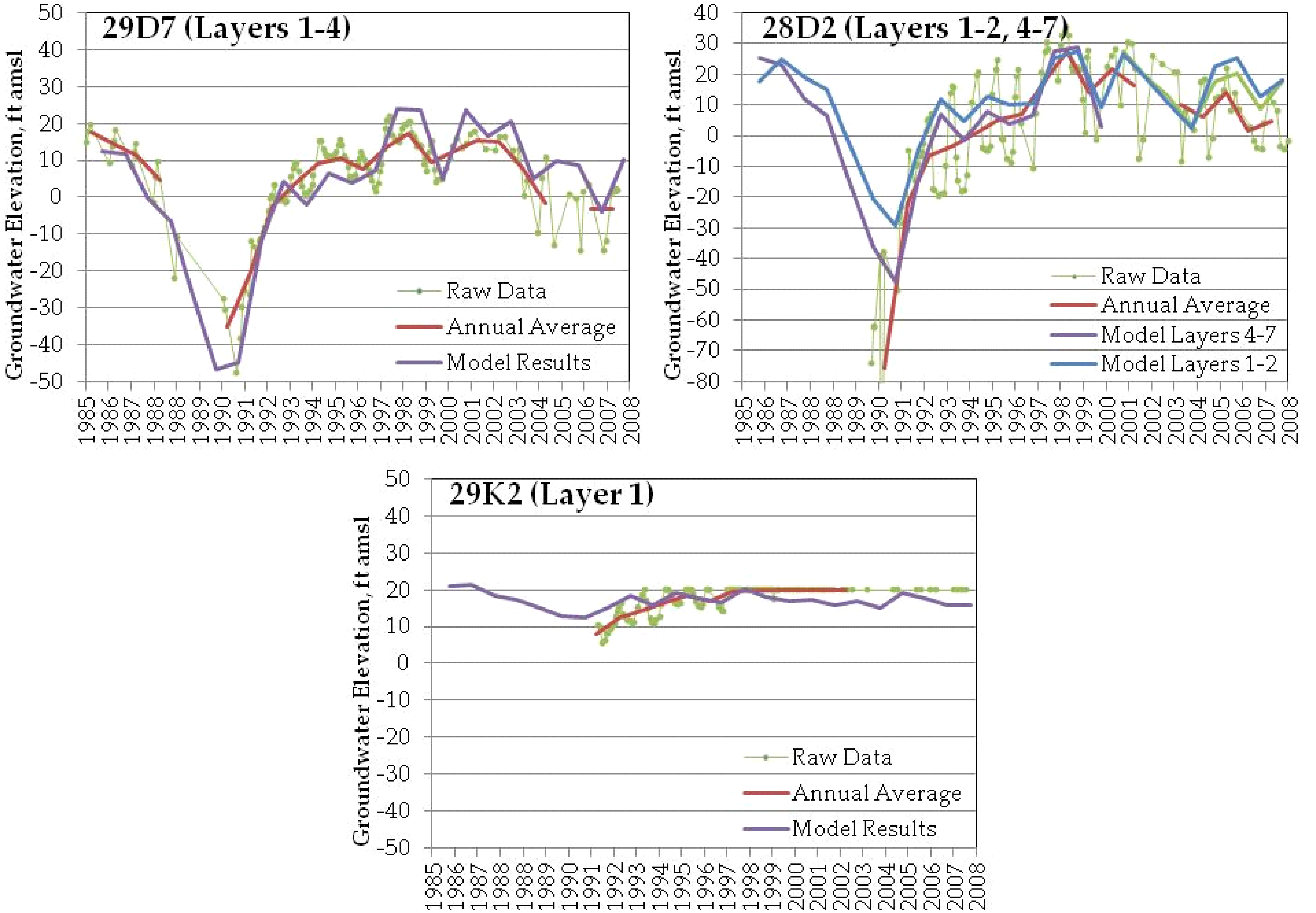
Source: HMWRI (2012)

FIGURE 40. CALIBRATION HYDROGRAPHS - SECTION 27
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 41. CALIBRATION HYDROGRAPHS - SECTION 28
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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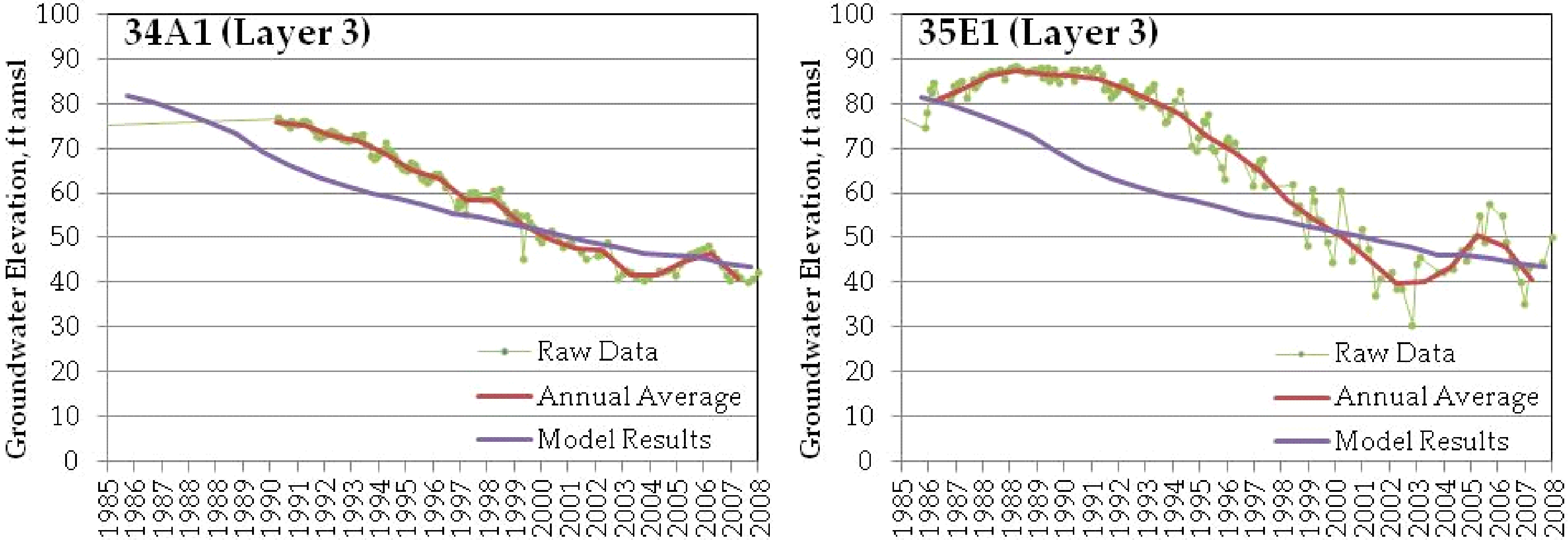
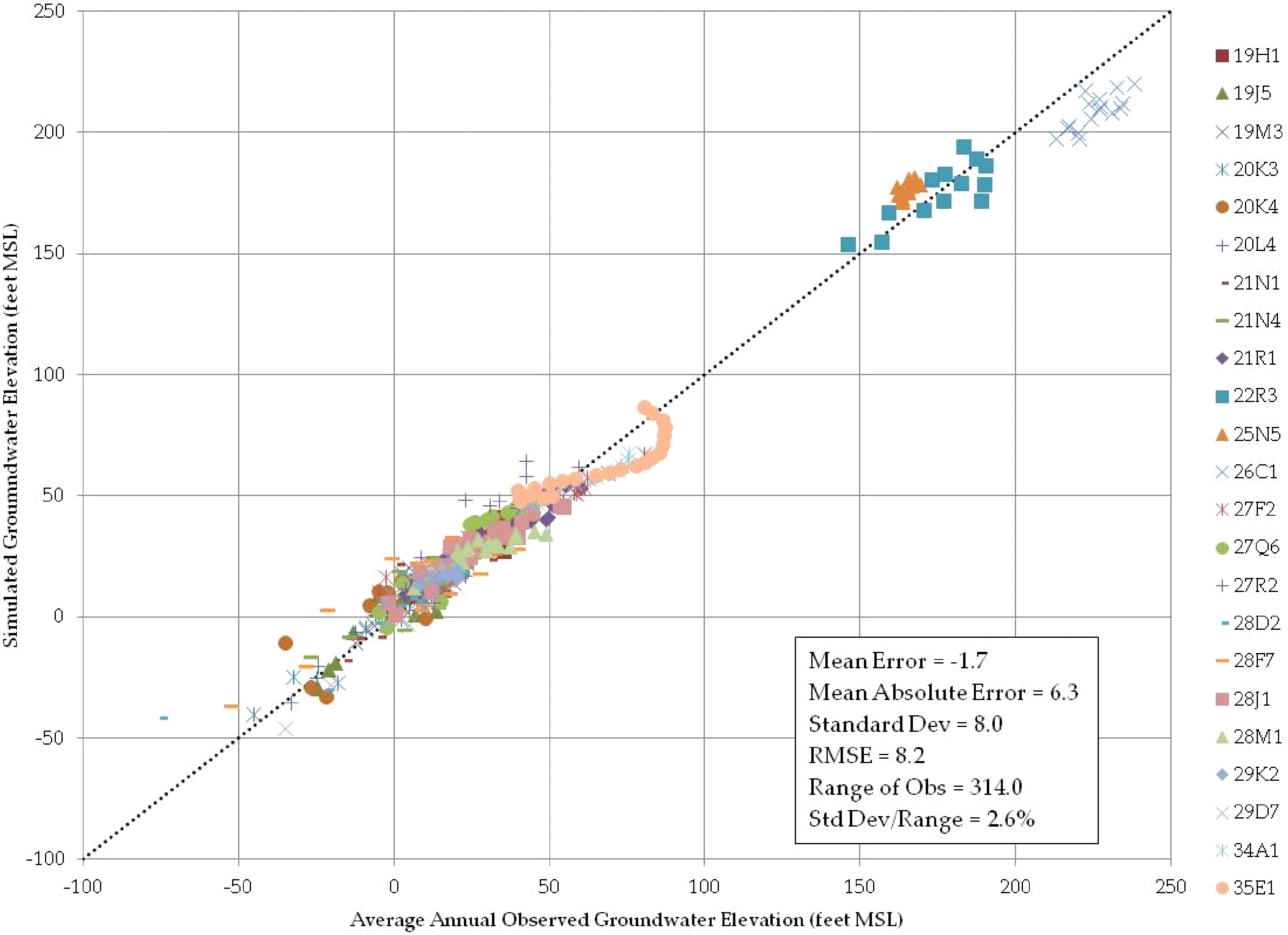
FIGURE 42. CALIBRATION HYDROGRAPHS - SECTIONS 28 AND 29
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

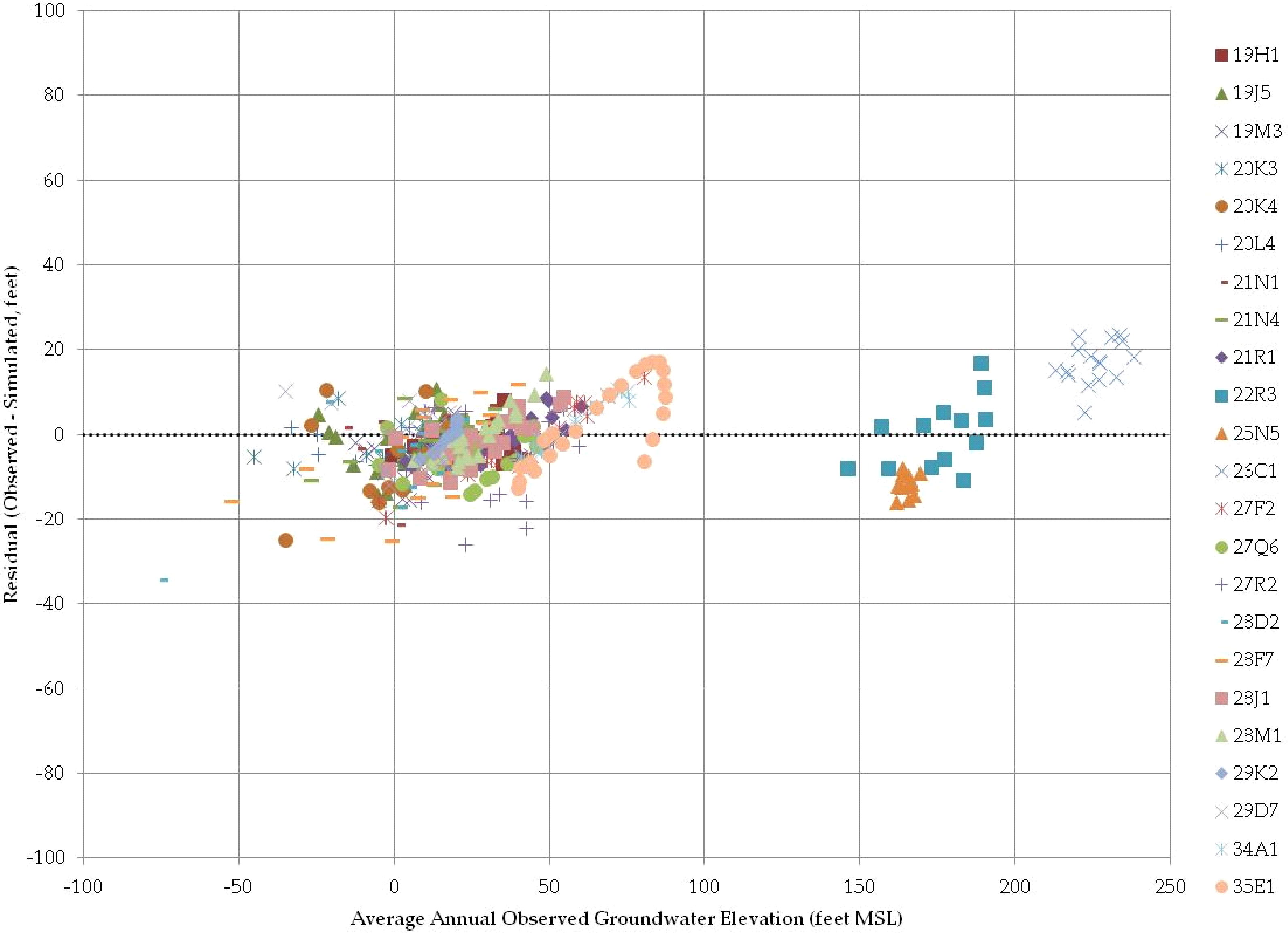
FIGURE 43. CALIBRATION HYDROGRAPHS - SECTIONS 34 AND 35
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Mean Error = -1.7
Mean Absolute Error = 6.3
Standard Dev = 8.0
RMSE = 8.2
Range of Obs = 314.0
Std Dev/Range = 2.6%

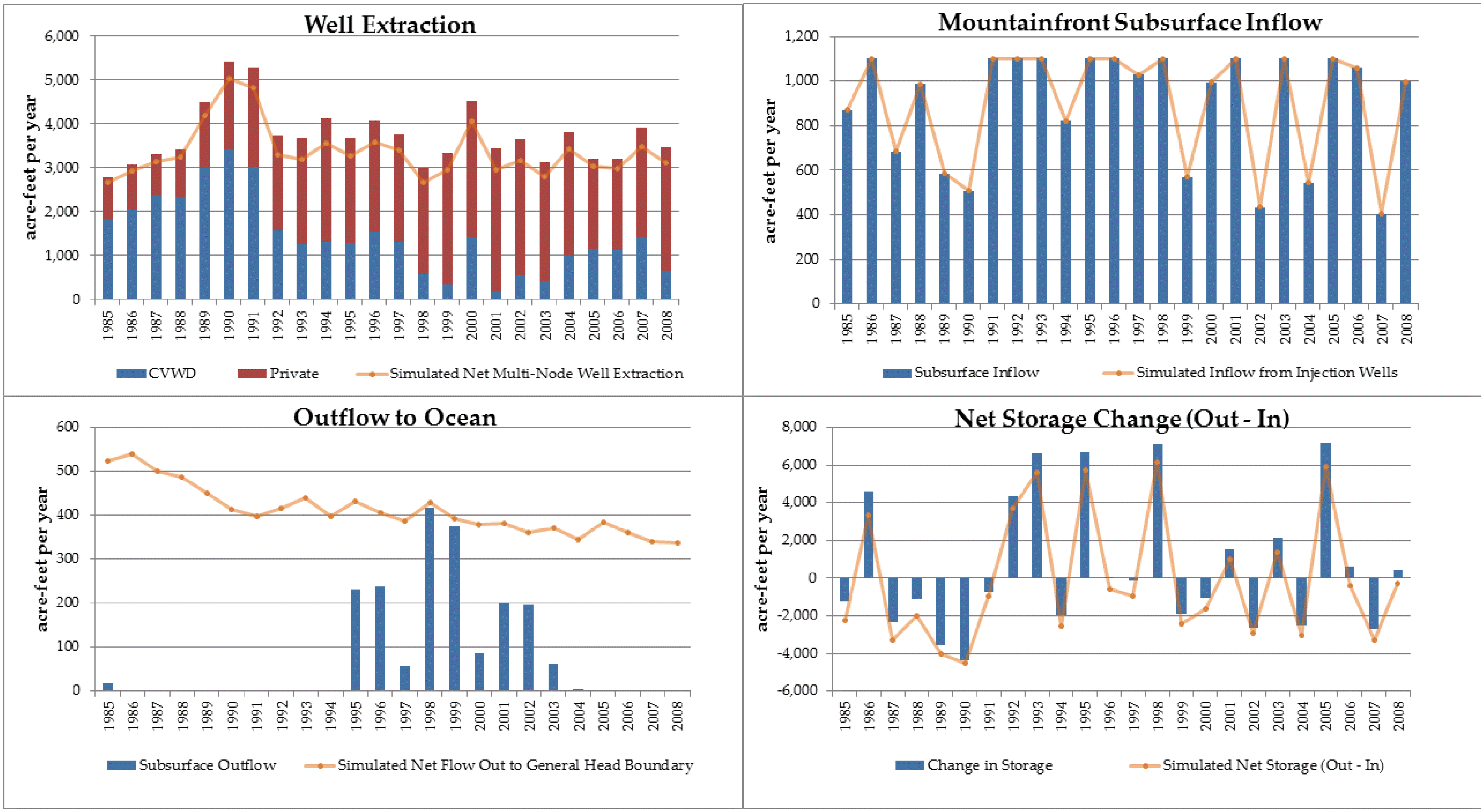
Source: HMWRI (2012)

FIGURE 44. SIMULATED VS. OBSERVED GROUNDWATER ELEVATIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 45. MODEL RESIDUAL VS. OBSERVED GROUNDWATER ELEVATIONS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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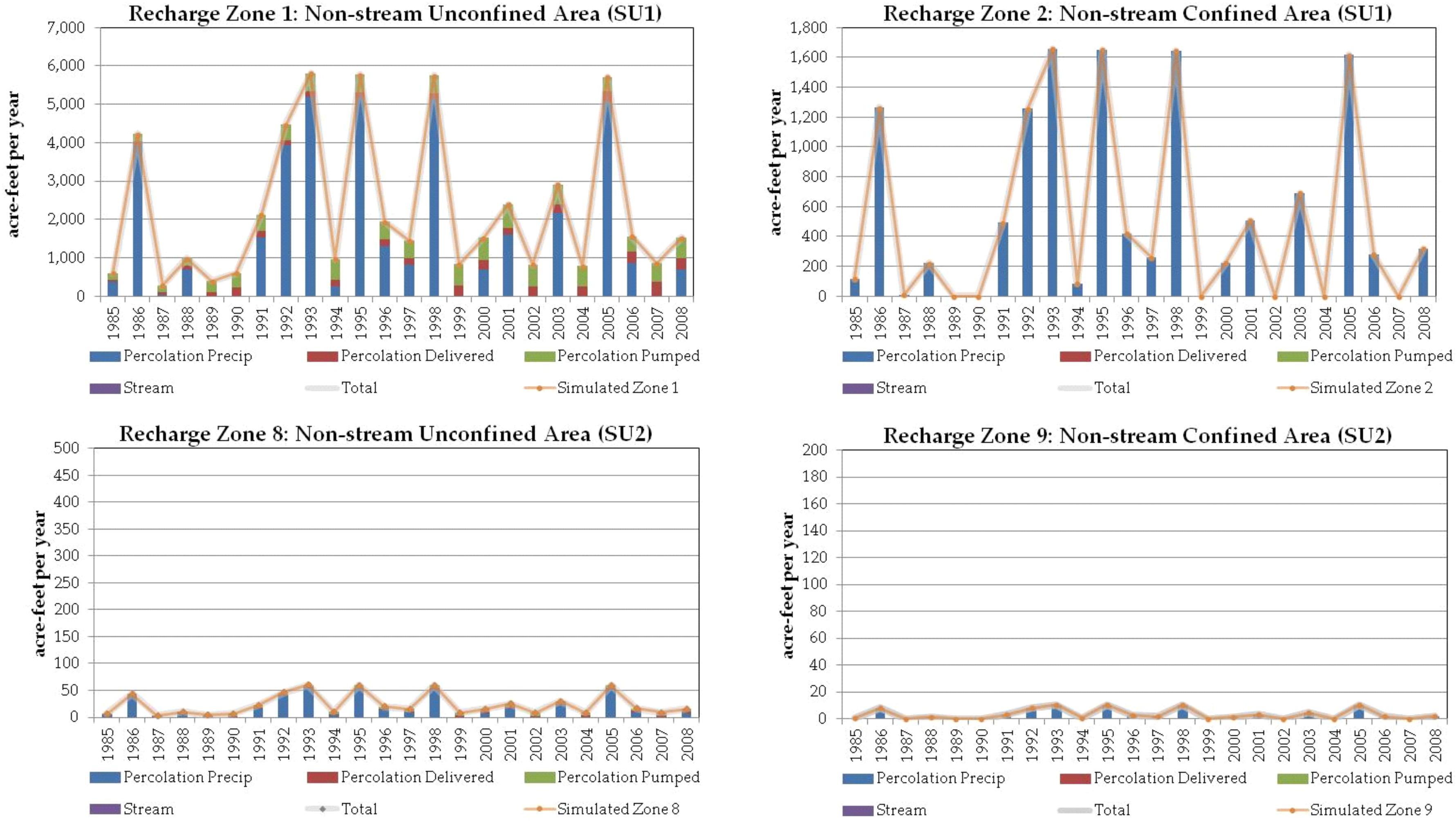
FIGURE 46. SIMULATED WATER BUDGET FOR NON-RECHARGE COMPONENTS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Recharge Zone 1: Non-stream Unconfined Area (SU1)

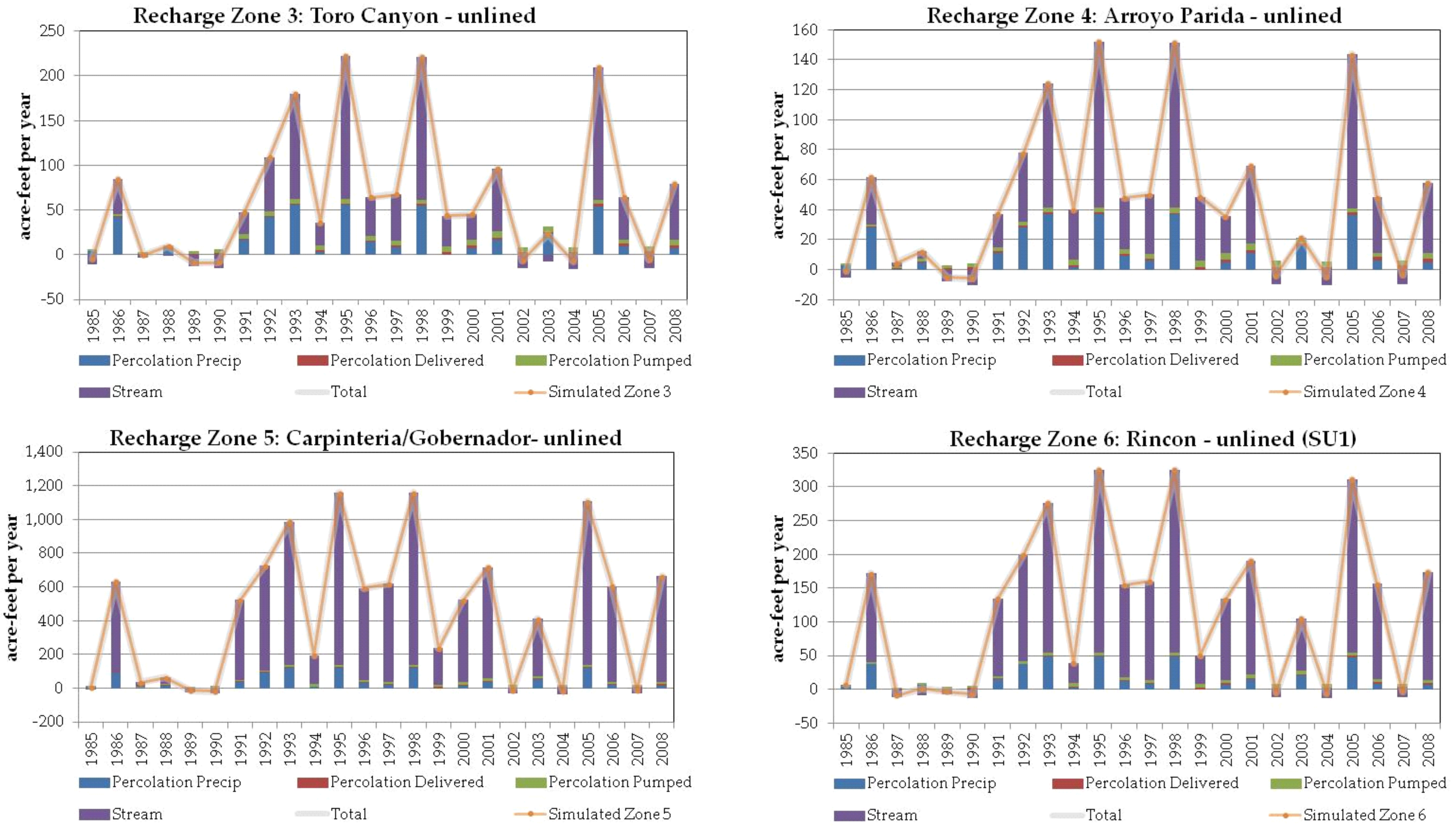
Recharge Zone 2: Non-stream Confined Area (SU1)

Recharge Zone 8: Non-stream Unconfined Area (SU2)

Recharge Zone 9: Non-stream Confined Area (SU2)

Source: HMWRI (2012)

FIGURE 47. SIMULATED WATER BUDGET FOR RECHARGE ZONES WITH NO STREAMS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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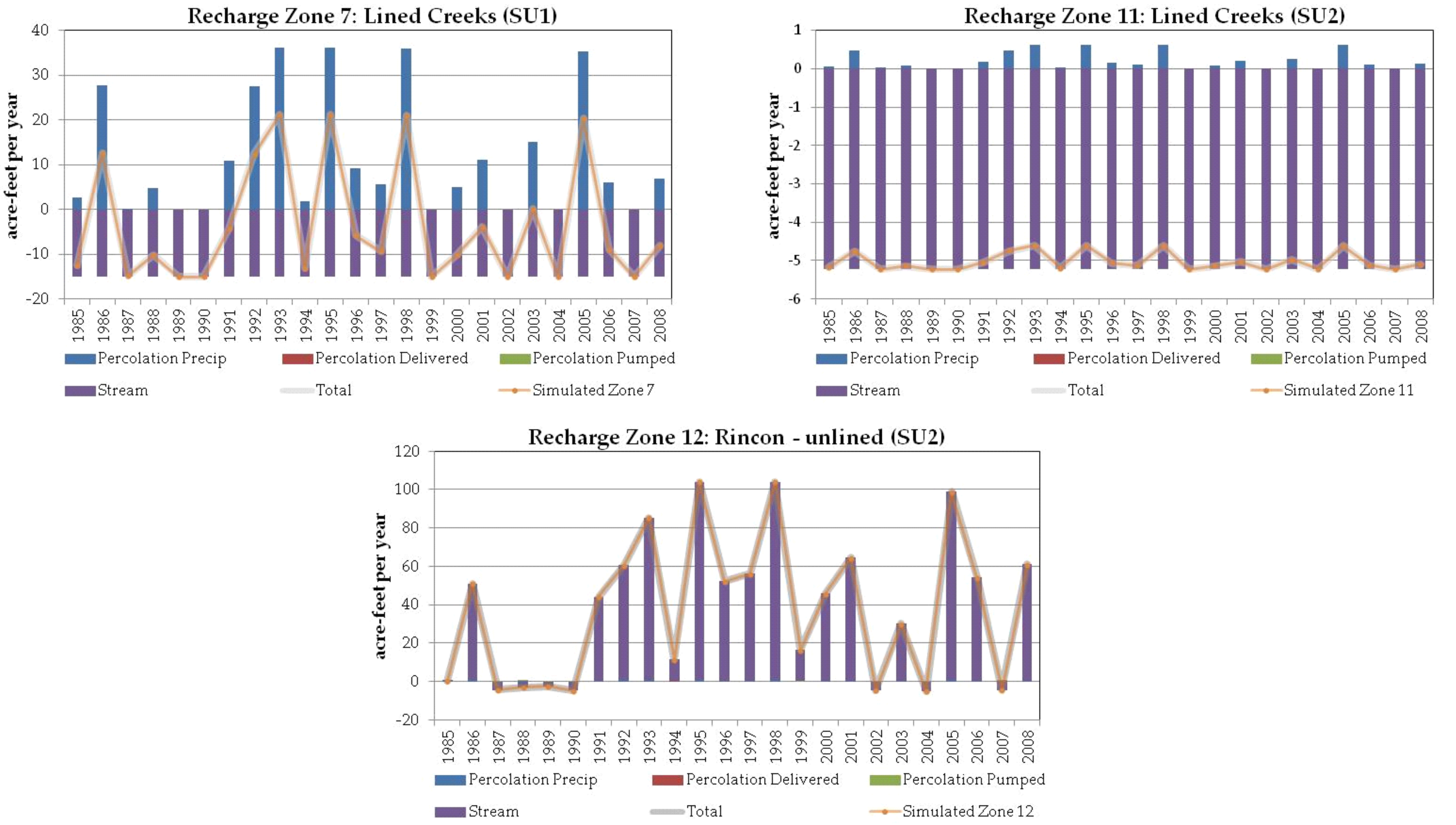
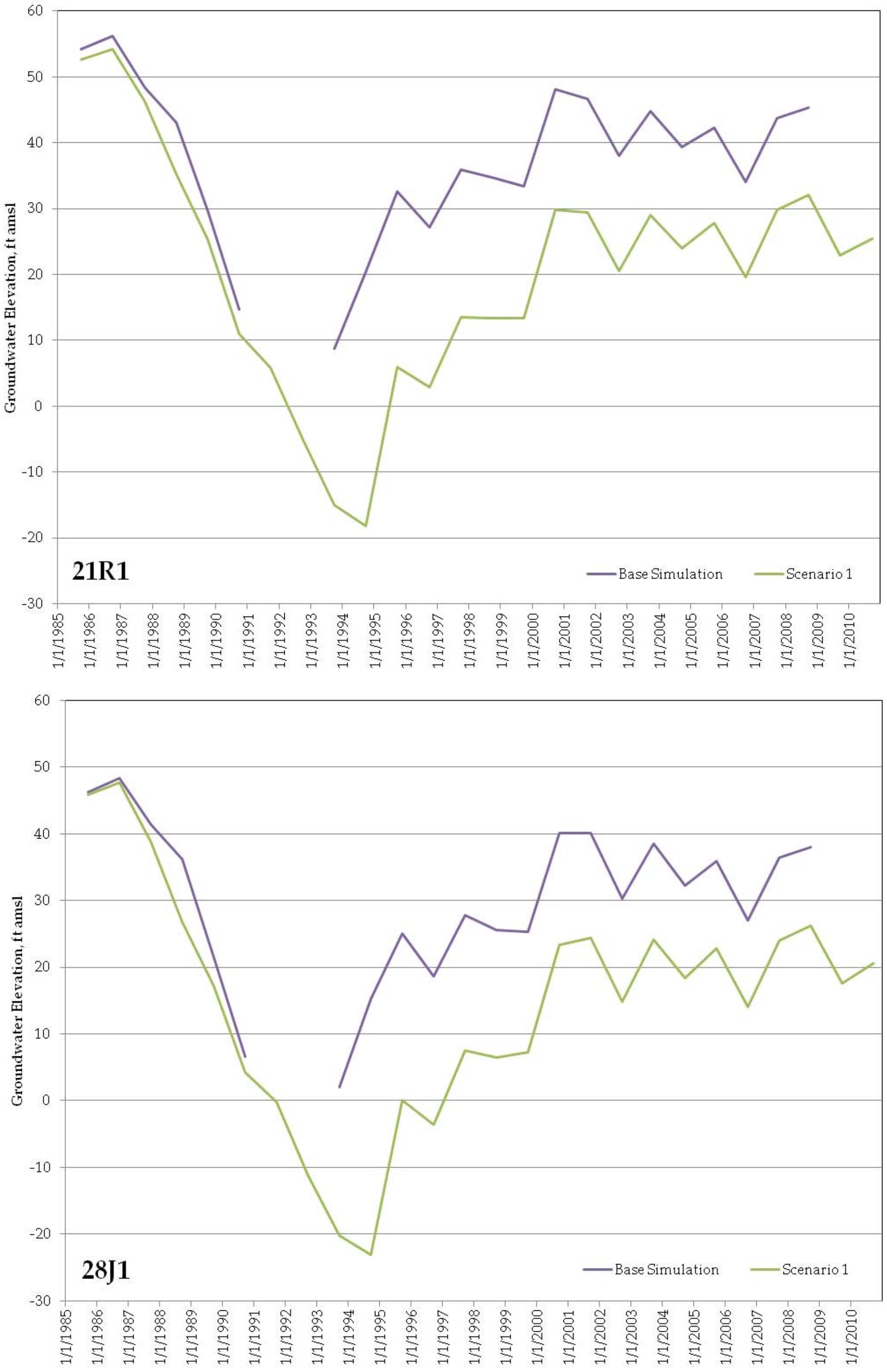
FIGURE 48. SIMULATED WATER BUDGET FOR RECHARGE ZONES WITH STREAMS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 49. SIMULATED WATER BUDGET FOR RECHARGE ZONES IN CONFINED AREA
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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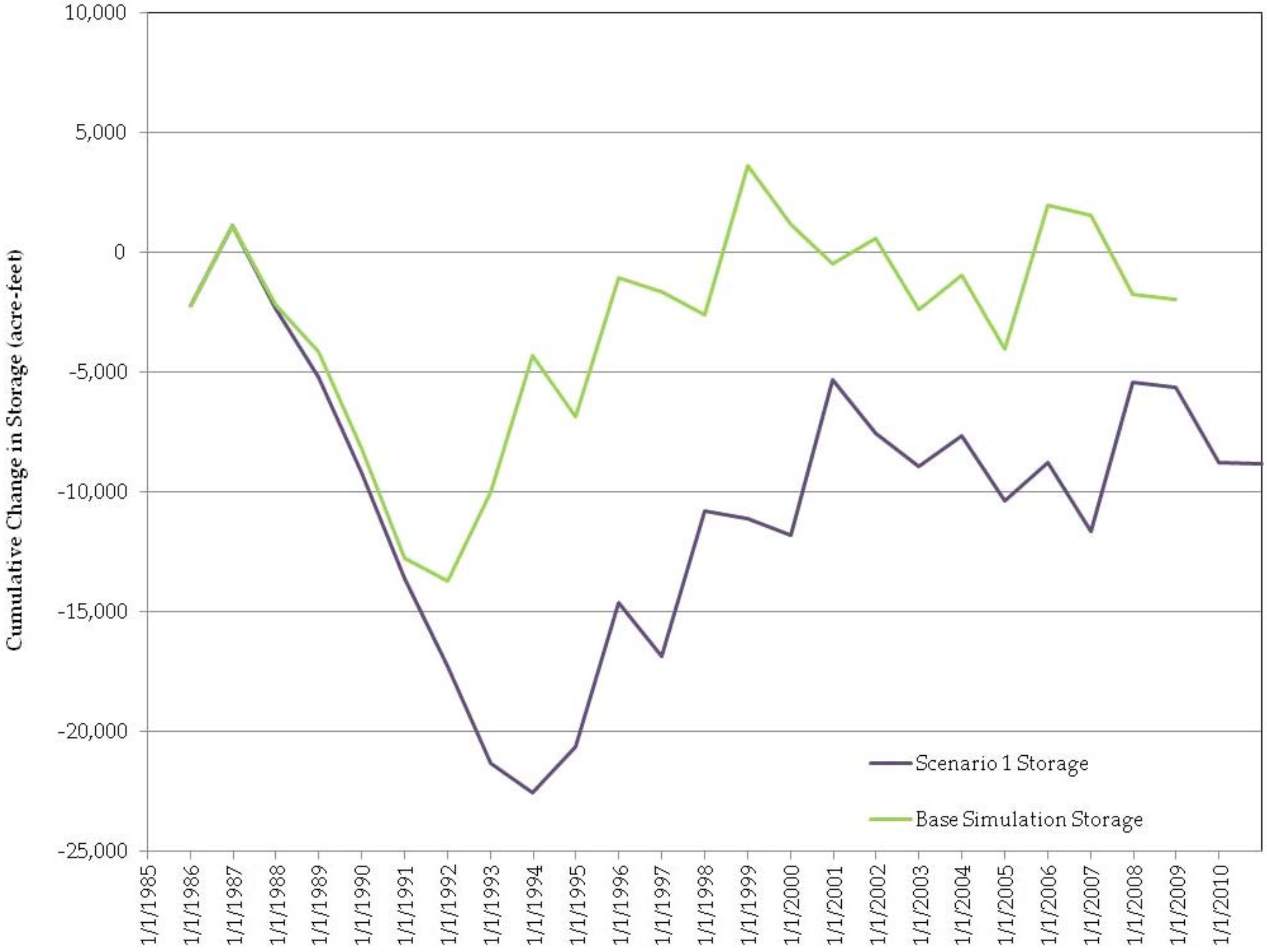
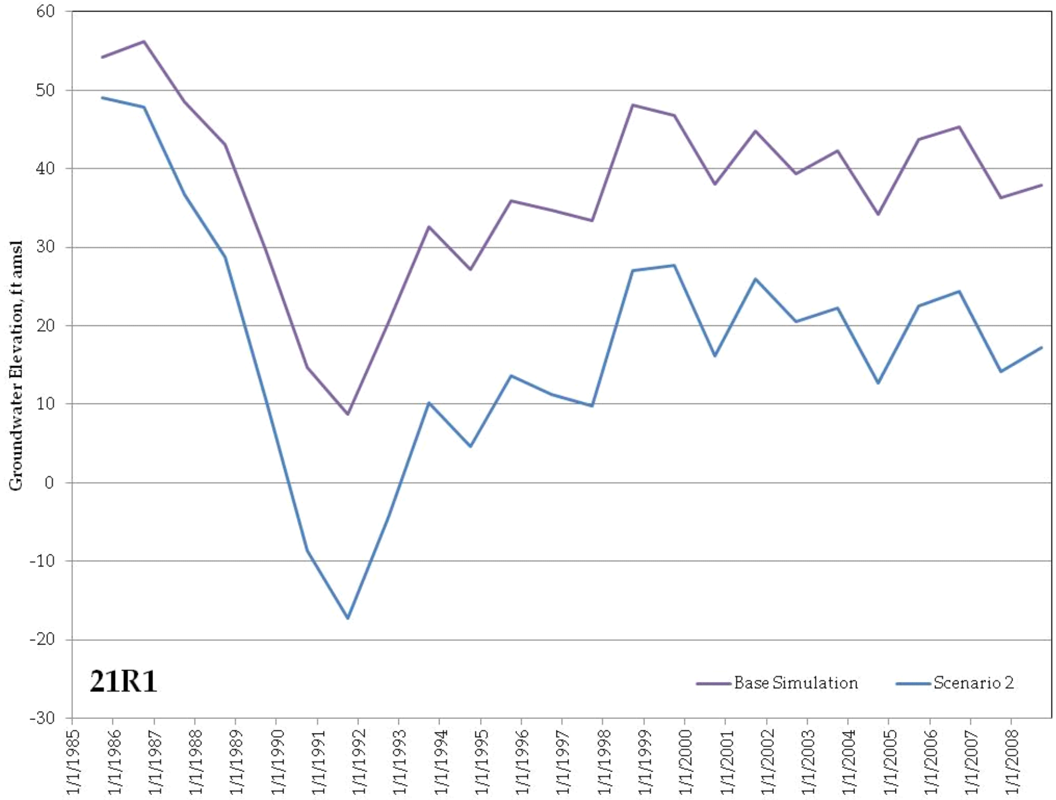
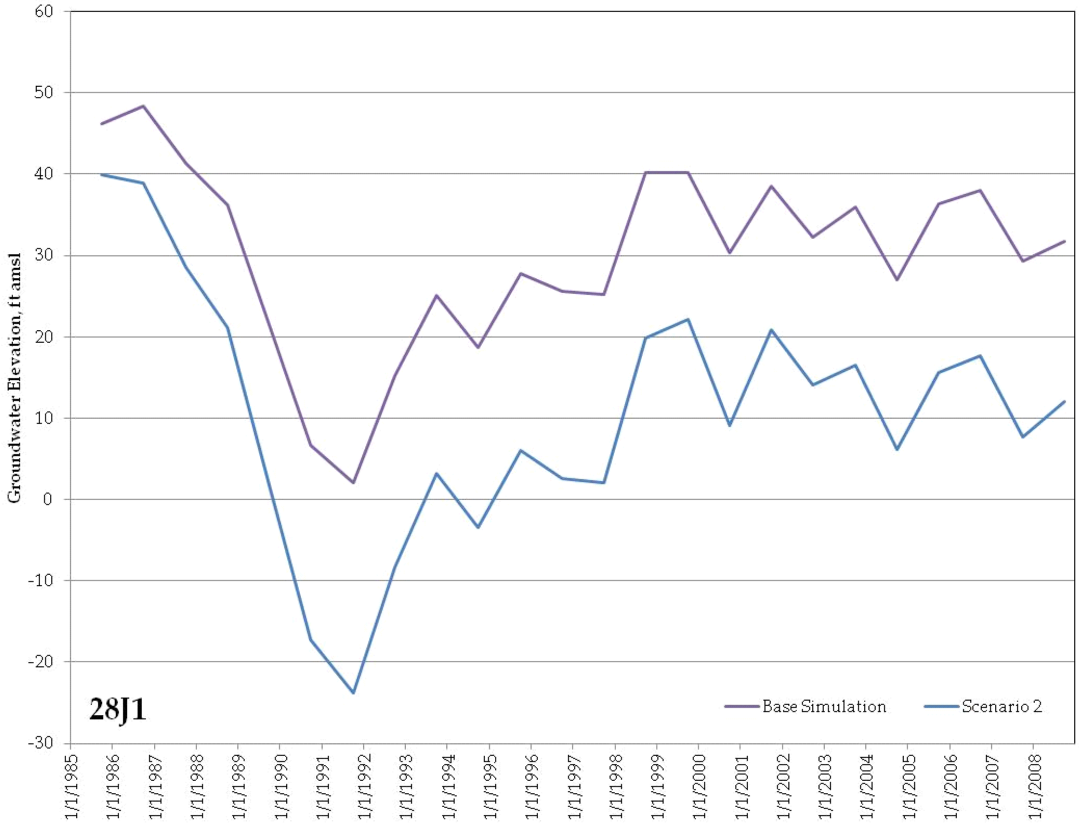
FIGURE 50. SCENARIO 1 - EXTENDED DROUGHT HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 51. SCENARIO 1 - EXTENDED DROUGHT CHANGE IN STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District





Source: HMWRI (2012)

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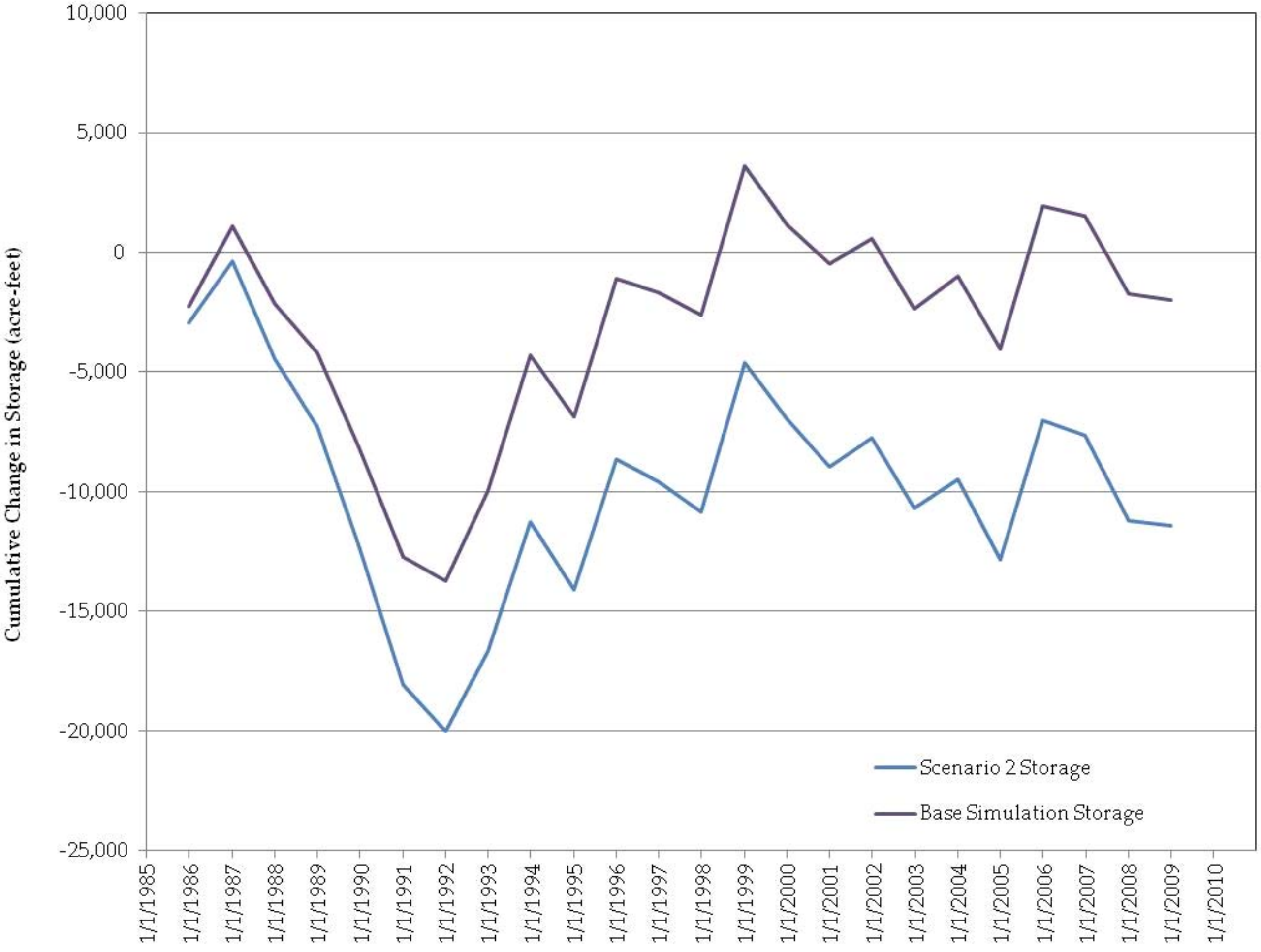
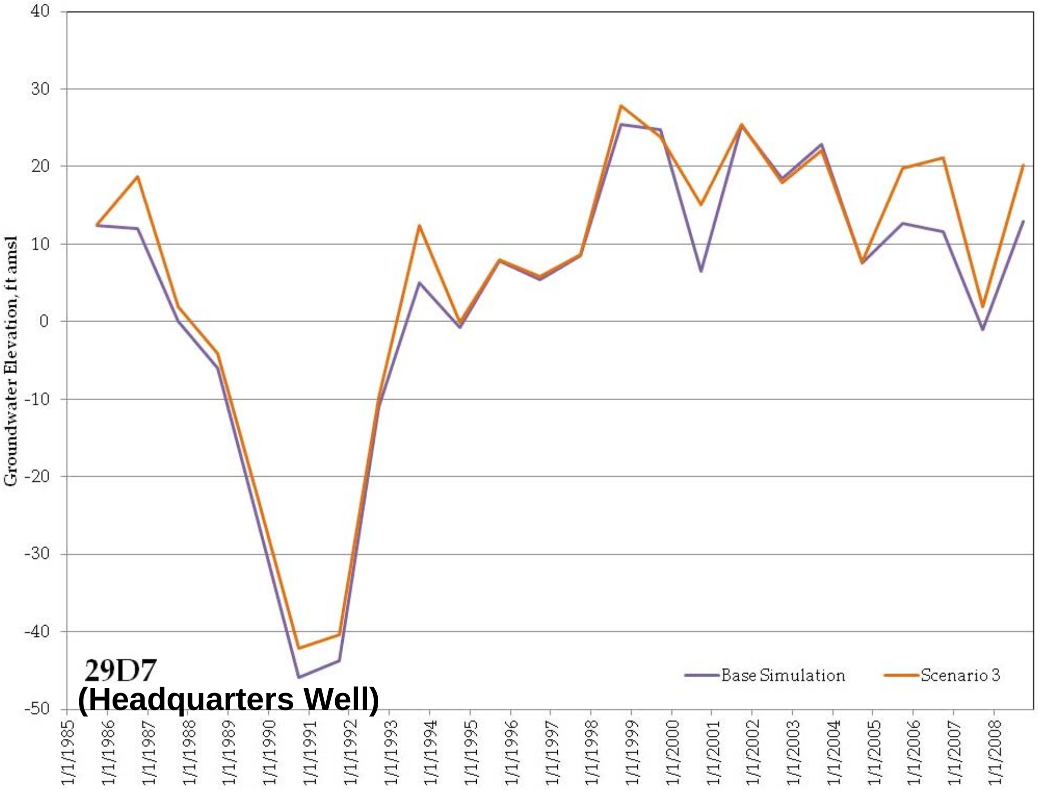
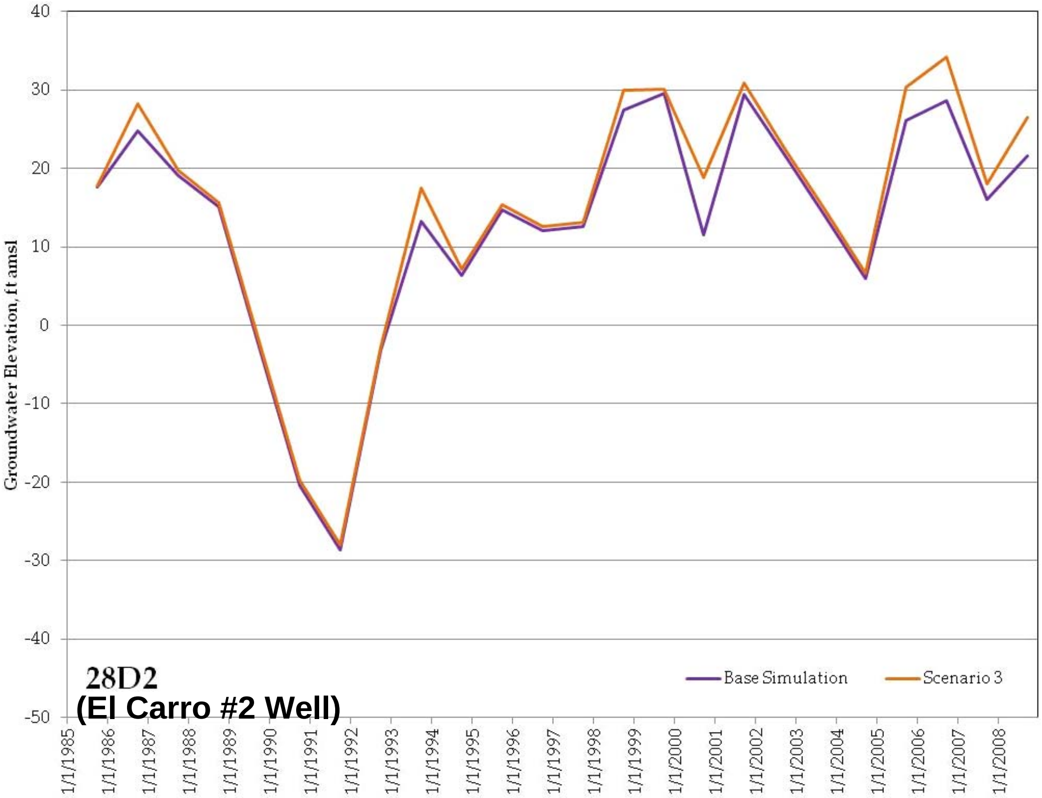
FIGURE 52. SCENARIO 2 - INCREASED GROUNDWATER DEMAND HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

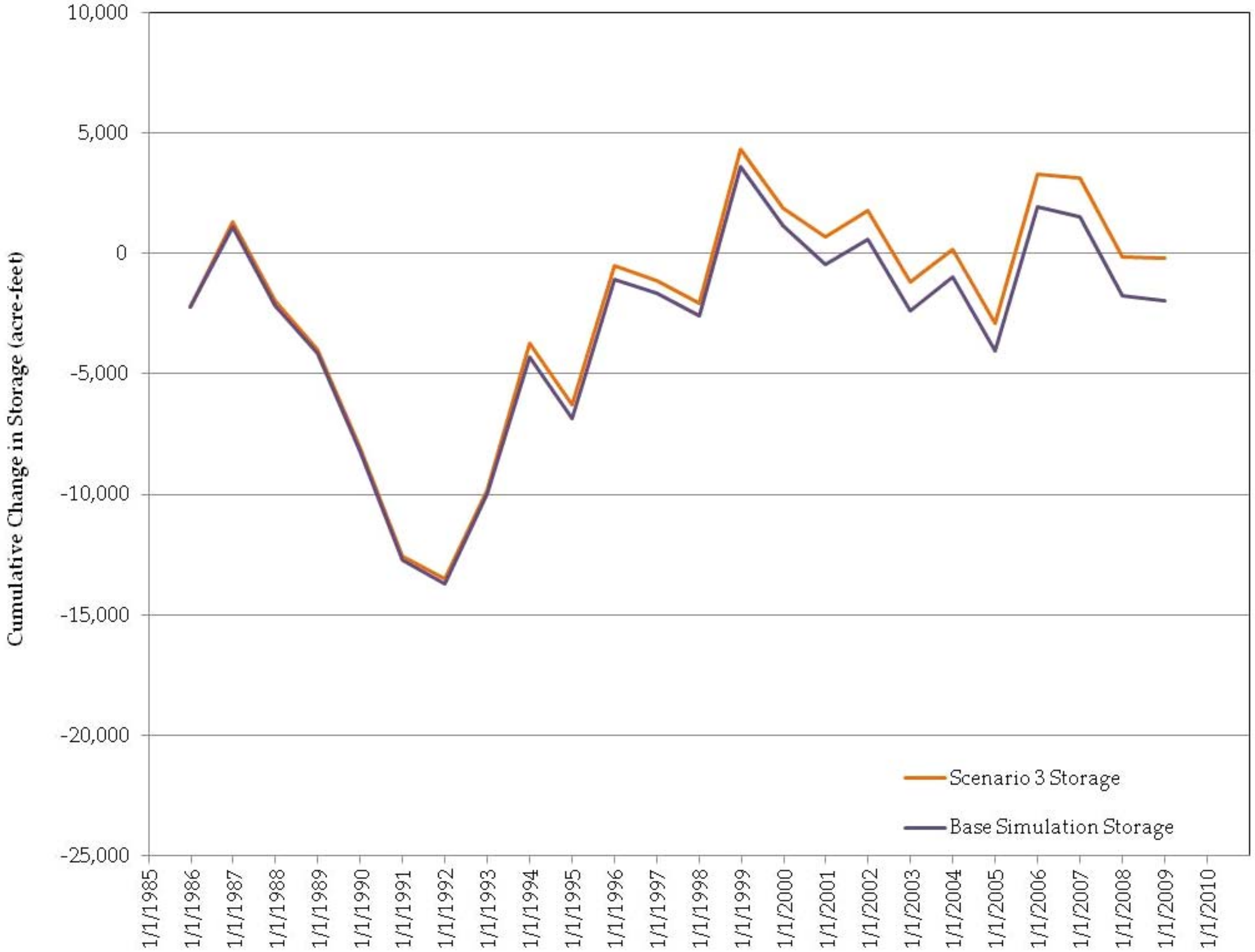
FIGURE 53. SCENARIO 2 - INCREASED GROUNDWATER DEMAND STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District





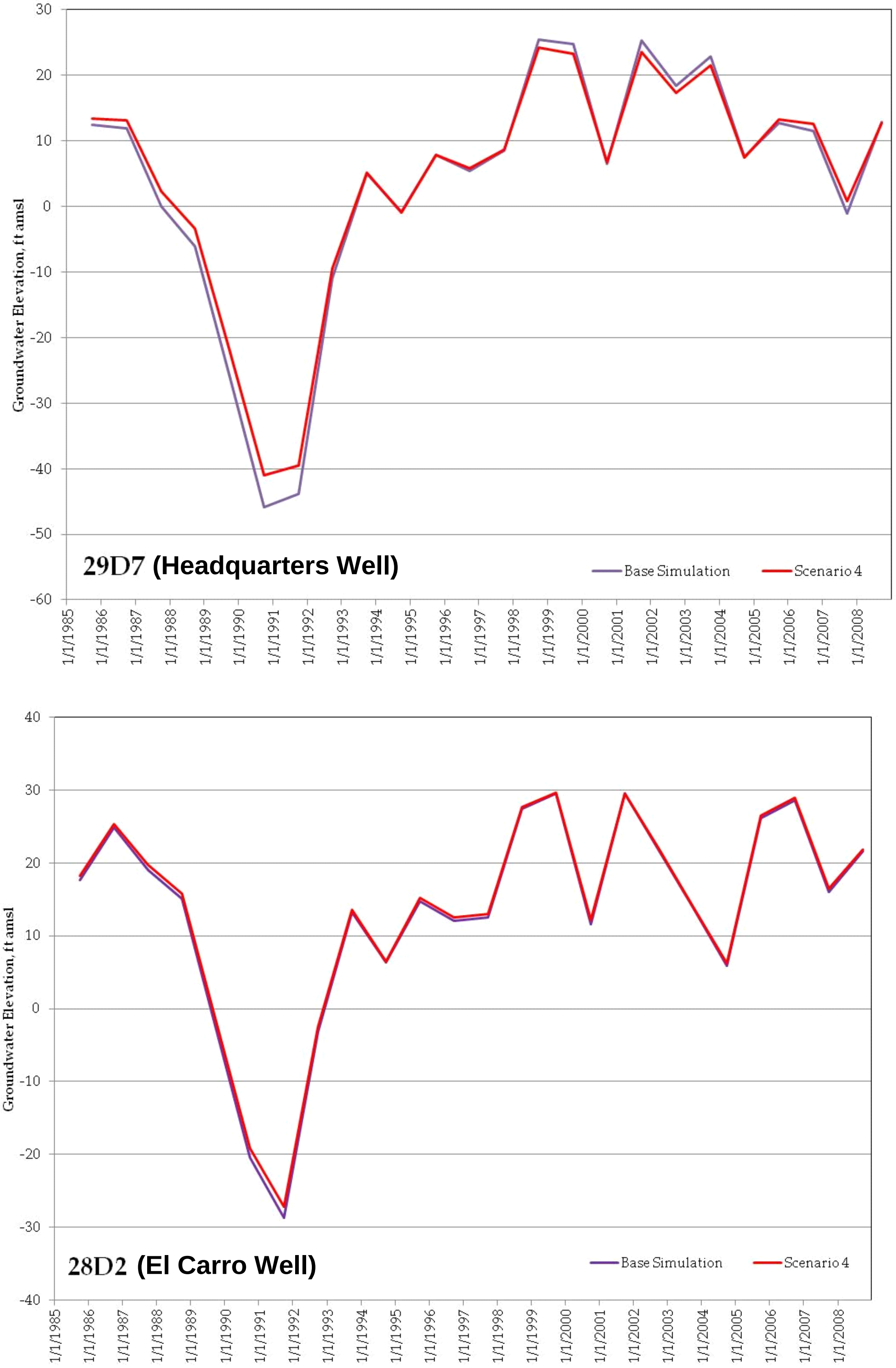
Source: HMWRI (2012)

FIGURE 54. SCENARIO 3 - ASR HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



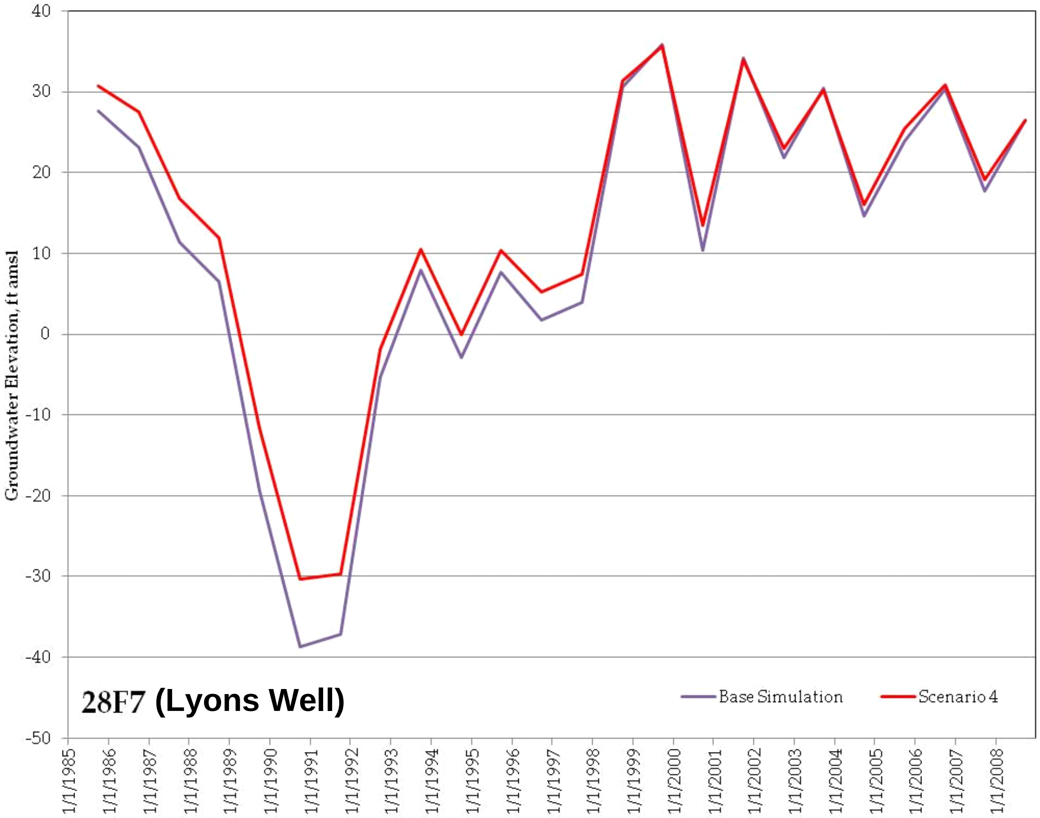
Source: HMWRI (2012)

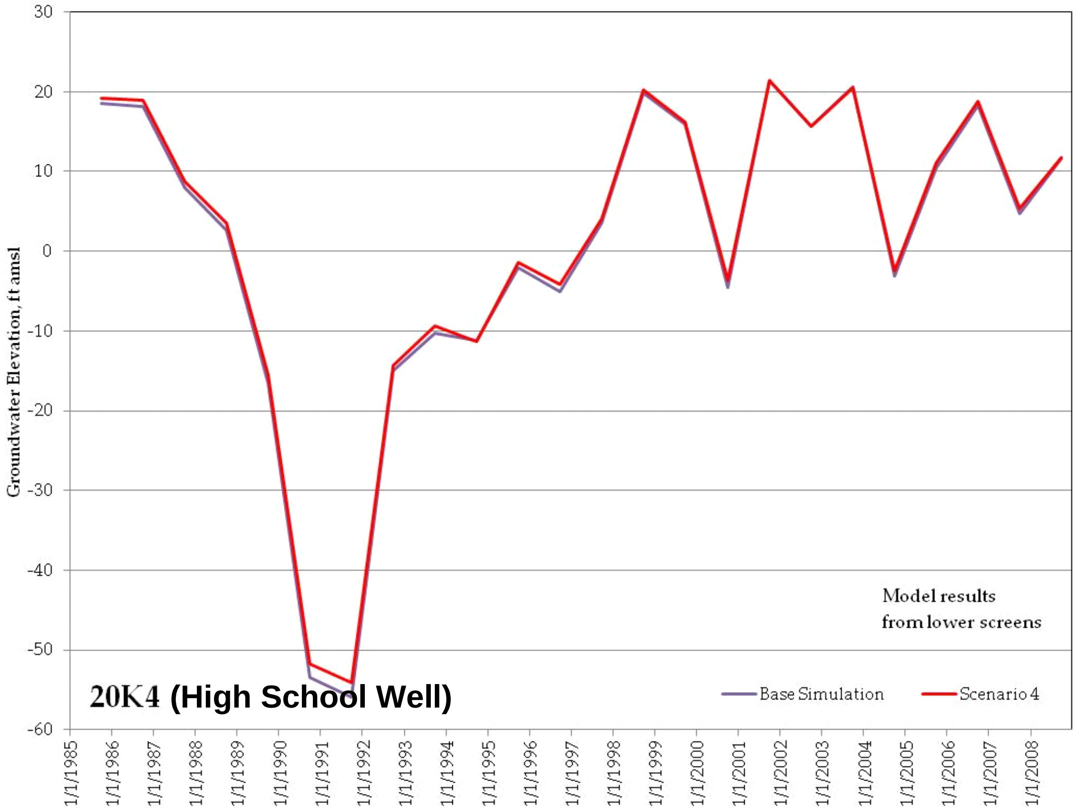
FIGURE 55. SCENARIO 3 - ASR CUMMULATIVE CHANGE IN STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 56. SCENARIO 4 - SUPPLEMENTAL WELLS HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District





Source: HMWRI (2012)

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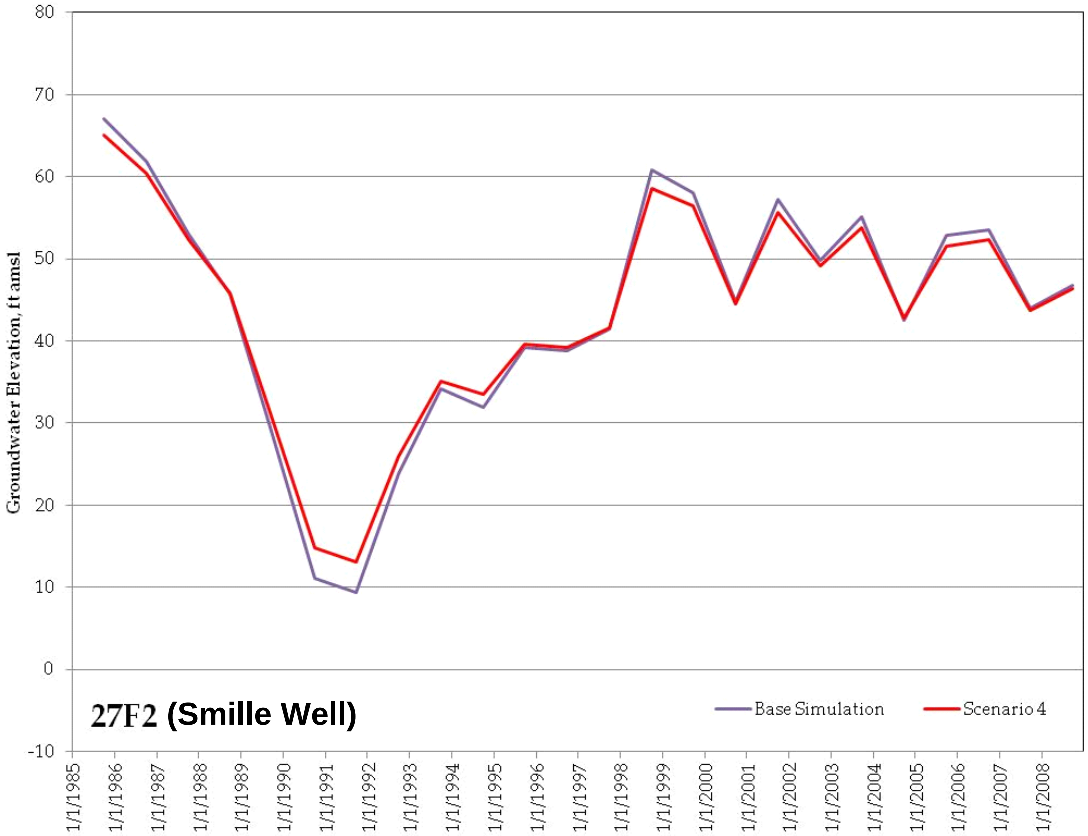
FIGURE 57. SCENARIO 4 - SUPPLEMENTAL WELLS HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

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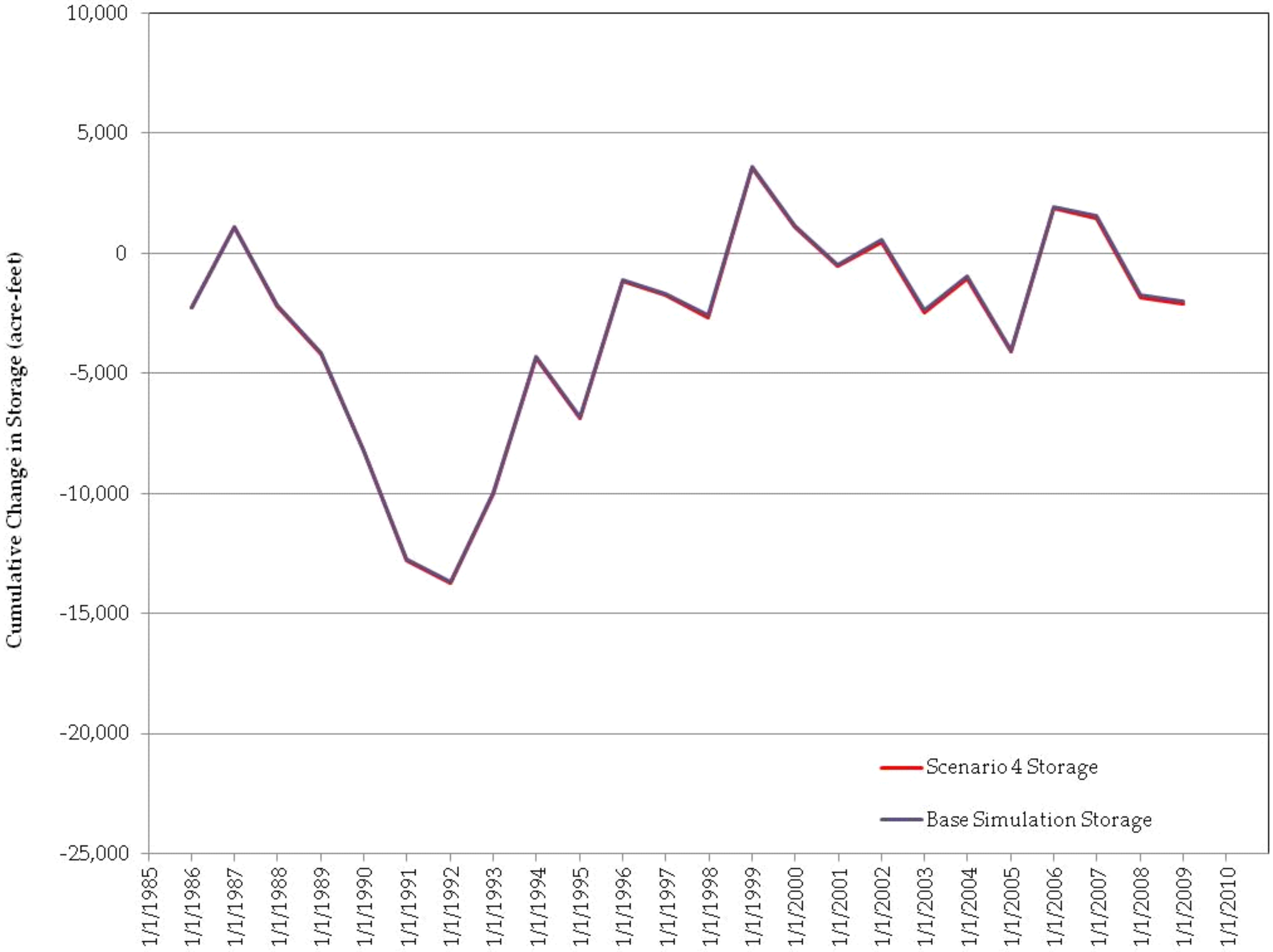
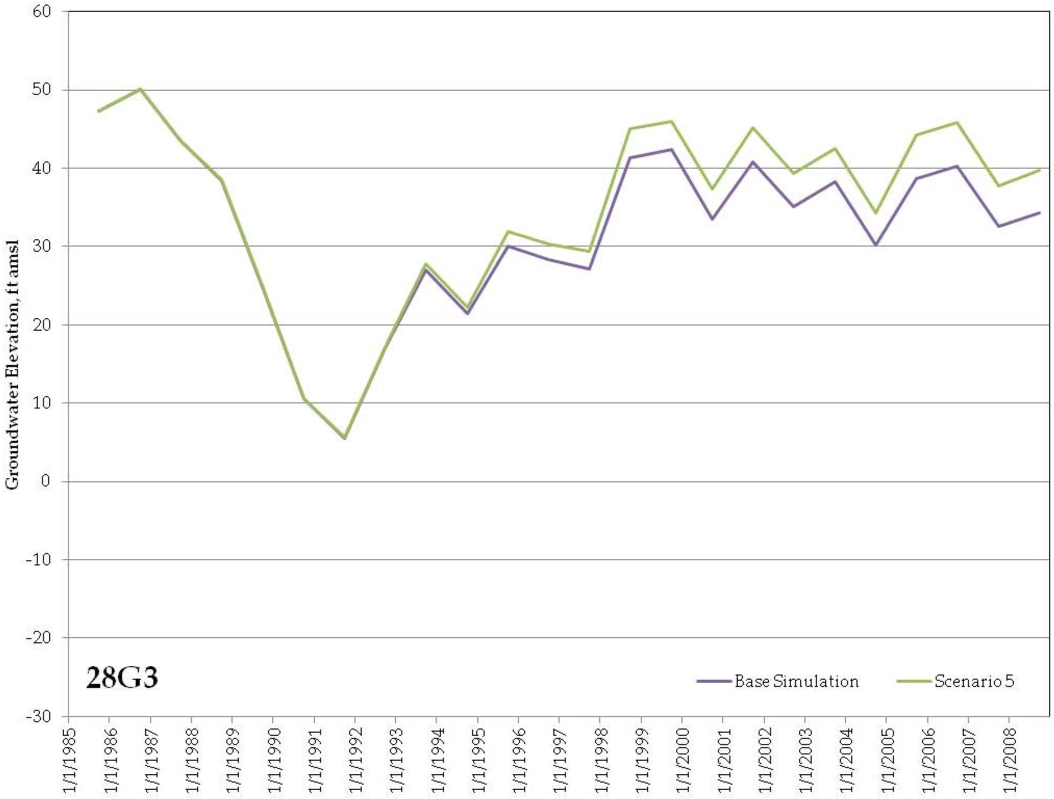
FIGURE 58. SCENARIO 4 - SUPPLEMENTAL WELLS HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 59. SCENARIO 4 - SUPPLEMENTAL WELLS CUMMULATIVE STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District



Source: HMWRI (2012)

FIGURE 60. SCENARIO 5 - CREEK DE-LINING HYDROGRAPHS
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

Source: HMWRI (2012)

FIGURE 61. SCENARIO 5 - CREEK DE-LINING CUMMULATIVE STORAGE
CGB Hydrogeologic Update and Groundwater Model Project
Carpinteria Valley Water District

APPENDIX A

TASK 1 HYDROGEOLOGIC UPDATE TECHNICAL MEMORANDUM

CARPINTERIA GROUNDWATER BASIN

HYDROGEOLOGIC UPDATE AND GROUNDWATER MODEL PROJECT

TASK 1 TECHNICAL MEMORANDUM

HYDROGEOLOGIC UPDATE

PREPARED FOR:
CARPINTERIA VALLEY WATER DISTRICT

FEBRUARY 2011

Pueblo Water Resources, Inc.
4478 Market Street, Suite 705, Ventura, CA 93003

INTRODUCTION

GENERAL STATEMENT

The Carpinteria Valley Water District (District) has initiated a project to develop a groundwater flow model of the Carpinteria Groundwater Basin. In December 2007, the District submitted a grant proposal for the project to the California Department of Water Resources (DWR) under the Local Groundwater Assistance (LGA) Grant Program for Fiscal Year 07-08. The District and DWR entered into a grant agreement for the project in December 2007 (amended December 2009). The project includes two primary tasks: Task 1 consists of an update of the hydrogeologic conditions within the basin; Task 2 consists of the development of a calibrated three-dimensional numerical groundwater model of the Basin. Presented in this technical memorandum are the principal findings, conclusions and recommendations resulting from Task 1 of the project.

PURPOSE AND SCOPE

The overall purpose of this project is to develop a numerical groundwater model of the Carpinteria Groundwater Basin (CGB) with sufficient detail and features to support efficient and cost-effective analysis and prediction of projected groundwater extractions and various alternative management scenarios for the groundwater basin.

The first task of the project consists of an update of the hydrogeologic conditions within the basin since the most recent comprehensive update of basin conditions was performed over 30 years ago by Geotechnical Consultants (GTC, 1976). Since that time, significant additional information has been developed. In particular, the District has constructed, tested, and operated several high-capacity municipal production wells, and has implemented basin-wide water level, water quality, and production data collection programs pursuant to the District's adopted Groundwater Management Plan. This task also includes updating the water balance equation for the CGB since the last time it was updated (GTC, 1986).

The hydrogeologic update performed as Task 1 of the project is to form the basis for Task 2, which consists of the development of a calibrated three-dimensional numerical groundwater model of the CGB. The United States Geological Survey (USGS) MODFLOW model code (McDonald and Harbaugh, 1988) is intended to be used to construct the groundwater model that would be used to simulate of the occurrence and movement of groundwater in the CGB.

The model is intended to be used as a basin management tool. For example, the model would allow the District to assess potential impacts of increases in groundwater pumping, evaluate how the basin would respond to long term drought (and potential reductions in surface water deliveries), and simulate alternative basin management scenarios, such as redistributing pumping, implementation of an Aquifer Storage and Recovery (ASR) program, or other strategies to maximize the efficient use of the groundwater basin. The model will also assist in verifying the long term safe yield of the basin.

Presented in this technical memorandum are the principal findings, conclusions and recommendations resulting from Task 1 of the project. The scope of work for Task 1 included the following:

- Compilation and review of existing and new data;
- Updating of basin cross sections and structural contours;
- Characterization of aquifer hydraulic parameters;
- Updating of water level hydrographs and groundwater surface contours;
- Performance of an updated hydrologic budget analysis, and;
- Preparation of this Task 1 summary Technical Memorandum

In addition to updating the hydrogeology of the basin where possible given the availability of new information, a project GIS database was developed as part of this project that complied electronic geographic information from the District, Environmental Systems Research Institute (ESRI) and the USGS. The GIS database includes digital information files generated from tables and Plates developed by the District and other consultants that have performed work for the District, as well as all new digital geographic information developed as part of the work for this project.

FINDINGS

AVAILABILITY OF BASIC DATA

The initial project task consisted of compiling and reviewing the available data for the hydrogeologic update of the Carpinteria Groundwater Basin. The types of data and information collected and evaluated include the following:

- Previous Reports on Basin Conditions
- Drilling Logs
- Pumping Tests
- Water Levels
- Precipitation
- Water Quality
- Stream Flow
- Municipal and Private Well Production
- Land Use and Soil Survey Information
- Imported Water

A detailed summary of the data obtained and an evaluation of the adequacy of the available data for the project was presented in a previous technical memorandum which is in Appendix A and will not be repeated here.

PREVIOUS INVESTIGATIONS

The hydrogeology of the Carpinteria Groundwater Basin (CGB) has been studied extensively over the last 60 years in previous investigations. The most significant reports include the following:

- Upson, J.E. and Thomasson, H.G. (1951), *Geology and Ground-Water Resources of the South-Coast Basins of Santa Barbara County, California,* U.S. Geological Survey Water Supply Paper 1108.
- Lian, H.M (1952), *The Geology and Paleontology of the Carpinteria District, Santa Barbara, California,* unpublished Ph. D. dissertation, University of California at Los Angeles.
- Evenson, R.E., Wilson, H.D., Jr., and Muir, K.S. (1962), *Yield of the Carpinteria and Goleta Ground Water Basins, Santa Barbara County, California, 1941 – 58,* U.S. Geological Survey Open-File Report.
- Slade, R.C. (1975), *Hydrogeologic Investigation of the Carpinteria Ground Water Basin,* unpublished M.A. Thesis, University of Southern California.
- Geotechnical Consultants, Inc. (1976), *Hydrogeologic Investigation of Carpinteria Ground Water Basin,* prepared for Carpinteria County Water District.
- Geotechnical Consultants, Inc. (1985), *Hydrogeologic Update, Carpinteria Groundwater Basin,* prepared for Carpinteria County Water District.
- Sullwold, H.H. (1996), *Carpinteria Groundwater Basin, A Geological Up-date,* prepared for Carpinteria Valley Water District.
- Integrated Water Resources, Inc. (2003), *Perennial Yield Review of the Carpinteria Valley Groundwater Basin,* prepared for Carpinteria Valley Water District.

These documents describe the stratigraphy, structure, and hydraulic characteristics of the aquifer systems of the CGB. Taken together, they also document the evolution of the understanding of the hydrogeology of the CGB.

The earliest detailed study of the hydrogeology of the basin was by the United States Geological Survey (USGS) and J.E. Upson (1951). This USGS report also contained a section on surface water hydrology in the basin by Thomasson (1951). Based on the available data at the time, Upson defined the boundaries of the basin and divided it into two main aquifer bodies - a shallow and deep aquifer. The current working conceptualization of CBG hydrostratigraphy (i.e., Aquifers A through D) was initially forward by Slade (1975). The most recent comprehensive report on the CGB was performed by Geotechnical Consultants, Inc. (GTC, 1976). The 1976 GTC report built upon Slade's work regarding the basin structure and hydraulic parameters to include a detailed analysis of the hydrologic budget equation for the basin. GTC also performed an update of their 1976 investigation in 1985, the focus of which was an update of the hydrologic budget for a base-period covering the water years between 1974 and 1984. Sullwold (1996) refined the structural and hydrostratigraphic delineations of the CGB, taking into consideration water and oil wells drilled after 1975. Most recently, Integrated

Water Resources, Inc. (IWR, 2003) performed a review of existing perennial yield estimates for the CGB, including a review of the data utilized to develop the estimates.

HYDROGEOLOGIC SETTING

This section presents a general description of the hydrogeology of the CGB and water-bearing strata within the basin boundaries. The description is based largely on a compilation of information from the sources listed above.

Basin Boundaries. The CGB is located on the south flank of the Santa Ynez Mountains, one of the east-west trending ridges of the Transverse Range Geomorphic Province. The basin represents the north limb of a structural syncline that has been filled with water-bearing sediments. In the CGB, water-bearing deposits include all unconsolidated and semi-consolidated sediments of Plio-Pleistocene and Holocene age, with older consolidated non-water bearing rocks bounding the basin.

For this hydrogeologic update, the most recent published geologic maps were utilized to refine the delineation of the basin boundaries. These maps include the following:

- Minor, S.A., Kellogg, K.S., Stanley, R.G., Gurrola, L.D., Keller, E.A., and Brandt, T.R. (2009), *Geologic Map of the Santa Barbara Coastal Plain Area, Santa Barbara County, California: U.S. Geological Survey Scientific Investigations Map 3001*.
- Tan, S.S., Clahan, K.B, Gutierrez, C.I., and Mascorro, M.T. (2004), *Geologic Map of the White Ledge Peak 7.5' Quadrangle, Santa Barbara and Ventura Counties, California, A Digital Database: California Geological Survey in Cooperation with the U.S. Geological Survey*

A geologic map showing the surficial geology from the above two sources the corresponding refined basin boundaries is presented as Plate 1.

Within the CGB, the Rincon Creek thrust fault has created a barrier to subsurface groundwater movement within the basin, and the surface trace of the fault has been used to segregate the basin into two Storage Units: Storage Unit No. 1 is on the north side of the fault trace, and Storage Unit No. 2 is to the south. For the most part, Storage Unit No. 1 is hydrogeologically separated from the ocean by the Rincon Creek thrust fault (except west of El Estero where shallow alluvial deposits are in contact with the ocean). Storage Unit No. 1 contains all of the District's principal municipal supply wells, and is the primary focus of this investigation. A map showing the boundaries of the two Storage Units is presented as Plate 2.

Hydrostratigraphy. In the CGB there exist major aquifers that are correlatable throughout the central and eastern portion of Storage Unit No. 1 (SU-1) which occur primarily within unconsolidated marine sediments of the Pleistocene and upper Pliocene-aged Carpinteria and Casitas Formations. These principal zones include Aquifers A, B, C, and D, with Aquifer A representing the shallowest major aquifer and Aquifer D being the deepest. Geologically, Aquifer A likely represents the basal conglomerate of the Carpinteria Formation, whereas Aquifers B, C, and D are contained within the Casitas Formation (Slade, 1975). The base of Aquifer D is considered to represent the effective base of freshwater in the basin (although no water wells are known to produce from this Aquifer). The base of Aquifer D is generally 1,200 to 1,600 feet below sea level in Storage Unit No. 1. Pliocene and older Tertiary sedimentary bedrock units are considered non water-bearing and constitute the boundaries of the groundwater basin. The top of bedrock in the deepest portion of the basin is as much as 4,000 feet below sea level in Storage Unit No. 1 and rises to approximately 500 feet above sea level along the northern boundary of the basin.

Lithologically, primary water bearing deposits in the basin consist of interbedded unconsolidated and semi-consolidated sand, gravel, silt and clay (and combinations thereof) deposits. The coarser grained sandy/gravelly strata in these deposits comprise the individual primary aquifer zones (i.e., Aquifers A through D). These primary aquifer zones are generally on the order of 50 to 100 feet thick each. Finer grained strata of silt and clay are generally thicker and form a series of aquitards between the primary aquifer zones. These aquitards are laterally extensive in the central alluvial plain portion of the basin and confine water held in the primary aquifers under artesian pressure. This area of the basin is referred to as the Confined Area.

Outside the Confined Area of the basin and extending to the bedrock boundaries, the principal aquifers become laterally discontinuous and generally non-correlatable. The older alluvium and Casitas Formation in these areas contain laterally discontinuous layers of both permeable and impermeable materials, and water held in these areas is generally unconfined (although various degrees of local confinement undoubtedly occur). The source of recharge water to the basin is primarily by infiltration of precipitation, irrigation water and streamflow seepage (discussed later); however, in the Confined Area, downward percolation of water is limited due to the presence of fine-grained low-permeability materials overlying most of the area of the principal aquifers; therefore, recharge to the primary aquifers is understood to take place in the areas between the Confined Area and the boundaries of consolidated bedrock. This area is referred to as the Recharge Area.

The well log collection obtained for the basin update is the primary source of information on basin lithology. Logs from the drilling of water wells, as wells as oil and gas wells, typically include formation logs and occasionally geophysical logs. Formation logs include physical descriptions of drilled cuttings or cores throughout the drilled depth of the hole. Geophysical logs indicate spontaneous potential, electric resistivity, and various other parameters of geologic units. This information has been used to refine the previous interpretations of the geologic structure and hydrostratigraphy of the CGB, and in the preparation of geologic cross sections through the basin. The locations of updated cross sections are shown on Plate 3 and the cross-sections are shown on Plates 4 through 7.

It is noted that no new information (i.e., correlatable aquitards from recently drilled wells) was developed for this project that indicated the previous delineations of the Confined and Recharge Areas (i.e., Slade and GTC) should be modified; therefore, the existing delineations of these areas of the basin have been initially adopted for this project. A map showing the existing delineations of the Confined and Recharge Areas of the CGB is presented as Plate 8.

Using the available geophysical logs, the depth to each of the principal aquifers within the confined was identified and structurally contoured to delineate the areal extent of each principal aquifer within the basin. A summary comparison of the aquifer depths and thicknesses utilized by previous investigators (GTC and Sullwold) and as updated for this project is presented in tabular form in Appendix B. As shown in Table B1, several recently drilled wells were available for Sullwold and the current study that were not available at the time of the 1976 GTC report. Logs for these more recent wells have allowed for a refinement of the structural contours. As shown in Table B1, there is general agreement between the various investigators regarding the interpretation of the logs for the contacts of Aquifers A, B and C. The only significant difference was the interpretation of the log for 4N/25W-30Ka ("Bryce #1", which is an oil well). PWR's interpretation of this log was consistent with GTC's original interpretation.

Updated structural contours of the top and bottom elevations of Aquifers A, B and C are shown on Plates 9 through 11, respectively. Structural contours of the top of bedrock for Storage Units 1 and 2 are shown on Plates 12 and 13, respectively.

Aquifer Parameters. The primary aquifer parameters necessary to characterize the hydraulics of groundwater movement and calculate basin storage include transmissivity, hydraulic conductivity, and storativity. Transmissivity and hydraulic conductivity are related (transmissivity is the product of hydraulic conductivity and aquifer thickness) and characterize the permeability of aquifer materials. Storativity is measure of the aquifer's ability to store and release water. These aquifer parameters are necessary input parameters for the numerical groundwater flow model. Estimates of these parameters are typically obtained from analysis of pumping test data.

Pumping test data available to previous investigations was generally limited to specific capacity data, from which transmissivity can be roughly estimated. The majority of this data was derived from the late-1940's when all wells in the basin powered by electrical motors were converted from 50 to 60 cycles and Southern California Edison Co. performed numerous pump efficiency tests. Limited specific capacity data was also available from Driller's Logs. Data from formal pumping test was limited to post-construction testing of the CVWD Smillie and Santa Ynez wells.

Since the time of the 1976 GTC study, CVWD has installed four high capacity municipal production wells (Lyons, High School, El Carro, and Headquarters). Formal post-construction pumping tests were conducted at the High School, El Carro, and Headquarters Wells and the summary of operations reports included aquifer analyses to determine aquifer parameters at these wells. Aquifer-specific hydraulic conductivities were estimated for the major aquifers in the Confined Area by dividing the transmissivity value by the well screen lengths. A summary of the aquifer parameters derived from controlled pumping tests in the Confined and Recharge Areas are presented in Tables 1 and 2 below, respectively.

Table 1. Aquifer Parameter Summary, Confined Area Pumping Test Data

Well Name / Owner	Well ID	Test Date	Length (hrs)	Q (gpm)	Q/s (gpm/ft)	T (gpd/ft)	S (dimensionless)	K (ft/d) / Aquifer		
								A	B	C
CVWD										
Headquarters	29D8	Apr-02	24	1723	7.0	16,276	8.97E-04	18.4	18.4	--
El Carro	28D2	Aug-90	24	1000	9.2	17,600	4.40E-04	11.8	11.8	11.8
High School	20K4	Aug-89	24	800	3.3	6,489		--	8.9	8.9
Private										
Lite Well #1	29K2	Mar-89	12	300	4.3	9,900	--	13.2	--	--
				Averages	6.0	12,566	6.56E-04	14.5	13.0	10.3

As shown in Table 1, transmissivities derived from pumping tests in the Confined Area range between approximately 6,500 to 17,600 gallons per day per foot (gpd/ft) and average approximately 12,600 gpd/ft. Storage coefficients are on the order of approximately 6.5 x 10^{-4} (dimensionless), indicative of confined conditions. Hydraulic conductivities for the primary aquifers in the Confined Area range between approximately 9 and 18 feet per day (ft/d), averaging approximately 14, 13 and 10 ft/d for Aquifers A, B and C, respectively.

Table 2. Aquifer Parameter Summary, Recharge Area Pumping Test Data

Well Name / Owner	Well ID	Test Date	Length (hrs)	Q (gpm)	Q/s (gpm/ft)	T (gpd/ft)	K (ft/d)
CVWD							
Smillie	27F2	Feb-75	9	340	1.2	18,000	7.0
Private							
Clark (Schaff)	21F1	Mar-91	24	50	0.3	660	0.4
Brown	35A7	Mar-90	24	150	1.2	2,084	1.0
Berberet (Delk)	26F1	Dec-90	24	80	0.6	918	0.5
				Averages	0.8	5,416	2.2

As shown in Table 2, transmissivities derived from the few pumping tests in the unconfined Recharge Area vary between approximately 660 and 18,000 gpd/ft, averaging approximately 5,400 gpd/ft. Hydraulic conductivities range between 0.4 and 7.0 ft/d, averaging 2.2 ft/d. Storage coefficients could not be calculated from the available pumping test data in the Recharge Area (calculation of storage coefficients requires a nearby monitoring well).

In addition to pumping tests, which allow direct calculation of aquifer parameters from analysis of water level drawdown and /or recovery curves, transmissivities can also be estimated from specific capacity data. For wells where only specific capacity data are available, the methods presented in Driscoll (1995, pg 1021) were utilized. Hydraulic conductivities were calculated by dividing transmissivity by total screen length. The available specific capacity and transmissivity / hydraulic conductivity data for the Confined and Recharge Areas are presented in Tables 3 and 4, respectively.

Table 3. Aquifer Parameter Summary, Confined Area Specific Capacity Data

Well Name / Owner	Well ID	Test Date	Length (hrs)	Q (gpm)	Q/s (gpm/ft)	T (gpd/ft)	K (ft/d) / Aquifer		
							A	B	C
Dal Pozzo #4 (Florido)	28G3	Oct-94	6	200	3.4	7,334	9.8	--	--
Huff	28H1	Apr-92	12	200	2.6	5,454	14.6		
Lyons (CVWD)	28F7	Aug-76	44	2100	10.1	21,578	14.2	14.2	14.2
			Averages		5.4	11,456	12.9	14.2	14.2

As shown in Table 3, transmissivity values estimated from specific capacity data in the Confined Area range between approximately 5,500 and 21,600 gpd/ft, averaging approximately 11,450 gpd/ft. Hydraulic conductivities for Aquifers A, B and C average approximately 13, 14, and 14 ft/d, respectively.

Table 4. Aquifer Parameter Summary, Recharge Area Specific Capacity Data

Well Name / Owner	Well ID	Test Date	Length (hrs)	Q (gpm)	Q/s (gpm/ft)	T (gpd/ft)	K (ft/d)
Sera #1	19E1	May-92	11	80	2.2	4,043	1.9
Endow	20N3	Jul-48	48	100	0.7	1,247	0.9
Brand Flower	21L1	Aug-91	24	200	2.7	5,061	1.8
Overgaag	21Q1	Mar-91	24	150	0.5	890	0.2
Vedder	22R4	Dec-46	56	200	1.2	2,200	0.9
Hicky #5	24F6	Jul-48		130	0.6	1,125	0.8
Polo Field #1	24F7	Oct-50		310	2.1	3,971	1.6
Polo Field #2	24F9	Jan-91	6	550	2.5	4,592	2.5
Nichols	25F1	Aug-89	24	80	2.1	3,937	1.5
Sunnyvale #1	25N5	Aug-89	19	80	0.7	1,312	0.8
Dautch	26B1	Jul-44		200	2.0	3,703	1.6
Vedder	26C4	Feb-47	72	225	1.4	2,663	0.8
Marsh	26C6	Jan-49		175	1.0	1,798	0.7
Oltman	26C8	Sep-47	73	160	1.2	2,216	1.4
Cate School (Thor)	26D1	Sep-91		25	2.3	4,250	3.3
Selbert #2	27F1	Jul-89	3	54	0.2	370	0.2
Twin Pines Ranch	34B4	Jul-90	3	20	0.1	234	0.1
California Tropics	35B6	Mar-91	12	250	3.6	6,775	2.7
Overgaag	35M5	May-49		250	1.0	1,833	0.5
			Averages		1.5	2,748	1.3

As shown in Table 4, transmissivity values estimated from specific capacity data in the Recharge Area average approximately 2,750 gpd/ft with hydraulic conductivities averaging approximately 1.3 ft/d.

Review of the aquifer parameter values derived from both controlled pumping tests and specific capacity estimates reveals general agreement between the two sources of values in both the Confined and Recharge Areas. Hydraulic conductivities for Aquifers A through C in the Confined Area average approximately 10 to 14 ft/d and in the Recharge Area average approximately 2.2 to 1.3 ft/d.

Water Levels and Groundwater Movement. Water-level data in the basin have historically been collected and maintained by the USGS and the CVWD. The USGS database contains water level records for 75 wells in the CGB, dating back to as early as 1919 (State Well No. 4N/25W-28J1); however, most records begin in either the 1940s or 1970s. The USGS database does not extend beyond 2001. The CVWD has historically made monthly measurements at over 40 wells in the basin, and up until 2001, the CVWD provided the USGS with these data to supplement their data base. After 2001 the CVWD continued measuring water levels at these wells as part of their Groundwater Management Program and assumed the responsibility for maintaining the water level records. Currently, there are records for 43 wells in the CVWD database. Water level records are maintained in digital (Excel) format.

Hydrographs for many of these wells have been updated for use in the hydrogeologic update and modeling project. Hydrographs for 22 wells that have relatively complete records either dating back to the early 1940's or dating back significantly before the start of the model base period are presented in Appendix C as Plates C-1 through C-22. Hydrographs for 23 wells with relatively complete records through the base period of 1985 through 2008 are presented as Plates C-23 through C-56.

The hydrographs are essential elements of the hydrogeologic update and model. They are used to identify water-level trends, assess aquifer response to various hydrogeologic conditions, and assess changes in groundwater storage between various periods in time. They are also important tools in the modeling as they are used as model calibration targets.

In general, the long-term hydrographs for Storage Unit No. 1 display seasonal and small amplitude annual fluctuations superimposed upon some larger, more prominent trends. Prior to the model base-period, the most notable trends occurred during the early 1940's through the mid-1950's when water levels in the basin declined substantially, and between approximately the early 1960's and about 1975 when water levels in the basin increased significantly.

There have been notable trends within the current base-period as well. Water levels declined relatively sharply starting at the beginning of the base period in 1984 through the fall of 1991, which was followed by a relatively steep upward trend in water levels peaking in the spring of 1998. Since then, water levels throughout the basin have generally been gradually declining. It is noted that during this 10-year period since 1998 (i.e.,1999 through 2008), the annual average rainfall was 16.8 inches, which is approximately 15 percent less than the long-term annual average of 19.8 inches. During this period, however, annual groundwater pumping averaged only approximately 3,600 afy, which is approximately 20 to 30 percent less than the previous estimates of basin yield that range between 4,500 to 5,000 afy. The observation that water levels gradually declined under these conditions of recharge and pumping suggests that previous estimates of basin yield may have been overestimated.

Analysis of the hydrographs led to the identification the basin high and the basin low periods within the model base period. Water-level contours were then prepared for the basin high and low periods, as well as for the periods coincident with the base period beginning and end. The four periods for which water-level contours were prepared include: Fall 1984 – beginning of base period; Fall 1991 – base period basin low; Spring 1998 – base period basin high; and Spring 2008 – end of base period. The purpose of the water-level contours was to help to identify general patterns in the flow regime within the basin, including those attributable to recharge sources and associated with discharge areas. The water-level contours are presented on Plate 14 –Water-Level Contours Storage Unit 1.

The water-level contours show that in Storage Unit No. 1, groundwater generally flows in a northeast to southwesterly direction in the eastern half of the basin, and north to south in the western half of the basin. The contour of data for the base-period low shows the development of a water level depression centered around the central portion of Storage Unit No. 1. In the center of the depression, water levels during this period declined to an elevation of more than 40 feet below mean sea level. Also notable on this contour map is the southeastward flow of groundwater from the Toro Canyon area toward the area of greatest water-level decline.

The water-level contours were then used to derive estimates of the changes in groundwater storage between the contoured periods. For this, the basin (SU1) was divided into two areas: the recharge area; and the confined area. The total difference in volume between the contour surfaces for two periods was determined for both the recharge and the confined areas. The storage changes for the two areas were then determined by multiplying the total volume change by a specific yield or storage value; 0.08 (dimensionless) for the recharge area and 0.00065 (dimensionless) for the confined area. The results of the change in groundwater storage calculations are summarized below:

Fall 1984 through Fall 1991:	15,988 acre-feet of storage depletion;
Fall 1991 through Spring 1998:	17,661 acre-feet storage increase;
Spring 1998 through Fall 2008:	5,879 acre-feet of storage depletion.

HYDROLOGIC BUDGET

An updated hydrologic budget for the CGB was performed in order to quantify the primary sources of recharge to and discharges from the basin for the base period 1985 through 2008. A hydrologic budget can be expressed by the following equation:

Inflow = Outflow (+/-) Change in Storage

where Inflow equals:

- Subsurface Inflow
- Streambed Percolation
- Percolation of Precipitation, and
- Percolation of Irrigation Return Water (pumped and imported);

and Outflow equals:

- Subsurface Outflow
- Gross Groundwater Pumpage, and
- Extraction by Phreatophytes.

This accounting is generally conducted for as long a period as practicable, in order to evaluate variations in the budget and identify those components to which the basin is most sensitive. GTC performed an inventory of the various components of inflow and outflow to the CGB in its 1976 study for Water Years 1935 to 1973 (39-year base period). GTC subsequently updated the inventory in 1986 for Water Years 1974 to 1984 (11-year base period). In 2003, IWR performed a review of the existing perennial yield estimates for the CGB, including a review of the data used to develop the estimates. IWR concluded that the existing / previous analyses provide a reasonable basis for establishing the water balance of the CGB, and forwarded an estimate of perennial yield between 4,500 to 5,500 afy.

For this project, the inventory was updated for Water Years 1985 to 2008 (24-year base period). Some data are available via direct measurement (e.g., District metered pumpage), whereas others are more difficult to quantify and require estimation based on commonly used techniques. In general, the techniques used for the current update were similar to those used by GTC in their 1976 and 1986 inventories, but were modified / improved where possible given the availability of new data and / or analytic tools. The updated hydrologic budget coupled with the previously-described information about the physical characteristics of the basin will form the principal basis for constructing and calibrating the numerical groundwater model of the basin (i.e., Task 2). A summary of the updated hydrologic budget for the 1985 – 2008 base-period is presented as Table 5 below. Each of the components of the updated hydrologic budget is discussed in greater detail below.

Rainfall. Rainfall is the primary source of inflow / recharge to the basin, whether it falls directly on the basin or on adjacent areas and flows into the basin via the surface or subsurface (a lesser source of water to the basin is return flows from imported water). The Santa Barbara County Flood Control District maintains precipitation data from the Carpinteria Fire Station with a period of record from 1949 to the present. Annual rainfall during the period is presented on Plate 15. As shown, the mean annual rainfall for this long-term period is 19.8 inches.

The line on Plate 15 indicates the cumulative departure of annual rainfall from the long-term mean. The cumulative departure from mean graphs the sum of annual departures over time, beginning with the first year departure and adding each subsequent year departure. The climatic trends present in the cumulative departure curve exhibit a series cyclic dry and wet periods in the basin.

It is noted that the base-period for the current update coincides with the beginning of a dry period that occurred from about 1984 through 1991, followed by a wet period from 1992 through 1998, and ending with a dry period from 1999 through 2008. The mean annual rainfall for this period is 20.2 inches, which is within 2 percent of the long-term mean. These observations are important for the updated water balance and calibration of the groundwater model, as will be discussed below.

Subsurface Inflow. Subsurface inflow is flow from consolidated rocks in the hill and mountain areas adjacent to the CGB. As discussed by Upson (1951) and Evenson (1962), underflow from the consolidated rocks must be considered as a source of recharge to the CGB. Studies conducted by DWR (Bulletin Nos. 104 and 104-2) similarly concluded that such components of recharge cannot be ignored. Amounts of subsurface inflow to the CGB were

Table 5. Estimated Seasonal Deep Percolation, Extractions, and Change in Storage (values in acre-feet per year)

Water Year	Rainfall (in)	Subsurface Inflow	Streambed Percolation	Percolation of Precipitation	Percolation of Irrigation Water		Total Inflow	Subsurface Outflow	Groundwater Pumpage		Extraction by Phreatophytes	Total Outflow	Change in Storage	
					Delivered	Pumped			CVWD	Private			Year	Cummulative
1985	15.26	869	57	391	58	190	**1,566**	16	1,836	949	100	**2,901**	-1,335	-1,335
1986	25.78	1,100	866	4,198	80	208	**6,451**	0	2,032	1,041	100	**3,173**	3,279	1,943
1987	11.99	683	91	30	90	186	**1,080**	0	2,363	932	100	**3,395**	-2,315	-372
1988	17.34	988	112	731	103	213	**2,147**	0	2,342	1,065	100	**3,507**	-1,359	-1,731
1989	10.27	585	26	0	116	304	**1,031**	0	2,984	1,520	100	**4,604**	-3,573	-5,304
1990	8.93	509	4	0	246	398	**1,157**	0	3,413	1,990	100	**5,503**	-4,346	-9,650
1991	20.11	1,100	758	1,634	166	452	**4,110**	0	3,014	2,261	100	**5,375**	-1,265	-10,915
1992	25.39	1,100	1,026	4,174	140	433	**6,873**	0	1,560	2,165	100	**3,825**	3,048	-7,867
1993	37.45	1,100	1,434	5,499	177	484	**8,695**	0	1,261	2,422	100	**3,783**	4,912	-2,954
1994	14.43	822	352	278	184	564	**2,200**	0	1,307	2,818	100	**4,225**	-2,025	-4,980
1995	41.59	1,100	1,746	5,487	162	478	**8,973**	231	1,291	2,389	100	**4,011**	4,961	-18
1996	19.55	1,100	894	1,401	162	502	**4,059**	239	1,557	2,510	100	**4,406**	-347	-365
1997	18.07	1,030	958	862	192	487	**3,529**	58	1,317	2,437	100	**3,912**	-383	-748
1998	51.48	1,100	1,744	5,467	149	486	**8,945**	418	575	2,428	100	**3,521**	5,424	4,675
1999	9.99	569	434	0	292	598	**1,893**	376	340	2,990	100	**3,806**	-1,913	2,763
2000	17.47	995	789	740	256	621	**3,401**	86	1,410	3,105	100	**4,702**	-1,301	1,462
2001	20.43	1,100	1,096	1,692	205	652	**4,745**	202	185	3,259	100	**3,746**	999	2,461
2002	7.66	436	7	0	257	621	**1,320**	196	558	3,103	100	**3,957**	-2,637	-175
2003	21.97	1,100	521	2,293	245	545	**4,704**	62	402	2,723	100	**3,287**	1,418	1,243
2004	9.57	545	2	0	277	561	**1,385**	4	999	2,803	100	**3,906**	-2,520	-1,278
2005	37.56	1,100	1,657	5,366	289	412	**8,825**	0	1,152	2,060	100	**3,312**	5,513	4,235
2006	18.58	1,059	927	930	316	417	**3,647**	0	1,120	2,083	100	**3,302**	345	4,580
2007	7.11	405	9	0	410	501	**1,325**	0	1,418	2,507	100	**4,025**	-2,700	1,880
2008	17.51	998	1,041	735	317	561	**3,652**	0	661	2,806	100	**3,567**	85	**1,966**
24-Year Avg.	20.23	896	690	1,746	204	453	**3,988**	79	1,462	2,265	100	**3,906**	**82**	
High	51.48	1,100	1,746	5,499	410	652	**8,973**	418	3,413	3,259	100	**5,503**	**5,513**	
Low	7.11	405	2	0	58	186	**1,031**	0	185	932	100	**2,901**	**-4,346**	
% of Total		22	17	44	5	11	**100**	2	37	58	3	**100**		

estimated in the 1976 GTC report utilizing several interrelated methods of analysis, including:

- Total precipitation less surface runoff and consumptive use;
- Natural water loss and recoverable water from mountain basins (the so-called Crippen methodology);
- Base flow regression curves, and;
- Comparison of Tecolote tunnel inflow volumes and Darcy's Law.

It is important to note that data on groundwater gradients, and average seasonal volumes of runoff and consumptive use of native vegetation in the watershed areas tributary to the CGB are subject to considerable uncertainty and interpretation. However, each method of analysis essentially limits the amount of water that can theoretically be available as a source of recharge to the basin. Based on GTC's analysis, the upper limit of subsurface inflow was estimated to be 1,100 afy and the low limit was 450 afy during the 1939 to 1973 base period.

A direct relationship between subsurface inflow and precipitation was developed from GTC's analysis, and seasonal amounts of subsurface inflow were then adjusted based on the establishment of a simple regression from the average annual rainfall in a given year to subsurface inflow during the base period. For this update, seasonal subsurface inflow was estimated using this same relationship. As shown in Table 5, for the 1985 to 2008 base period, a low of 405 afy and a high of 1,100 afy with an average of 896 afy was estimated. This compares to averages of 890 and 939 afy estimated by GTC for the 1939 to 1973 and 1974 to 1984 base periods, respectively.

Streambed Percolation. There are five principal streams in the CGB; Carpinteria, Gobernador, Santa Monica, Arroyo Parida, and Rincon Creeks. Additional drainages include Toro and Franklin Creeks. Only two of these creeks have runoff records – Carpinteria Creek and Franklin Creek. Stream gages have historically been maintained and monitored by the USGS, and the data is stored and retrievable from the USGS Water Resources website. The Carpinteria Creek gage is the only currently active gage, and has essentially continuous data since 1941 (there is a brief hiatus in the record for Water Year 1978). Records for Franklin Creek are limited to Water Years 1971 through 1978. Available data for the other drainages in the CGB is limited to miscellaneous measurements made by the USGS from 1941 to 1945.

GTC (1976) developed a correlation index for each drainage in the basin to reflect the variation in precipitation with elevation, drainage area, and runoff lost as seepage based on seepage loss measurements made during the 6-year period of Water Years 1968 through 1973. Runoff from the ungaged streams was then estimated by GTC for Water Years 1935 through 1984 utilizing these rainfall-runoff relationships. Similar rainfall-runoff relationships have been utilized to estimate streamflow in the ungaged streams for the 1985 through 2008 base period for this update.

Streambed percolation is assumed to occur only where the stream reaches cross the Recharge Area. Once streamflow reaches the Confined Area, the amount of deep percolation to the main groundwater system is assumed to be insignificant. The 1976 GTC study included an analysis of annual runoff and seepage losses for streams in the basin, and developed runoff vs. streambed percolation relationships for each individual stream. These same relationships were utilized for this update (refer to Appendix D for supporting data and calculations).

As shown in Table 5 above, the amount of estimated streambed percolation varies from very little during dry years (e.g., 1990, 2004) to as much as approximately 1,750 afy in wet years (e.g., 1995, 1998). It is also noted that Carpinteria and Gobernador Creeks combined contribute over 60 percent of the total streamed percolation, with Rincon Creek contributing approximately 20 percent. The 24-year average streambed percolation was estimated at 690 afy. This compares to 940 and 1,232 afy estimated by GTC for the 1935 through 1973 and 1974 through 1984 base periods, respectively.

It is noted that the reaches of both Santa Monica and Franklin Creek that cross the Recharge Area were channelized into concrete-lined box channels as part of the Carpinteria Valley Watershed Project in 1974; therefore, these two streams are considered to no longer recharge the CGB in a significant way. The 1986 GTC update, however, did include these two streams in their analysis. As such, the total streambed percolation estimated by GTC for the 1974 through 1984 period is likely overestimated. For reference, these two streams would have contributed approximately 160 afy, respectively, on average during the current 24-year base period, equivalent to approximately 20 percent of the total streambed percolation.

Percolation of Precipitation. Infiltration of precipitation is one of the most important sources of recharge to the basin. Precipitation recharges the basin principally through deep percolation to the zone of saturation in the Recharge Area (see Plate 8). The amount of precipitation that percolates downward to a groundwater basin can vary considerably, depending mostly upon the type of soil, density of vegetation, the quantity, intensity and duration of rainfall, the vertical permeability of the soil, and topography. Much of the infiltrating rainfall is held within the root zone because at the beginning of each rainy season there is an initial deficiency of soil moisture. During the summer months the capillary soil moisture is more or less completely depleted from the soil within the root zone by the processes of evaporation and transpiration. No deep percolation of rainfall can occur until the initial fall soil moisture deficiency is exceeded. Many years may pass before any rainfall penetrates beyond the root zone of native vegetation. In irrigated soils, because of the artificial application of water, the initial fall moisture content is greater and less annual rainfall is required to meet the soil moisture deficiency. Once the soil moisture deficiency within the root zone has been satisfied, the excess precipitation will percolate downward until it eventually reaches the water table.

There are two primary considerations in calculating the volume of precipitation that percolates beyond the root zone and contributes to the groundwater body: first; the determination of deep percolation of rainfall in inches for various land uses / vegetative covers, and, second, the determination of the total area of the various covers for which inches of percolation is determined. The total volume of percolation in acre-feet is then calculated (i.e., inches of percolation x acreage).

The precise field measurement of the amount of total rainfall that percolates below the root zone and reaches the main water body requires special equipment, is time consuming, and, to be of value, must be continued over several years and under a variety of conditions. Another method developed by the Soil Conservation Service involves modeling of a “Soil Reservoir”, where inputs to the reservoir (rainfall) exceed output (evapotranspiration of vegetation and runoff) and soil reservoir storage capacity, deep percolation to groundwater is assumed to occur. This “Soil Moisture Balance” methodology involves the use of monthly rainfall data, site specific parameters such as vegetative type, soil type, and the amounts of applied irrigation water. Measurements of these types were beyond the scope of this study; therefore, in order to estimate the amount of rainfall that percolates to the CGB, it was necessary to rely upon measurements made by Blaney (1933) in Ventura and Santa Barbara Counties. Although conditions in the CGB are not exactly the same as in Ventura County, it is believed that they are sufficiently similar for the estimates to be valid.

Blaney empirically tabulated the amounts of rain that percolated beyond the root zone, depending upon the type of vegetation and amount of seasonal precipitation. Blaney’s values of deep percolation (in inches) versus seasonal rainfall were plotted for land covers similar to those in the CGB, and best-fit curves drawn trough these points, as shown on Plate E1 (Appendix E). Values of percolation of rainfall corresponding to seasonal rainfall and vegetative cover types in the CGB were calculated from these curves. Where precipitation greatly exceeded the long-term average (e.g., 1993, 1995, 1998 and 2005) an upper limit of deep percolation was fixed at 8 and 15 inches in the native and irrigated land use categories, respectively. It is noted that GTC also utilized Blaney’s curves for estimating deep percolation of precipitation in their 1976 and 1986 studies.

Blaney developed curves for many, but not all of the land cover types that are in the CGB. For the residential / commercial / industrial areas, Blaney’s curve for grass and weeds was utilized. While the actual land use is very different, the grass and weeds curve was considered reasonable because the amount of deep percolation occurring on grass and weeds is the most limited of all the Blaney curves, due primarily to the large initial soil moisture deficiencies. Due to the presence of impervious surfaces in the residential / commercial / industrial areas where no percolation can occur and much of the rainfall runs off, a relatively limited amount of deep percolation is expected to occur in these areas. The Blaney curve for irrigated crops land covers was utilized for the public parks / schools / polo grounds areas in the CGB. Again, it is acknowledged that the actual land use is somewhat different; however, the curve for irrigated truck crops was considered to better reflect the deep percolation conditions on irrigated turf, primarily due to the similarly shallow rooting depths, as compared to, for example, deciduous crops with relatively deep rooting depths.

As discussed above, Blaney’s curves are utilized to determine the inches of percolation during each rainfall year for the various land covers. In 2002, the CVWD undertook a comprehensive land use study utilizing a combination of digital imagery, GIS layers of land use and parcel boundaries, and statistical analysis to evaluate land use activities and estimate private well extractions. Prior to 2002, CVWD relied on periodic aerial photography of the basin and staff to update land use records (“paper cards”) when changes in land use activities were noticed as part of other CVWD duties. Since 2002, the land use studies have been GIS-based. For this project, GIS (ArcView 9.3) was utilized to intersect land use acreages within the delineated Recharge Area. For the period 1985 through 2001, annual changes in the acreages of each land use category within the Recharge Area were proportioned consistent with annual changes in the percentage of each land use category within the basin as whole. The land use acreages in the Recharge Area for each year in the base period are presented in Table E2 (Appendix E).

The amount of precipitation that infiltrated as deep percolation for each of the land covers in the CGB is shown in Table E3 (Appendix E), as is the total volume of deep percolation for each year of the base period and the average for the 24-year period. The total volume of deep percolation for each year of the base period is also shown in Table 5.

Based on the data presented in Tables 5, E1, and E3, it is evident that significant deep percolation only occurs in the wettest years (particularly on non-irrigated native lands), which is to be expected given the soil moisture discussion above. On irrigated lands, some additional deep percolation occurred in years when the average annual precipitation exceeded approximately 12 inches. In years when the average annual rainfall is less than approximately 12 inches, no deep percolation is estimated to occur. During wet years (e.g., 1993, 1995, 1998, and 2005) when average annual rainfall exceeds approximately 30 inches, over 5,000 af of deep percolation is estimated to occur.

The average annual recharge to the basin during the base period from deep percolation of rainfall is estimated to be approximately 1,750 afy. This represents a significant percentage (approximately 44%) of the overall water budget. For comparison, GTC estimated average annual deep percolation of rainfall to be approximately 1,560 and 1,960 afy for the 1935 to 1973 and 1974 to 1984 base periods, respectively.

Percolation of Irrigation Water. Percolation of irrigation return water in the CGB is dependent on a variety of factors, including climatic factors, crop type, irrigation practices, etc. An estimate of the amount of irrigation return water was one of the primary objectives of studies conducted in the Lompoc area by Blaney in 1962. The study area was within the coastal zone where consumptive use is depressed due to the influence of the coastal fog belt, similar to conditions in the CGB. The studies were also conducted on crops with consumptive use factors similar to those in the CGB. The results indicated irrigation efficiencies ranged varied from 60 to 80 percent. In addition, studies by the U.S. Soil Conversation Service for Santa Barbara County indicate irrigation efficiencies, under good practice, range from 65 to 70 percent. For purposes of estimating deep percolation of irrigation return water in the CGB, a conservative factor of 20 percent of applied water (both pumped and delivered) has been utilized. This factor takes into account the relatively steeper slopes found in many portions of the Recharge Area, and hence greater amounts of runoff, as well as the relatively more efficient sprinkler-type irrigation commonly used in the basin.

The amounts of total irrigation (delivered and pumped) and the corresponding amounts irrigation water seasonally percolating into the basin are shown in Table F1 (Appendix F). The estimated amount of water seasonally percolating into the basin from irrigation water is also shown in Table 5 above. As shown, the total amount of irrigation return water percolation was estimated to range annually between approximately 250 and 910 afy, averaging approximately 660 afy. For comparison, GTC estimated averages of approximately 830 and 740 afy of irrigation return flows for the 1935 to 1973 and 1974 to 1984 based periods, respectively.

Subsurface Outflow. Groundwater outflow from the CGB is difficult to ascertain because there is no known outcropping of the principal aquifer formations offshore. As such, groundwater discharge from the basin is assumed to occur only through shallow alluvial sediments where they are in contact with the ocean boundary. Groundwater within the principal aquifers of Storage Unit No. 1 does not discharge directly to the ocean in the southeastern portion of the basin due to the presence of overlying confining layers and the barrier created by the Rincon Creek Fault. Groundwater is believed to be rising in and around El Estero along the fault boundary, and that subsurface water enters the alluvium through notches eroded in the fault by streams in the area. Subsurface outflow from Storage Unit No. 1 could occur, therefore, in the general area from Serene Park to Sand Point (a distance of approximately 9,000 ft.). In Storage Unit No. 2, significant subsurface outflow is not believed to occur due to the contact of unconsolidated water-bearing materials with consolidated bedrock, which effectively isolates Storage Unit No.2 from the ocean, with the exception of a relatively narrow (3,500 ft.) strip of alluvium on the western boundary of Storage Unit No. 2 with the ocean.

The quantity of subsurface outflow from Storage Unit No. 1 was calculated using Darcy's Law in which the rate of discharge through a given cross section of saturated material is proportional to the hydraulic gradient. A hydraulic conductivity value of 20 ft/day for alluvial materials was assumed. A cross sectional area of 900,000 ft^2 was utilized, based on length of 9,000 ft and an average alluvial thickness of 100 ft. Seasonal groundwater gradients normal to the coastline were based on water level data from monitoring wells 4N/25W-19J5 (upgradient) and -30D1 (downgradient), separated by a distance of approximately 4,000 ft.

The results of the subsurface outflow calculations are shown in Table 5. As shown, subsurface outflow varied from a maximum of approximately 420 af in 1998 (historic high water levels in the basin) to 0 outflow during periods of deficient recharge (e.g., the 1987 to 1991 drought period). The 24-year average subsurface outflow was estimated to be approximately 80 afy. This estimate is considerably less than the estimate of 340 afy on average in GTC's analysis of the 1935 to 1973 base period.

Groundwater Pumpage. Groundwater extractions from the CGB occur from both CVWD production wells and from approximately 50 to 170 private wells in any given year. CVWD well production is metered, and monthly totals of production from each of the five CVWD wells have been obtained for the period of 1985 through 2008. Monthly totals were summed by Water Year, and are shown in Table 5. As shown, CVWD municipal pumping ranged between approximately 340 to 3,400 afy, averaging approximately 1,460 afy during the current 24-year base period.

Private pumping in the basin is not metered and has been estimated on an annual basis by CVWD since 1984 utilizing land use survey and imported water delivery information. CVWD supplies imported water and/or local groundwater to numerous agricultural parcels of know acreage and crop type (e.g., avocados, cherimoyas, open and covered nurseries, etc.). From these metered deliveries, unit use values (known by CVWD as "determining factors") for various crop types have been estimated each year since 1984. These unit use values have been combined with land use acreage data to estimate aggregate annual private well production in the basin.

As mentioned previously, in 2002 the CVWD undertook a comprehensive land use study for the first time utilizing a combination of digital imagery, GIS layers of land use and parcel boundaries, and statistical analysis to evaluate land use activities and estimate private well extractions. For this project, estimates of annual pumping was assigned to individual private wells in the basin by CVWD by intersecting land use "determining factors", acreages of land use per parcel (APN numbers), and well IDs by APN for each year during the period 1985 through 2008. As shown in Table 5, aggregate private pumpage is estimated to have ranged between approximately 930 to 3,260 afy, averaging approximately 2,270 afy during the current 24-year base period.

Total combined municipal and private pumpage was estimated to average approximately 3,730 afy during the 1985 to 2008 base period. This compares to approximately 3,330 and 1,830 afy estimated by GTC for the 1935 to 1973 and 1974 to 1984 base periods, respectively.

Extraction by Phreatophytes. Phreatophytes are water loving plants (roots extend into the water table) that live in the vicinity of stream channels and in areas of high groundwater. Groundwater consumed by phreatophytes is dependent on many factors, including plant species, vegetative density, climate, soil, and depth to groundwater. Measurements of consumptive use by phreatophytes in the CGB do not exist. GTC (1976) roughly estimated phreatophytes extractions for the CGB by applying results of a 5-year study in San Diego County utilizing the Blaney-Criddle formula (Blaney and Criddle, 1963). Extractions by phreatophytes were estimated to be approximately 120 to 130 afy from the 1930s through 1970, then reduced to approximately 100 afy as a result of removal of phreatophytes from the Santa Monica and Franklin Creek channels as part of the flood control channelization projects. It has been similarly assumed that extraction by phreatophytes is about 100 afy for this update.

Changes in Storage. The difference between the groundwater volume from one year to the next is the annual change in groundwater storage. The change in the amount of groundwater in storage depends on the annual water supply surplus or deficiency as expressed in the water balance equation. As shown in Table 5, using the water balance inventory method the total annual water demand (outflows) was slightly less than the total recharge (inflows) by approximately 82 afy on average during the 24-year base period. This resulted in a net accumulation of groundwater in storage of approximately 1,965 af from 1985 to 2008.

As discussed previously, changes in the amount of groundwater in storage were also calculated by the specific yield method. By this method, there was a net decrease in storage of approximately 4,200 af during the 24-year base period. A comparison of the net changes in groundwater storage for select periods during the 1985 – 2008 base period is presented in Table 6 below.

Table 6. Changes in Storage Calculation Comparison

Period	Description	Estimated Change in Storage (af)	
		Inventory Method	Specific Yield Method
1985 – 1991	Beginning of base period to basin low.	-10,915	-15,988
1991 – 1998	Basin low to basin high.	+15,590	+17,661
1998 – 2008	Basin high to end of base period.	-2,710	-5,879
1985 - 2008	Cumulative over 24-year base period.	+1,965	-4,206

Hydrologic Budget Summary. Table 5 presents the annual amounts of each component of the water balance equation for the CGB as computed by the inventory method. As shown, average annual inflow during the current 1985 to 2008 base period (24 years) was estimated at approximately 3,990 afy and average annual outflow estimated at 3,910 afy.

GTC performed an inventory of the various components of inflow and outflow to the CGB in its 1976 study for Water Years 1935 to 1973. Total inflow to the basin was estimated to range from 1,450 to 9,940 acre feet per year (afy), and averaged 4,220 afy over the 39-year base period. Total outflows were estimated to range between 2,420 and 5,880 afy, and averaged 3,790 afy. GTC subsequently updated the inventory in 1986 for Water Years 1974 to 1984, and estimated total inflows and outflows to average 4,870 and 3,730 afy, respectively, over that 11-year base period. A comparison of the estimated amounts of average annual total inflow, outflow, and changes in storage for previous base periods with the current base period is presented in Table 7 below.

Table 7. Hydrologic Budget Comparison

Base Period	Investigator	Total Inflow (afy)	Total Outflow (afy)	Change in Storage (afy)
1935 – 1973	GTC	4,220	3,790	+440
1974 – 1984	GTC	4,870	3,730	+1,150
1985 - 2008	PWR	3,988	3,906	+82
	Averages	4,359	3,809	+557

As show, there is general agreement between the inventories for the three base periods, with the average annual inflow to the basin ranging between approximately 3,990 to 4,870 afy, averaging approximately 4,360 afy, and average annual outflow from the basin averaging approximately 3,810 afy. As noted previously, the methodologies utilized for the inventories of each base period were similar (but not identical). As such, the general agreement is not unexpected, and the slight differences in the total inflow and outflow values largely reflect differences in precipitation and land uses during each respective base period.

CONCLUSIONS

The hydrogeologic update performed as Task 1 of the project will form the basis for the development and calibration of a numerical groundwater flow model of the CGB. Specific conclusions regarding the results of Task 1 include the following:

- The updated aquifer geometry and structural contours of the principal aquifer aquifers and bedrock in the CGB have been prepared as ArcGIS files, which are suitable for direct import into the model development environment.
- The development of aquifer-specific hydraulic parameters represents a significant advancement in the hydrogeologic framework of the CGB, and will be of significant importance to the construction and reliable calibration of the numerical model.
- The development of individually assigned groundwater pumpage to wells in the basin, combined with available well construction information, is also of significance to the development of the numerical model. This information allows for the reliable input of both spatial (laterally and vertically) and temporal well extractions from the basin.
- There is general agreement between this hydrogeologic update and previous investigations on estimates of the water balance equation for the basin. Total average annual inflow to the basin was estimated at approximately 3,990 afy for this update, compared to approximately 4,220 afy estimated by GTC in their 1976 study of the basin.
- The base-period of this update (1985 – 2008) represents a reasonably good base-period for model development and calibration. Typically, the criteria for selecting a base-period must include at least one period each of overall wet and dry conditions (relative to the mean annual condition) and have an average rainfall that is close to the average rainfall for the entire period of record. In addition, the beginning of the base-period should be during a period of overall relatively dry conditions to eliminate the potential for “in-transit” recharge water that might not be reflected in storage changes. The base-period should also begin and end at similar points of the cumulative departure from the mean in order to represent the average rainfall over the base period. The 1985 – 2008 base-period for this update satisfies these criteria reasonably well, and it also represents current cultural conditions in the basin.

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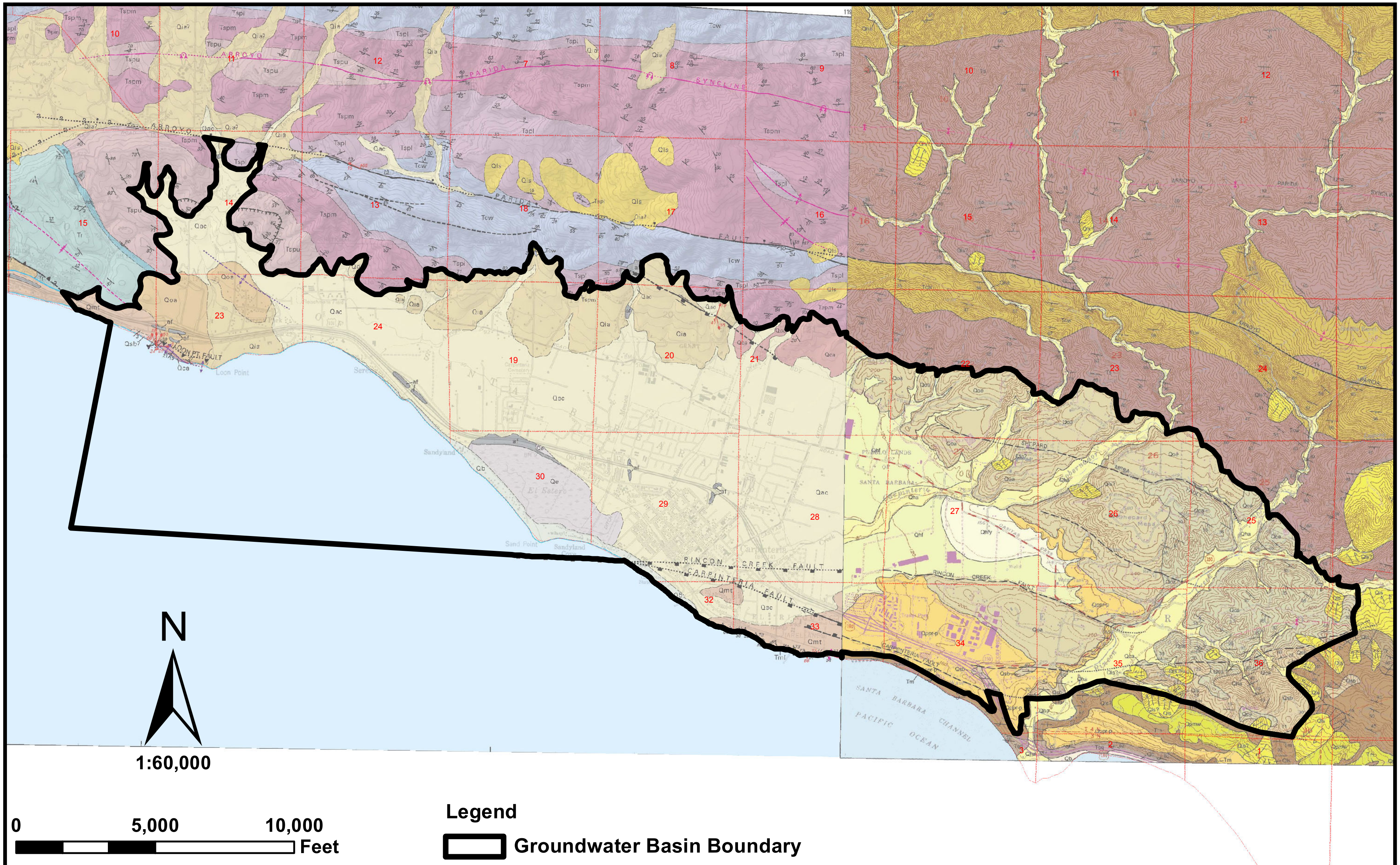

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PLATE 1. GEOLOGIC MAP AND BASIN BOUNDARIES
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125

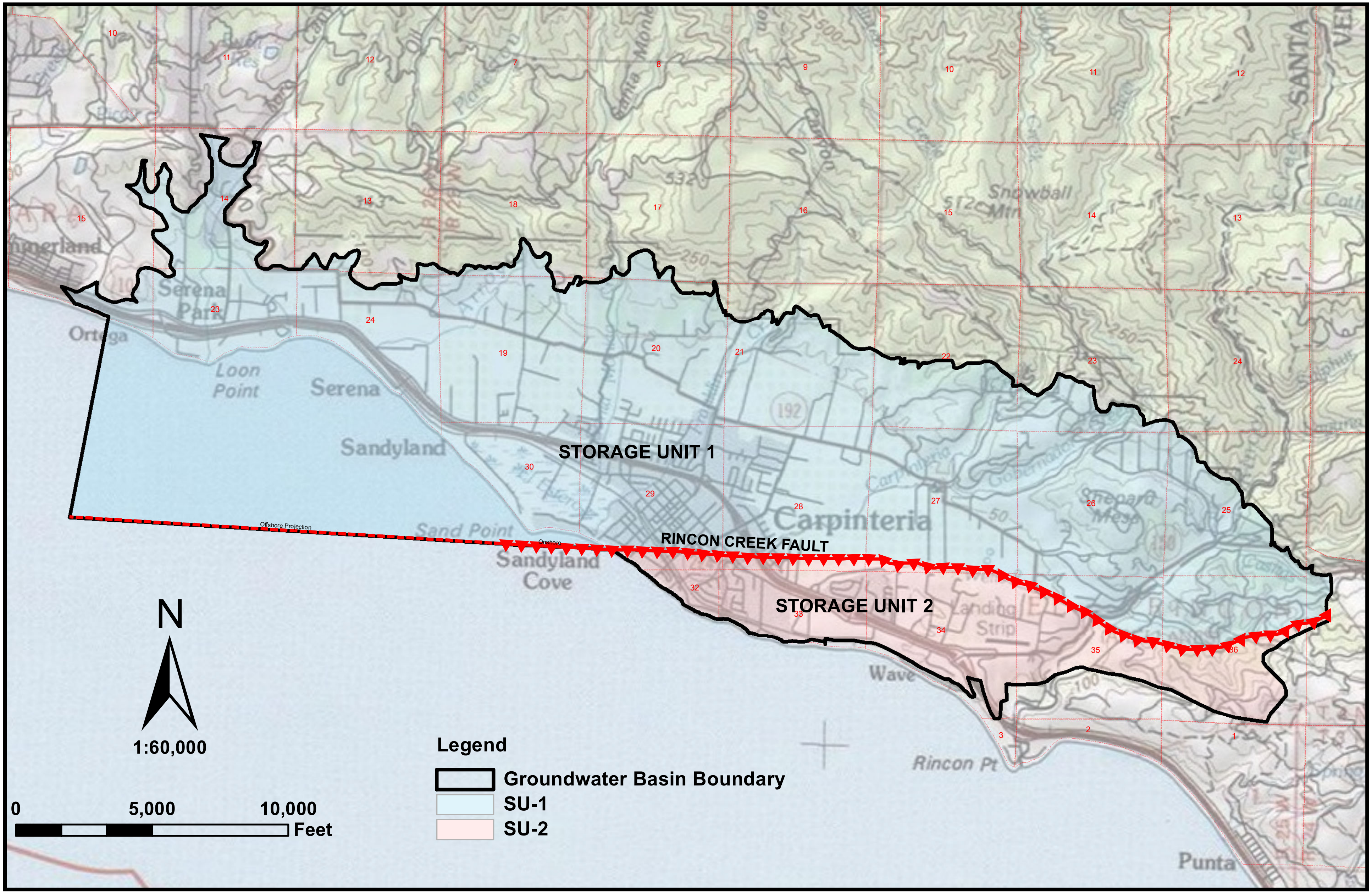

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PLATE 2. STORAGE UNITS 1 AND 2
CGB Hydrogeologic Update
Carpinteria Valley Water District

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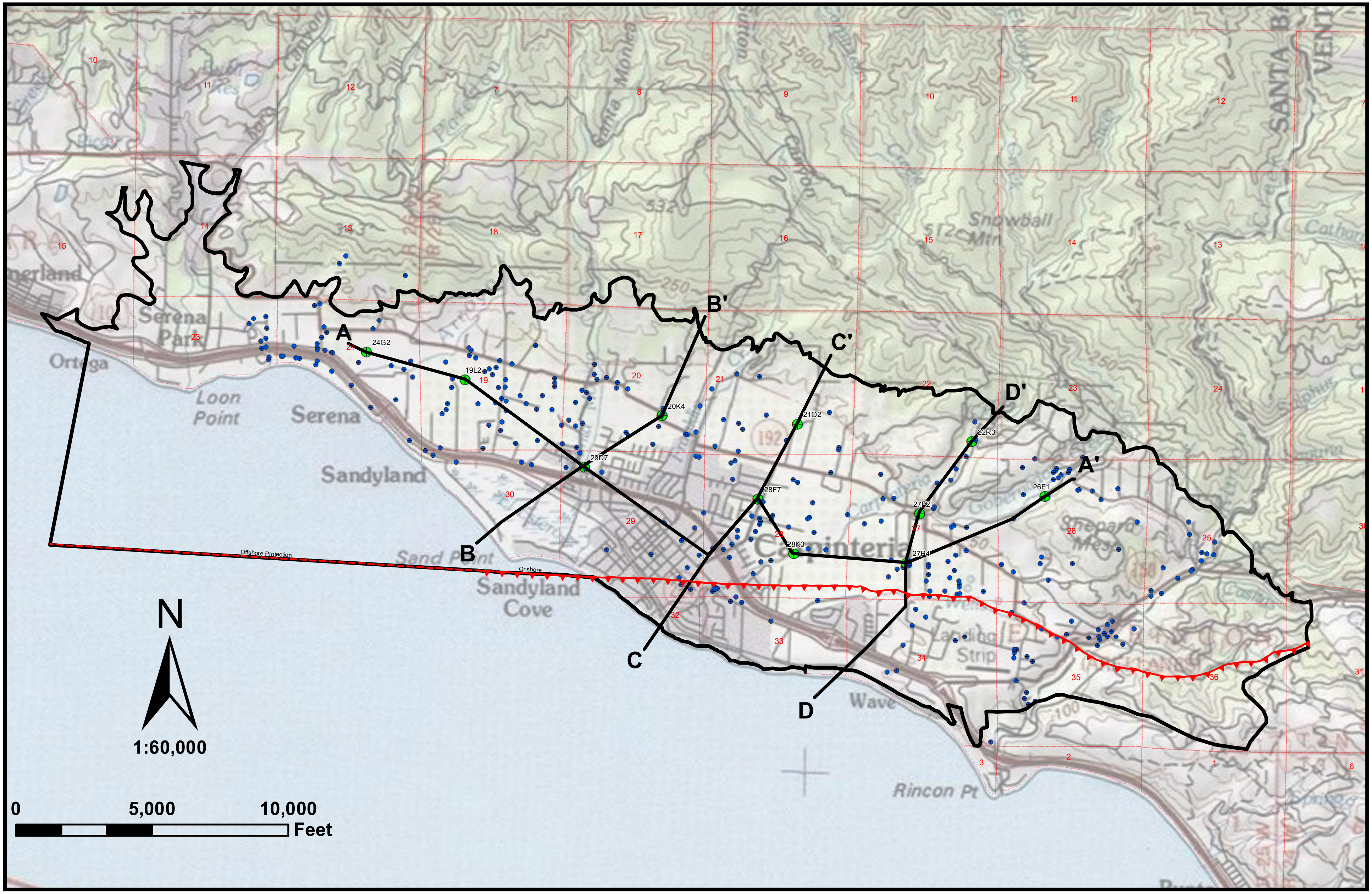

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PLATE 3. CROSS-SECTION LOCATION MAP
CGB Hydrogeologic Update
Carpinteria Valley Water District

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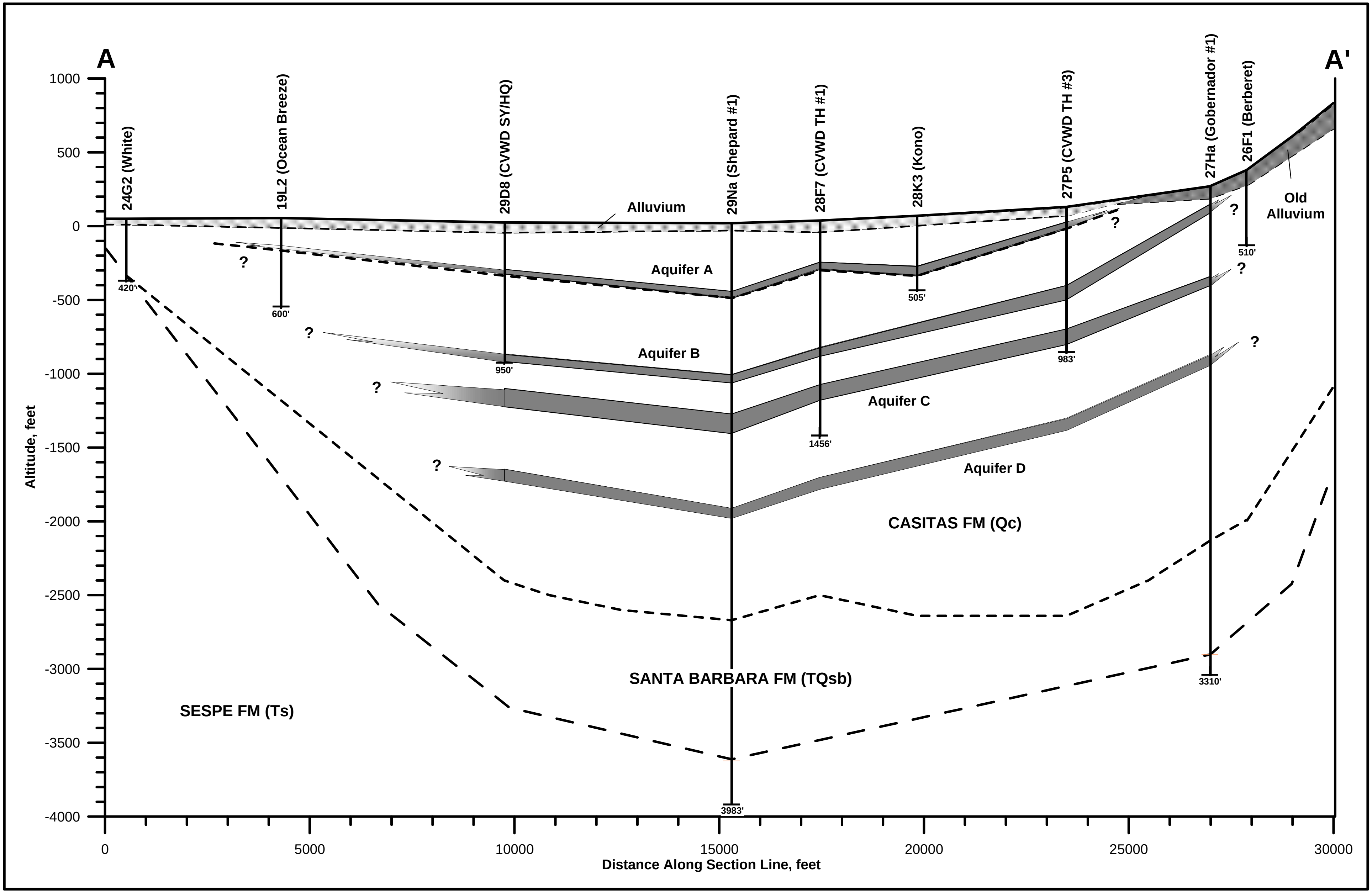

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PLATE 4. HYDROGEOLOGIC CROSS SECTION A-A'
CGB Hydrogeologic Update
Carpinteria Valley Water District

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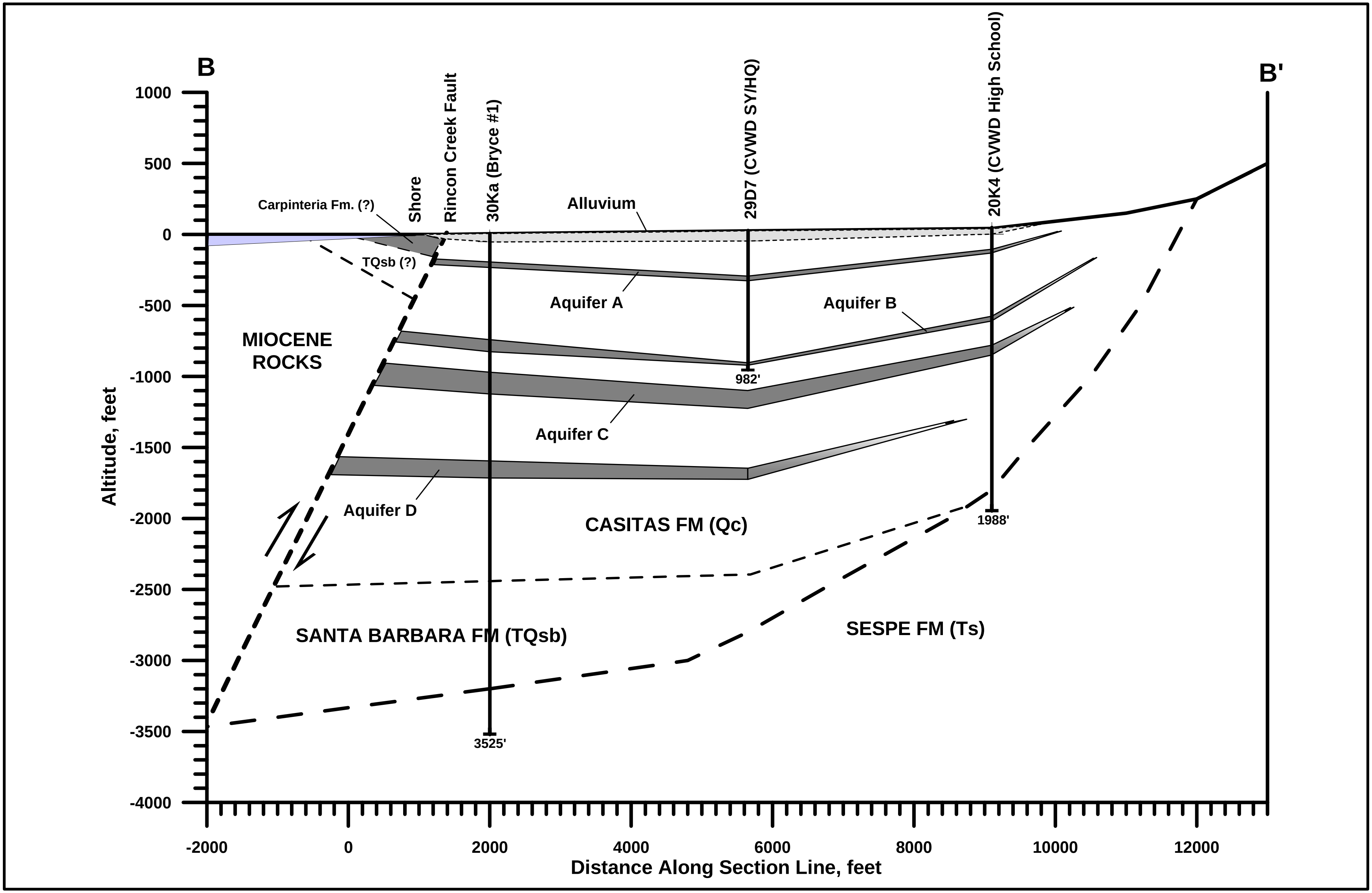

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PLATE 5. HYDROGEOLOGIC CROSS SECTION B-B'
CGB Hydrogeologic Update
Carpinteria Valley Water District

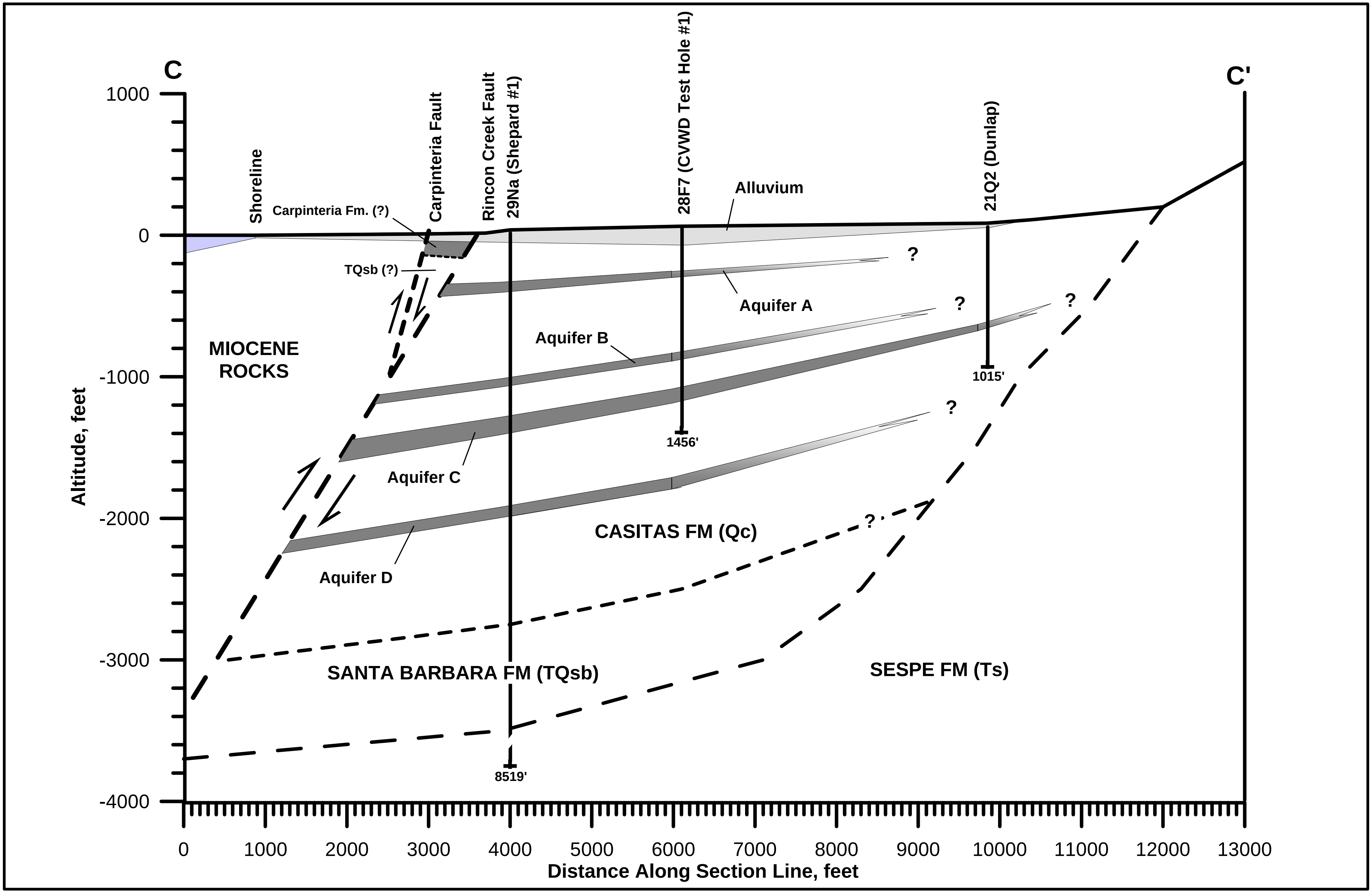

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PLATE 6. HYDROGEOLOGIC CROSS SECTION C-C'
CGB Hydrogeologic Update
Carpinteria Valley Water District

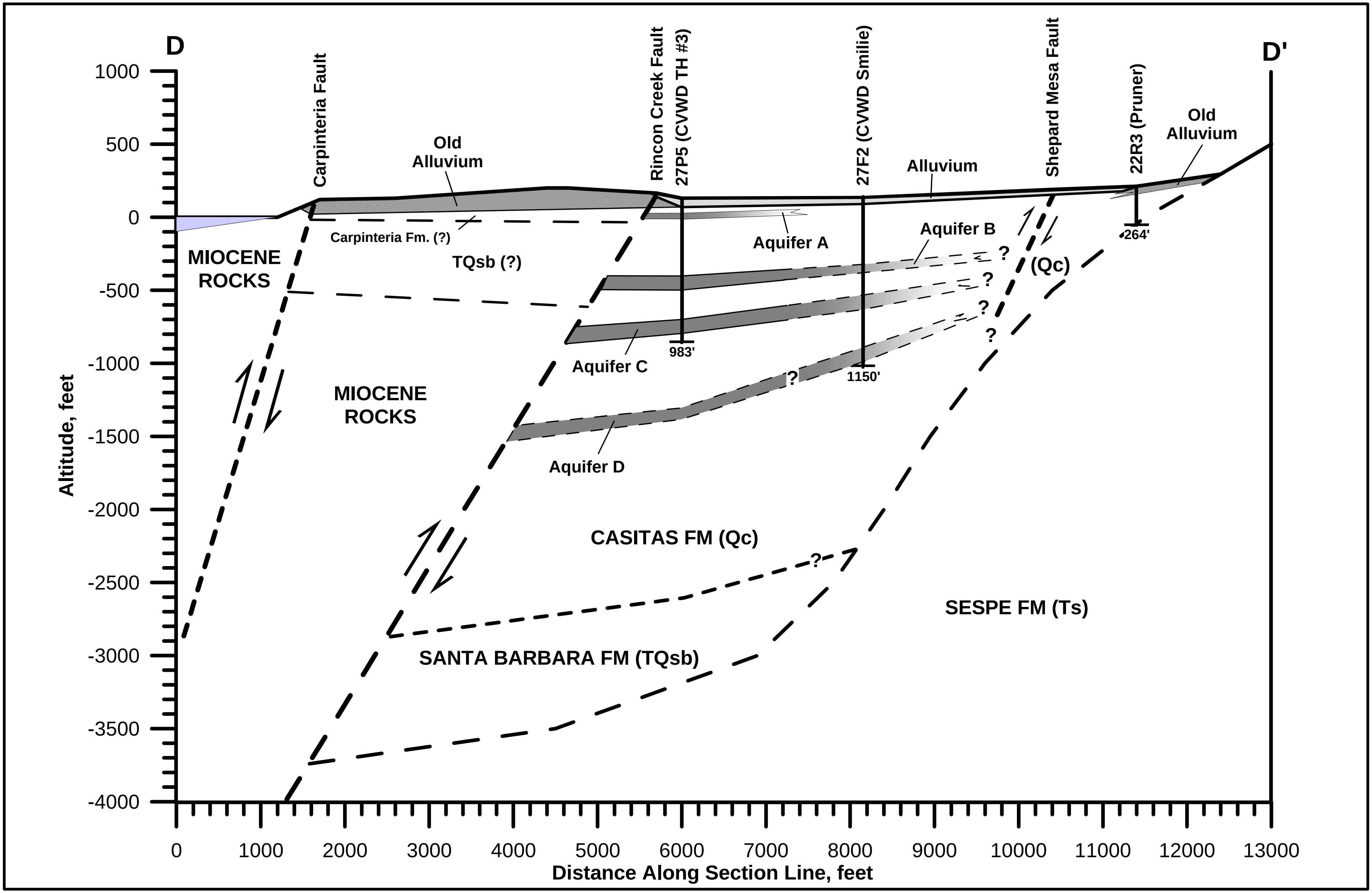

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PLATE 7. HYDROGEOLOGIC CROSS SECTION D-D'
CGB Hydrogeologic Update
Carpinteria Valley Water District

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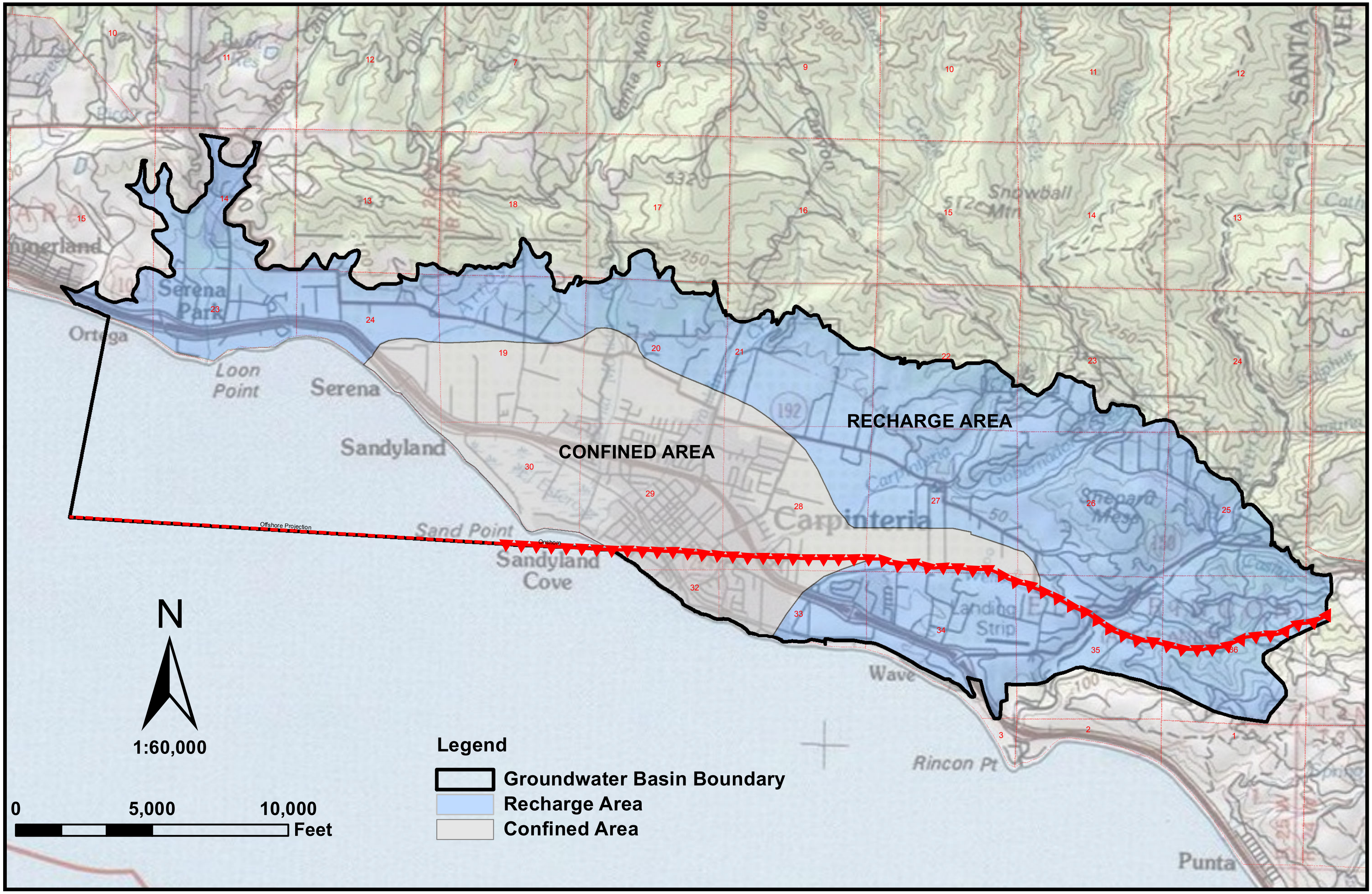

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PLATE 8. CONFINED AND RECHARGE AREAS
CGB Hydrogeologic Update
Carpinteria Valley Water District

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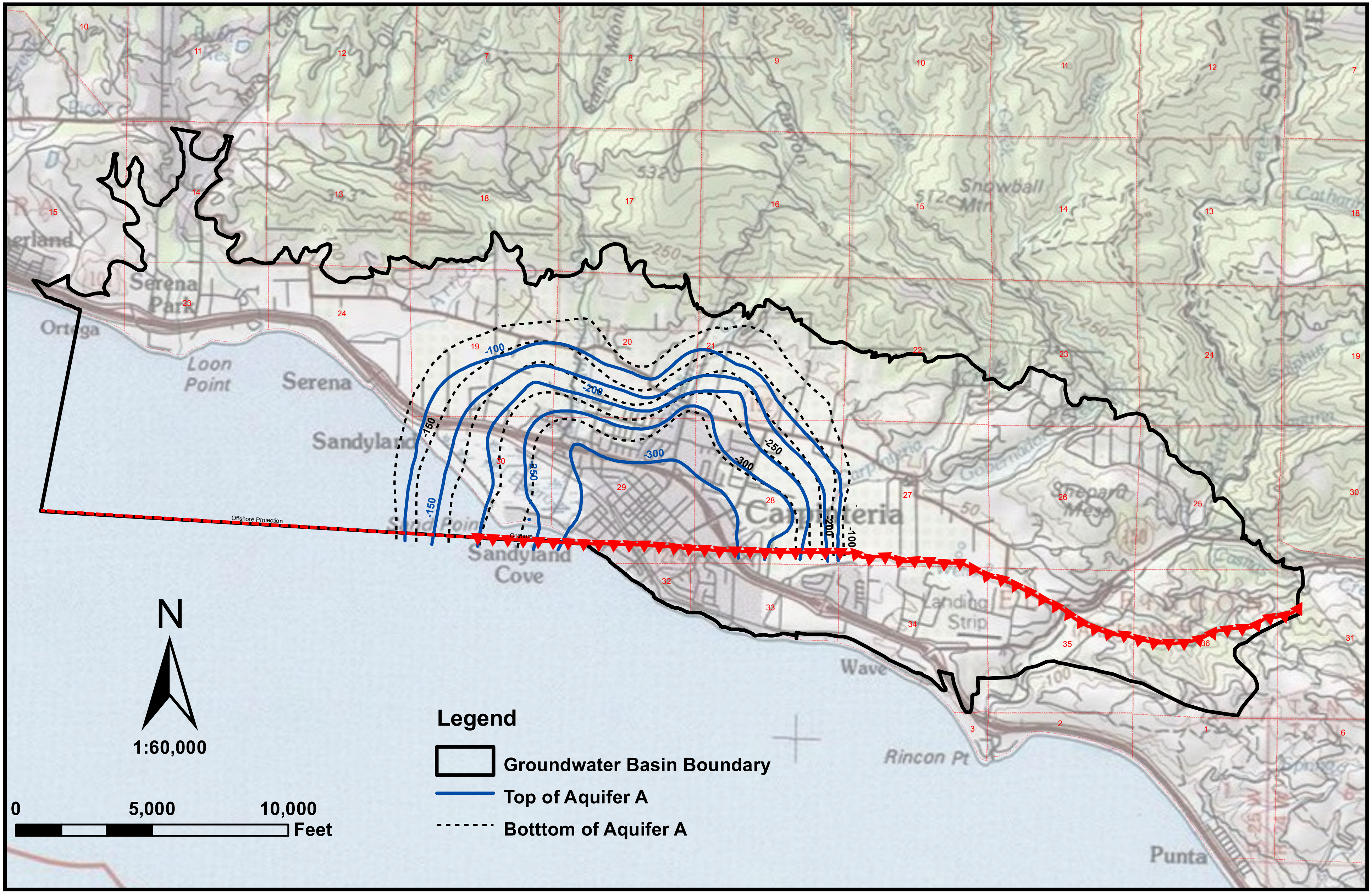

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PLATE 9. STRUCTURAL CONTOURS - AQUIFER A
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125

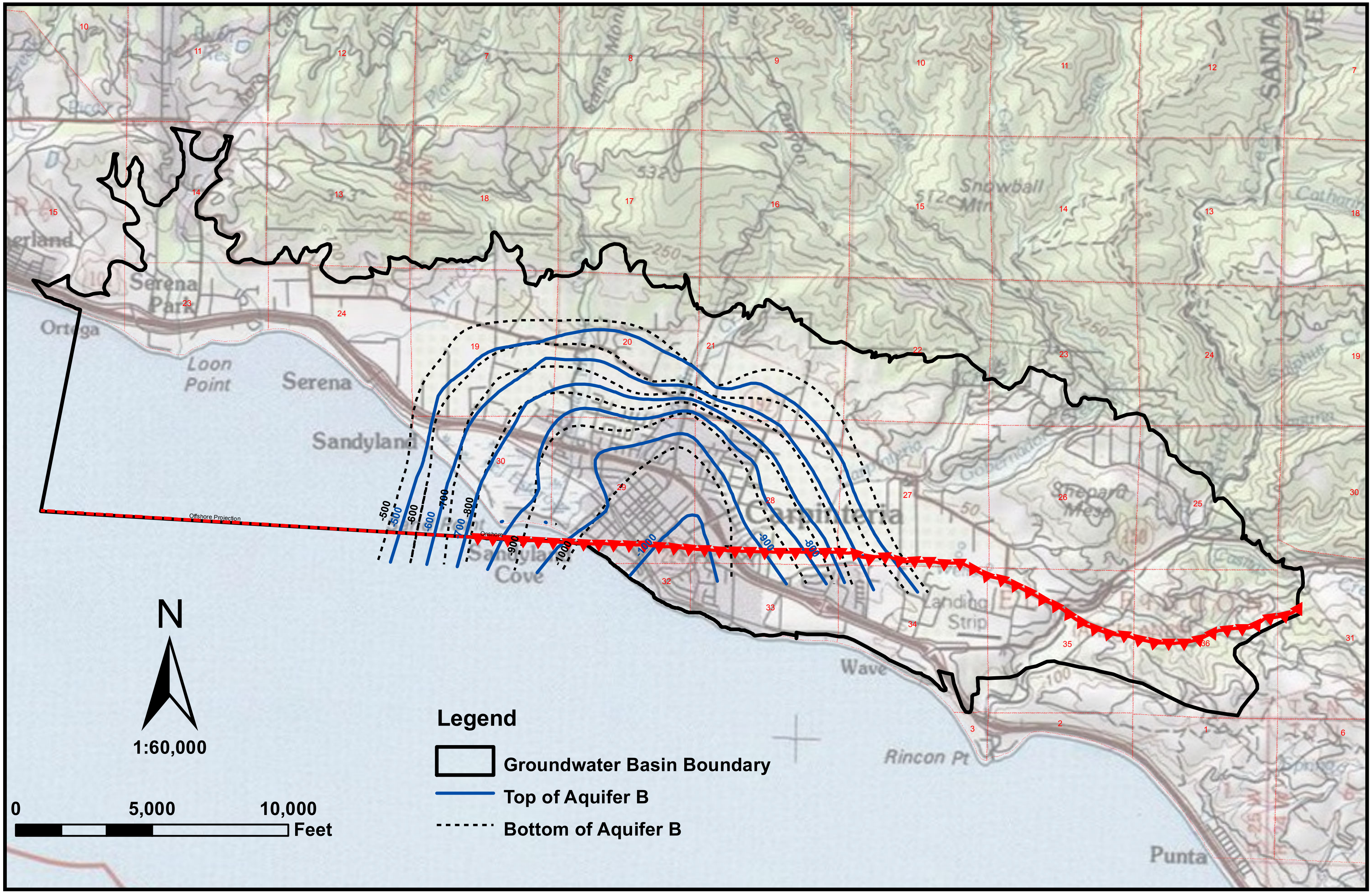

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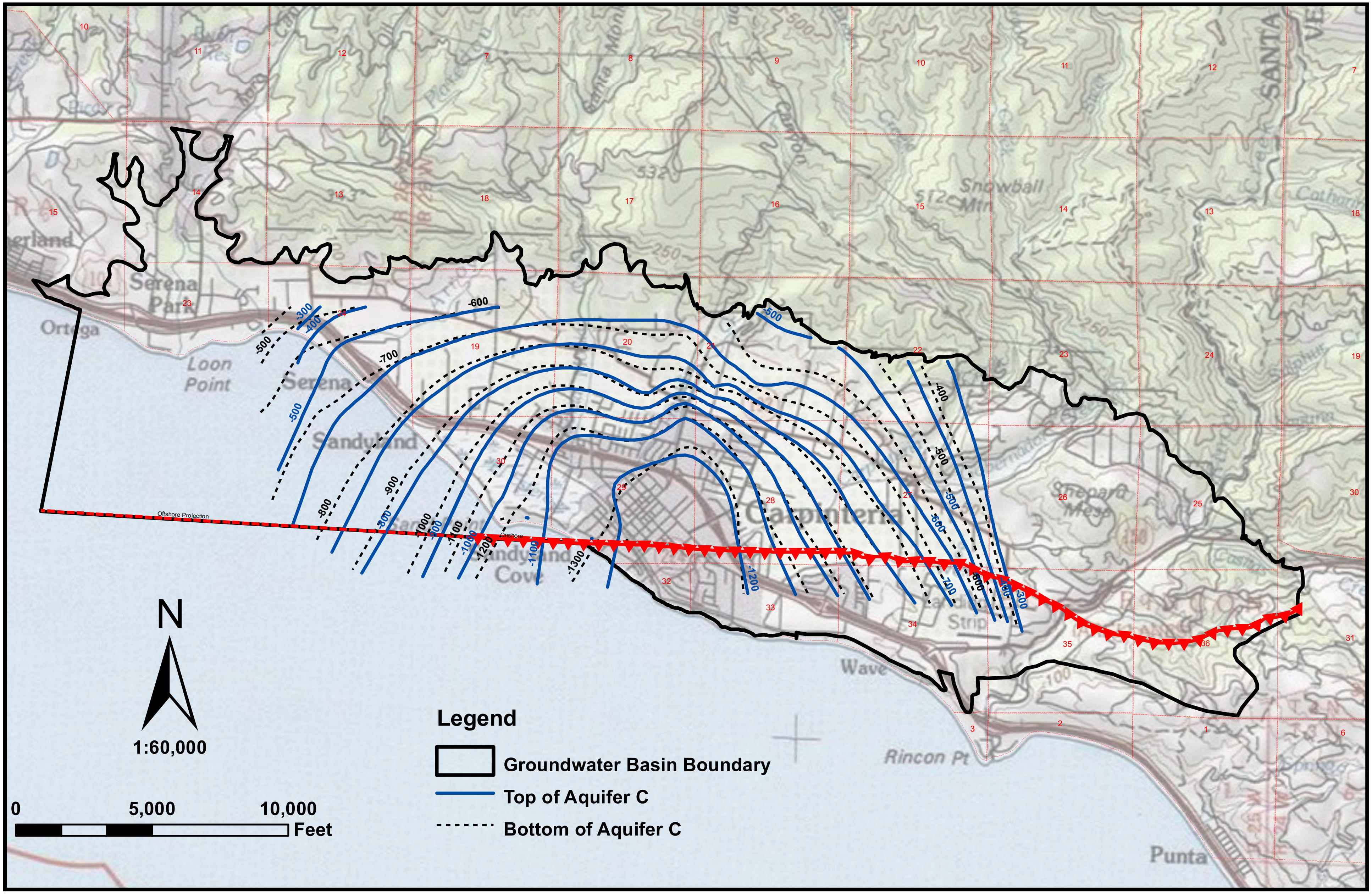
PLATE 10. STRUCTURAL CONTOURS - AQUIFER B
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125



Legend

▭ Groundwater Basin Boundary

Top of Aquifer C

Bottom of Aquifer C

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PLATE 11. STRUCTURAL CONTOURS - AQUIFER C
CGB Hydrogeologic Update
Carpinteria Valley Water District

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Project No. 06-0125

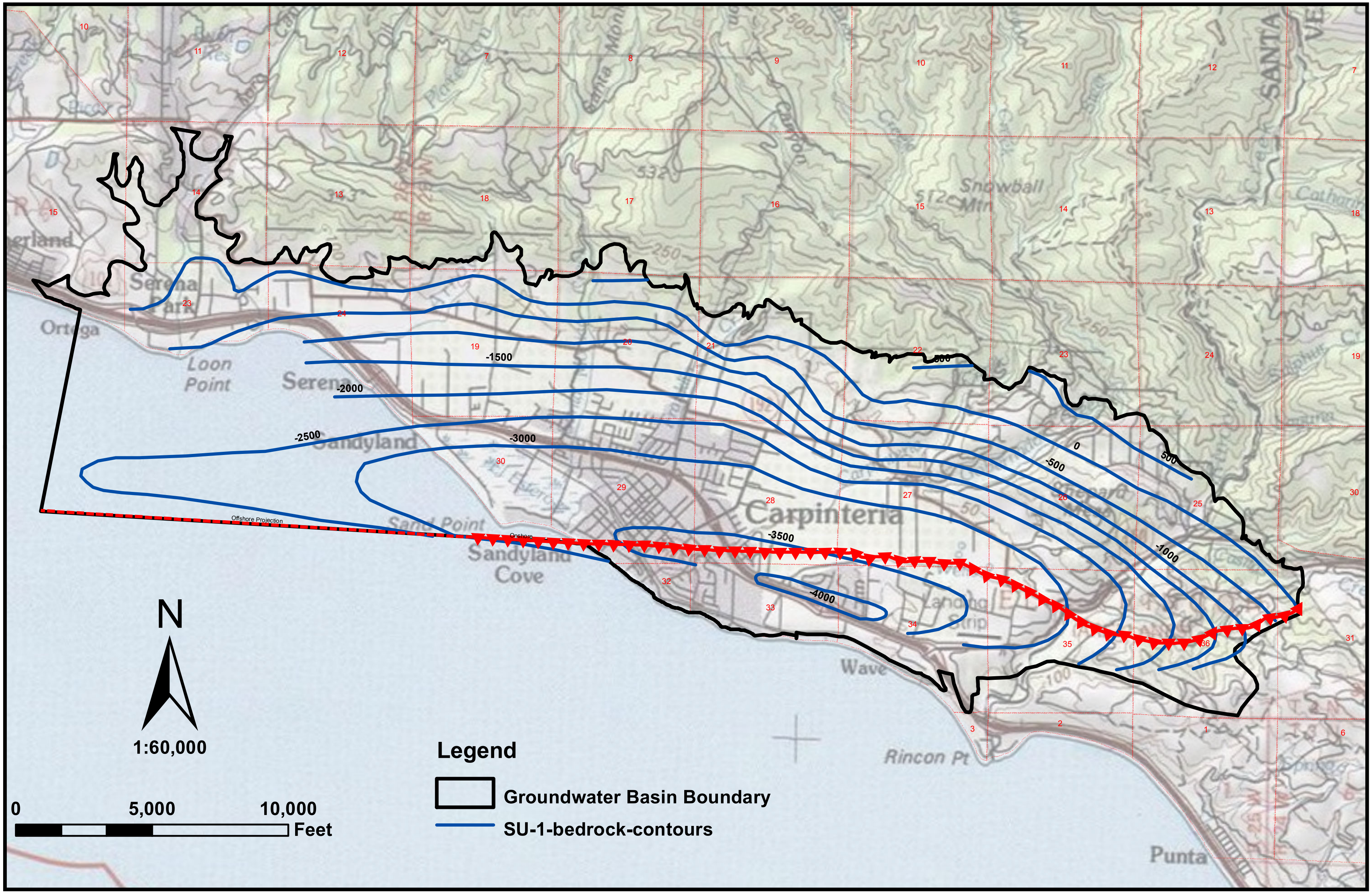

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PLATE 12. STRUCTURAL CONTOURS - BEDROCK STORAGE UNIT 1

CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125

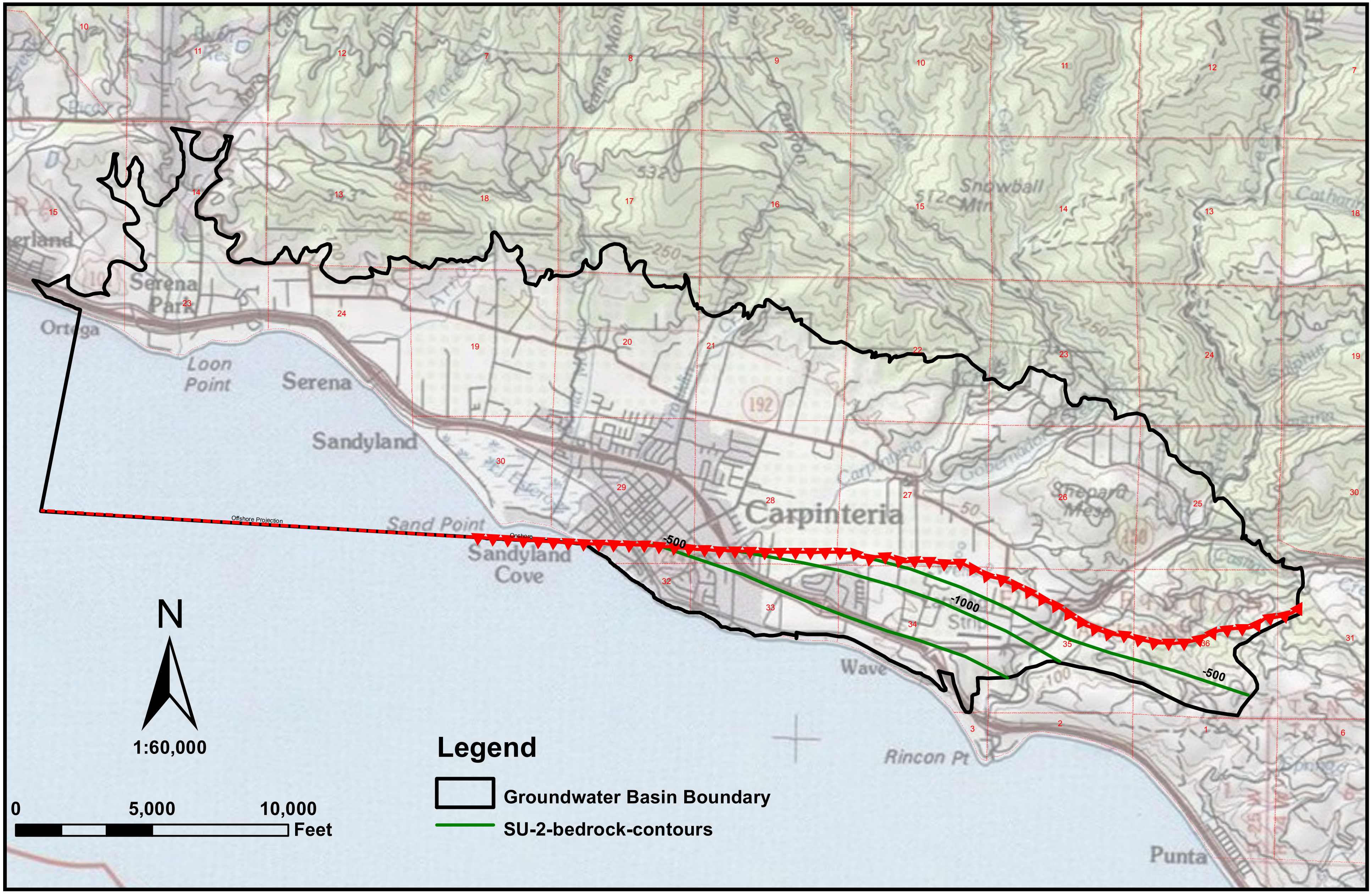

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PLATE 13. STRUCTURAL CONTOURS - BEDROCK STORAGE UNIT 2
CGB Hydrogeologic Update
Carpinteria Valley Water District

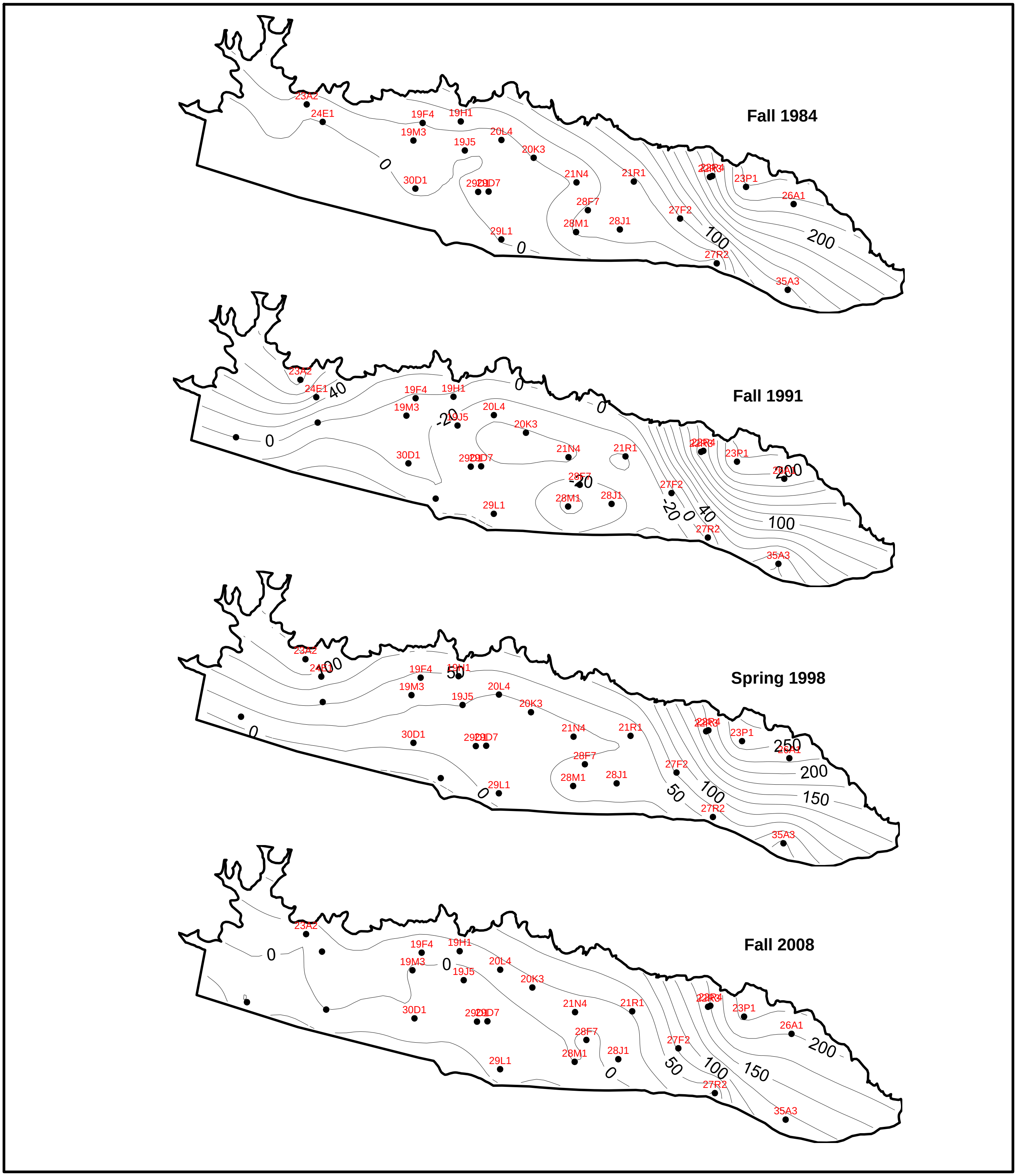

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PLATE 14. WATER LEVEL CONTOURS - STORAGE UNIT 1

CGB Hydrogeologic Update
Carpinteria Valley Water District

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Project No. 06-0125

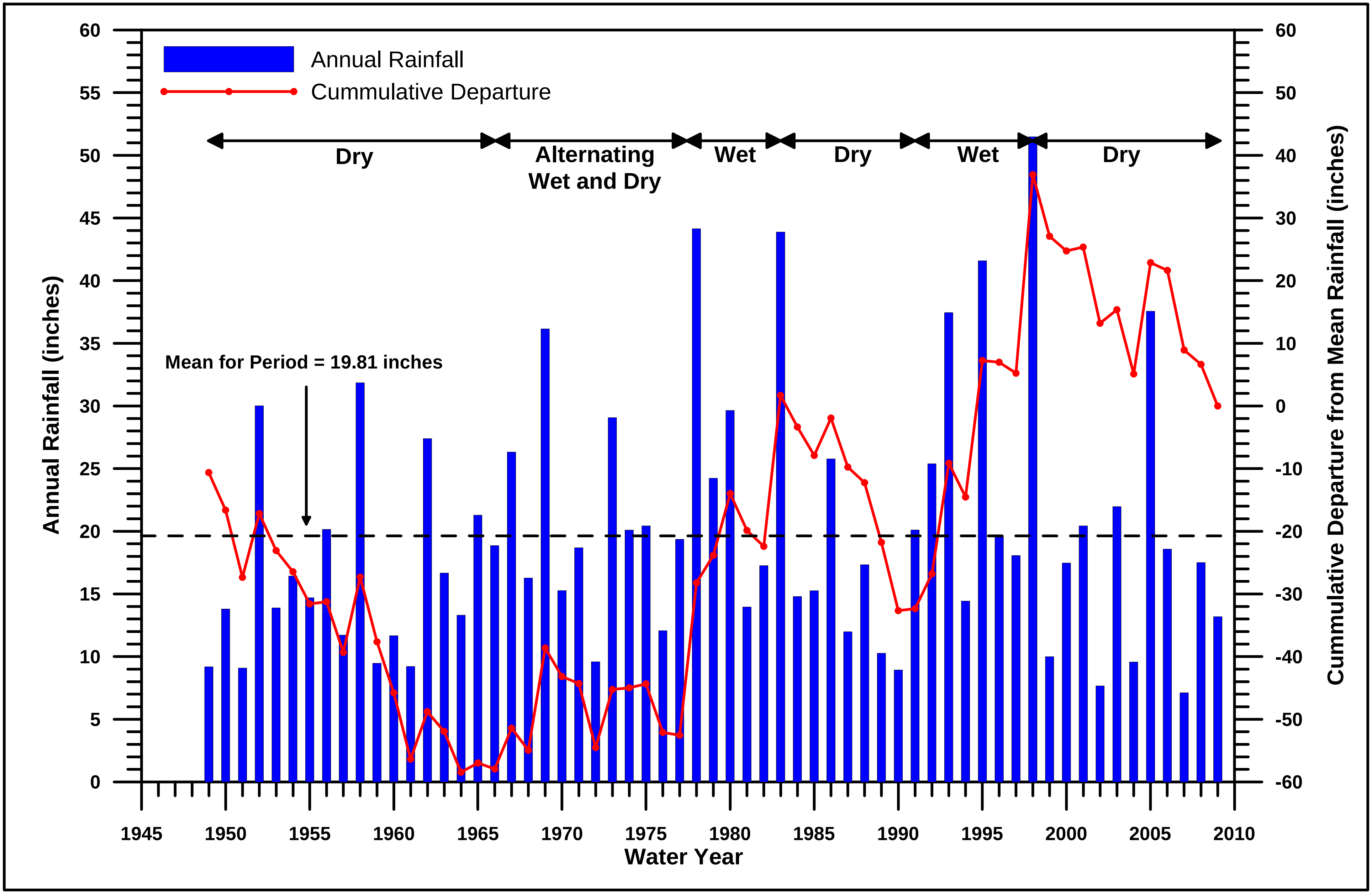

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PLATE 15. CUMULATIVE DEPARTURE OF ANNUAL RAINFALL - CARPINTERIA FIRE STATION (208)
CGB Hydrogeologic Update
Carpinteria Valley Water District

APPENDIX A
DATA COLLECTION, COMPILATION, AND REVIEW

Presented in this Appendix is a summary of the results of Tasks 1.1 and 1.2 of the subject project. Tasks 1.1 and 1.2 consisted of compiling and reviewing the available data for the hydrogeologic update of the Carpinteria Groundwater Basin. The types of data and information collected and evaluated include the following:

- Previous Reports on Basin Conditions
- Drilling Logs
- Pumping Tests
- Water Levels
- Precipitation
- Water Quality
- Stream Flow
- Municipal and Private Well Production
- Land Use and Soil Survey Information
- Imported Water

PREVIOUS REPORTS ON BASIN CONDITIONS

A variety of USGS and consultant reports on the Carpinteria Groundwater Basin (CGB) has been acquired and they are listed in the attached bibliography. The most significant reports include the following:

- Upson and Thomasson (1951)
- Lian (1954)
- Evenson, et al, (1962)
- Slade (1975)
- GTC (1976)
- GTC (1985)
- Sullwold (1996)
- IWR (2003)

Taken together, these studies document the evolution of the understanding of the hydrogeology of the CGB. The earliest detailed study of the hydrogeology of the basin was conducted by Upson (1951). This USGS report also contained a section on surface water hydrology in the basin by Thomasson (1951). Based on the available data at the time, Upson defined the boundaries of the basin and divided it into two main aquifer bodies - a shallow and deep aquifer. The current working conceptualization of CBG hydrostratigraphy (i.e., Aquifers A through D) was initially forward by Slade (1975). The most recent comprehensive report on the CGB was performed by Geotechnical Consultants (GTC) in 1976 – over 30 years ago. GTC performed an update of their 1976 investigation in 1985, the focus of which was an update of the hydrologic budget and safe yield analysis for a base period covering the water years between 1974 and 1984. Sullwold (1996) refined the structural and hydrostratigraphic delineations of the CGB, taking into consideration water and oil wells drilled after 1975 (i.e., the time of the GTC report). Most recently, Integrated Water Resources, Inc. (IWR, 2003) performed a review of existing perennial yield estimates for the CGB, including a review of the data utilized to develop the estimates.

DATA COLLECTION SUMMARY

DRILLING LOGS

The well log collection obtained for the basin study will be the primary source of information on basin lithology. Logs from the drilling of water wells, as wells as oil and gas wells, typically include formation logs and occasionally geophysical logs. Formation logs include physical descriptions of drilled cuttings or cores throughout the drilled depth of the hole. Geophysical logs indicate spontaneous potential, electric resistivity, and various other parameters of geologic units. This information will be used to refine, if possible, the previous interpretations of the geologic structure and hydrostratigraphy of the CGB, and in the preparation of geologic cross sections through the basin.

Water Well Completion Reports. Drillers of all public and private water wells in California are required to submit Water Well Completion Reports (WWCRs) on State of California Department of Water Resources forms. WWCRs for wells within the CGB are stored and maintained at the Santa Barbara County Environmental Health Department (SBEHD). Completion reports are filed at the SBEHD according to Assessor’s Parcel Number (APN). Copies of the reports have been periodically forwarded to the CVWD and filed according to location by Township, Range and Section.

Well inventory data for over 300 wells drilled in the CGB were obtained in table format (Microsoft Excel) from CVWD. The inventory includes State Well Number, latitude/longitude, owner’s name, use of the well, well depth, diameter, drilling method, year drilled, pump type, ground surface elevation, and APN.

Fugro West, Inc. (Fugro) conducted a survey of all wells in the CGB as part of a wellhead protection/demonstration project in 2002 (funded by an AB303 DWR grant). The program included the creation of an ArcGIS database to link APNs to known water wells in the basin. Fugro conducted field validation site visits and physically identified 106 water wells, 64 of which were active and 43 determined to be abandoned. Fugro also determined that 47 wells had been destroyed and/or built over. The disposition of the approximate 150 other wells in the well inventory database could not be verified.

One of the most important items on the WWCRs is the formation log; therefore, copies of available reports were obtained from CVWD and SBEHD. Copies of **102** reports were obtained for wells drilled within the CGB study area and tabulated according to Township, Range, and Section and the number of wells greater than 500 feet in depth. Deeper wells are generally more useful in preparing geologic cross sections than the shallow wells, because a greater range of geologic information is described on the well logs. In addition, available geophysical logs have been tabulated. The Plates for well distribution and well depth will be useful in evaluating where geologic cross-sections can be drawn with the greatest control, and which areas would benefit from more focused study. A summary of the spatial distribution of WWCRs according to Township, Range, and Section is shown on Table A1 – Drilling Logs Summary.

Oil and Gas Well Logs. Records of oil and gas wells are maintained at the office of the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources (DOGGR), District 2, located in Ventura. Records include electric logs and formation logs of individual wells. Other types of information that may be found in oil and gas data files that are useful to water resource studies include water shut-off depths, the base of fresh water, temperature logs, daily logs of activities (which may describe artesian pressures or difficulties in sealing the fresh water zone), and formation contacts.

A summary of oil and gas wells drilled in District 2 was obtained in database format (Microsoft Access) from the DOGGR Internet File Transfer Protocol (FTP) site. A well location map in Adobe PDF format was also downloaded from the DOGGER FTP site (interestingly, the well location map [W3-1] was from District 3, whereas the well database was from District 2).

Locations for 52 oil or gas wells drilled within the CGB have been tabulated. Fields describing each well include the name of the map showing the well location, name of the well field, operator, lease, well name, status of the well, Township, Range, and Section, total depth, latitude, and longitude. A summary of the spatial distribution of available drilling logs according to Township, Range, and Section is shown on Table 1 – CGB Drilling Logs Summary.

Table A1. CGB Drilling Logs Summary

Township/Range - Section	Water Well Completion Reports			No. of DOGGR Logs
	No. of Driller's Logs	No. of Geophysical Logs	No. of Well Depths >500 ft	
4N/25W-18	0	--	--	1
4N/25W-19	5	2	3	0
4N/25W-20	8	3	1	0
4N/25W-21	10	7	5	0
4N/25W-22	2	0	1	0
4N/25W-23	0	0	--	0
4N/25W-25	4	1	1	0
4N/25W-26	14	5	7	2
4N/25W-27	12	5	7	1
4N/25W-28	12	4	6	0
4N/25W-29	3	2	1	4
4N/25W-30	2	0	0	1
4N/25W-32	0	0	--	8
4N/25W-33	0	0	--	16

Township/Range - Section	**Water Well Completion Reports**			**No. of DOGGR Logs**
	No. of Driller's Logs	**No. of Geophysical Logs**	**No. of Well Depths >500 ft**	
4N/25W-34	5	1	2	8
4N/25W-35	8	4	3	1
4N/25W-36	0	--	--	0
4N/26W-14	9	1	8	0
4N/26W-23	2	2	0	9
4N/26W-24	6	3	1	1
Totals	**102**	**40**	**46**	**52**

Review of Table A1 reveals that of the 102 acquired Water Well Completion Reports, approximately 40% have accompanying geophysical logs, and a similar percentage are for wells deeper than 500 feet bgs. Table A1 also indicates those Sections with relatively deficient data. No well logs have been acquired for Sections 4N/25W-18, -23, -32, -33, and -36; however, these areas are generally on the margins of the basin.

A review of the DOGGR well locations indicates a relatively high concentration of wells along the coast and south of the surface trace of the Rincon Creek Thrust Fault (i.e., in Storage Unit No. 2). The distribution of wells north of the Rincon Creek Thrust Fault (i.e., in Storage Unit No. 1) shows 20 DOGGR wells are recorded. Of these, 7 logs have been obtained from CVWD files. For the preparation of geologic cross sections, PWR may obtain additional oil and/or gas well data from the DOGGR Ventura District 2 office after selecting specific wells from the database.

PUMPING TESTS

The results of pumping tests are a critical part of estimating aquifer parameters such as transmissivity, hydraulic conductivity, and storativity. These parameters are necessary to characterize the hydraulics of groundwater movement and calculate basin storage. Most importantly, these aquifer parameters are necessary input parameters for the groundwater flow model.

Pumping test data available to GTC in 1976 was generally limited to specific capacity data (from which transmissivity can be roughly estimated) from 77 well logs. The majority of this data was derived from the late-1940's when all wells in the basin powered by electrical motors were converted from 50 to 60 cycles, and Southern California Edison Co. performed numerous pump efficiency tests. Data from formal pumping test was limited to post-construction testing of the CVWD Smillie and Santa Ynez wells. Although the specific capacity data was relatively well distributed throughout the basin, it is important to note that all of these data were derived from wells that were either shallow in depth or completed within multiple aquifer zones; therefore, aquifer parameters for individual aquifer zones (i.e., Aquifers A – D) in the confined area of the basin could not be determined.

Since the time of the GTC study, CVWD has installed four high capacity municipal production wells (Lyons, High School, El Carro, and Headquarters). Formal post-construction pumping tests were conducted at the High School, El Carro, and Headquarters Wells and the summary of operations reports included aquifer analyses to determine aquifer parameters at these wells. In addition, Fugro performed a well interference assessment in 1996 which included aquifer analysis of drawdown curves from the Lyons and El Carro Wells.

Although all of these CVWD wells are also completed across multiple aquifer zones, downhole spinner surveys were performed at the El Carro and Headquarters Wells from which aquifer-specific transmissivities may be estimated. The Headquarters Well project (which replaced the Santa Ynez Well) also included the conversion of the Santa Ynez Well into a nested monitoring well with wells completed in Aquifers A and B, which were monitored during production and injection testing at the Headquarters Well.

In addition to the above-noted aquifer testing, specific capacity data from Water Well Completion Reports since 1975 will be tabulated, from which rough values of transmissivity can be estimated.

An extensive database of pumping tests and aquifer parameter estimates is probably not necessary for the success of the project. What are necessary are a few reliable data points in each area of the basin. Based on our initial review of the available date, it appears sufficient data exists to reasonably estimate the aquifer parameters throughout the CGB; however, it is anticipated that the aquifer parameter estimates will be refined through calibration of the groundwater flow model.

WATER LEVELS

Water level data in the basin have historically been collected and maintained by the USGS and the CVWD. Water level data will be used to generate hydrographs and groundwater elevation contour maps, which will be used for groundwater storage calculations. The USGS database contains water level records for 75 wells in the CGB, dating back to as early as 1919 (State Well No. 4N/25W-28J1); however, most records begin in either the 1940s or 1970s. The USGS database does not extend beyond 2001. The CVWD has historically made monthly measurements at over 40 wells in the basin, and had forwarded these data to the USGS until 2001. After 2001, the CVWD continued the monitoring program as part of its Groundwater Management Plan and these data have been obtained in digital (Excel) format. A summary of the spatial distribution of water level data according to Township, Range, and Section is shown on Table A2 – Water Level Data Distribution Summary.

Table A2. Water Level Data Distribution Summary

Township/Range-Section	No. of Wells with Water Level Data
4N/25W-18	0
4N/25W-19	6

Township/Range-Section	No. of Wells with Water Level Data
4N/25W-20	5
4N/25W-21	5
4N/25W-22	3
4N/25W-23	1
4N/25W-25	4
4N/25W-26	6
4N/25W-27	7
4N/25W-28	10
4N/25W-29	7
4N/25W-30	1
4N/25W-32	0
4N/25W-33	0
4N/25W-34	2
4N/25W-35	4
4N/25W-36	0
4N/26W-14	3
4N/26W-23	11
4N/26W-24	0

As shown in Table A2, the spatial distribution of the available water level data is relatively good throughout the basin. Those Sections without any records are generally limited to the margins of the basin. Of the approximate 40 wells that CVWD currently monitors, over 70 percent of them (29) have water level records dating back to the 1940s or earlier. The rest have generally been monitored since the 1970s or the 1990s.

Water level hydrographs for key wells with significant periods of record will be updated and utilized as calibration targets for the groundwater flow model. Water level contour maps for selected years (e.g., historical basin water level highs and lows, beginning and ending of the study base period, etc.) will also be prepared as ArcGIS layers and utilized to estimate changes in groundwater storage.

PRECIPITATION

Infiltration of precipitation is one of the most important sources of recharge to the basin. The Santa Barbara County Flood Control District maintains precipitation data from the Carpinteria Fire Station with a period of record from 1949 to the present. Data from other precipitation gages in the basin (e.g., Carpinteria High School and Carpinteria Reservoir) that had more limited periods of record were utilized in combination with data from the Fire Station by GTC (1976) to prepare an isohyetal map for the CGB watershed. Based on the GTC isohyetal map, precipitation within the unconfined recharge area is estimated to be approximately 10 percent greater than the precipitation over the confined area (i.e., where the Fire Station Gage is located).

WATER QUALITY

The CVWD initiated a semiannual water quality data collection program in 1999, which consists of analysis of samples collected from over 30 wells and 6 surface water monitoring stations located throughout the basin. Laboratory analyses performed include a full range of inorganic chemical constituents typically referred to as "Irrigation Suitability Analysis", and includes major anions and cations, boron, nitrate, total dissolved solids, electrical conductance, pH, and various other constituents. Water quality data is also available for all of its municipal production wells as part of routine compliance with Department of Public Health Services (CDPH) regulations for public water systems.

In addition to the CVWD data, limited water quality data is available from the USGS and USEPA. The USGS database contains records for 87 wells in the CGB, with data dating back to the 1920's. The vast majority of the USGS data is quite limited, typically consisting of less than a half dozen sampling events at any given individual well. Only 4 wells have reasonably continuous data with more than 20 samples. None of the USGS data extend beyond the late 1970's.

Water quality data are also stored electronically by the USEPA Office of Drinking Water in its STORET data management system. The Legacy Data Center (LDC) contains historical water quality data from 38 wells in the CGB dating back to the early 1950's collected up to the mid-1980's. Search of the Modernized STORET database, which contains data collected beginning in 1999, reveals that it does not contain any data for wells within the CGB.

STREAMFLOW

There are five principal streams in the CGB; Carpinteria, Gobernador, Santa Monica, Arroyo Parida, and Rincon Creeks. Additional drainages include Toro and Franklin Creeks. Stream gages have historically been maintained and monitored by the USGS, and the data is stored and retrievable from the USGS Water Resources website. Only two creeks have runoff records – Carpinteria Creek and Franklin Creek. The Carpinteria Creek gage is currently active and has essentially continuous data since 1941 (there is a brief hiatus in the record for Water Year 1978). Records are available for Franklin Creek for Water Years 1971 through 1978. Available data for the other drainages in the CGB is limited to miscellaneous measurements made by the USGS from 1941 to 1945.

GTC (1976) developed a correlation index for each drainage in the basin to reflect the variation in precipitation with elevation, drainage area, and runoff lost as seepage. Runoff from the ungaged streams was then estimated for Water Years 1935 through 1984 utilizing these rainfall-runoff relationships. It is anticipated that similar rainfall-runoff relationships will be utilized to update streamflow data for the base period selected for this project.

MUNICIPAL AND PRIVATE WELL PRODUCTION

Groundwater extractions from the CGB occur from both CVWD production wells and from approximately 50 to 100 private wells in any given year. CVWD well production is metered, and monthly totals of production from each of the CVWD wells have been obtained for the period of 1982 to current.

Private pumping in the basin has been estimated on an annual basis by CVWD since 1984 utilizing land use survey and imported water delivery information. CVWD supplies imported water and/or local groundwater to numerous agricultural parcels of know acreage and crop type (e.g., avocados, cherimoyas, open and covered nurseries, etc.). From these metered deliveries, unit use values (known as “determining factors”) for various crop types have been estimated each year since 1984. These unit use values have been combined with land use acreage data to estimate aggregate annual private well production in the basin.

In 2002, the CVWD undertook a comprehensive land use study for the first time utilizing a combination of digital imagery, GIS layers of land use and parcel boundaries, and statistical analysis to evaluate land use activities and estimate private well extractions. Prior to 2002, CVWD relied on staff to update land use records (“paper cards”) when changes in land use activities were noticed as part of other CVWD duties. Since 2002, the land use studies have been GIS-based. For this project, CVWD staff is currently transcribing data contained on the “paper cards” for the period 1984 through 2001 into digital format. Once completed, estimates of pumpage from individual wells will be developed by CVWD by intersecting land use “determining factors”, acreages of land use per parcel (APN numbers), and well IDs by APN for each year during the period 1984 through current.

LAND USE AND SOIL SURVEYS

As discussed above, CVWD has maintained detailed land use records for each rural parcel in the basin since 1984 (?). Prior to 2002, land use survey information was recorded annually on individual “paper cards” for each parcel, from which the total acreages of various land uses was estimated. After 2002, land use survey information has been compiled into the District’s GIS.

The results of land use surveys conducted by DWR for the Southern Central Coast Region (San Luis Obispo and Santa Barbara Counties) in 1959, 1968, 1977, 1985, and 1996 are also available from DWR Division of Planning and Local Assistance (DPLA), Southern District. Land use data vector files (DWG and shape files) are available for the 1996 land use survey on a USGS 7.5-Minute Quadrangle basis.

The Soil Survey Geographic (SSURGO) database for Santa Barbara County, South Coastal Part has also been obtained. The SSURGO data set is a digital soil survey depicting the kinds and distribution of soils on the landscape. The data set consists of georeferenced map data, with soil map units linked to attributes in the National Soil Information System relational database, which gives the proportionate extent of the component soils and their properties.

IMPORTED WATER

In addition to supplying water from its municipal wells, the District also imports water from outside the CGB. Imported water was first made available in 1954 from Lake Cachuma, and in 1995 State Water Project (SWP) was made available. Imported water deliveries are metered by the District, and annual totals for the period 1985 to 2008 have been obtained.

CONCLUSIONS

Previous studies of the CGB have led to the current understanding of the basin structure, hydrostratigraphy, water balance and safe-yield. This study will utilize new data to perform a hydrogeologic update of the basin. The collection, compilation, and review of the available data for conducting the CGB Hydrogeologic Update are summarized below:

- <u>Drilling Logs</u>: Sufficient numbers of well logs are available throughout most of the basin. The quantity of logs in some areas along the margins of the basin is slightly deficient; however, the overall data availability, quantity, and quality are *adequate*.
- <u>Pumping Tests</u>: Significant additional pumping test data are available for this update compared to that available for the GTC investigation (1976), principally from CVWD municipal wells. However, virtually all of the available data is from wells completed within multiple aquifer zones; therefore, the availability of aquifer parameters for individual aquifer zones is *deficient, but may be attainable* with further analysis of available downhole spinner surveys.
- <u>Water Levels</u>: The coverage of water level data from observation wells throughout most of the basin is *adequate*.
- <u>Precipitation</u>: Only one precipitation station is located in the basin with a sufficient period of record; therefore, the availability of precipitation data is *deficient, but attainable* through utilization existing isohyetal mapping.
- <u>Water Quality</u>: Overall, the quantity and quality of the available water quality data is *adequate*.
- <u>Stream Flow</u>: Of the 5 principal streams in the CGB, only the Carpinteria Creek gage has a significant period of record; therefore, the available stream flow data is *deficient, but attainable* through correlations of watershed size to stream flow for the other streams.
- <u>Municipal and Private Well Production</u>: Municipal well production by CVWD has been historically metered and the available data is *adequate*. Private well pumping is not metered and has historically been estimated on an annual aggregate basis from land use data and “determining factors” (i.e., water duty factors); however, to date estimates of individual well production have not been developed; therefore, the availability of private pumping data is *deficient, but attainable* through additional correlation of land use data, APNs, and individual wells.
- <u>Land Use and Soil Surveys</u>: Overall, the quantity and quality of the available land use and soil survey data is *adequate.*

- Imported Water: Overall, the quantity and quality of the available imported water data is *adequate.*

Based on our initial review of the previous studies and currently available data, re-conceptualization of basin hydrostratigraphy and water balance components is not anticipated. This is consistent with the envisioned scope of the project Work Plan. Rather, new available subsurface data will be used to refine hydrostratigraphic delineations, where appropriate. The water balance will be updated for a more recent base-period (e.g. 1984 through current) utilizing methodology similar to that used by GTC in 1976 and 1985. A significant focus of the Task 1 hydrogeologic update will be preparation of geologic structure, hydrostratigraphy and spatial distributions of the various water balance components into ArcGIS layers that will serve as the platform for developing the groundwater model in Task 2.

RECOMENDATIONS

It is recommended that the approach to the various remaining hydrogeologic update tasks in light of the available data be the focus of discussion at the project's first technical advisory meeting, tentatively scheduled for mid- to late-January 2009. A general outline for the meeting agenda is as follows:

1. Review project Work Plan
2. Review data availability and deficiencies
3. Discuss viable approaches to various Work Plan tasks
4. Discuss anticipated format of task results for compatibility with groundwater model input parameters

APPENDIX B
SUMMARY COMPARISON OF AQUIFER DEPTHS AND THICKNESSES

Table B1. Comparison of Aquifer Depths and Thicknesses Used in Structural Contours

AQUIFER A

State Well No.	Well Name	TD (ft)	GS Elev (ft msl)	Elev of Top of Aquifer "A"			Elev of Bottom of Aquifer "A"			Thickness of Aquifer "A"		
				GTC	HSS	PWR	GTC	HSS	PWR	GTC	HSS	PWR
4N/25W-20K4	CVWD High School	1988	42	NA	-105	-105	NA	-127	-127	NA	22	22
4N/25W-20Q3	J&C Farms	1000	40	NA	-132	-132	NA	-167	-167	NA	35	35
4N/25W-20R3	CVWD Test Hole #2	1393	40	-265	-265	-265	-302	-305	-305	37	40	40
4N/25W-28D2	CVWD El Carro	2706	49	NA	-225	-236	Na	-290	-276	NA	65	40
4N/25W-28F7	CVWD Lyons	1271	63	-244	-243	-243	-284	-288	-288	40	45	45
4N/25W-28K3	Kono	505	70	NA	-270	-270	NA	-330	-330	NA	60	60
4N/25W-28H1	Huff	522	100	NA	-110	-110	NA	-142	-142	NA	32	32
4N/25W-29D7/8	CVWD Santa Ynez/HQ	950	25	-295	-293	-293	-332	-323	-323	37	30	30
4N/25W-30Ka	"Bryce #1"	3525	5	-195	-550	-195	-229	-670	-229	34	120	34

AQUIFER B

State Well No.	Well Name	TD (ft)	GS Elev (ft msl)	Elev of Top of Aquifer "B"			Elev of Bottom of Aquifer "B"			Thickness of Aquifer "B"		
				GTC	HSS	PWR	GTC	HSS	PWR	GTC	HSS	PWR
4N/25W-20K4	CVWD High School	1988	42	NA	-577	-577	NA	-607	-607	NA	30	30
4N/25W-20Q3	J&C Farms	1000	40	NA	-660	-660	NA	-696	-696	NA	36	36
4N/25W-20R3	CVWD Test Hole #2	1393	40	-825	-825	-825	-885	-885	-885	60	60	60
4N/25W-21N5	Horton	960	58	NA	-490	-492	NA	-515	-517	NA	25	25
4N/25W-21N6	Bonebakker	921	56	NA	-510	-514	NA	-530	-534	NA	20	20
4N/25W-27Ha	"Gobernador #1"	3310		0	abs	abs	-15	abs	abs	15	abs	abs
4N/25W-28D2	CVWD El Carro	2706	49	NA	-790	-796	NA	-855	-861	NA	65	65
4N/25W-28F7	CVWD Lyons	1271	63	-819	-820	-820	-884	-878	-878	65	58	58
4N/25W-29D7/8	CVWD Santa Ynez/HQ	950	25	-860	-860	-865	-910	-910	-915	50	50	50
4N/25W-29Na	"Shepard #1"	8512	35	-1015	-1004	-1004	-1070	-1059	-1059	55	55	55
4N/25W-30Ka	"Bryce #1"	3525	5	-740	-1000	-740	-800	-1080	-827	60	80	87

AQUIFER C

State Well No.	Well Name	TD (ft)	GS Elev (ft msl)	Elev of Top of Aquifer "C"			Elev of Bottom of Aquifer "C"			Thickness of Aquifer "C"		
				GTC	HSS	PWR	GTC	HSS	PWR	GTC	HSS	PWR
4N/25W-20K4	CVWD High School	1988	42	NA	-780	-780	NA	-845	-848	NA	65	68
4N/25W-20Q3	J&C Farms	1000	40	NA	-808	-808	NA	-878	-878	NA	70	70
4N/25W-20R3	CVWD Test Hole #2	1393	40	-1060	-1060	-1060	-1157	-1168	-1168	97	108	108
4N/25W-21L1	Bradley	810	66	NA	-590	-590	NA	-645	-645	NA	55	55
4N/25W-21N5	Horton	960	58	NA	-705	-707	NA	-765	-767	NA	60	60
4N/25W-21N6	Bonebakker	921	56	NA	-725	-734	NA	-797	-804	NA	72	70
4N/25W-21Q1	Overgaag	820	77	NA	-685	-685	NA	-740	-740	NA	55	55
4N/25W-21Q2	Dunlap	1015	85	NA	-620	-620	NA	-665	-665	NA	45	45
4N/25W-27Ha	"Gobernador #1"	3310		-355	-340	-340	-410	-400	-400	55	60	60
4N/25W-28D2	CVWD El Carro	2706	49	NA	-1032	-1041	NA	-1132	-1136	NA	100	95
4N/25W-28F7	CVWD Lyons	1271	63	-1070	-1075	-1075	-1170	-1178	-1175	100	103	100
4N/25W-29D7/8	CVWD Santa Ynez/HQ	950	25	-1100	-1103	-1100	-1220	-1223	-1220	120	120	120
4N/25W-29Na	"Shepard #1"	8512	35	-1284	-1275	-1275	-1409	-1400	-1400	125	125	125
4N/25W-30Ka	"Bryce #1"	3525	5	-970	-1367	-970	-1125	-1512	-1125	155	145	155

Notes:

GTC - Geotechical Consulatants (1976)

HSS - Harold S Sullwold (1996)

PWR - Pueblo Water Resources (2010)

NA - Not Available

Abs - Absent

APPENDIX C
WATER LEVEL HYDROGRAPHS

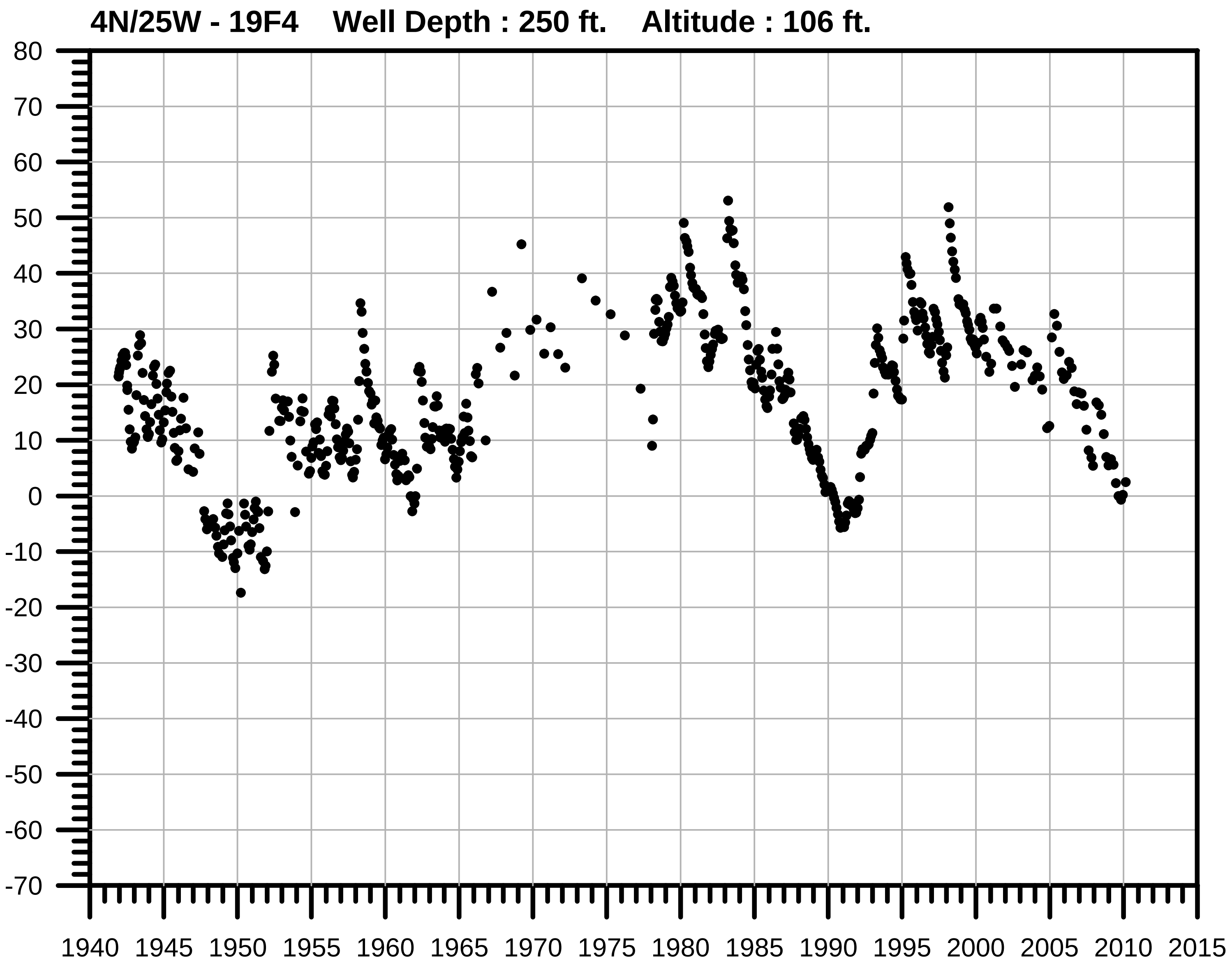

PLATE C-1. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

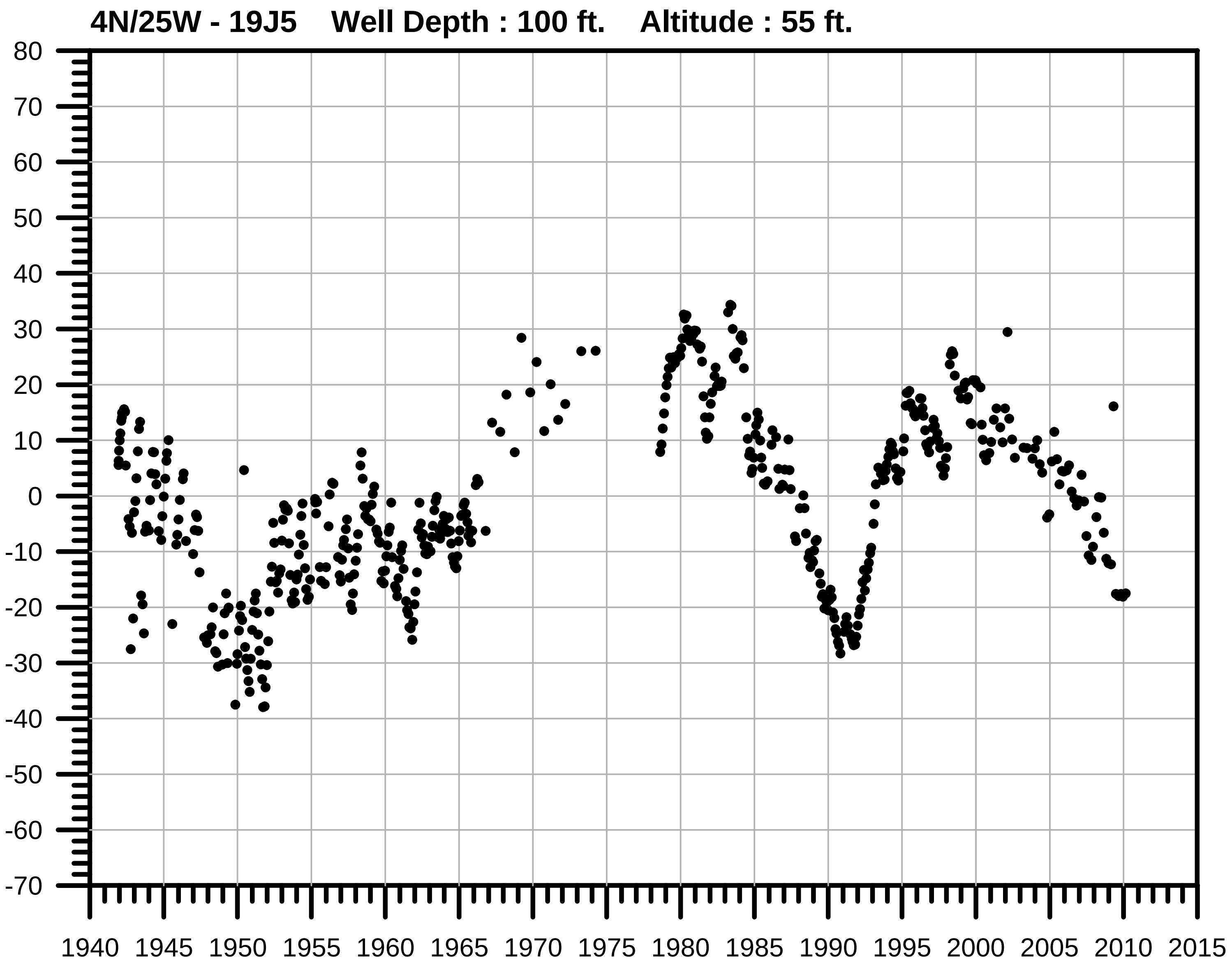

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PLATE C-2. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

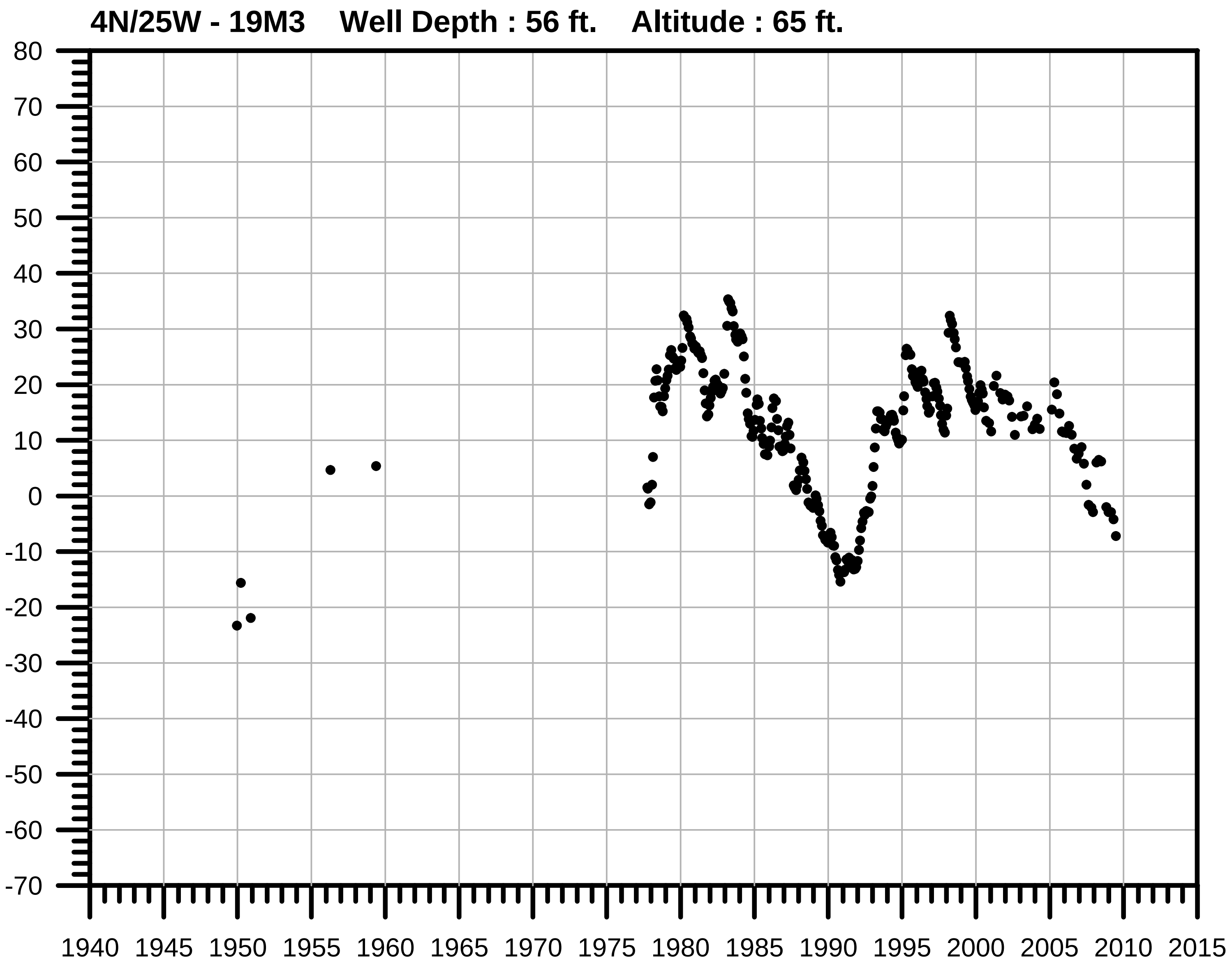

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PLATE C-3. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

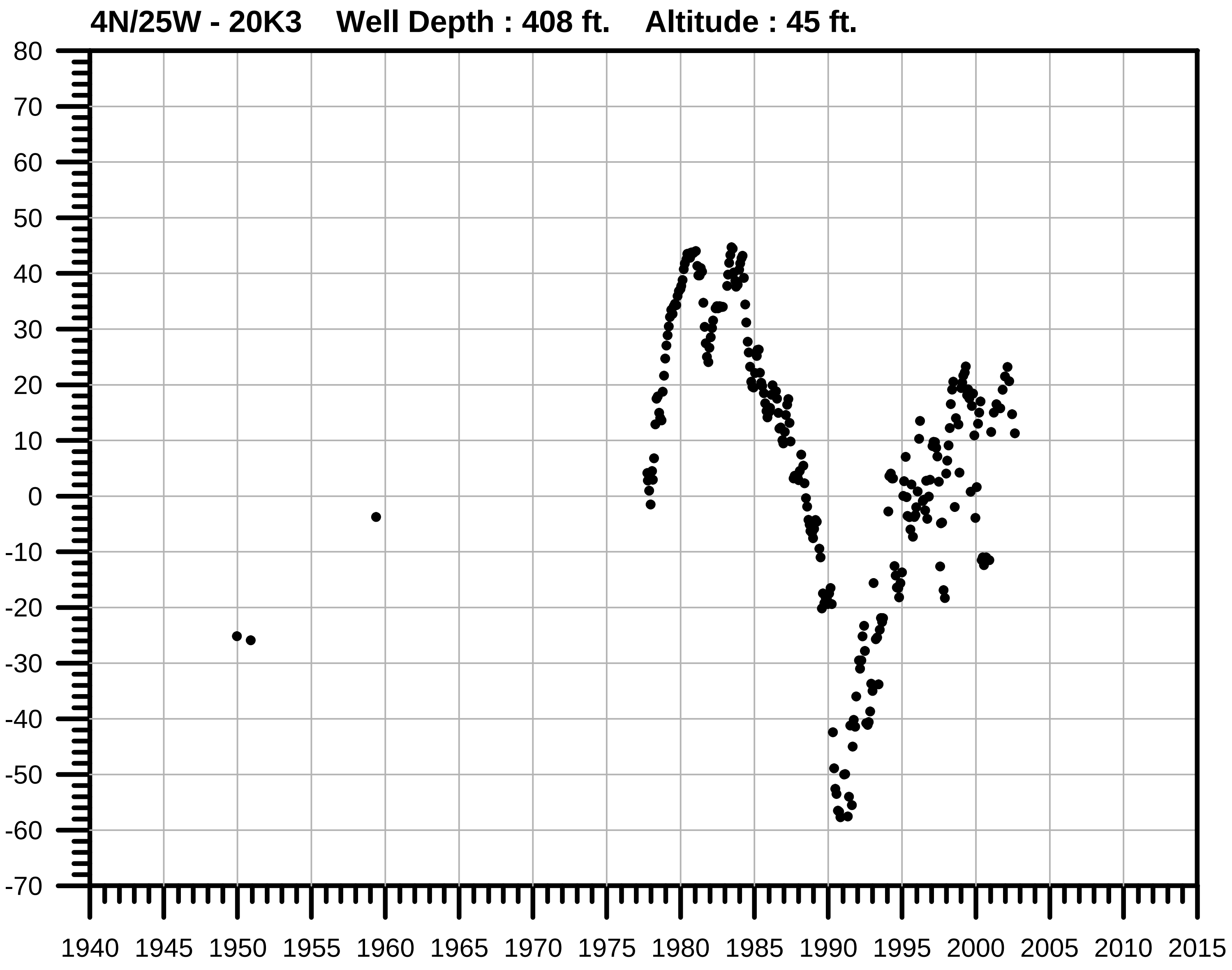

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PLATE C-4. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

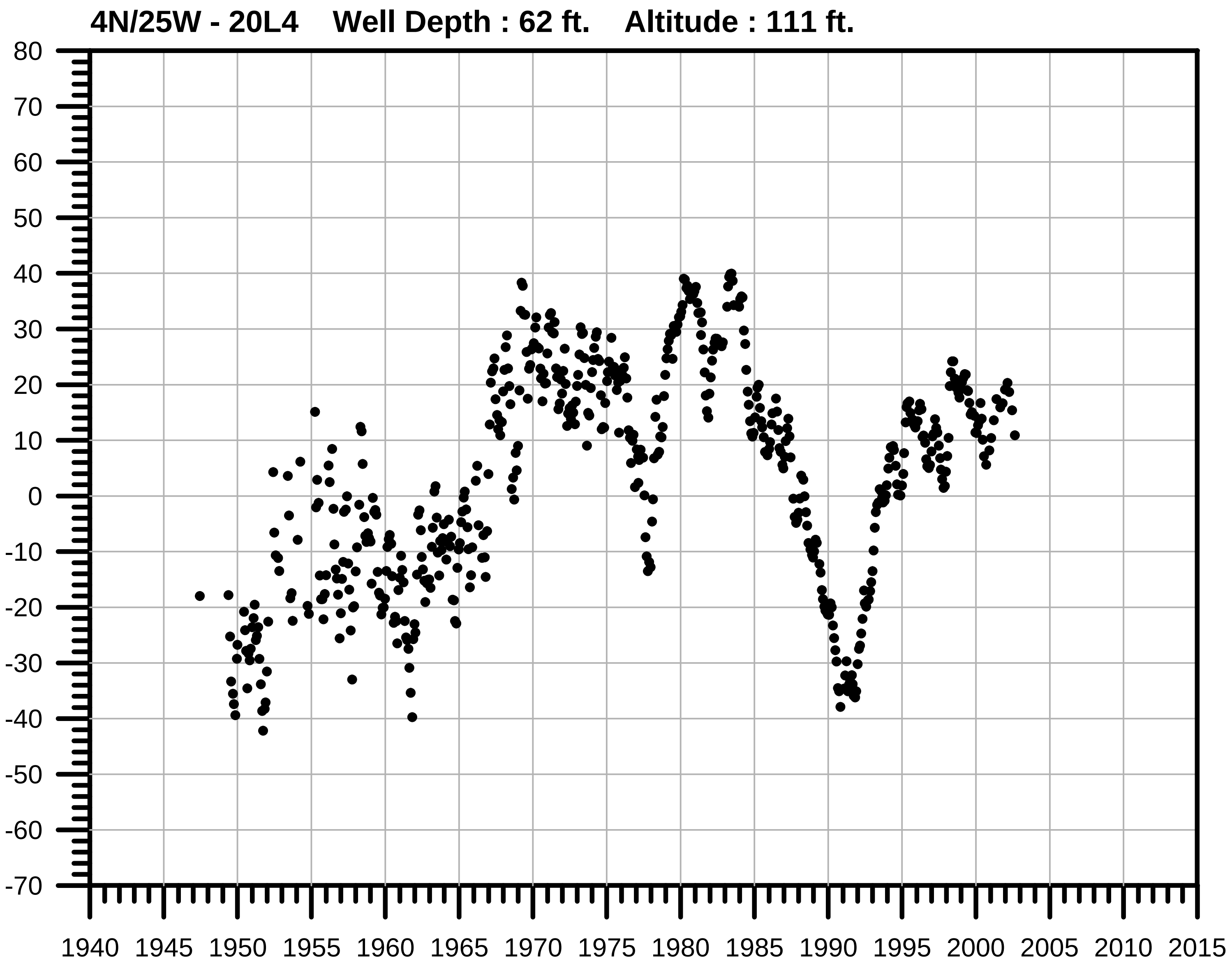

PLATE C-5. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

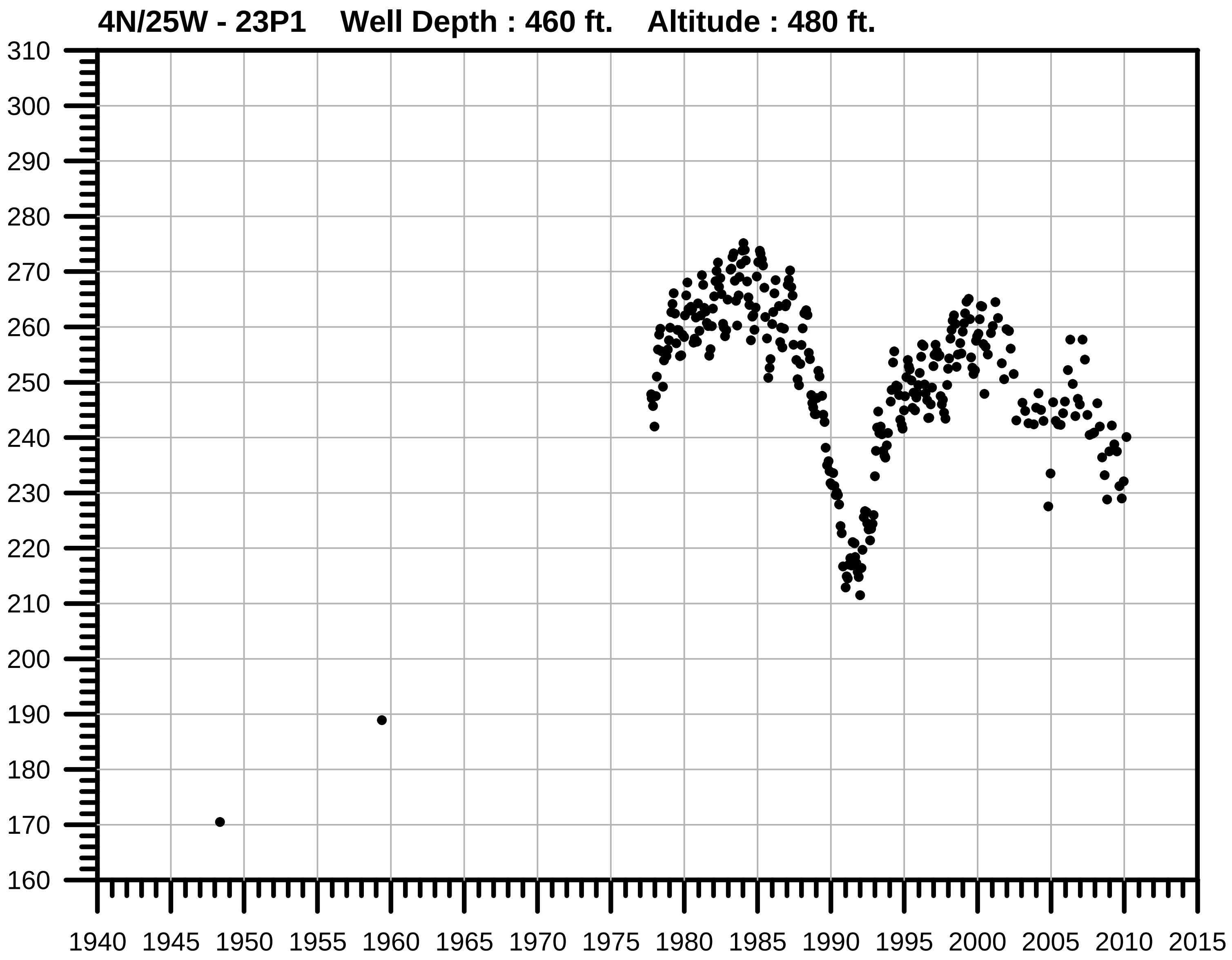

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PLATE C-6. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

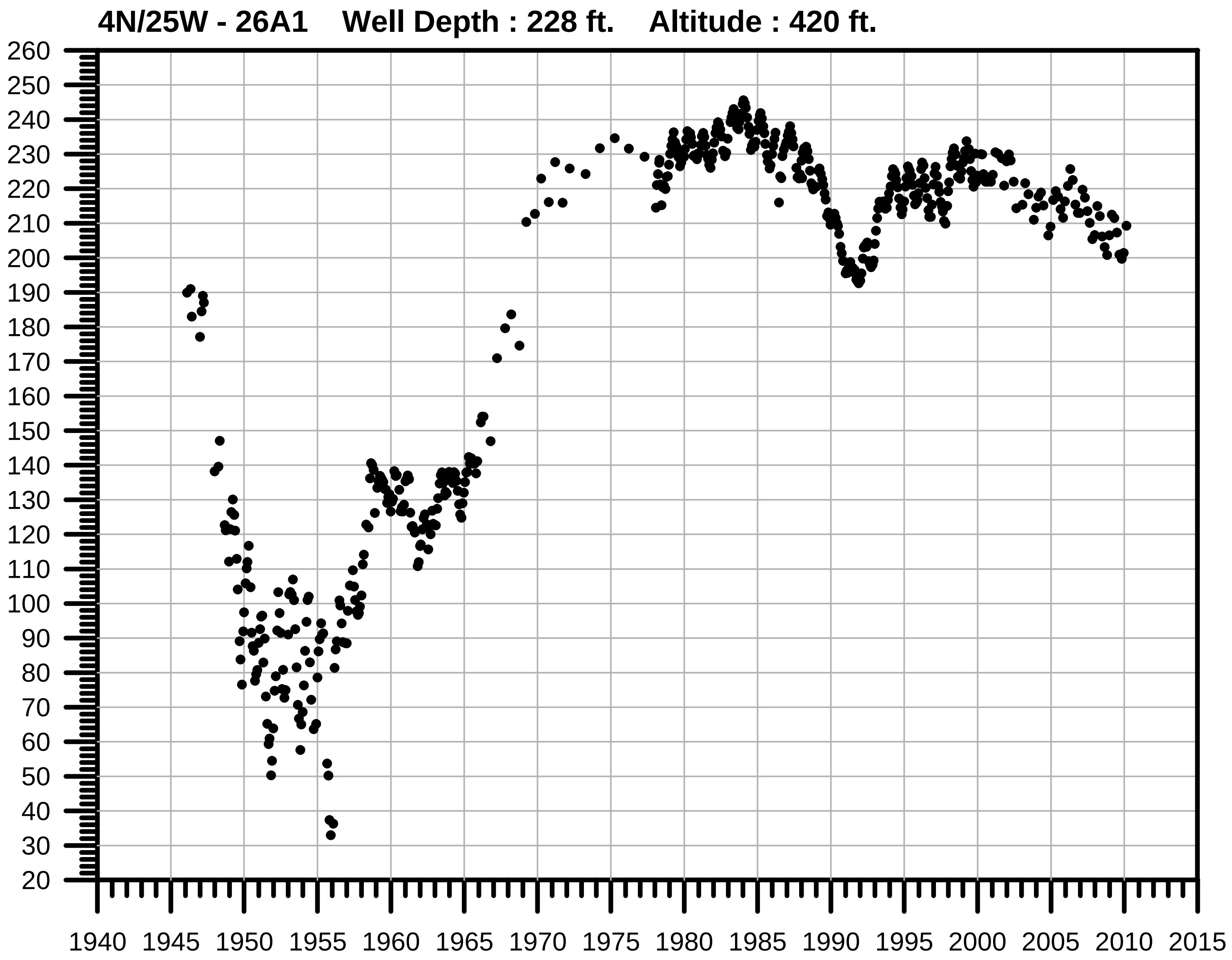

PLATE C-7. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

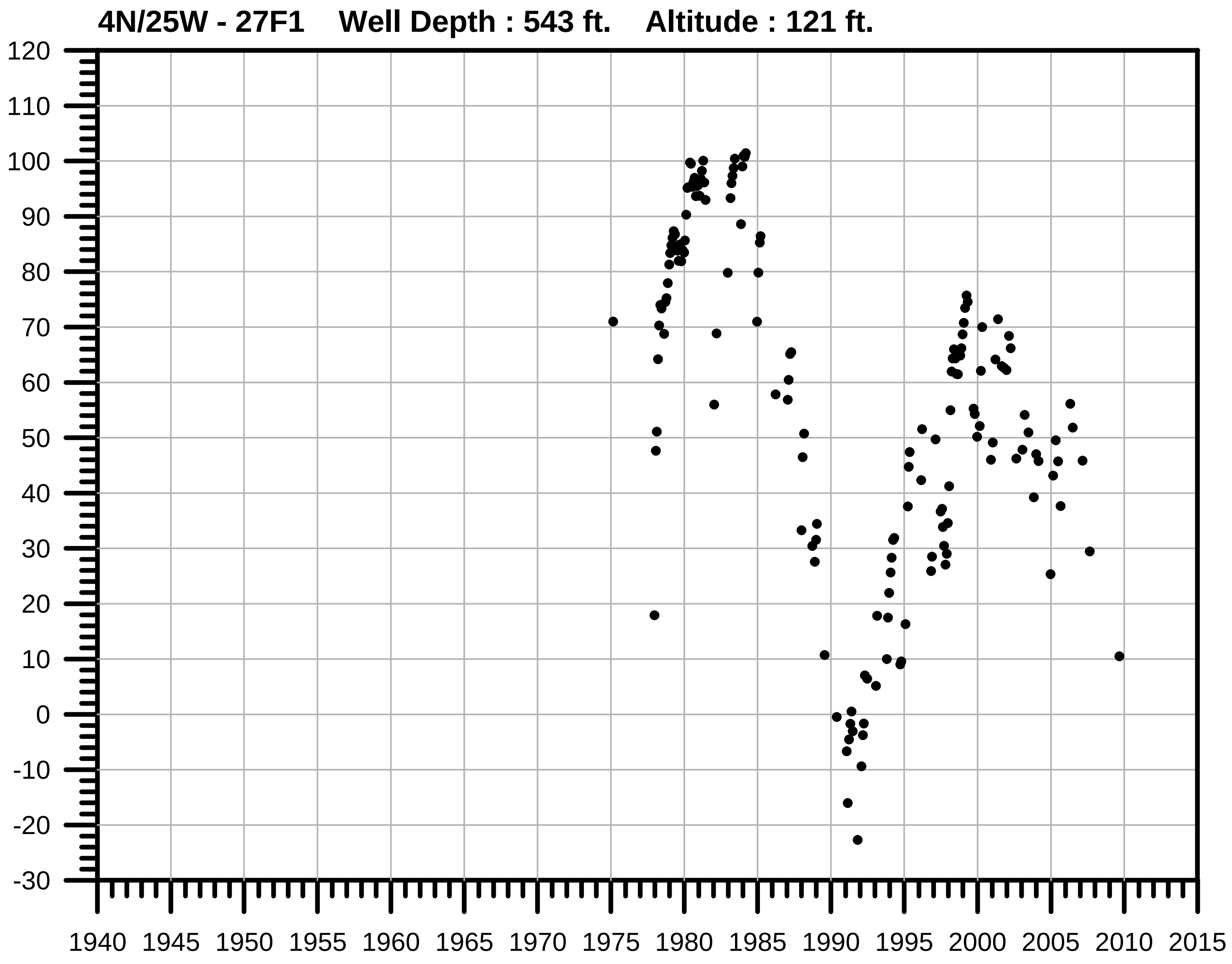

PLATE C-8. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

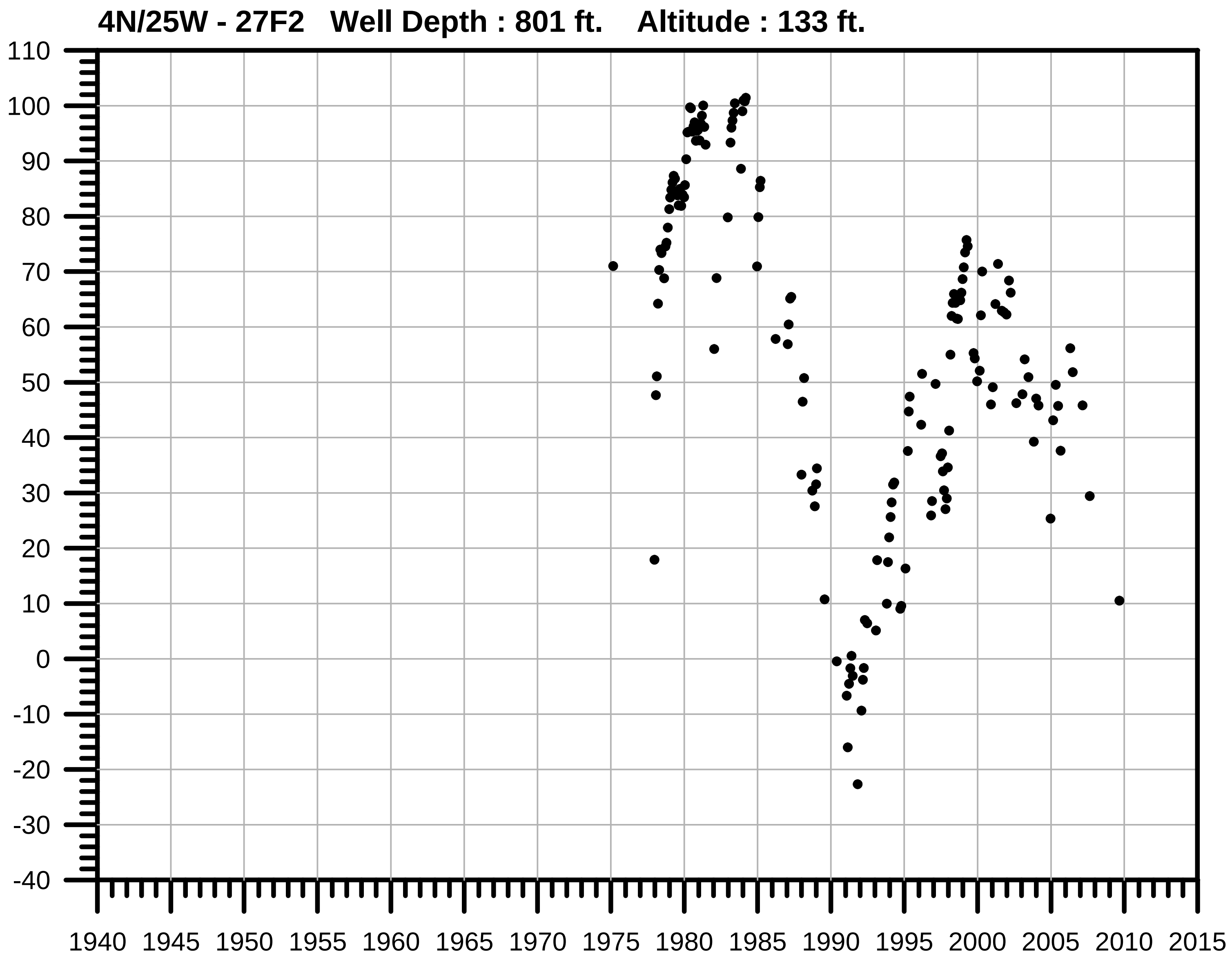

PLATE C-9. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125

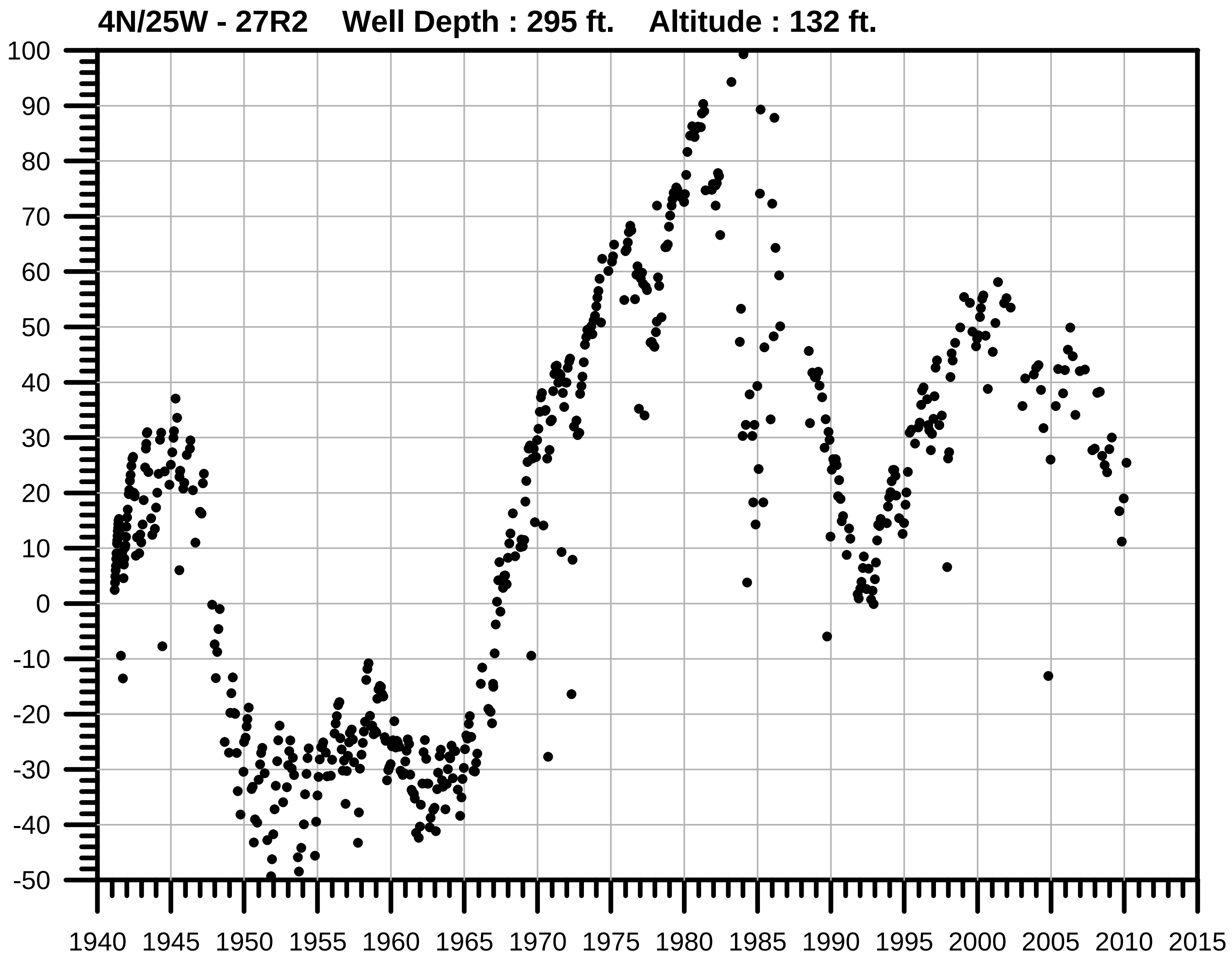

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PLATE C-10. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

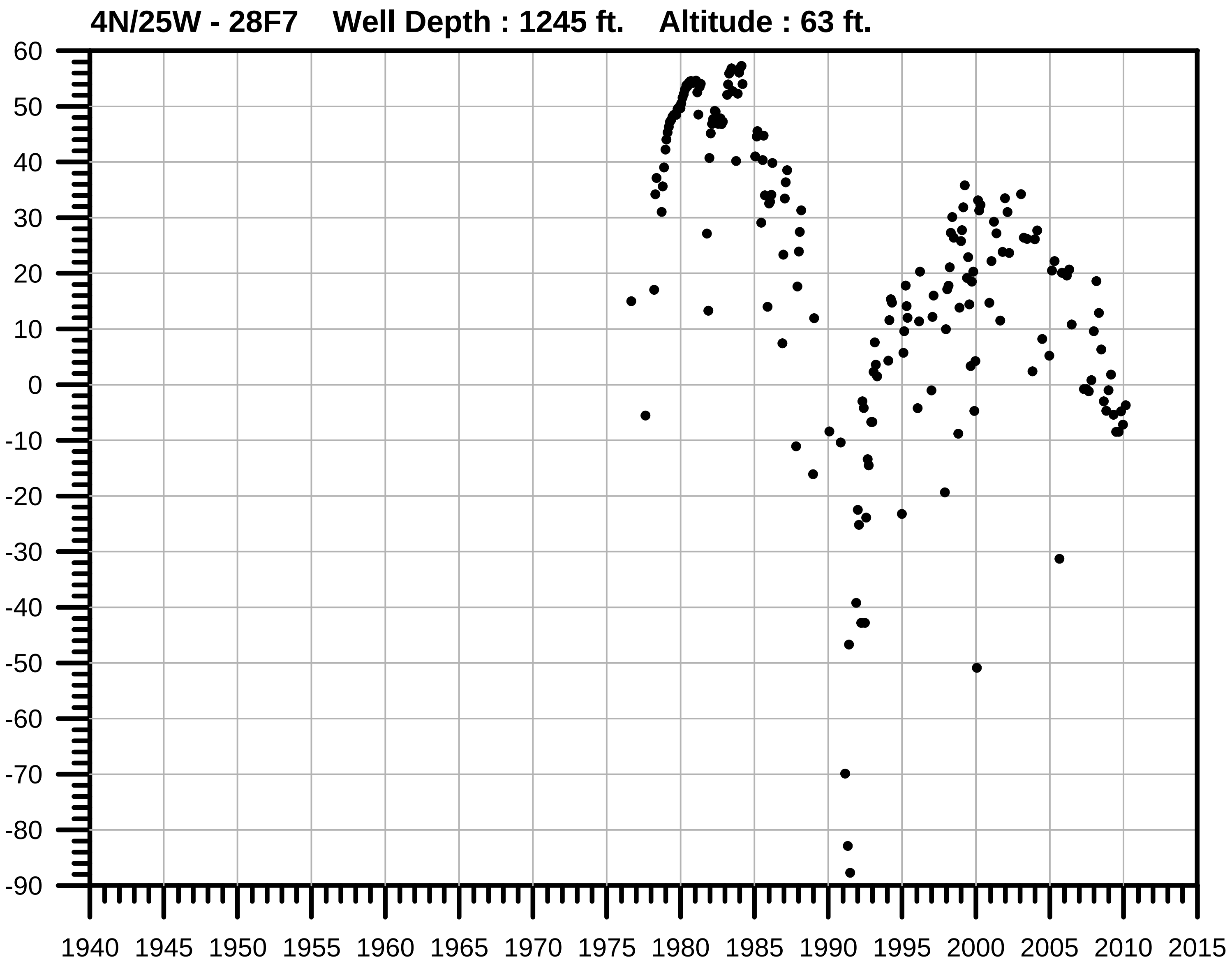

PLATE C-11. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

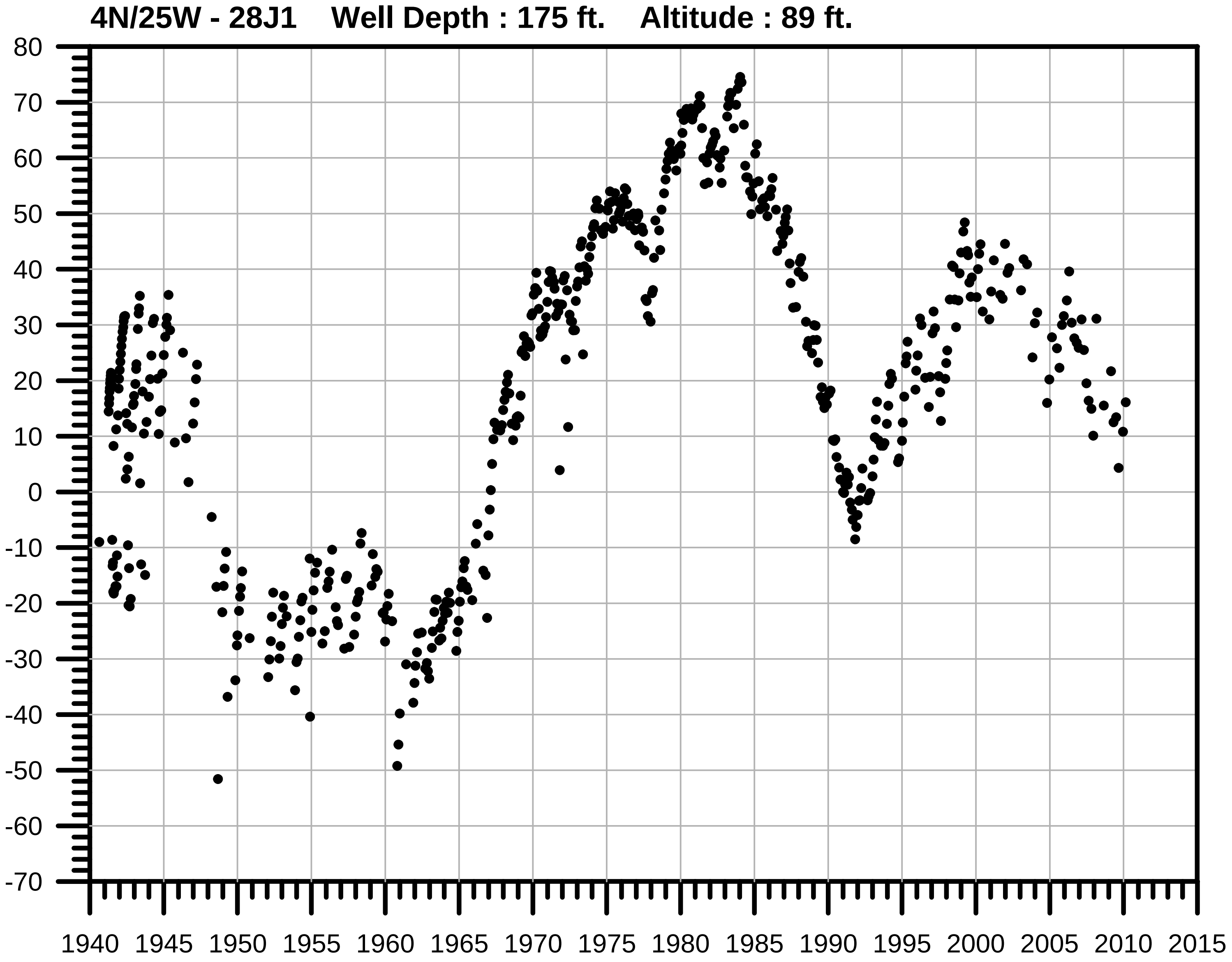

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PLATE C-12. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

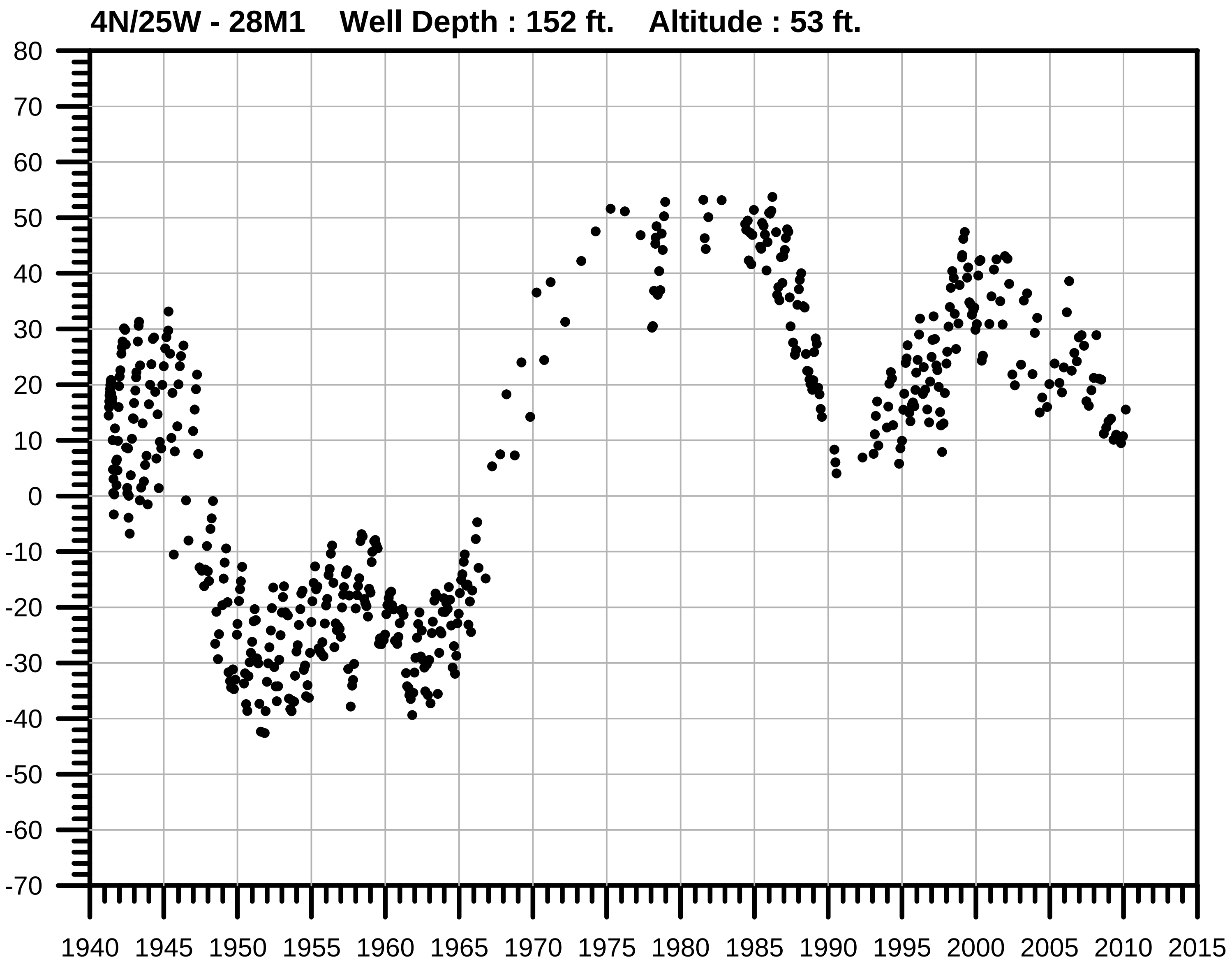

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PLATE C-13. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

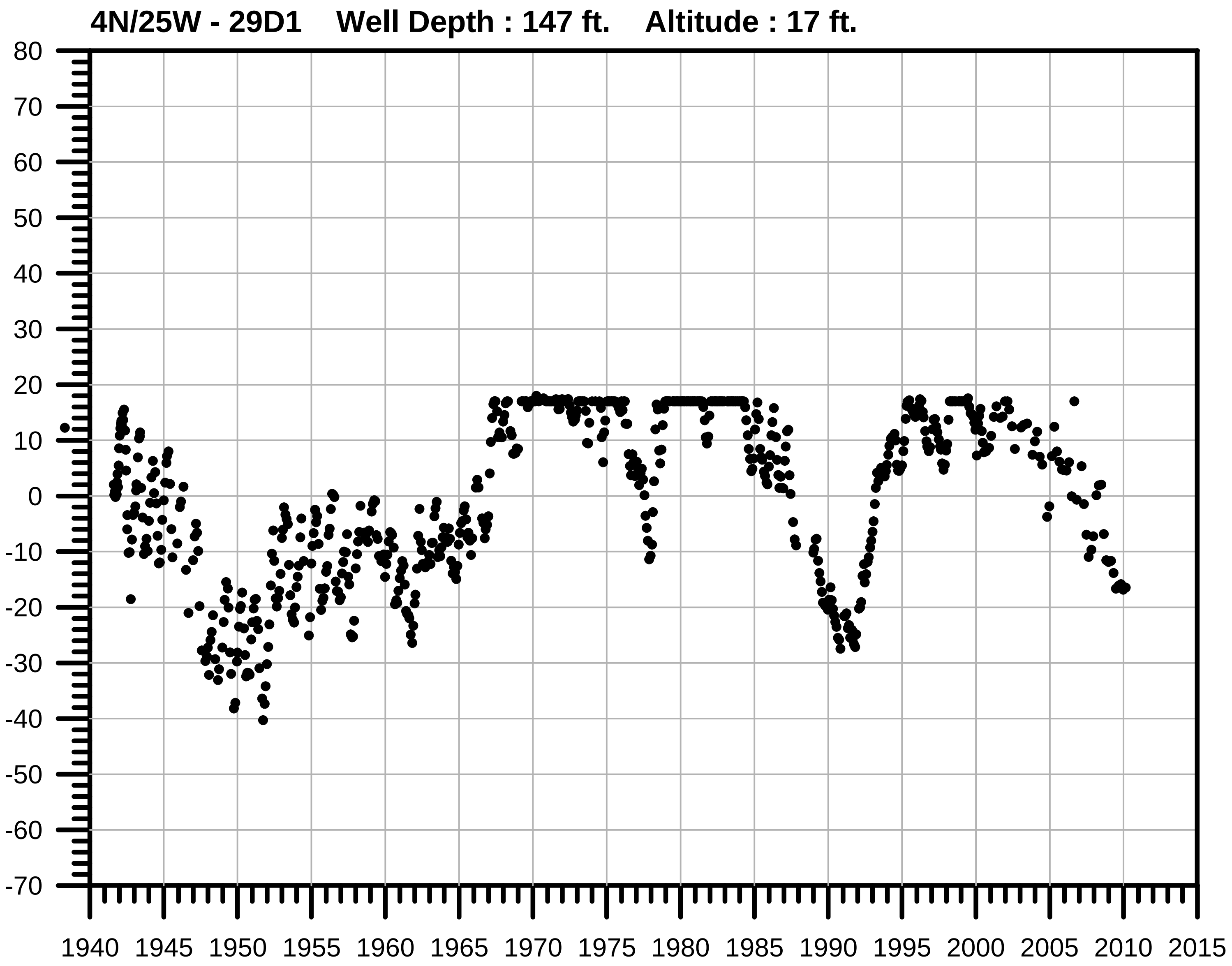

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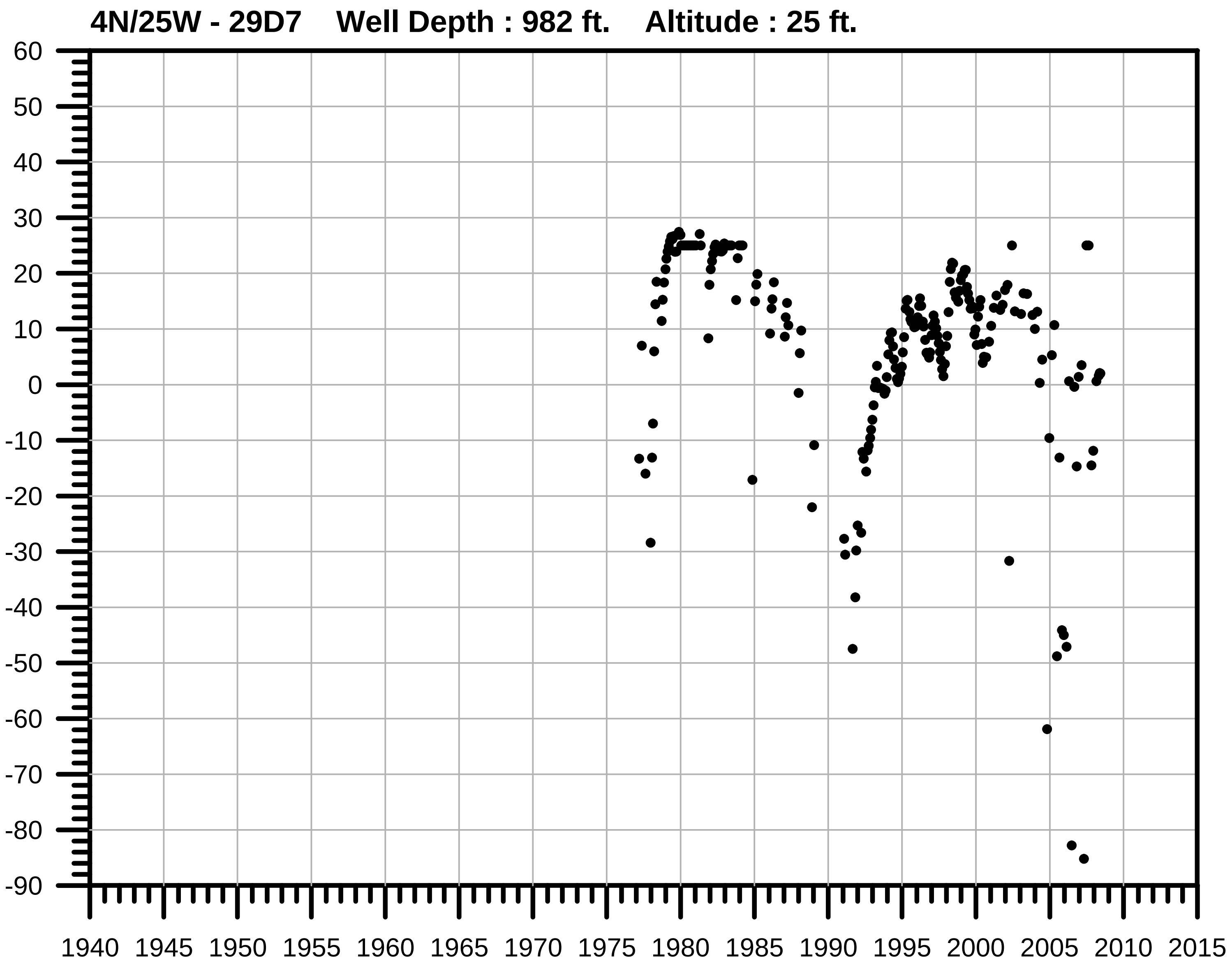
PLATE C-14. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125



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water resources

PLATE C-15. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

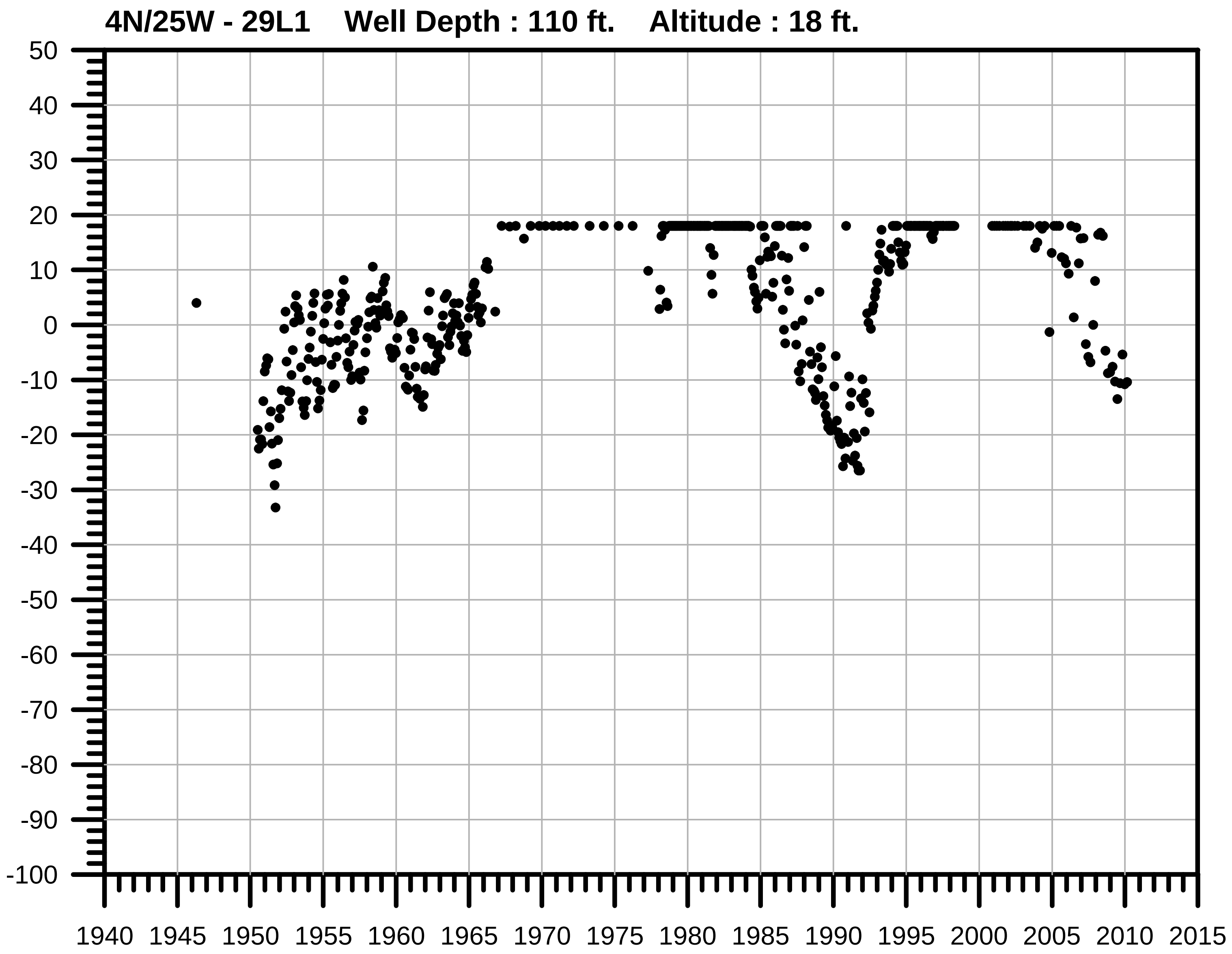

PLATE C-16. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

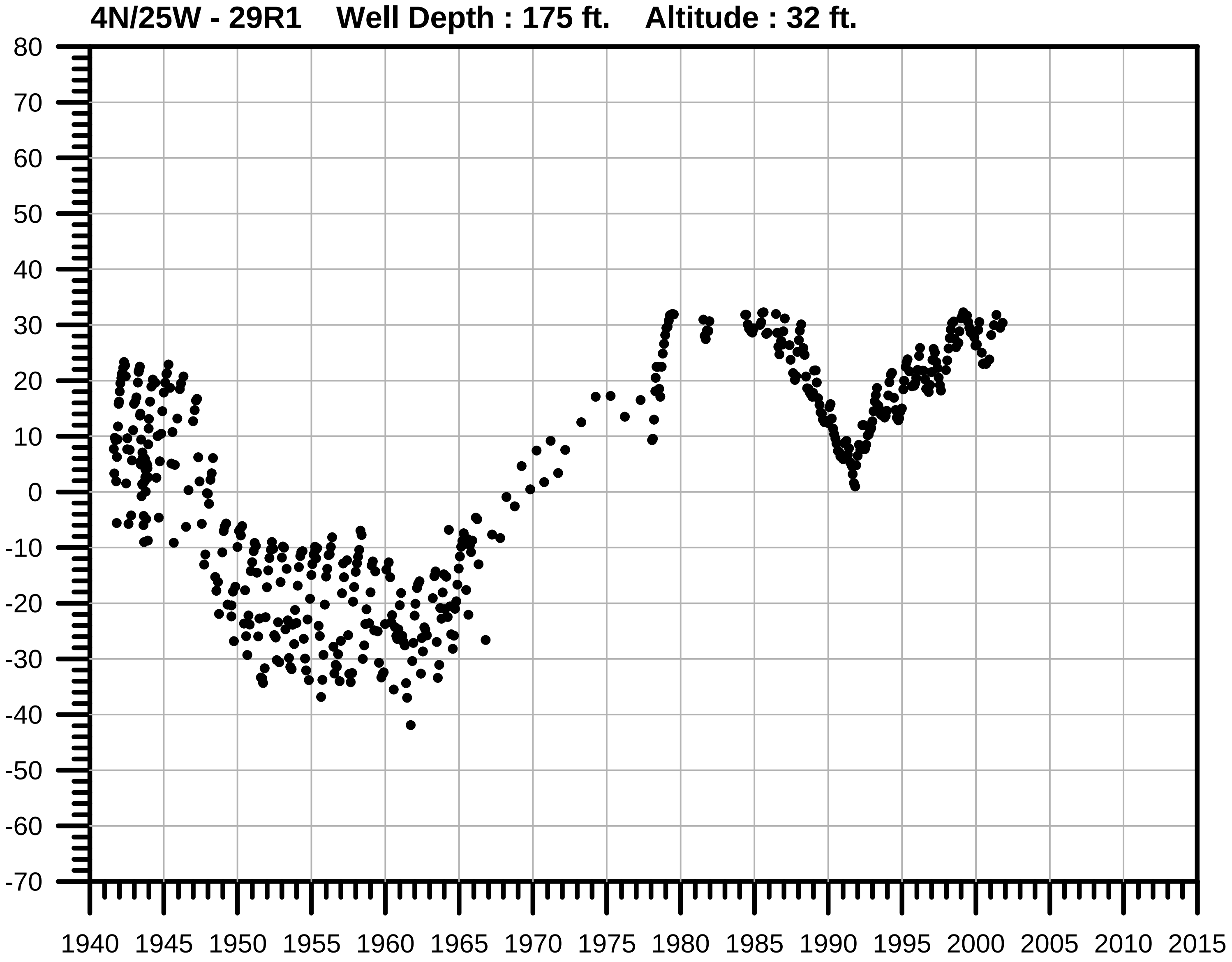

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PLATE C-17. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

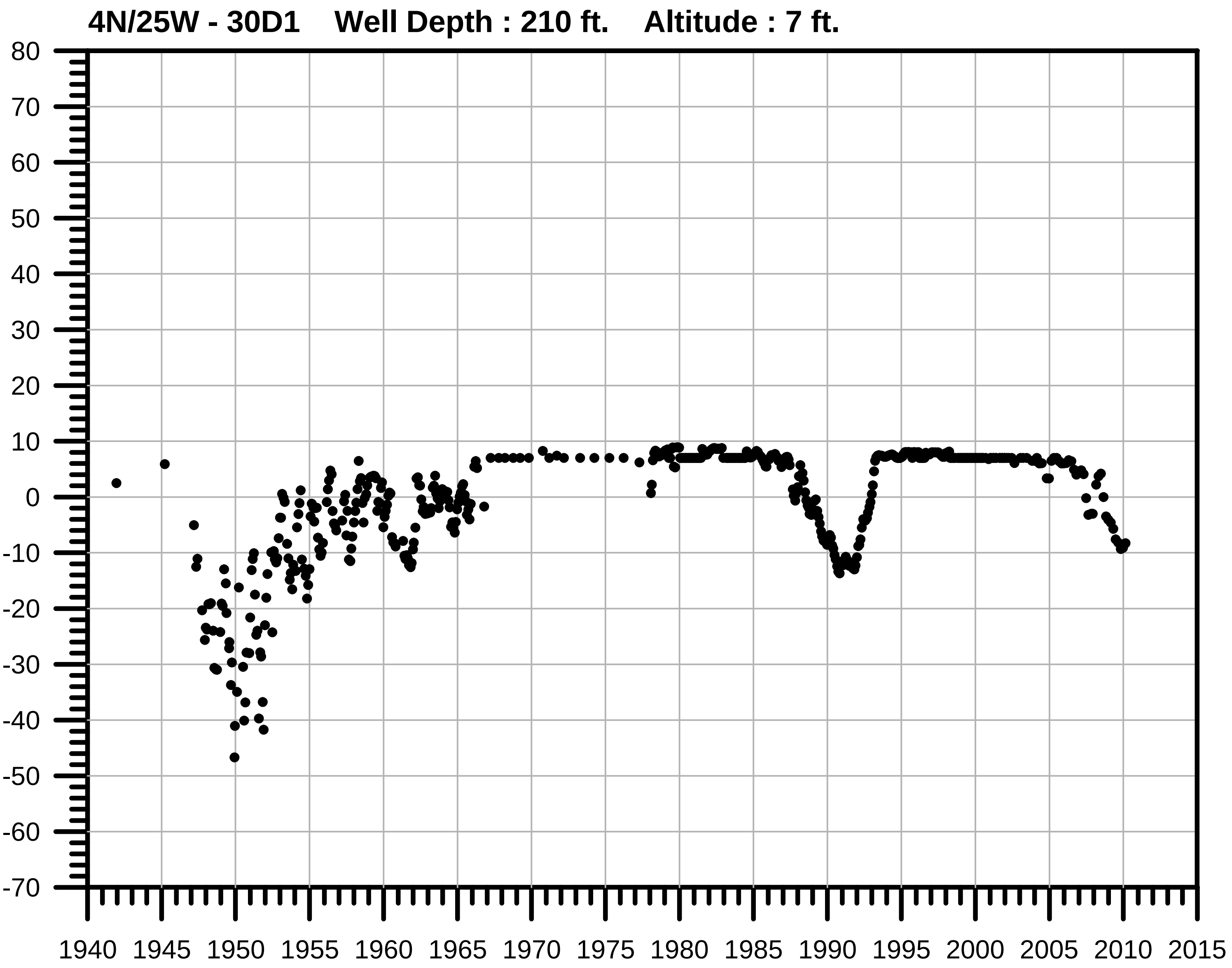

PLATE C-18. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

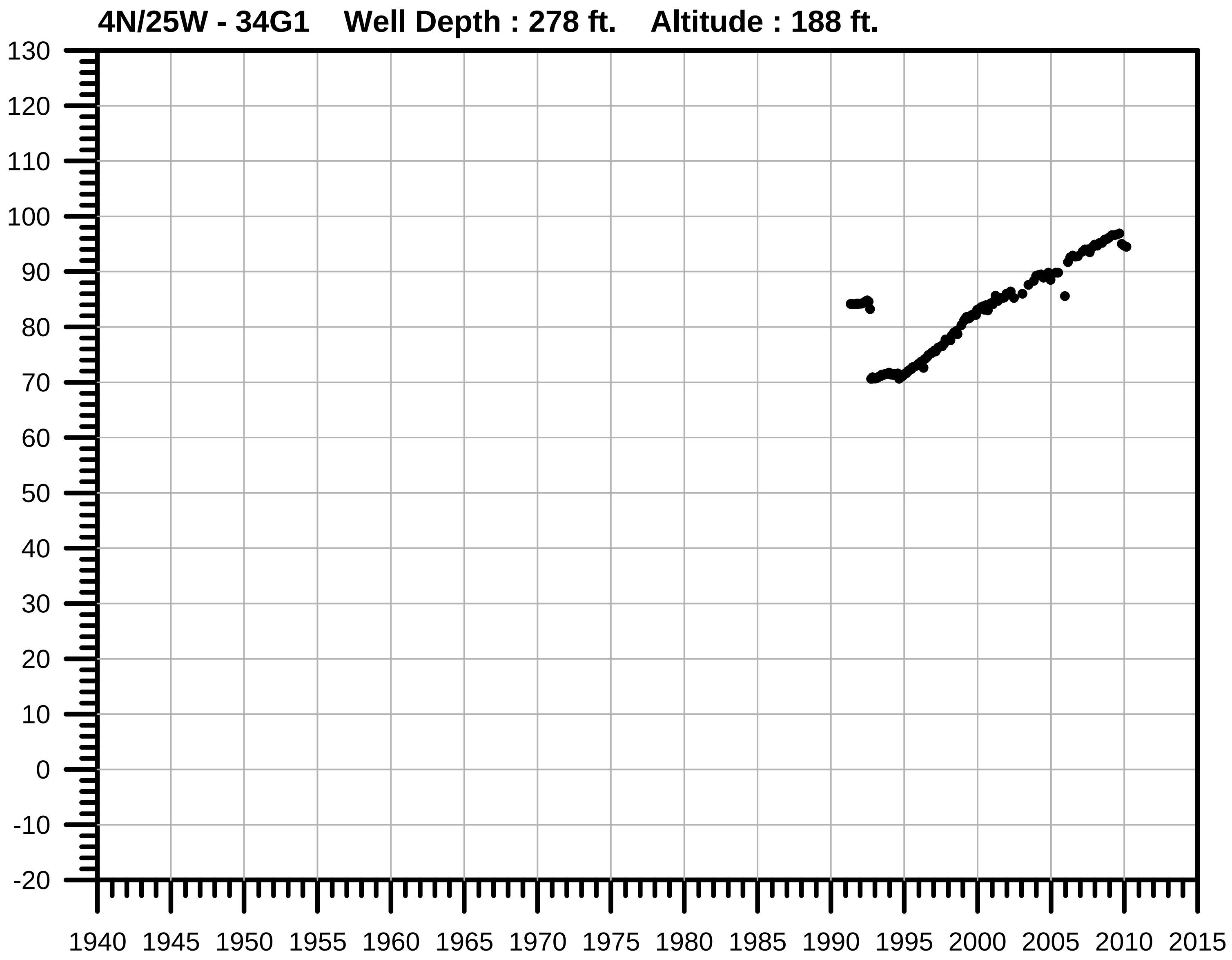

PLATE C-19. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

4N/25W - 35A3 Well Depth : 146 ft. Altitude : 147 ft.

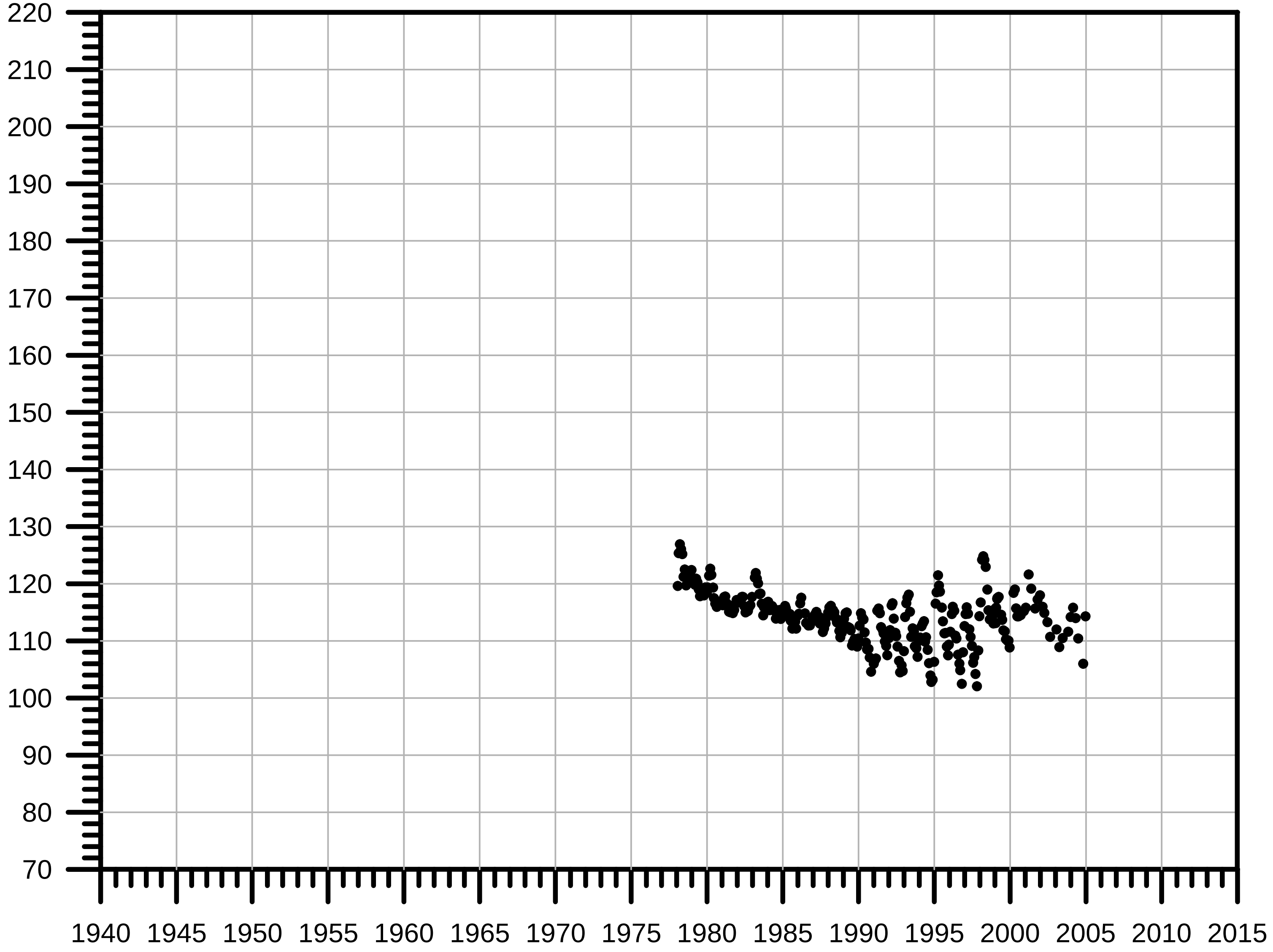

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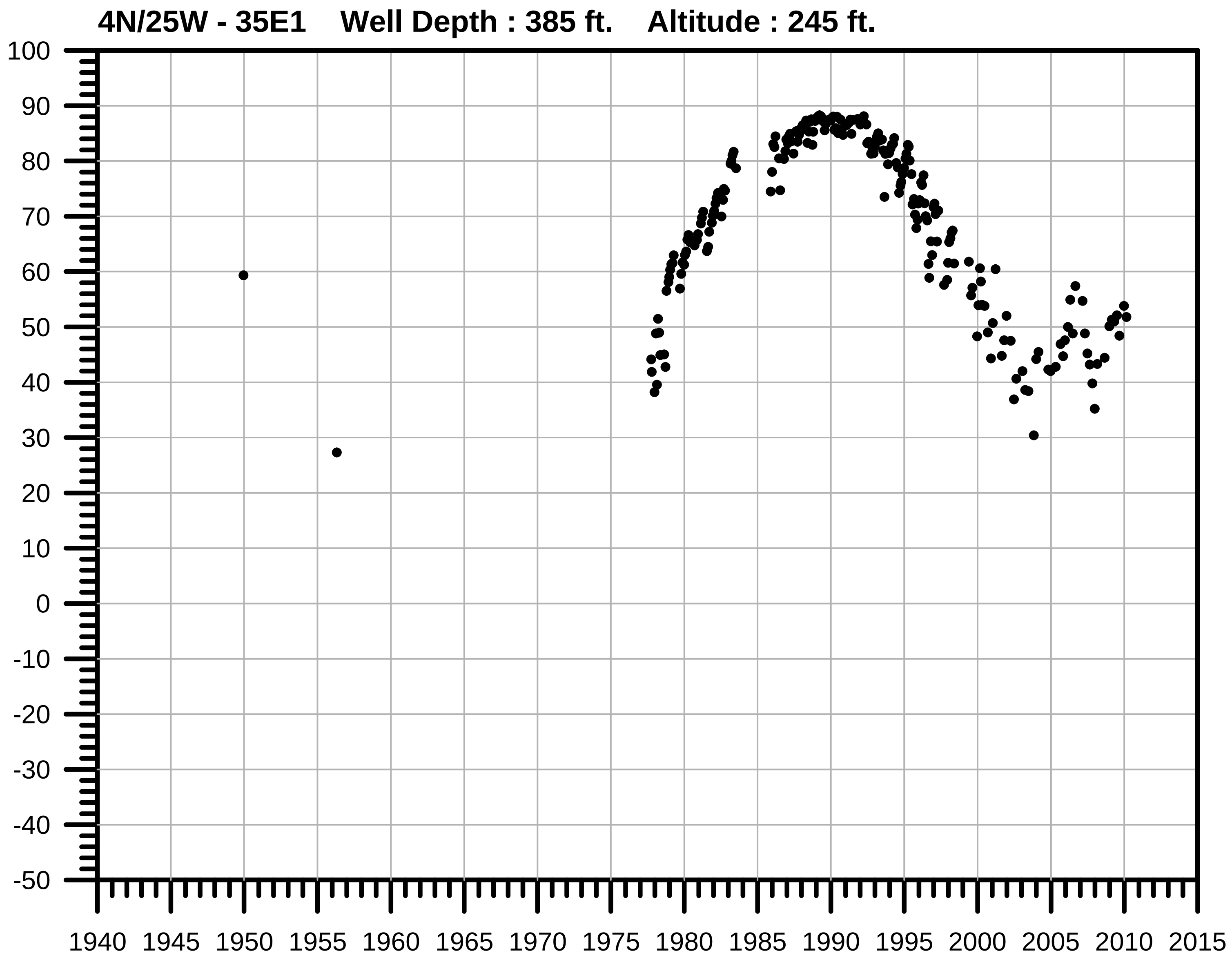
PLATE C-20. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District



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water resources

PLATE C-21. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

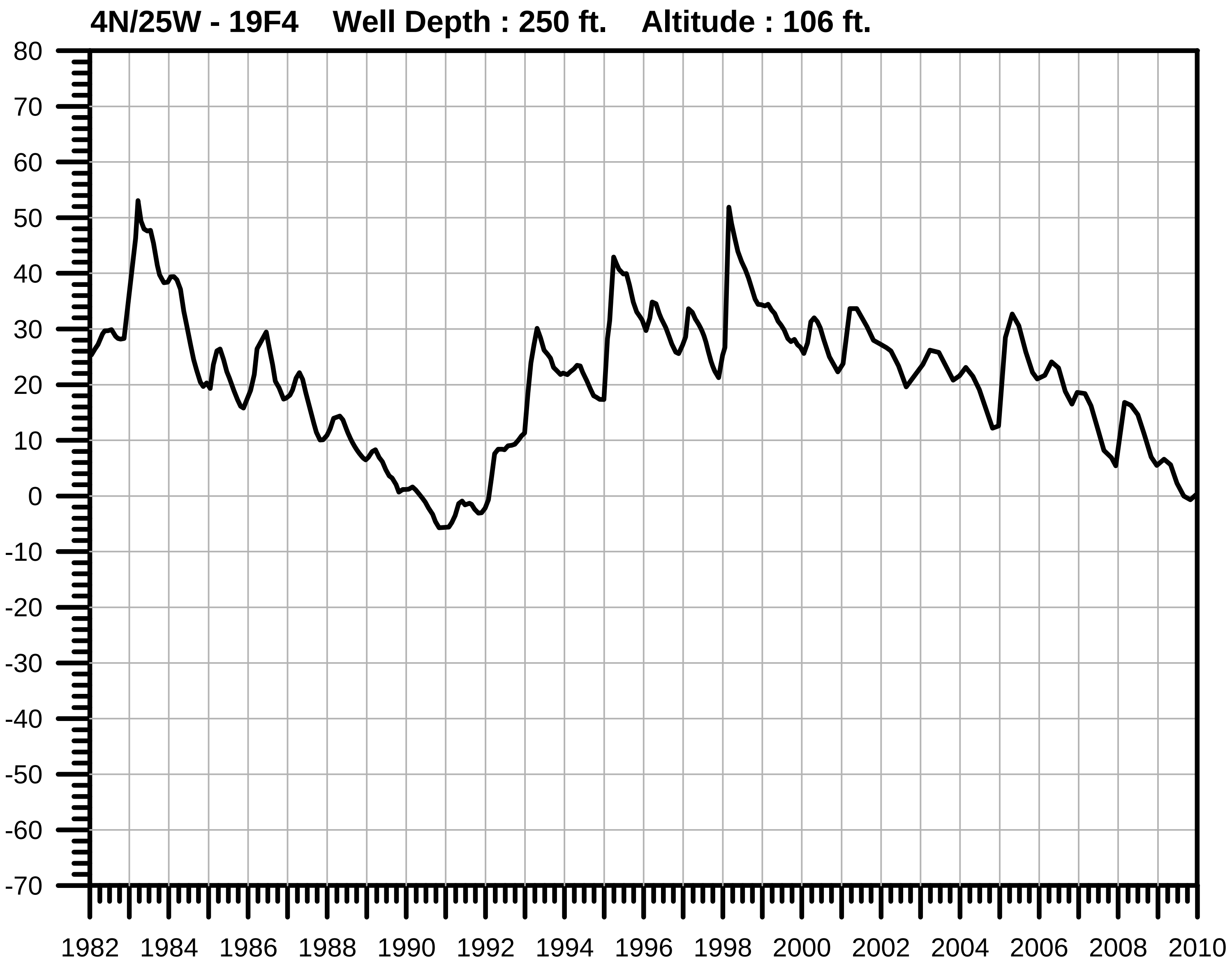

PLATE C-23. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

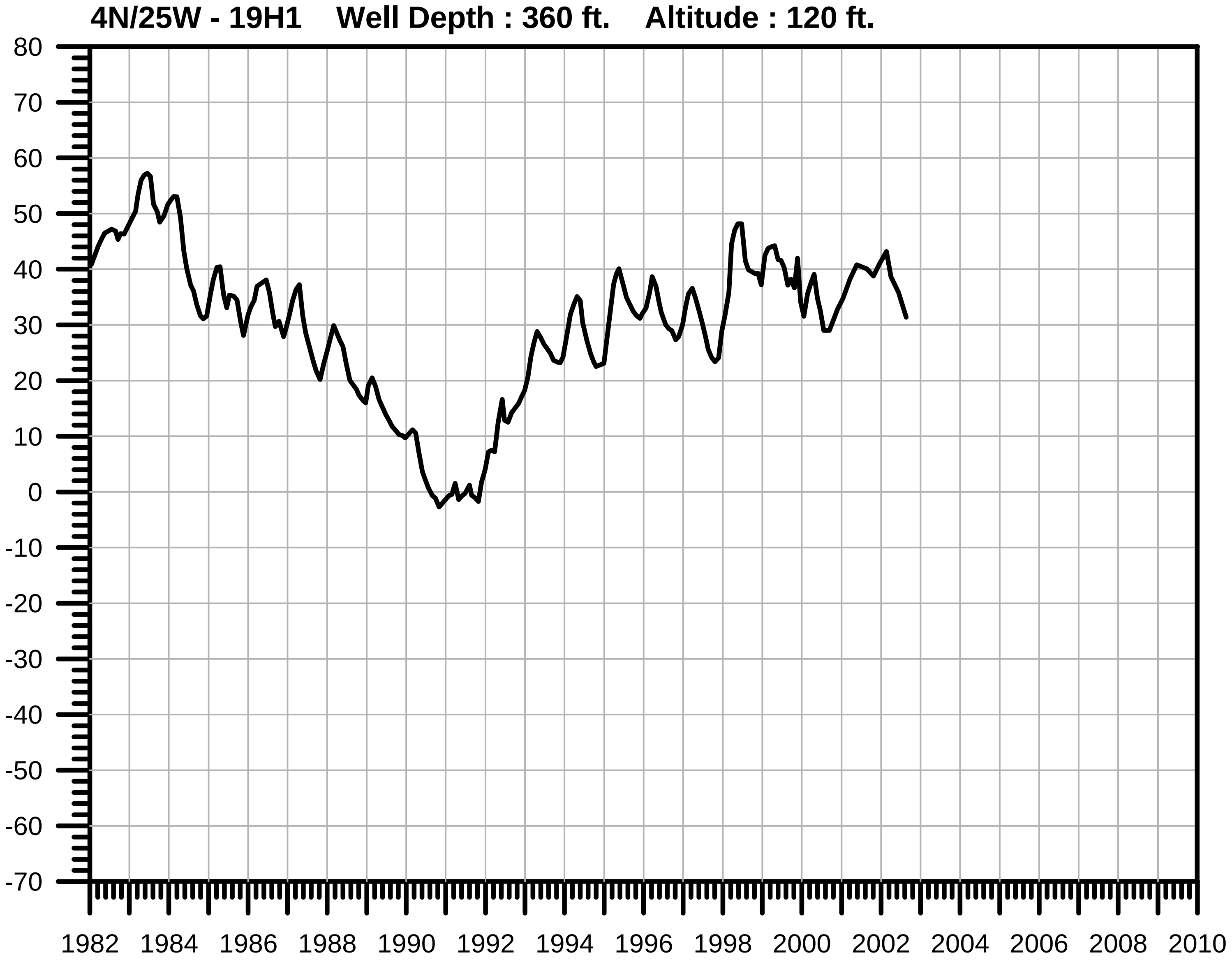

PLATE C-24. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

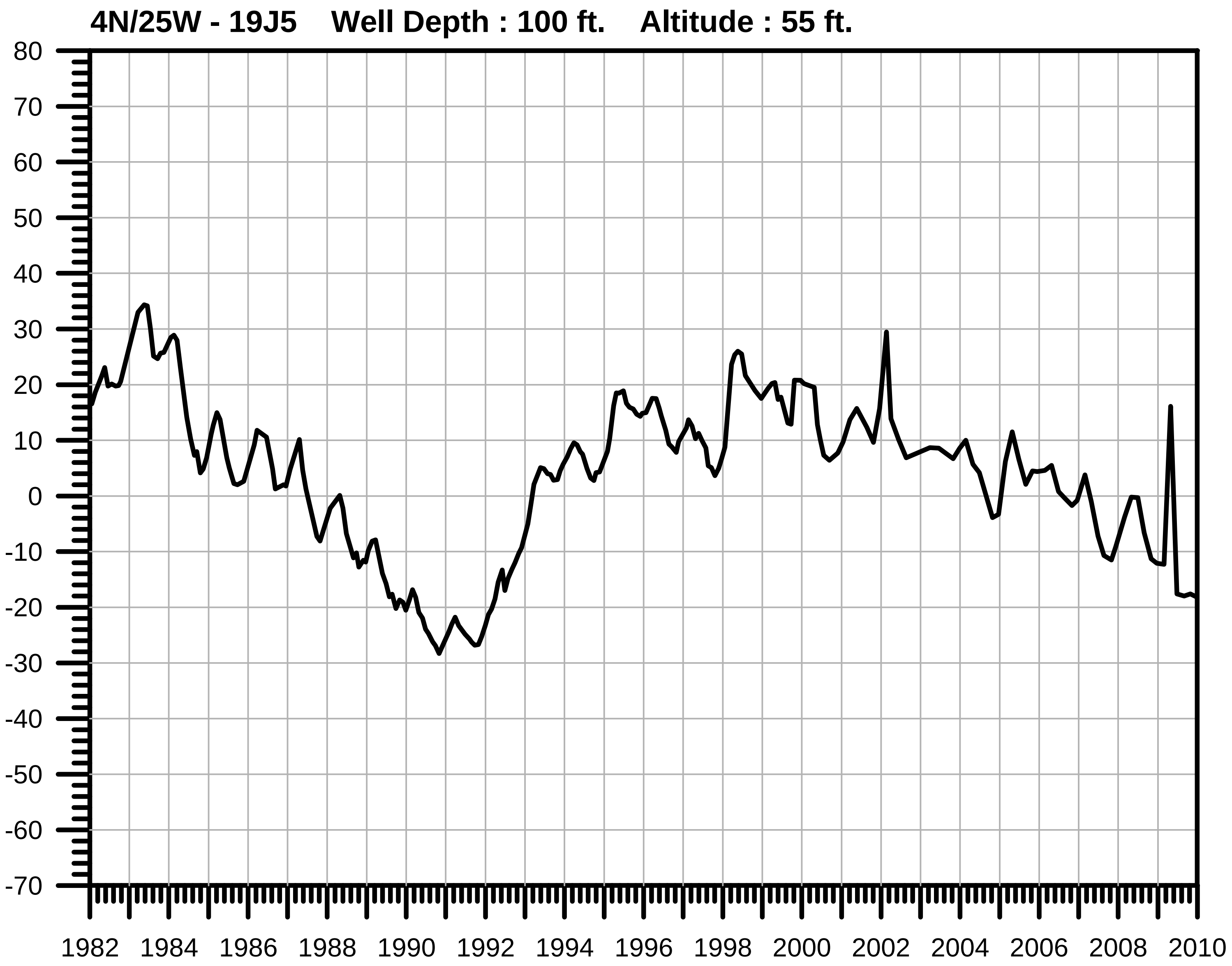

PLATE C-25. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

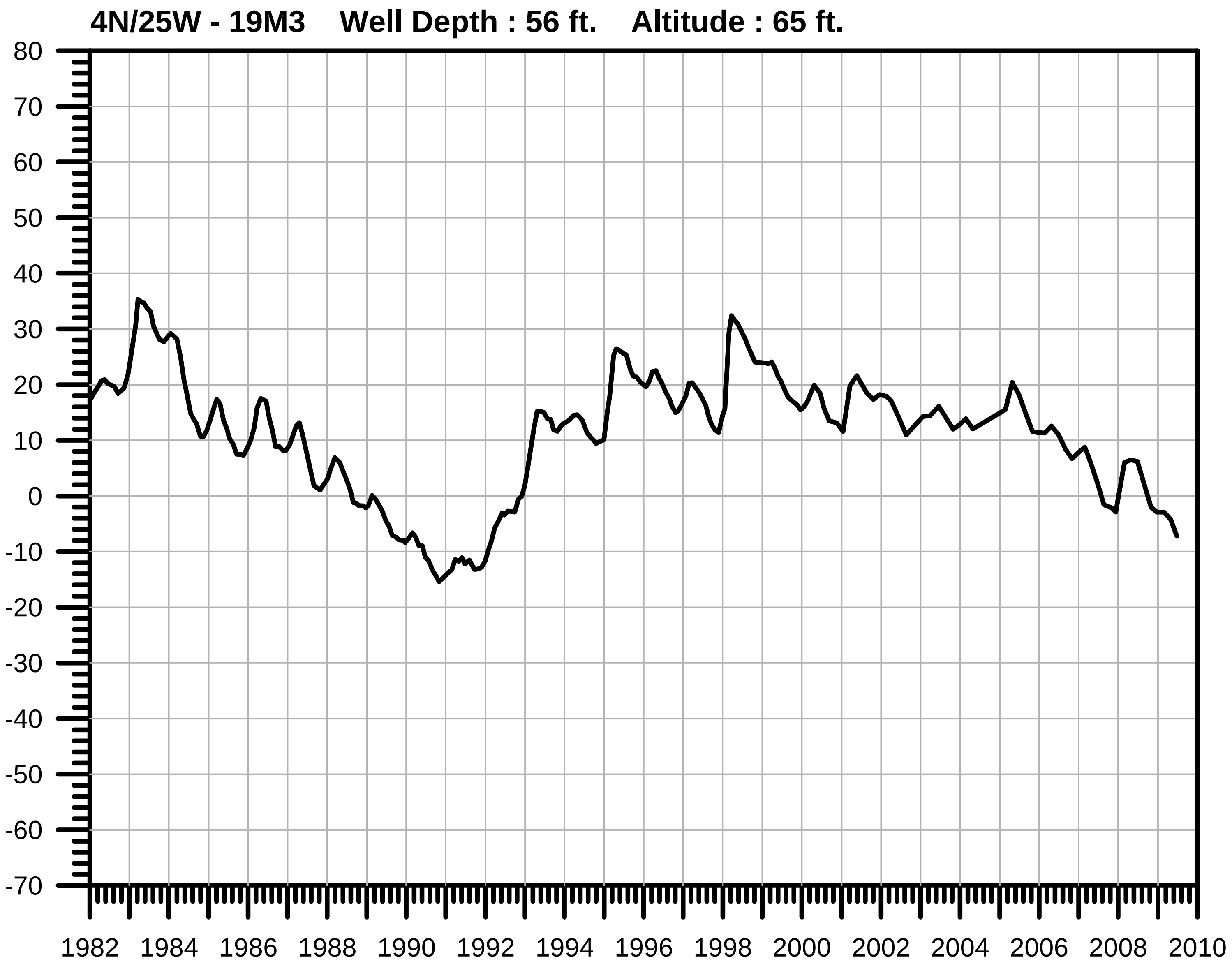

PLATE C-26. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

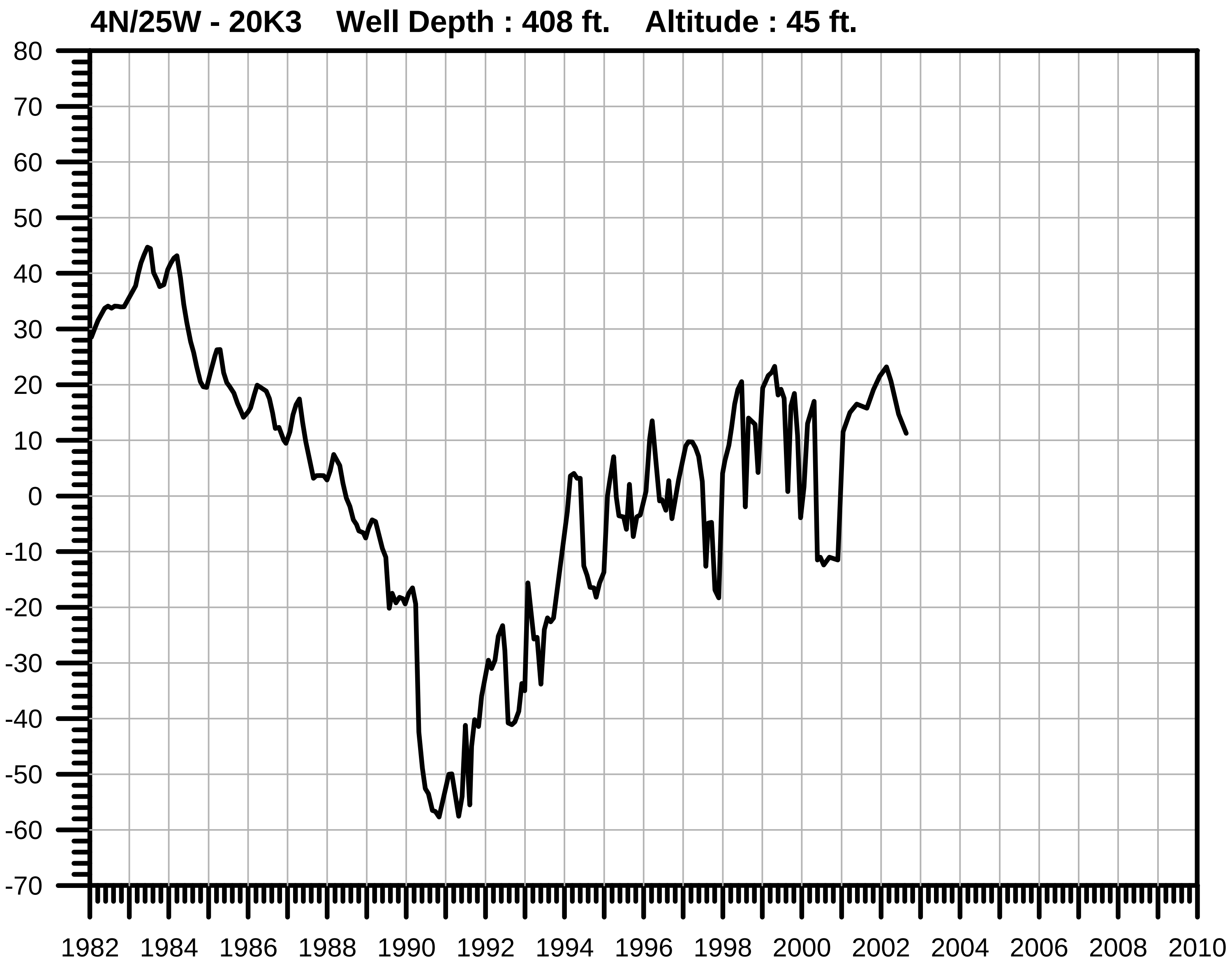

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PLATE C-27. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

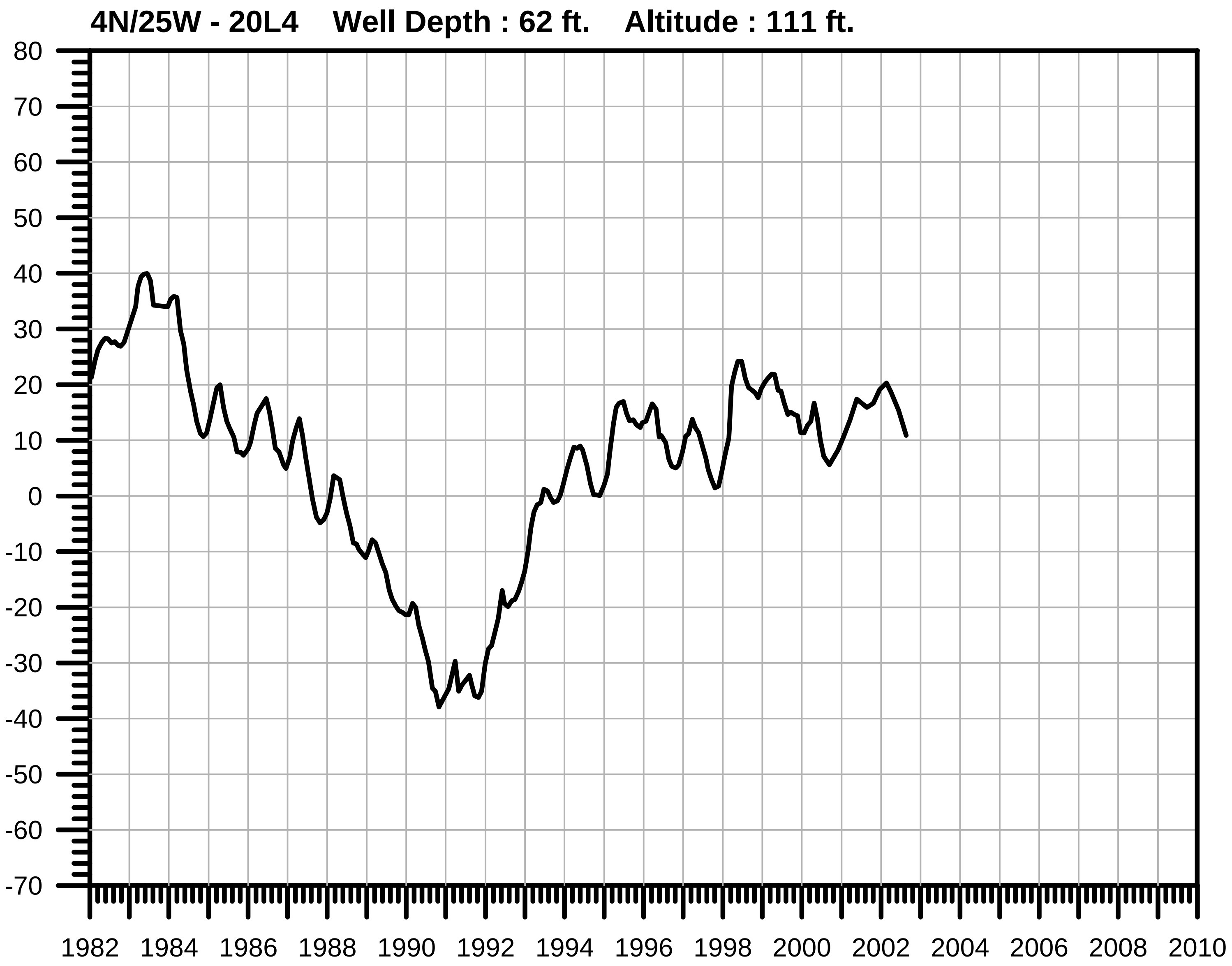

PLATE C-28. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

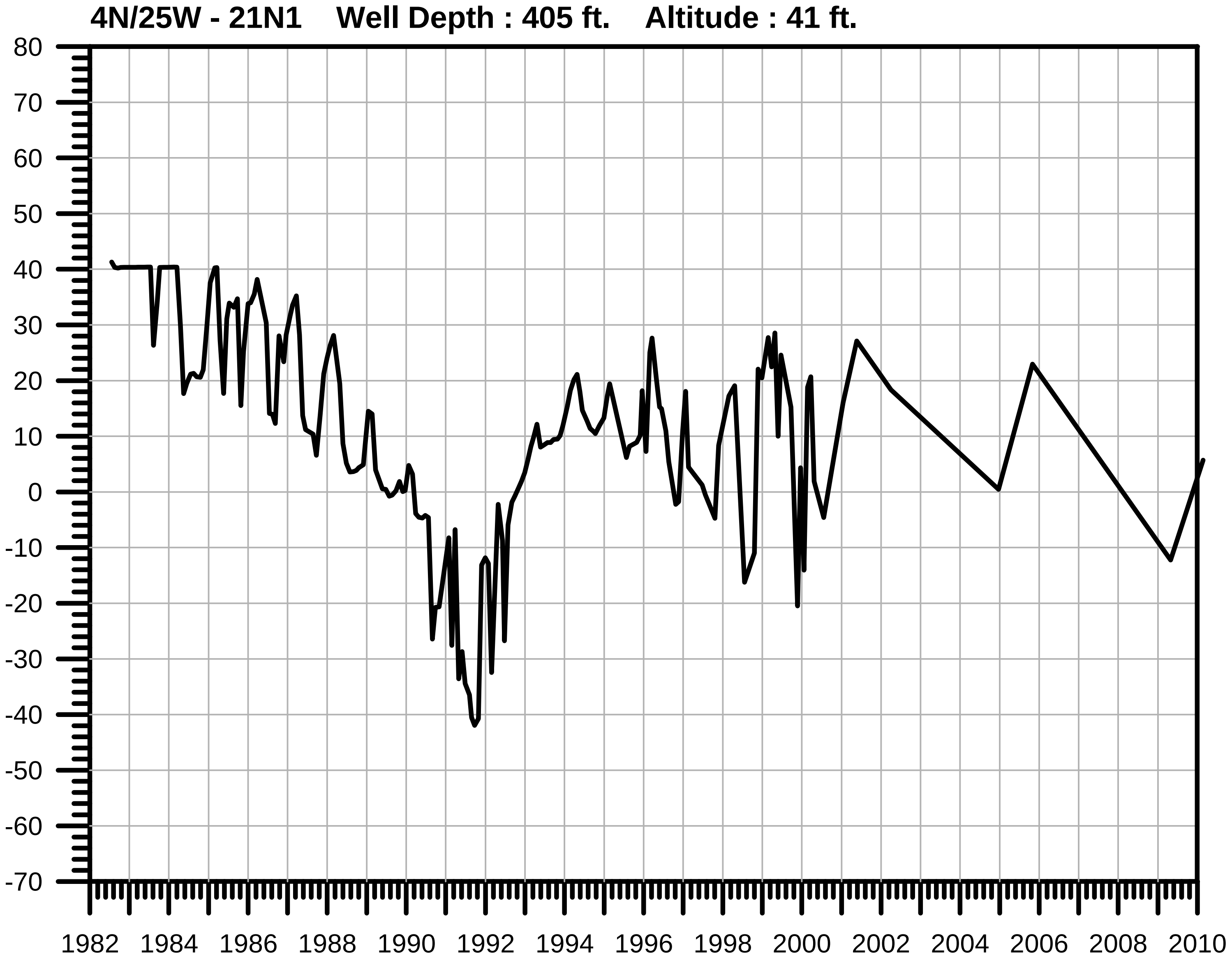

PLATE C-29. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

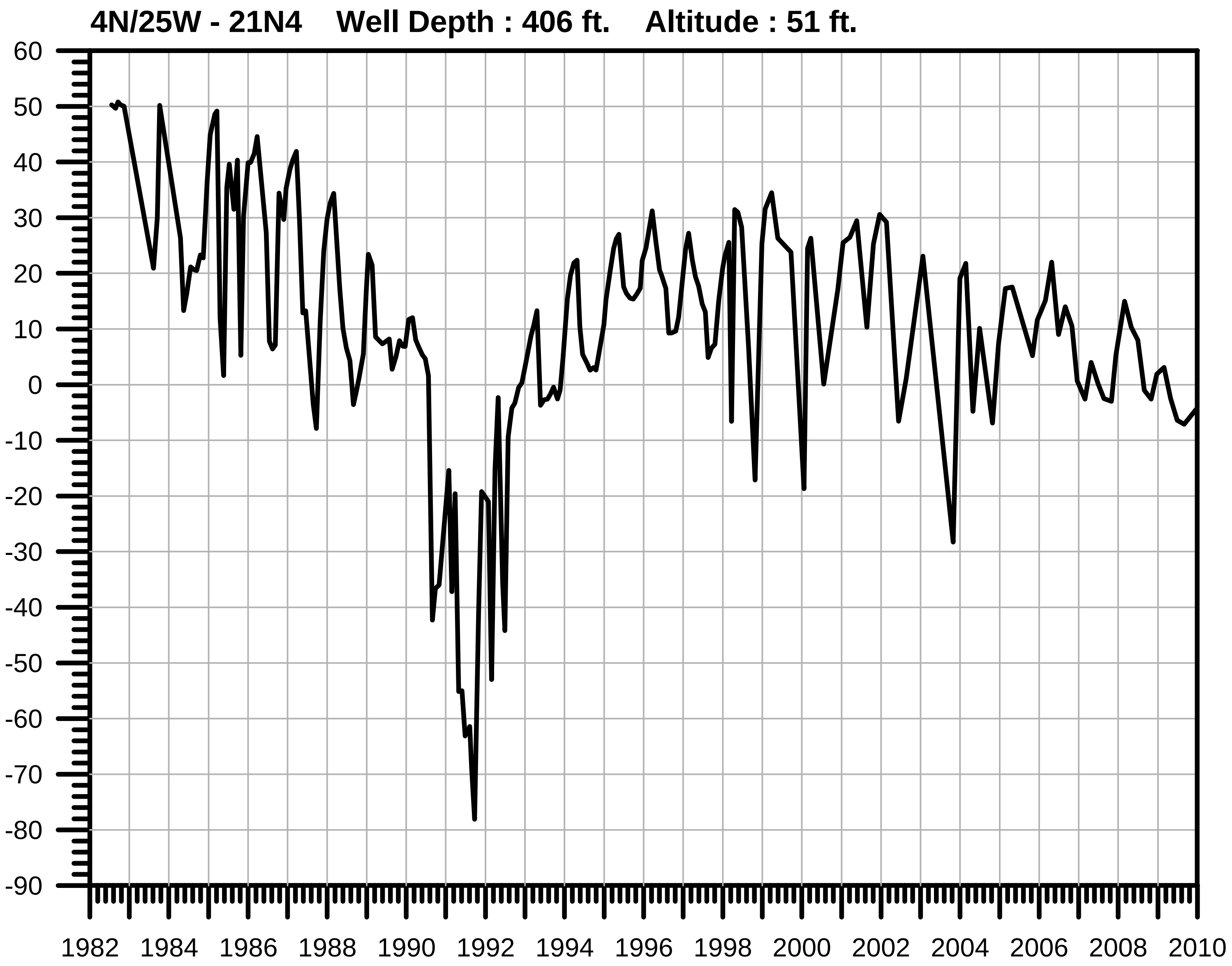

PLATE C-30. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

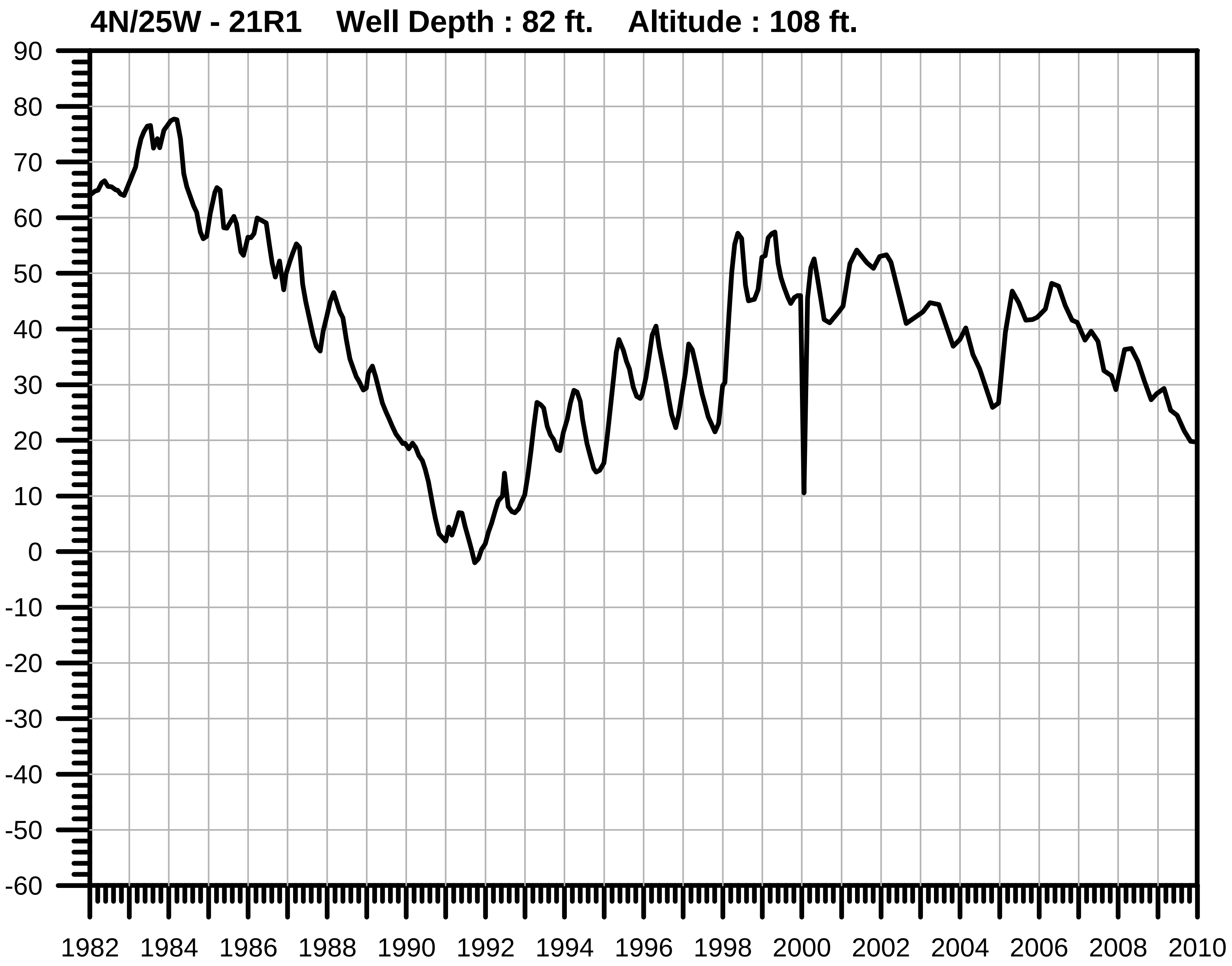

PLATE C-31. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

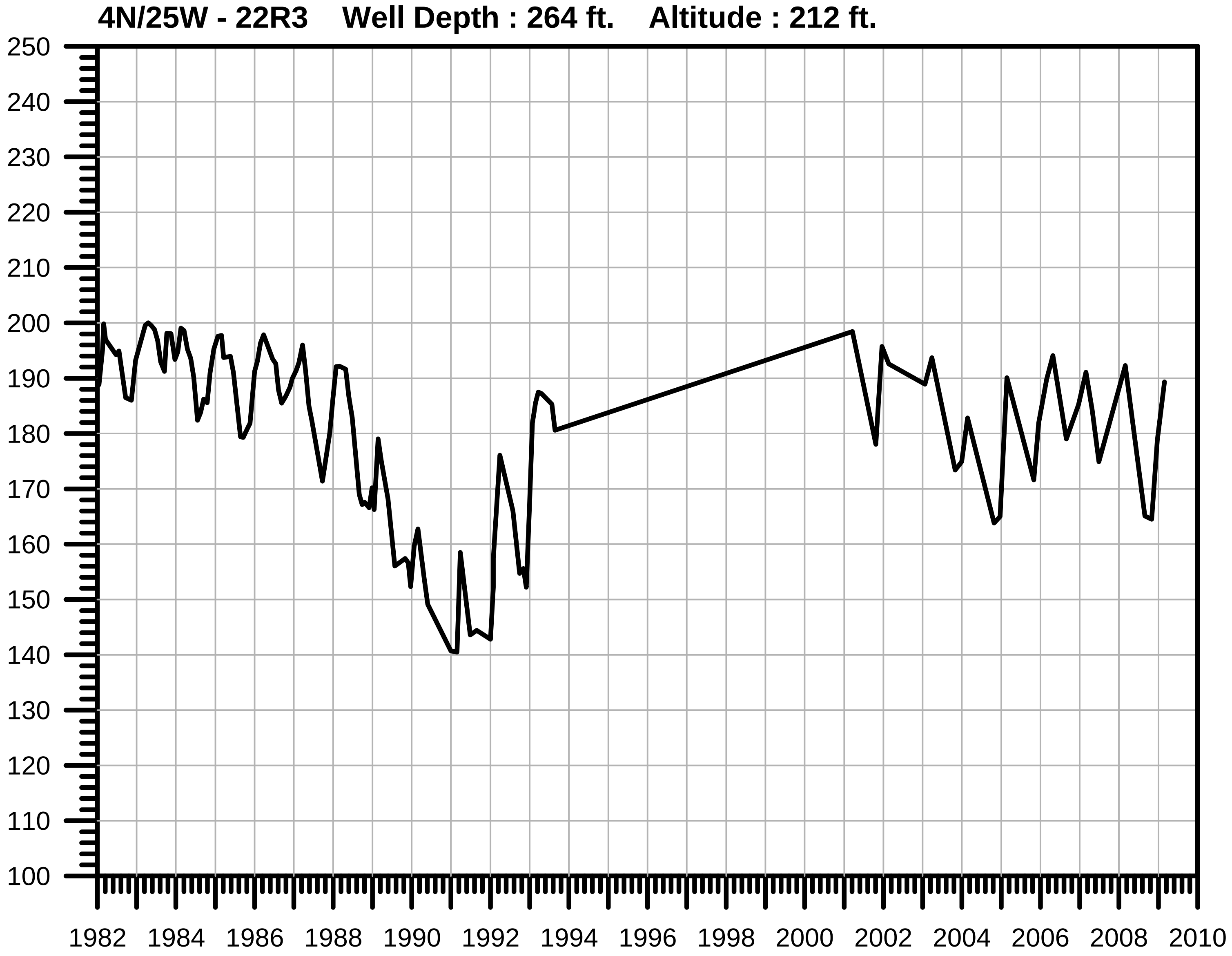

PLATE C-32. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

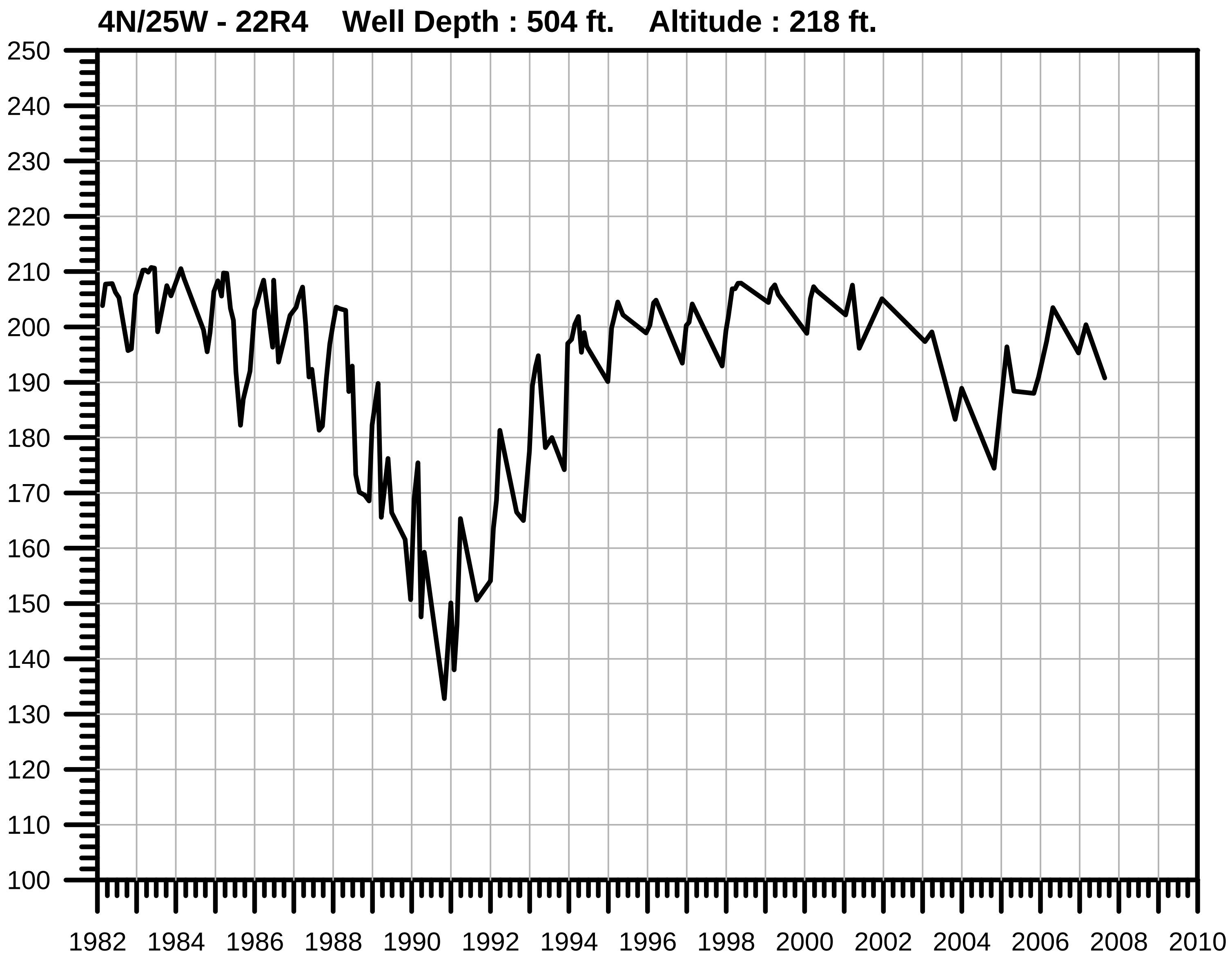

PLATE C-33. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

February 2011
Project No. 06-0125

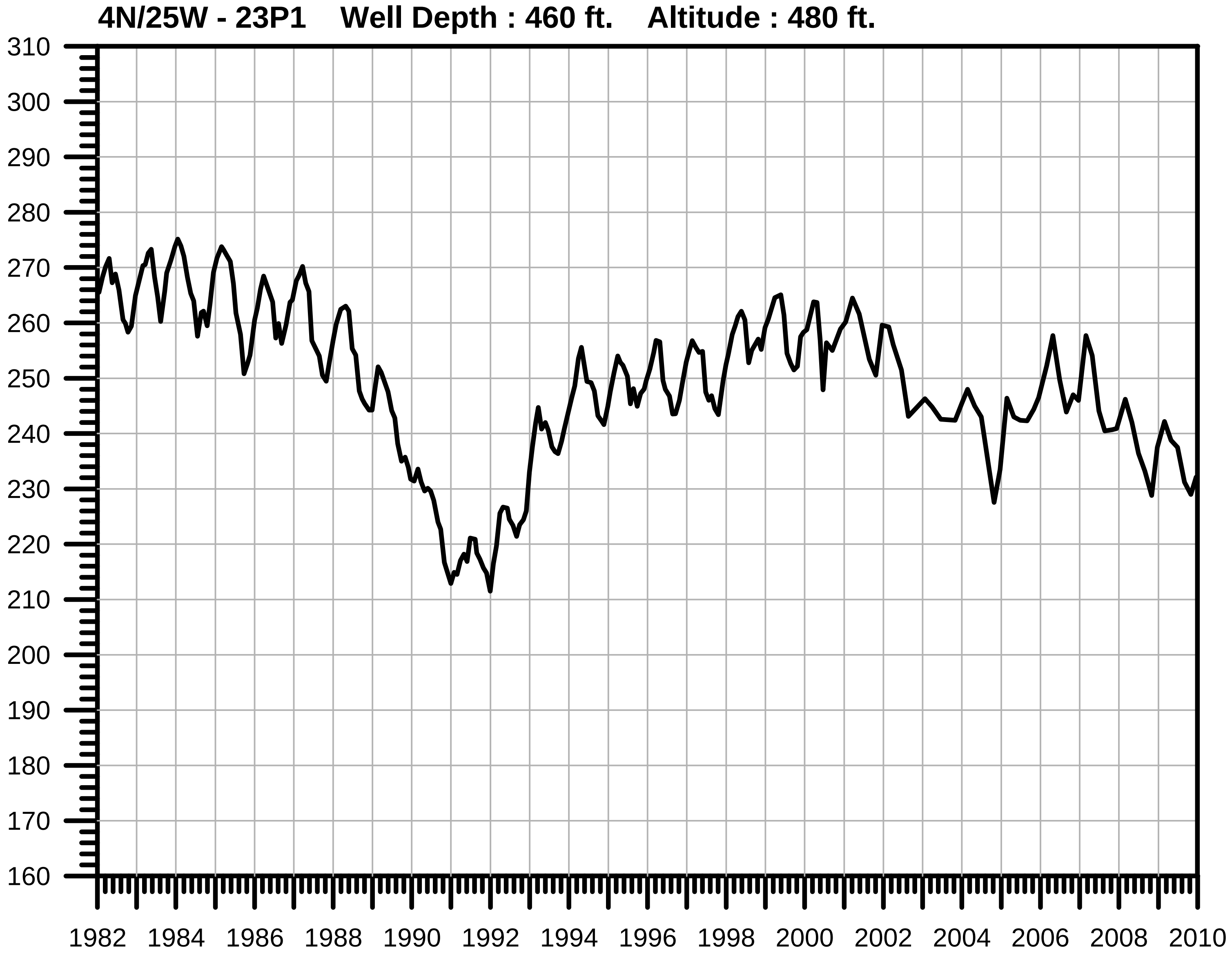

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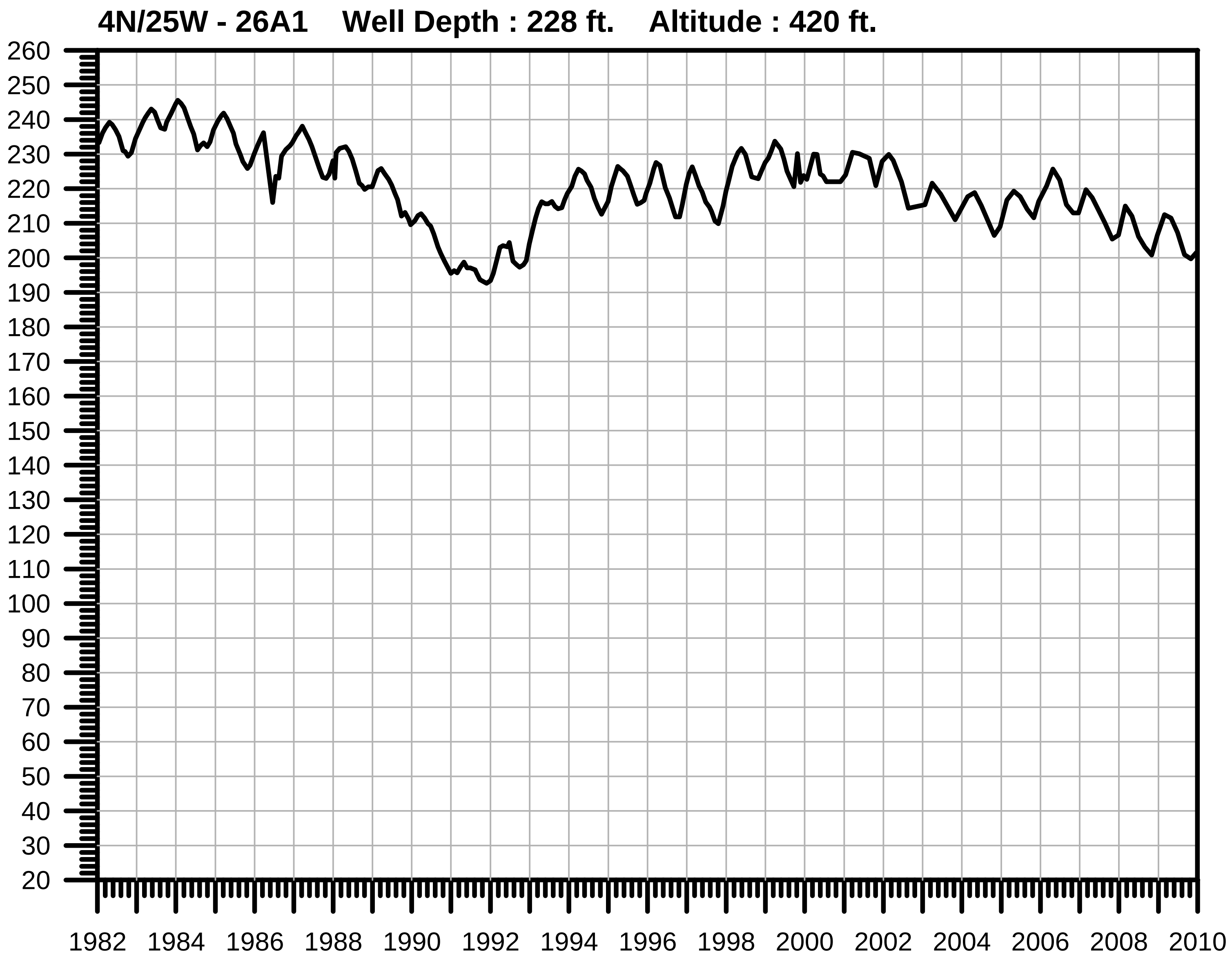
PLATE C-34. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District



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water resources

PLATE C-35. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

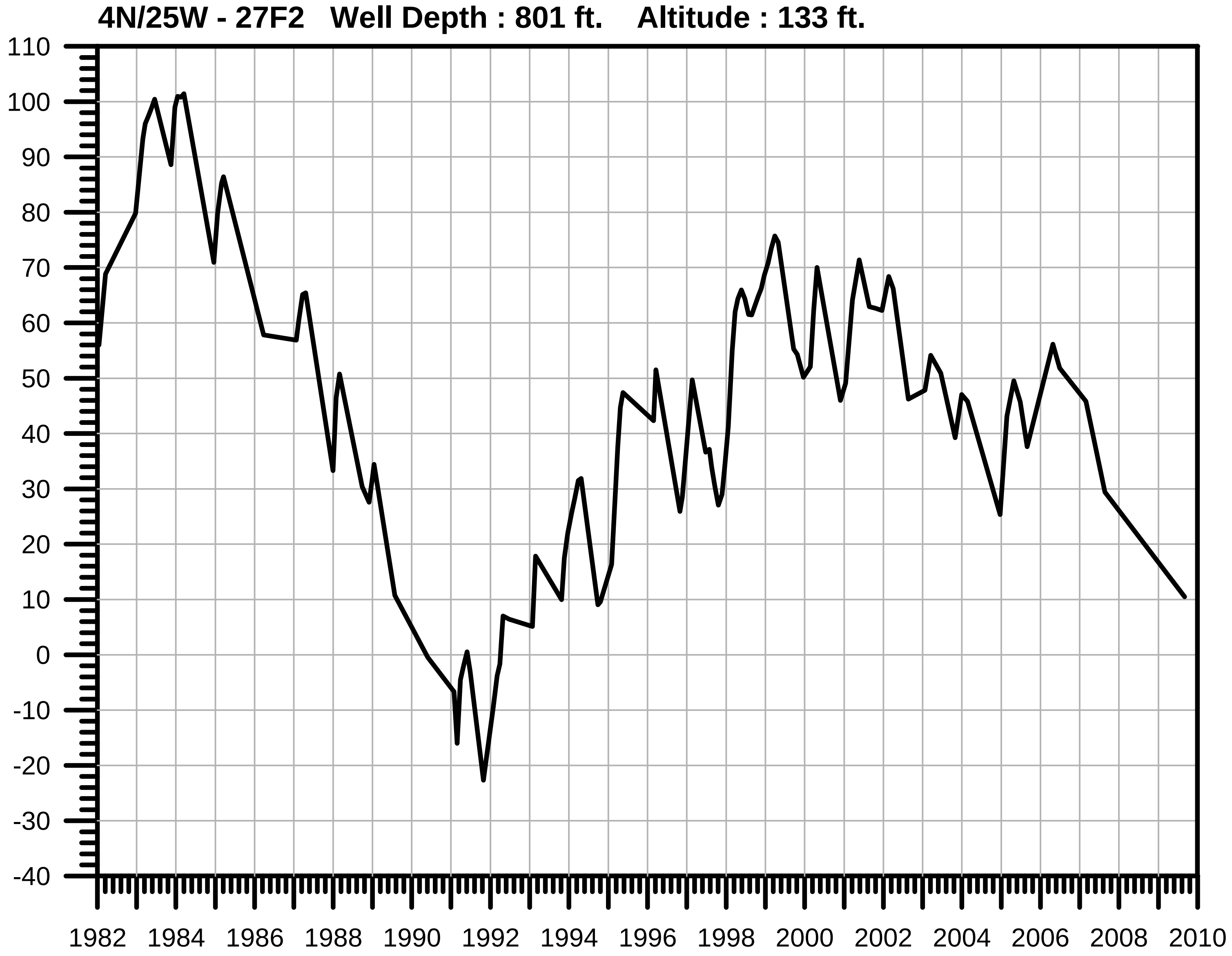


PLATE C-36. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

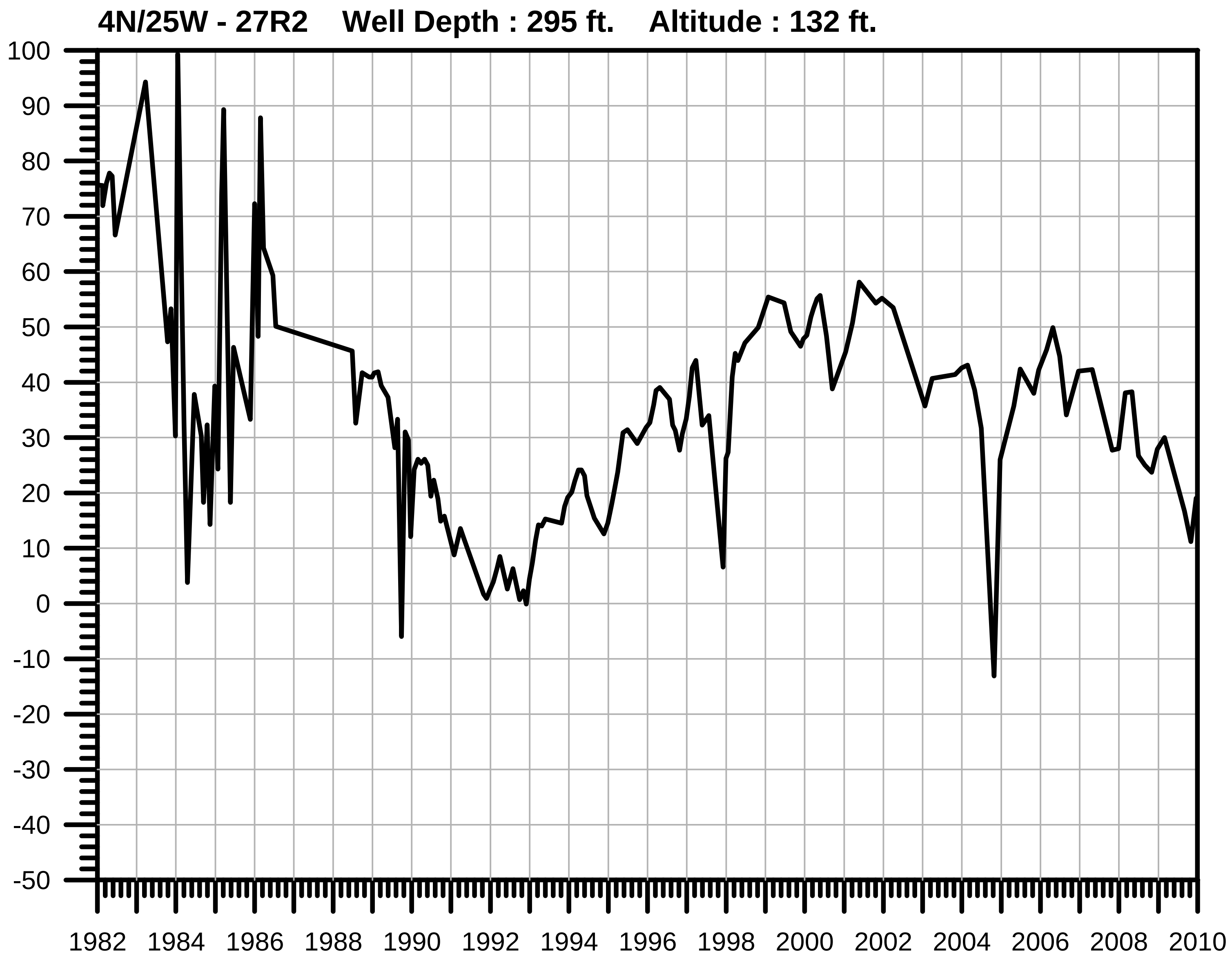
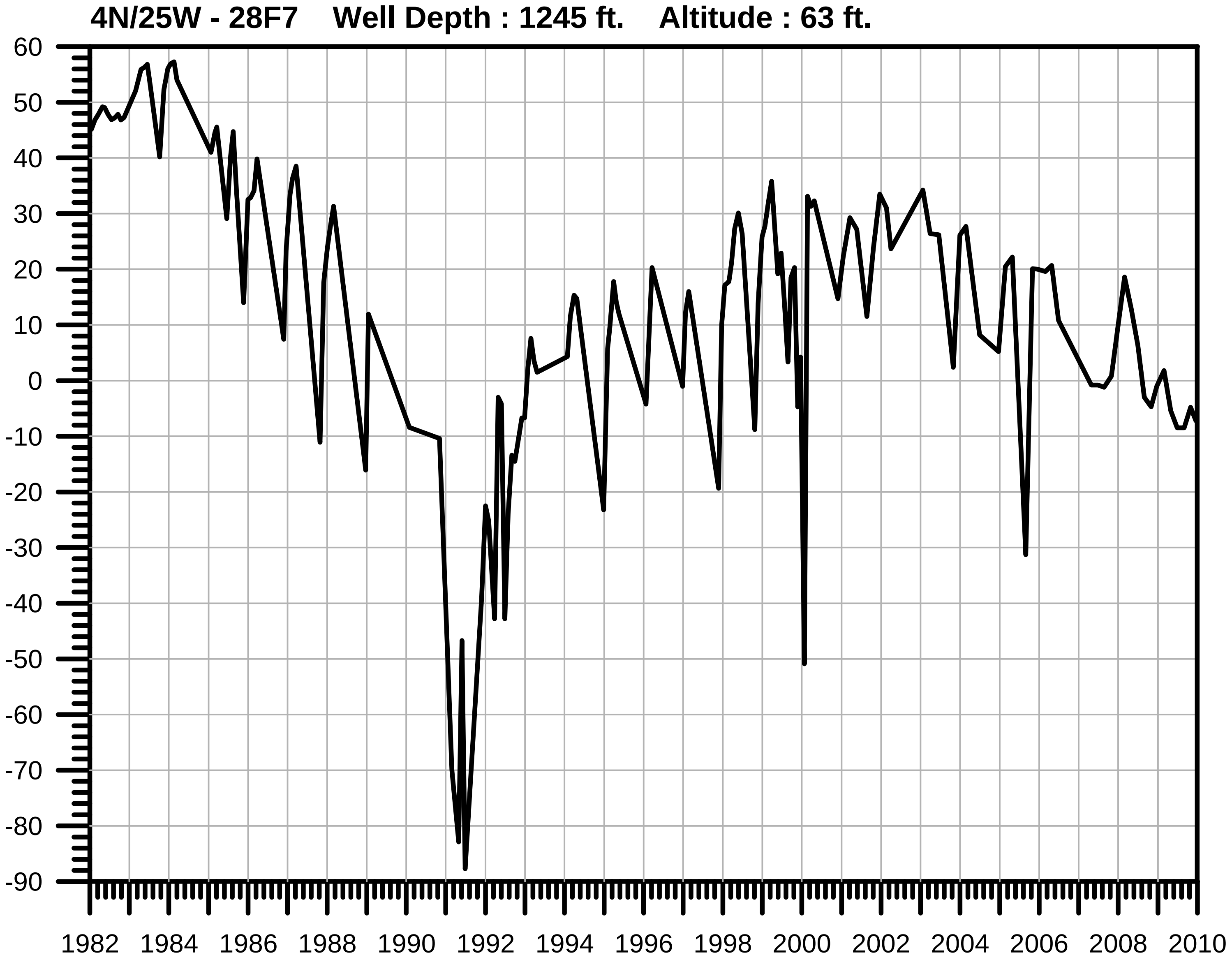


PLATE C-37. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District



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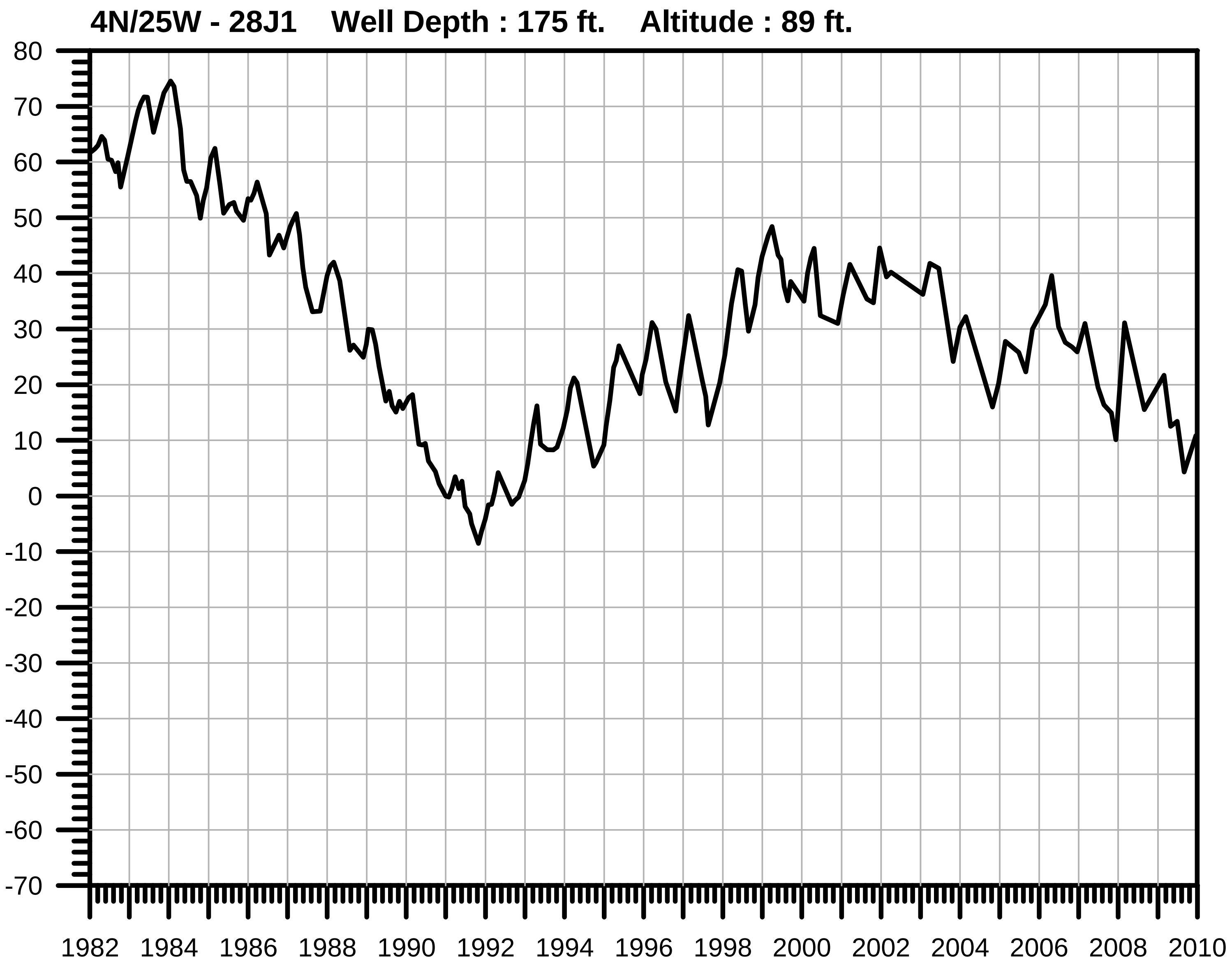
water resources

PLATE C-38. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District



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water resources

PLATE C-39. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

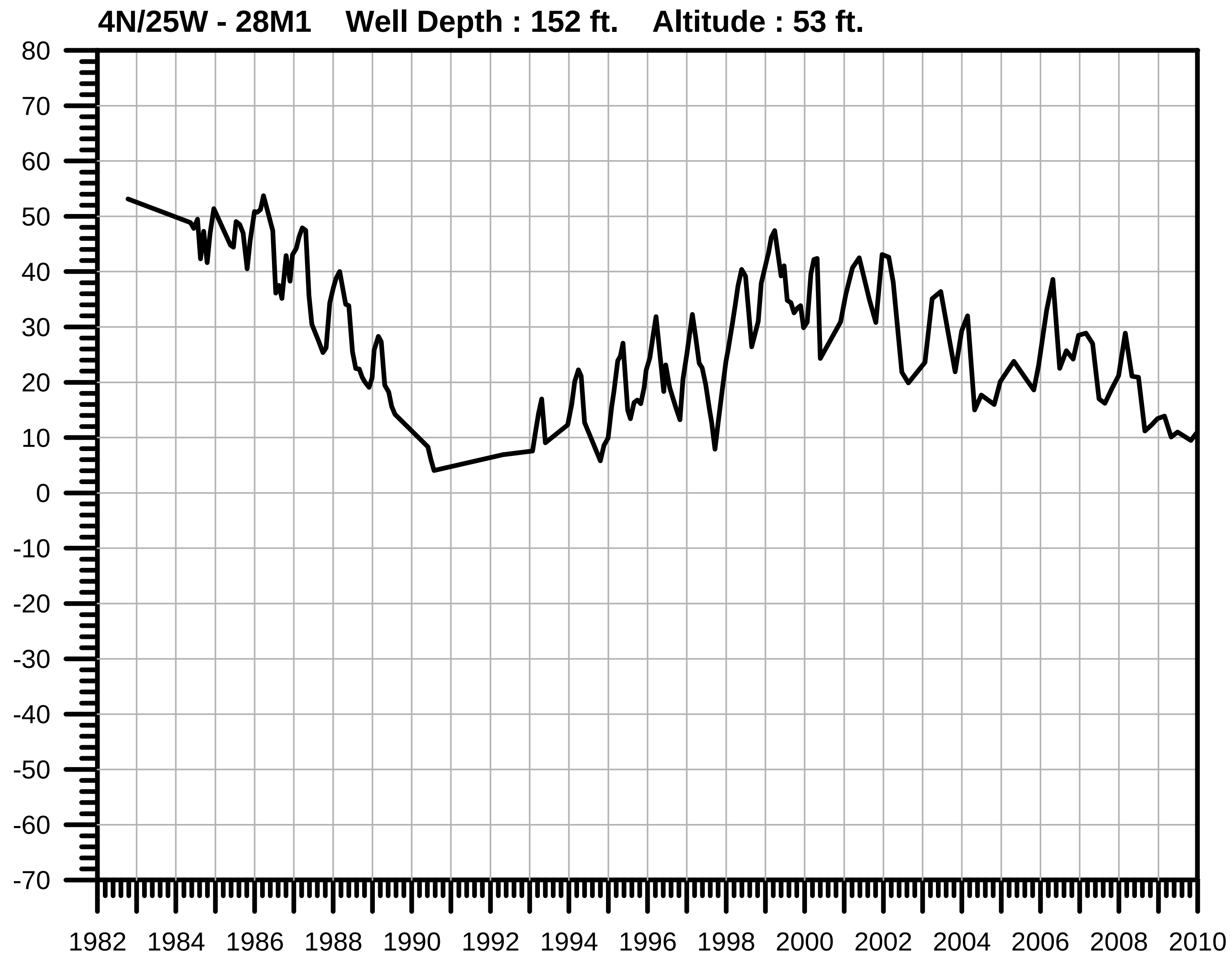

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PLATE C-40. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

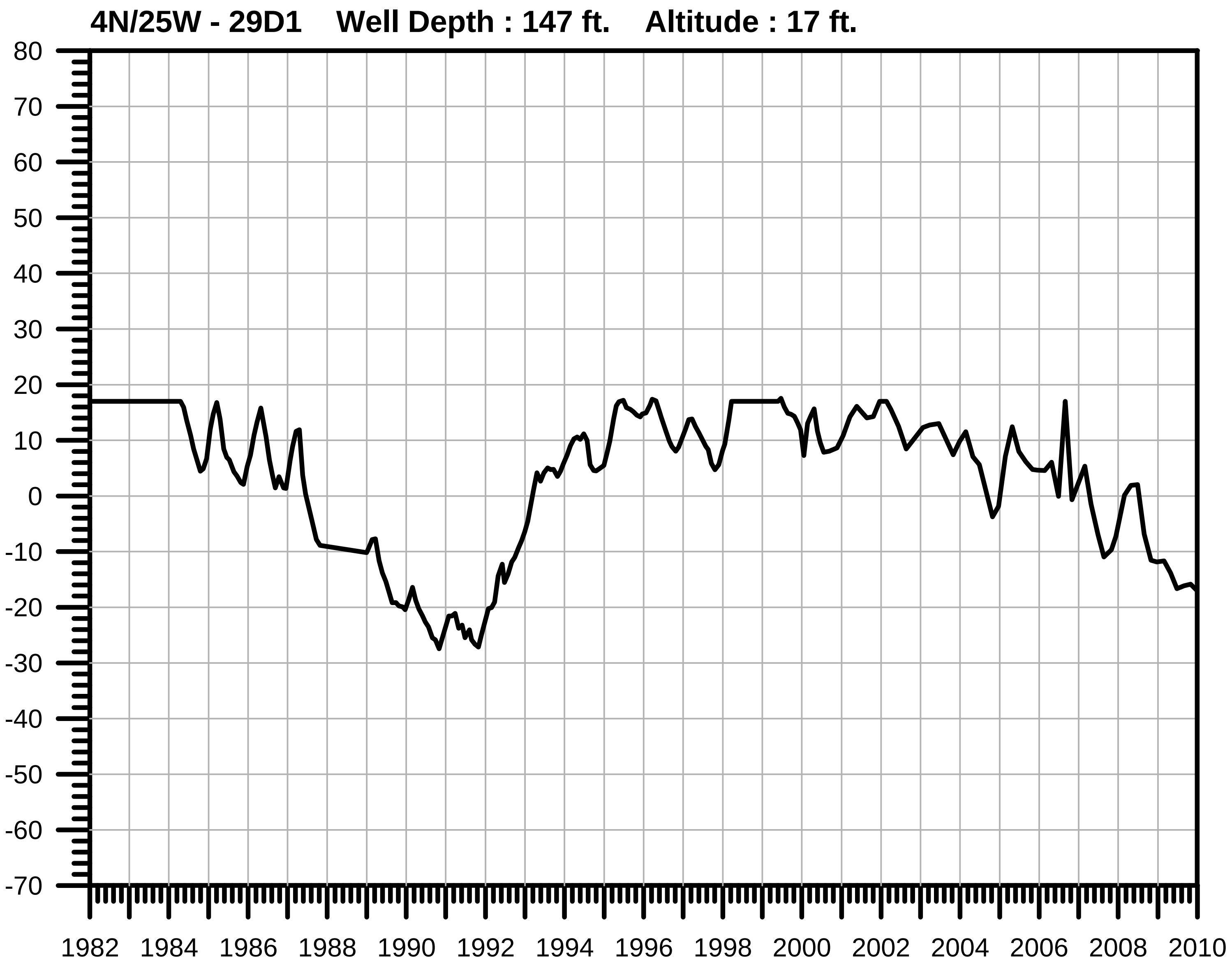

PLATE C-41. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

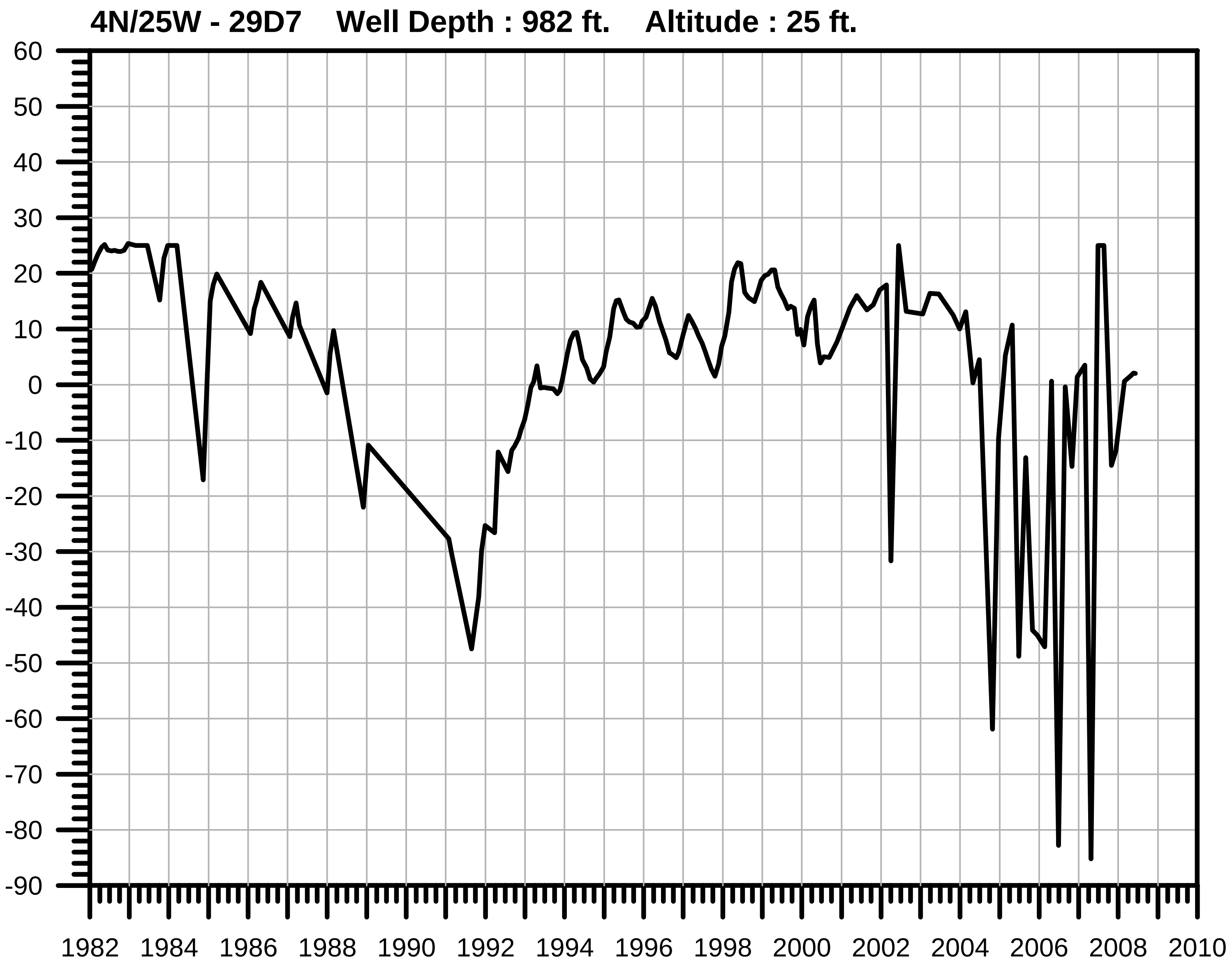

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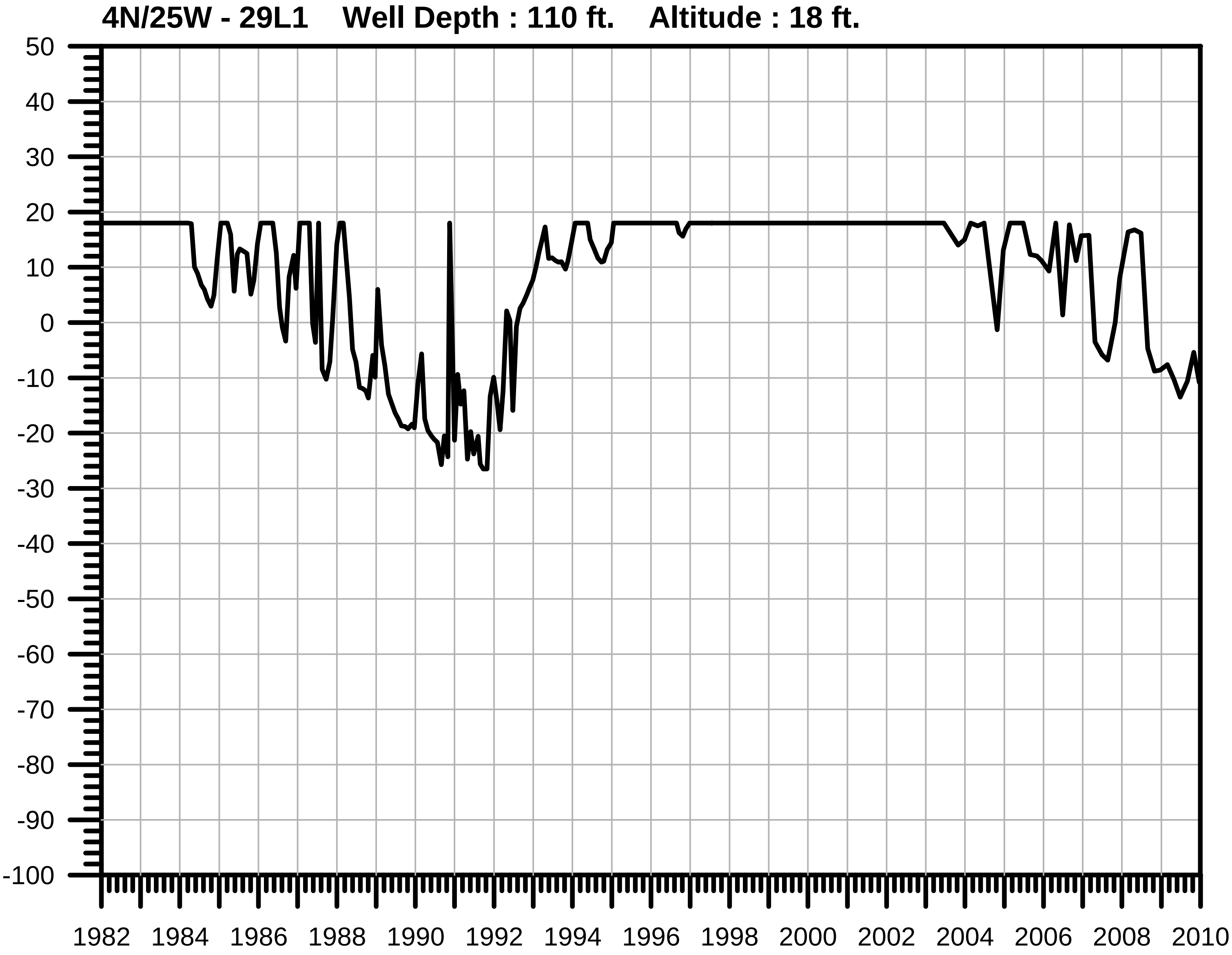
PLATE C-42. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District



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water resources

PLATE C-43. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

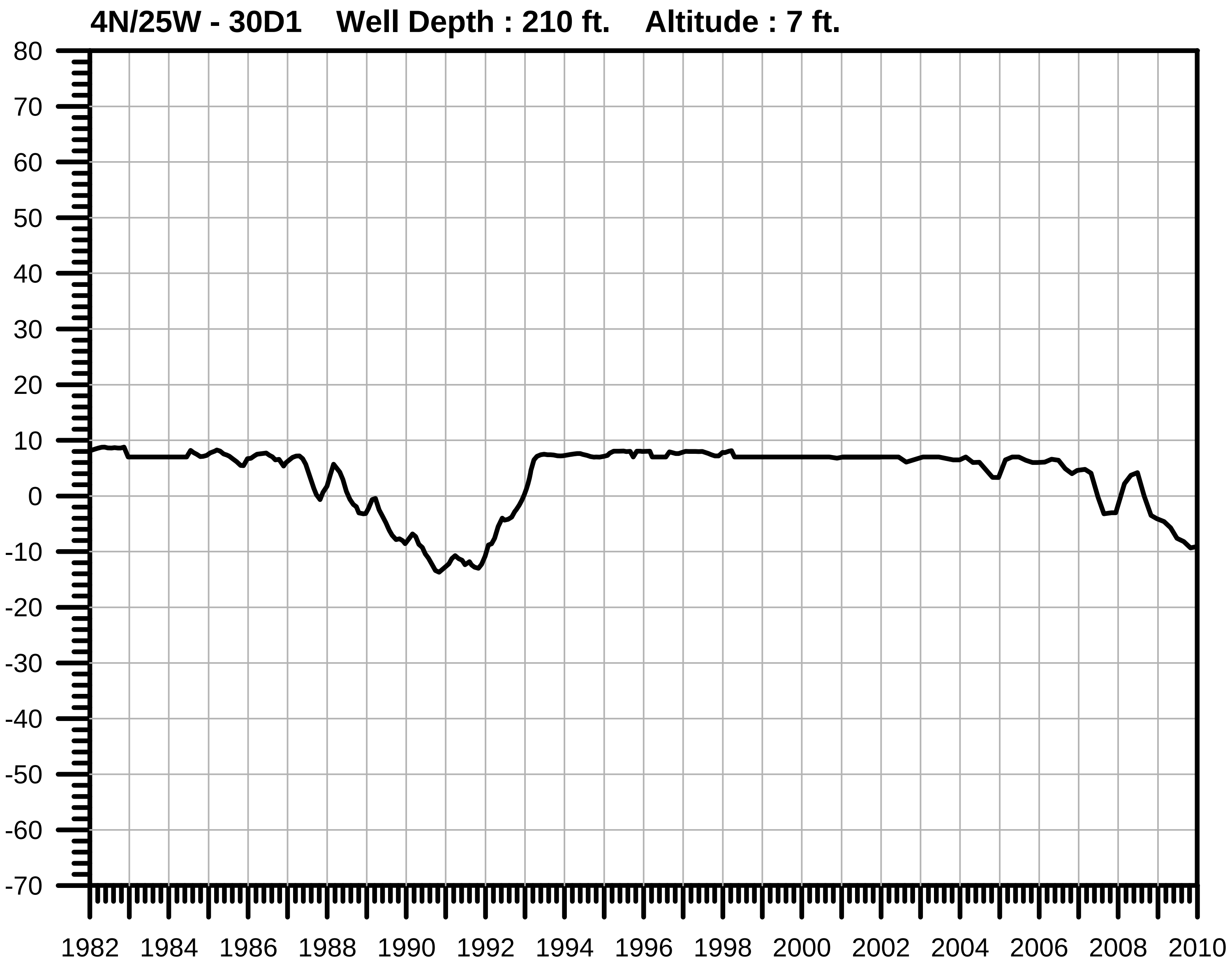

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PLATE C-44. WATER LEVEL HYDROGRAPH
CGB Hydrogeologic Update
Carpinteria Valley Water District

APPENDIX D
STREAMBED PERCOLATION SUPPORTING DATA

Water Year	Gaged (AF) Carpinteria - Gobernador	Reconstructed Streamflow Data for Ungaged (GTC Table C-2 ratios) (AF)					Total Streamflow (AF)
		Toro	Arroyo Parida	Santa Monica	Rincon	Local Drainages	
1985	179	36	38	36	138	33	460
1986	2,265	453	484	458	1,752	424	5,836
1987	211	42	45	43	164	40	545
1988	224	45	48	45	173	42	577
1989	78	16	17	16	61	15	202
1990	14	3	3	3	11	3	35
1991	1,711	342	365	346	1,323	320	4,408
1992	3,439	688	735	695	2,660	643	8,859
1993	9,975	1,997	2,131	2,015	7,715	1,866	25,700
1994	418	84	89	84	323	78	1,076
1995	22,451	4,495	4,796	4,536	17,365	4,200	57,844
1996	2,438	488	521	493	1,886	456	6,282
1997	2,879	576	615	582	2,227	539	7,418
1998	22,343	4,473	4,773	4,515	17,281	4,180	57,566
1999	516	103	110	104	399	97	1,330
2000	1,853	371	396	374	1,433	347	4,775
2001	4,124	826	881	833	3,190	772	10,625
2002	20	4	4	4	16	4	53
2003	923	185	197	187	714	173	2,378
2004	8	2	2	2	6	1	20
2005	17,839	3,571	3,811	3,605	13,798	3,337	45,962
2006	2,654	531	567	536	2,053	497	6,838
2007	29	6	6	6	23	5	76
2008	3,581	717	765	724	2,770	670	9,226
Averages	3,169	634	677	640	2,451	593	8,164

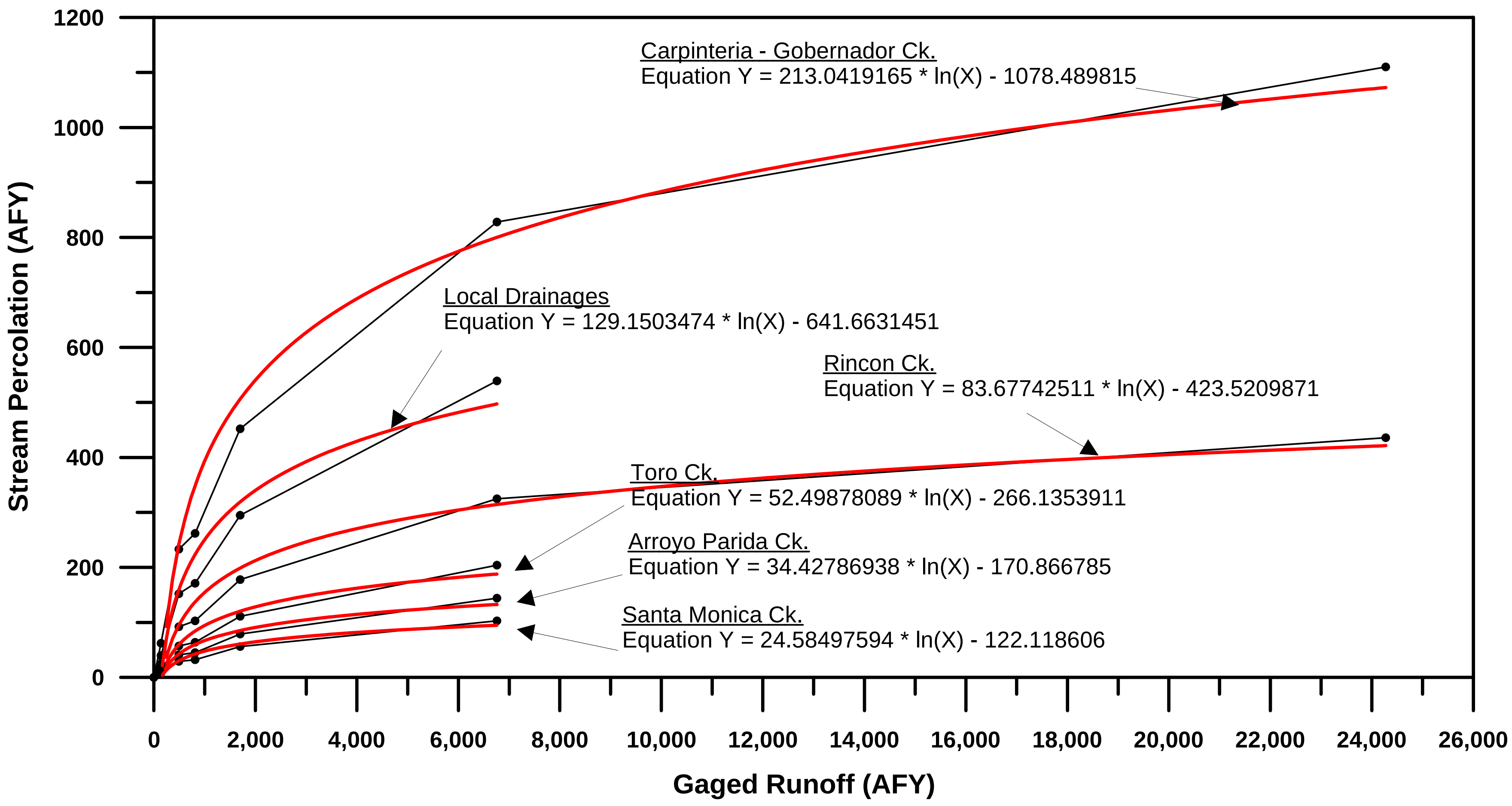

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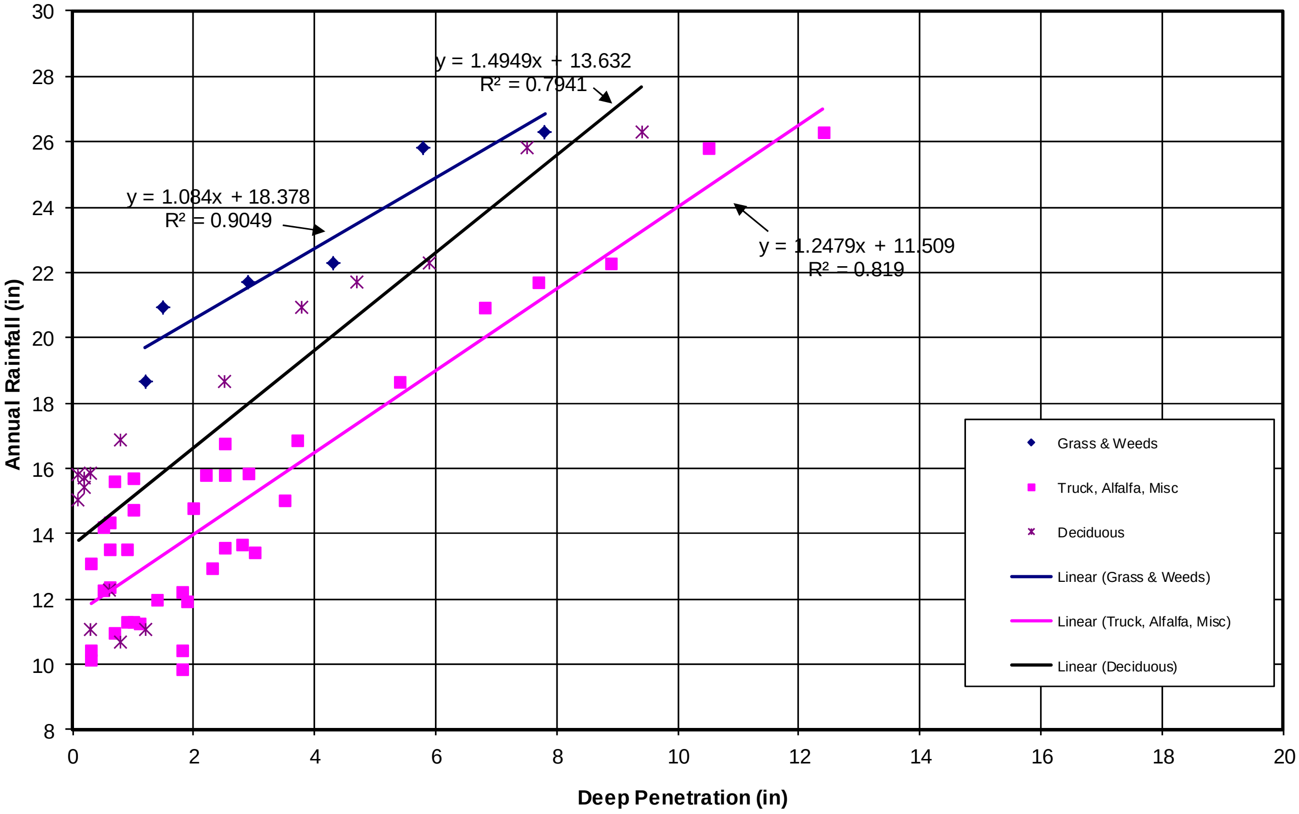
PLATE D1. RUNOFF VS. STREAM PERCOLATION
Hydrogeologic Update
Carpinteria Valley Water District

Water Year	Streambed Percolation (AF) from Streamflow				
	Carpinteria - Gobernador	Toro Cyn	Arroyo Parida	Rincon	Basin Total
1985	26	5	5	20	**57**
1986	567	55	42	201	**866**
1987	62	12	13	3	**91**
1988	74	15	16	8	**112**
1989	12	2	3	9	**26**
1990	2	0	0	2	**4**
1991	508	40	32	178	**758**
1992	656	77	56	236	**1,026**
1993	883	133	93	325	**1,434**
1994	207	41	43	60	**352**
1995	1,056	175	121	393	**1,746**
1996	583	59	45	208	**894**
1997	618	68	50	221	**958**
1998	1,055	175	121	393	**1,744**
1999	252	50	53	78	**434**
2000	525	44	35	185	**789**
2001	695	86	63	252	**1,096**
2002	3	1	1	2	**7**
2003	376	8	11	126	**521**
2004	1	0	0	1	**2**
2005	1,007	163	113	374	**1,657**
2006	601	63	47	215	**927**
2007	4	1	1	3	**9**
2008	665	79	58	240	**1,041**
24-year Avg.	435	56	43	156	**690**
High	1,056	175	121	393	**1,746**
Low	1	0	0	1	**2**
% of Total	63%	8%	6%	23%	**100%**

APPENDIX E
PERCOLATION OF PRECIPITATION SUPPORTING DATA



Precipitation vs. Deep Penetration Curves
(based on Blaney, 1963)

Table E1. Deep Percolation of Precipitation, 1985 through 2008

Water Year	RF (in)	Deep Penetration (in) (from Blaney Curves)		
		Grass/Weeds	Truck, Alfalfa, Misc	Deciduous
1985	15.26	0.00	2.98	1.09
1986	25.78	8.00	11.39	8.13
1987	11.99	0.00	0.37	0.00
1988	17.34	0.00	4.65	2.48
1989	10.27	0.00	0.00	0.00
1990	8.93	0.00	0.00	0.00
1991	20.11	1.60	6.86	4.33
1992	25.39	8.00	11.08	7.87
1993	37.45	8.00	15.00	15.00
1994	14.43	0.00	2.32	0.53
1995	41.59	8.00	15.00	15.00
1996	19.55	1.08	6.41	3.96
1997	18.07	0.00	5.23	2.97
1998	51.48	8.00	15.00	15.00
1999	9.99	0.00	0.00	0.00
2000	17.47	0.00	4.75	2.57
2001	20.43	1.89	7.12	4.55
2002	7.66	0.00	0.00	0.00
2003	21.97	3.31	8.35	5.58
2004	9.57	0.00	0.00	0.00
2005	37.56	8.00	15.00	15.00
2006	18.58	0.19	5.64	3.31
2007	7.11	0.00	0.00	0.00
2008	17.51	0.00	4.78	2.59
24-Year Avg.	20.23	2.34	5.91	4.58
High	51.48	8.00	15.00	15.00
Low	7.11	0.00	0.00	0.00
% of Total	--			

Table E2. Land Use Acreages in the Recharge Area, 1985 through 2008

Water Year	Acreage within the Recharge Area											
	Native	Irr. Orchard	Irr. Crops	Nurseries	Vacant	Residential	Commercial	Industrial	Public Parks, School	Polo Grounds	Roads, etc.	Total
1985	1,240	1,816	5	571	479	795	95	50	336	0	494	**5,880**
1986	1,217	1,780	7	569	525	797	96	50	341	0	497	**5,880**
1987	1,213	1,725	6	615	534	804	97	50	343	0	493	**5,880**
1988	1,191	1,676	6	631	568	808	97	50	356	0	496	**5,880**
1989	1,190	1,703	18	619	502	818	102	51	358	0	520	**5,880**
1990	1,158	1,695	43	632	487	831	103	51	360	0	521	**5,880**
1991	1,158	1,674	74	635	463	835	103	51	362	0	527	**5,880**
1992	1,160	1,667	63	633	480	838	101	51	367	0	519	**5,880**
1993	1,163	1,663	43	634	501	844	102	51	366	0	513	**5,880**
1994	1,158	1,638	78	621	511	850	104	51	361	0	508	**5,880**
1995	1,110	1,601	57	698	511	876	112	54	329	0	531	**5,880**
1996	1,108	1,592	70	702	502	878	112	54	329	0	532	**5,880**
1997	1,104	1,567	81	671	542	879	108	55	337	0	536	**5,880**
1998	1,102	1,561	100	654	540	884	108	56	337	0	538	**5,880**
1999	1,102	1,557	101	654	540	886	109	57	337	0	538	**5,880**
2000	1,222	1,538	95	616	456	874	109	57	298	29	585	**5,880**
2001	1,343	1,518	89	577	373	861	109	57	260	59	633	**5,880**
2002	1,463	1,498	84	539	290	849	109	57	222	88	681	**5,880**
2003	1,509	1,482	94	540	269	784	109	55	201	94	744	**5,880**
2004	1,509	1,482	94	540	269	784	109	55	201	94	744	**5,880**
2005	1,514	1,483	106	528	257	784	109	55	259	103	682	**5,880**
2006	1,514	1,483	106	528	257	784	109	55	259	103	682	**5,880**
2007	1,514	1,483	106	528	257	784	109	55	259	103	682	**5,880**
2008	1,396	1,373	95	530	230	761	106	53	238	238	990	**5,880**

Table E3. Deep Percolation of Precipitation, 1985 through 2008

Water Year	Deep Percolation (af)											Total
	Native	Irr. Orchard	Irr. Crops	Nurseries	Vacant	Residential	Commercial	Industrial	Parks, Schools, Et	Polo Grounds	Roads, Other	
1985	0	165	1	142	0	0	0	0	84	0	0	**391**
1986	811	1,206	6	540	350	532	64	33	324	0	331	**4,198**
1987	0	0	0	19	0	0	0	0	11	0	0	**30**
1988	0	347	2	244	0	0	0	0	138	0	0	**731**
1989	0	0	0	0	0	0	0	0	0	0	0	**0**
1990	0	0	0	0	0	0	0	0	0	0	0	**0**
1991	154	604	42	363	62	111	14	7	207	0	70	**1,634**
1992	774	1,093	59	585	320	559	67	34	339	0	346	**4,174**
1993	775	2,079	53	793	334	562	68	34	458	0	342	**5,499**
1994	0	73	15	120	0	0	0	0	70	0	0	**278**
1995	740	2,001	72	873	340	584	75	36	411	0	354	**5,487**
1996	100	525	37	375	45	79	10	5	176	0	48	**1,401**
1997	0	388	35	293	0	0	0	0	147	0	0	**862**
1998	735	1,951	125	817	360	590	72	37	421	0	358	**5,467**
1999	0	0	0	0	0	0	0	0	0	0	0	**0**
2000	0	329	38	244	0	0	0	0	118	12	0	**740**
2001	212	575	53	342	59	136	17	9	154	35	100	**1,692**
2002	0	0	0	0	0	0	0	0	0	0	0	**0**
2003	417	689	66	376	74	216	30	15	140	65	205	**2,293**
2004	0	0	0	0	0	0	0	0	0	0	0	**0**
2005	1,010	1,854	132	660	171	522	73	37	324	128	454	**5,366**
2006	24	409	50	248	4	12	2	1	122	48	11	**930**
2007	0	0	0	0	0	0	0	0	0	0	0	**0**
2008	0	297	38	211	0	0	0	0	95	95	0	**735**
24-Year Avg.	240	608	34	302	88	163	20	10	156	16	109	**1,746**
High	1,010	2,079	132	873	360	590	75	37	458	128	454	**5,499**
Low	0	0	0	0	0	0	0	0	0	0	0	**0**
% of Total	14	35	2	17	5	9	1	1	9	1	6	**100**

APPENDIX F
DEEP PERCOLATION OF IRRIGATION WATER SUPPORTING DATA

Table F1. Deep Percolation of Irrigation Water

Water Year	Total Irrigation (af)		Percolation of Irrigation Water (af)		
	Delivered	Pumped	Delivered	Pumped	Total
1985	292	949	58	190	248
1986	398	1,041	80	208	288
1987	450	932	90	186	276
1988	514	1,065	103	213	316
1989	579	1,520	116	304	420
1990	1,229	1,990	246	398	644
1991	828	2,261	166	452	618
1992	701	2,165	140	433	573
1993	887	2,422	177	484	662
1994	921	2,818	184	564	748
1995	812	2,389	162	478	640
1996	812	2,510	162	502	664
1997	960	2,437	192	487	679
1998	743	2,428	149	486	634
1999	1,461	2,990	292	598	890
2000	1,279	3,105	256	621	877
2001	1,026	3,259	205	652	857
2002	1,283	3,103	257	621	877
2003	1,227	2,723	245	545	790
2004	1,386	2,803	277	561	838
2005	1,447	2,060	289	412	701
2006	1,581	2,083	316	417	733
2007	2,048	2,507	410	501	911
2008	1,583	2,806	317	561	878
24-Year Avg.	1,019	2,265	204	453	657
High	2,048	3,259	410	652	911
Low	292	932	58	186	248

APPENDIX B

TASK 2 GROUNDWATER MODEL DEVELOPMENT TECHNICAL MEMORANDUM

Carpinteria Valley
Groundwater Model Development

Prepared for:
Pueblo Water Resources

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ABBREVIATIONS

amsl	above mean sea level
afy	acre-feet per year
ASR	Aquifer Storage and Recovery
DEM	digital elevation model
GHB	MODFLOW General Head Boundary Package
GIS	Geographical Information System
gpm	gallons per minute
HFB	MODFLOW Horizontal Flow Barrier Package
LPF	MODFLOW Layer Property Flow Package
MNW2	MODFLOW Multi-Node Well Package
Msl	mean sea level
RIV	MODFLOW River Package
SVD	Singular Value Decomposition
TIN	Triangular Irregular Network
UPW	MODFLOW-NWT Upstream-Weighting Package
WEL	MODFLOW Well Package

EXECUTIVE SUMMARY

A numerical groundwater flow model for the Carpinteria Groundwater Basin is developed to provide general guidance on predicted impacts of projected groundwater extractions and various alternative management scenarios. The model is based on the conceptual model developed by Pueblo Water Resources Inc. (PWR Inc., 2011).

The Carpinteria Groundwater Basin flow model (model) is implemented using MODFLOW-NWT (Niswonger et al., 2011). The model's finite difference grid uses a uniform grid spacing of 300 feet to cover the Carpinteria Basin extent of approximately 36 square miles. The model consists of seven model layers, with all seven layers active in Storage Unit 1 and only three layers active in Storage Unit 2. Model layer elevations are based on contours of the tops and bottoms of A, B, and C aquifers, and bedrock provided by PWR Inc. (2011).

The model implements the following boundary conditions:

- No-flow cells and boundary representing the basin boundary and bedrock,
- General head boundary representing the Pacific Ocean,
- Injection wells representing mountain front subsurface inflow, and
- Horizontal flow barrier and quasi-3D confining bed representing the Rincon Creek Fault.

The annual water budget provided by PWR Inc. (2011) is implemented using annual stress periods using the MODFLOW recharge and well packages. The recharge package is used to define percolation of precipitation, percolation of irrigation water, streambed percolation, and extraction by phreatophytes. The well package is used to define subsurface inflow at the northern boundary and the multi-node well package is used to simulate extraction by groundwater pumping.

The model was calibrated to groundwater level data for Water Years 1985 to 2008 by varying the following parameters:

- Horizontal hydraulic conductivity,
- Vertical hydraulic conductivity using vertical anisotropy,
- Specific storage, and

- Rincon Creek Fault conductance using horizontal flow barrier hydraulic characteristic and quasi-3D confining bed hydraulic conductivity.

A pilot point approach and regularization was used to smoothly distribute hydraulic conductivity and specific storage over each layer. Prior information from pumping test estimates for horizontal hydraulic conductivity was also used to constrain calibration. Based on graphical and statistical evaluations, the model is calibrated for the purpose of providing general guidance on impacts of different groundwater management scenarios in Storage Unit 1. However, Storage Unit 2 is not as well calibrated as Storage Unit 1 and will need further refinement.

The calibrated model was used to estimate the effects of five general water management strategies and scenarios, including:

- Scenario 1: Pumping during an extended drought,
- Scenario 2: Pumping to meet increased water demands,
- Scenario 3: Implementing Aquifer Storage and Recovery (ASR),
- Scenario 4: Adding supplemental wells to the Carpinteria Valley Water District's existing well field, and
- Scenario 5: Recharging additional water through stream beds.

Simulation of Scenario 1 results in extremely low groundwater levels during a period of extended drought and a lack of recovery after the drought ends.

Simulation of Scenario 2 results in a significant decrease in groundwater levels throughout the basin as a result of increased pumping demands.

Simulation of Scenario 3 results in a subtle basin-wide groundwater level increase due to increased recharge from ASR.

Simulation of Scenario 4 results in no significant effect from adding supplemental wells on District wells with the only noticeable improvement occurring during drought years.

Simulation of Scenario 5 results in higher groundwater levels during periods of normal rainfall and recharge, but little effect during drought periods from recharging additional water through stream beds.

Recommendations for further model development are included if more detailed evaluation of groundwater management scenarios is required. These recommendations include:

- Implement quarterly stress periods to represent seasonal variation,
- Refine conceptual model and water budget for Storage Unit 2,
- Implement stream routing package for stream percolation from creeks,
- Evaluate effect of pumping constraints in model-node well package on simulation results, and
- Perform uncertainty analysis on calibrated model.

SECTION 1
INTRODUCTION

1.1 SCOPE AND PURPOSE

The purpose of this project is to develop a numerical groundwater flow model of the Carpinteria Groundwater Basin with sufficient details and features to provide general guidance on predicted impacts of projected groundwater extractions and various alternative management scenarios for the groundwater basin.

1.2 AVAILABLE DATA

The numerical model is based on the conceptual model of the basin developed by Pueblo Water Resources Inc. (PWR Inc., 2011). Data provided by PWR Inc. from the conceptual model included:

- Outline of the basin boundary;
- Contours for the top and bottom of Aquifers A, B, and C, and top of bedrock;
- Locations of boundary conditions such as the ocean and Rincon Creek Fault;
- Water budget estimates including percolation of precipitation, percolation of irrigation water, streambed percolation, mountain front subsurface inflow, groundwater pumping, and extraction by phreatophytes;
- Watershed contact boundaries for mountain front subsurface inflow;
- Pumping well data including production and screen intervals;
- Pumping test estimates of hydraulic conductivity; and
- Groundwater level data for calibration.

Other data used for the model included the 10 meter digital elevation model (DEM) used to define surface elevations (Gesch, 2007 and Gesch et al., 2002).

SECTION 2
NUMERICAL FLOW MODEL CONSTRUCTION

Numerical flow model construction consists of selecting a model code, defining the structure of the model, and incorporating data from the conceptual model. Defining the model structure includes defining the model domain, constructing a model grid, and delineating model layers. Incorporating the conceptual model includes assigning boundary conditions, assigning hydrogeologic parameters, and incorporating components of the water balance. The recharge fluxes and discharge fluxes in the water balance are expressed in the model through areal recharge rates, well pumping rates, and flow rates across model boundaries.

2.1 MODEL CODE

The model code MODFLOW-NWT (Niswonger et al., 2011) was selected for the Carpinteria Groundwater Basin flow model (model). MODFLOW-NWT was developed by the U.S. Geological Survey as a standalone version of MODFLOW-2005 (Harbaugh, 2005) to better solve nonlinearities of the unconfined groundwater flow equation. MODFLOW-2005 was used for initial model development and calibration, but model results showed difficulties converging on a solution for drying and rewetting cells that represent a fluctuating groundwater table. The use of the Upstream-Weighting (UPW) package in MODFLOW-NWT addressed this issue. The U.S. Geological Survey's MODFLOW codes are an industry standard and well documented.

2.2 MODEL DOMAIN

The model domain is based on the Carpinteria basin extent (Figure 1) defined in the conceptual model (Pueblo Water Resources Inc., 2011). The model domain covers approximately 36 square miles.

2.3 FINITE DIFFERENCE GRID

Figure 1 shows the finite difference model grid on which the numerical model is built. The grid comprises 72 rows and 156 columns. A uniform grid spacing of 300 feet is used.

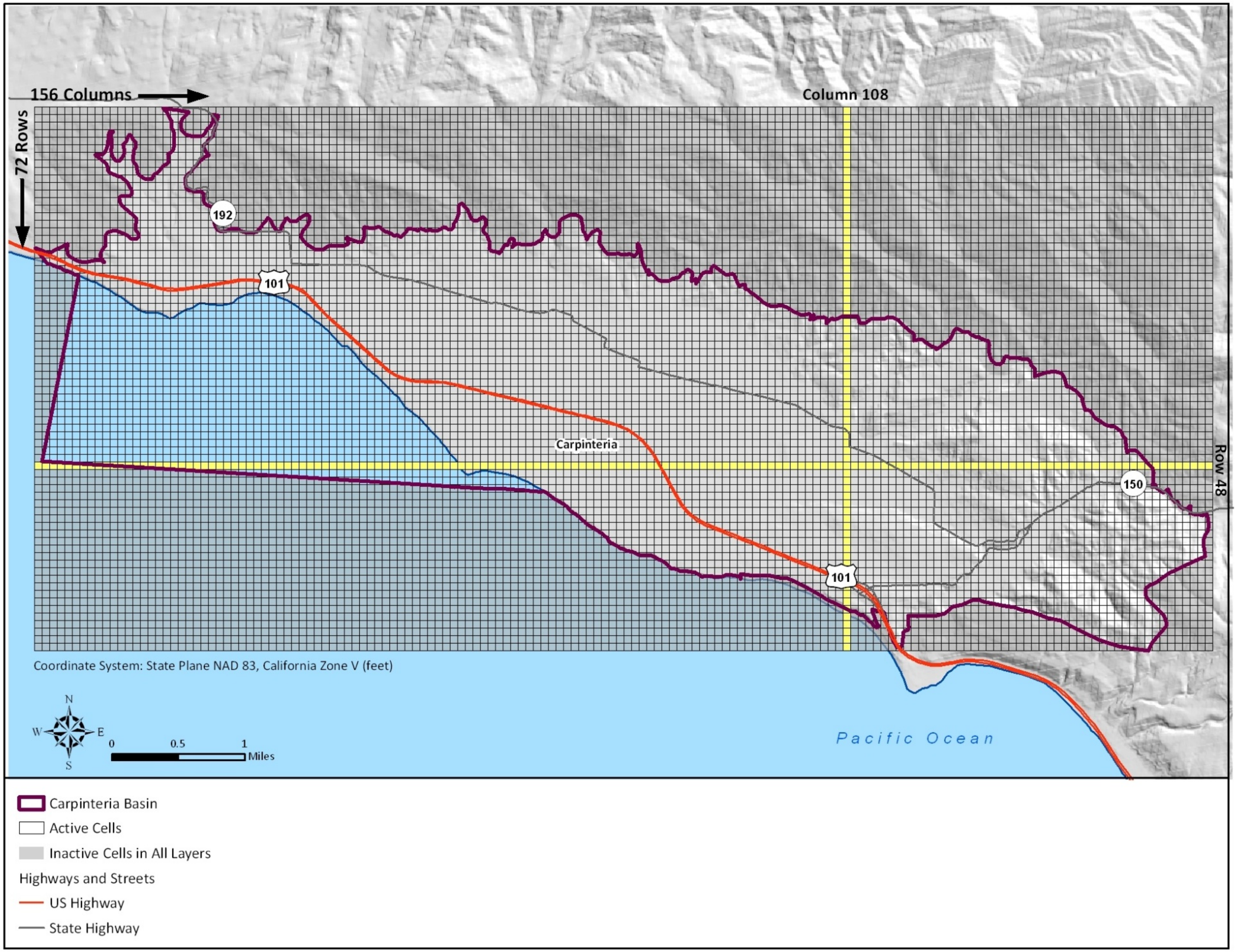


Figure 1: Finite Difference Model Grid

2.4 MODEL LAYERS

The model consists of seven layers. All seven layers are active for Storage Unit 1 north of the Rincon Creek fault, while only three layers are active for Storage Unit 2 south of the Rincon Creek fault.

Geographical Information System (GIS) shapefiles provided by Pueblo Water Resources Inc. (PWR Inc.) included contours for the top and bottom of the A, B, and C aquifers in Storage Unit 1; and the top of bedrock in both Storage Units 1 and 2. The contours did not cover the entire active portion of the model; therefore we extrapolated the contours based on various assumptions. The model layers were developed starting from the lowest layer and working upwards. The process for developing the layers in each storage unit is described below. Figure 2 through Figure 4 show the relative vertical position of model layers and aquifers.

2.4.1 STORAGE UNIT 1

We developed Storage Unit 1 model layers by first extrapolating the contours provided by PWR Inc. to cover the entire model domain, and second ensuring that model layers did not intersect each other.

The aquifer tops and bottoms were extrapolated by adding an estimated contour to each surface just outside the active model area. This new contour was assigned an elevation that extended the gradient measured in the outermost contours provided by PWR Inc. Some of the provided contours were lengthened, keeping the same gradient between original contours, to reach the model boundaries. Once the contours had been extrapolated, a triangular irregular network (TIN) was produced from the contours to define elevations at the center of each model cell. Elevations for the seven model layers (Figure 2) were derived as follows:

- The bottom of the lowermost layer of the model (Layer 7) was assigned elevations from the top of bedrock contours.
- Bottom of Layer 6 elevations were obtained from bottom of Aquifer C contours.
- Bottom of Layer 5 elevations were obtained from top of Aquifer C contours.
- Bottom of Layer 4 elevations were obtained from bottom of Aquifer B contours.

- Bottom of Layer 3 elevations were obtained from top of Aquifer B contours.
- Bottom of Layer 2 elevations were obtained from bottom of Aquifer A contours.
- Bottom of Layer 1 elevations were obtained from top of Aquifer A contours.
- Top of Layer 1 elevations were obtained from a 10 meter digital elevation model (DEM).

The model layer elevations were checked for layer intersections. Bedrock elevations were higher than the ground surface elevation in places along the northern basin boundary where the bedrock contour had little or no geologic control. A geologic map was used to check whether bedrock outcropped in these areas. If bedrock did not outcrop, the elevation of the bottom of the model was lowered to an elevation that ensured a minimum of 10 foot thickness and a smooth transition with adjacent cells. For areas where bedrock did outcrop, model cells in all layers were made inactive.

Where the top of a model layer intersected bedrock, the geologic layer was assumed to pinch out against the edge of the bowl-like structure of the bedrock. Cells were outside of the bedrock boundary were made inactive (Figure 2). Bottom elevations of active cells overlying bedrock were made equivalent to bedrock elevations. All extrapolated geologic surfaces were adjusted so that they did not overlap, the model layer thickness was a minimum of 10 feet, and there was a smooth transition between the adjusted elevations and adjacent cells.

There is only one layer active along the northern boundary (Figure 2). The active layer in these areas is the highest layer to intersect the bedrock in the approach to the model boundary. In El Toro Canyon in the northwest, the only active layer is Layer 6. In a short distance moving east along the northern boundary, the model transitions to L 1 as the only active layer along most of the northern boundary. There is another transition to L 6 being the only layer at the northeast of the model. These thin layers serve as a shelf that can transmit recharge to the deeper parts of the model. The layers step down southwards to the area where L 7 intersects the bedrock boundary and becomes active (Figure 4).

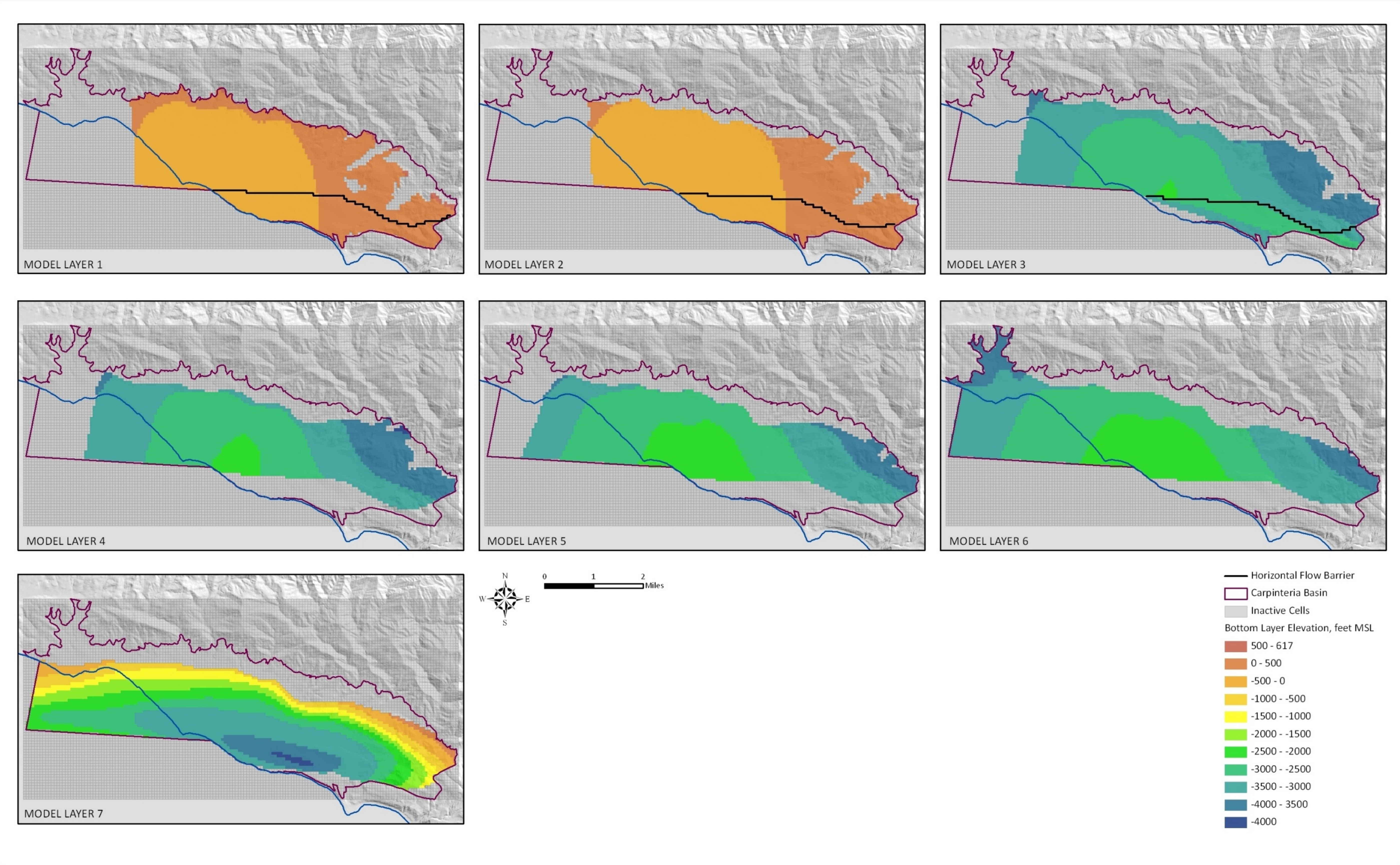


Figure 2: Model Bottom Layer Elevations

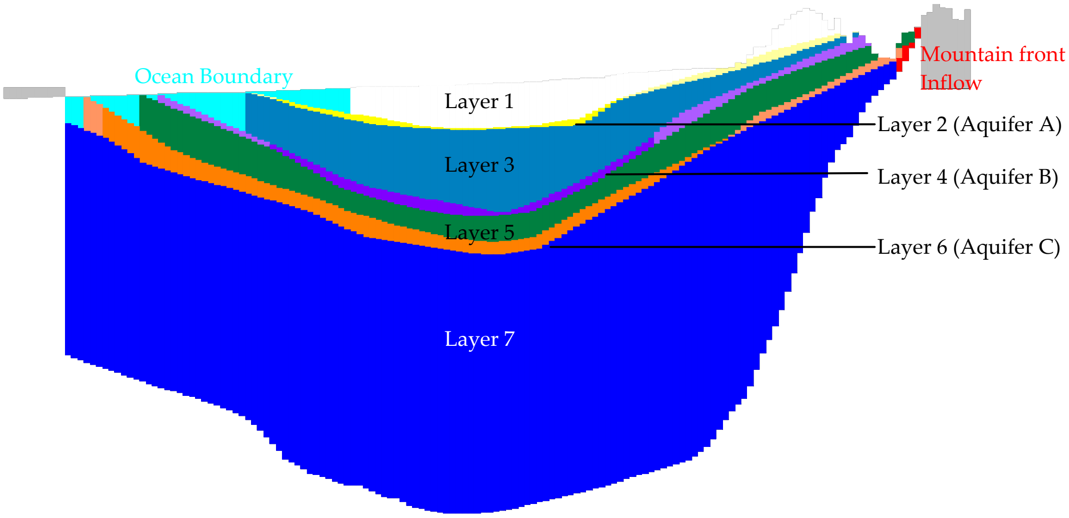


Figure 3: West-East Cross-Section (6x Vertical Exaggeration) Along Row 48 (Approximately A-A' in PWR Inc., 2011)

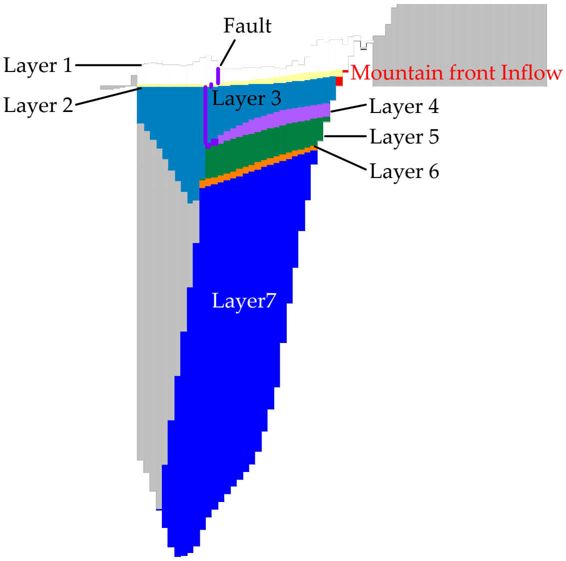


Figure 4: South-North Cross-section (6x Vertical Exaggeration) Along Column 108 through Well 27F2 (Approximately D-D' in PWR Inc., 2011)

2.4.2 STORAGE UNIT 2

Storage Unit 2, south of the Rincon Creek fault, was modeled with three model layers. The uppermost layer simulates the shallow sediments, most similar to Layer 1 in Storage Unit 1. The second layer simulates the Carpinteria Formation, most similar to Layer 2 in Storage Unit 1. The lowest model layer simulates the Santa Barbara Formation, and was assumed to be most similar to Layer 7 seven in Storage Unit 1.

The lowest layer in Storage Unit 2 (Layer 3) was assigned bottom elevations from the top of bedrock contours developed by PWR Inc. (2011). The bottom elevations of Layer 1 and Layer 2 were assigned the bottom elevation of Layer 1 and Layer 2 just north of the Rincon Creek Fault. These elevations were maintained horizontally south from the Rincon Creek along model columns.

The Rincon Fault was simulated as a dipping at approximately 50˚ from horizontal. The dipping fault acts as the separator between Storage Unit 1 and Storage Unit 2, and allows Storage Unit 1 Layer to occur at depth below Storage Unit 2 (Figure 5). This is consistent with PWR Inc.'s cross-sections (2011). Due to the thickness of Layer 7 (~2,000 feet), the layer underlies all of Unit 2 this is consistent with PWR Inc's cross-sections C and D, which show the toe of the Santa Barbara Formation between 3,000 and 4,000 feet horizontally distant from the ground surface trace of the Rincon Fault (PWR Inc., 2011).

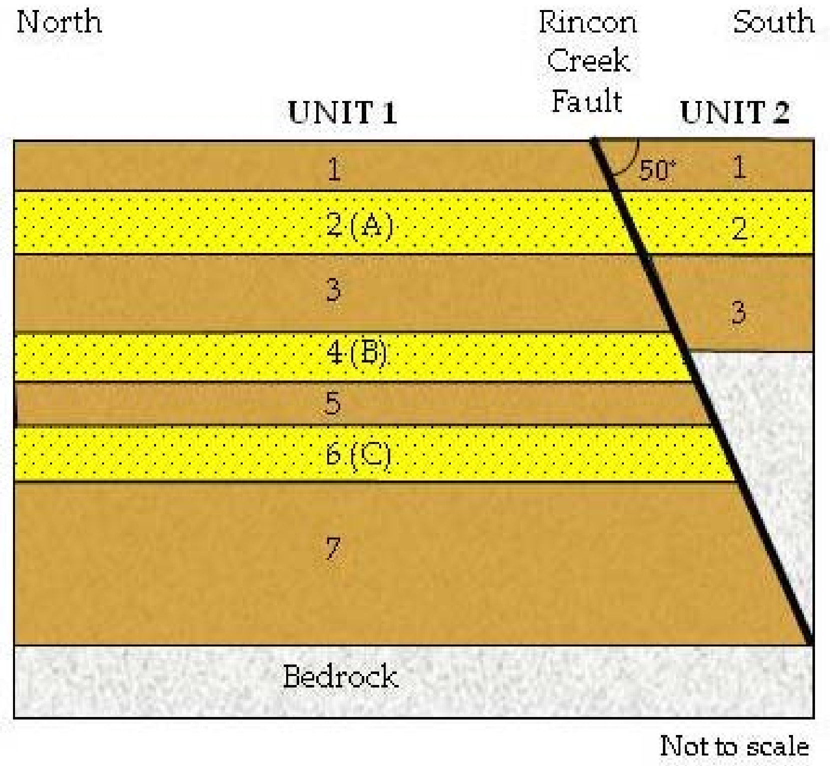


Figure 5: Schematic Cross-Section through Storage Units 1 and 2 (model layers are numbered and aquifers are lettered)

2.5 BOUNDARY CONDITIONS

2.5.1 NO-FLOW CELLS

Model cells are made inactive by designating them as no-flow cells. The extent of no-flow cells in each layer is shown on Figure 6. No-flow cells are designated for one of three reasons:

1. The cell is outside the basin boundary based on the latest geologic mapping (PWR Inc., 2011)
2. The cell has an extrapolated top elevation below bedrock, i.e. the model layer is pinched out; and
3. The cell is adjacent to no-flow cells such that the cell was isolated from the rest of the model so the cell was designated as no-flow.

The bottom boundary representing bedrock is also designated a no-flow boundary.

2.5.2 OCEAN GENERAL HEAD BOUNDARY

Groundwater may flow into or out of the Pacific Ocean in the southwestern portion of the model. The ocean boundary is simulated using MODFLOW's General Head Boundary (GHB) package (Harbaugh, 2005). The GHB package assigns a known groundwater elevation to the model boundary at a specified distance from the model boundary. In this model, the specified distance is used to represent the thickness of the seabed as the ocean overlies outcropping model layers (Figure 3).

The general head boundary condition is assigned to the top active cells directly underlying the Pacific Ocean. These general head boundary cells occur in Layers 1 through 6 due to the way shallow layers outcrop at the surface. At the model's western boundary, the ocean boundary occurs in Layer 6 and the boundary moves to shallower layers to the east (Figure 6). All GHB cells are assigned a reference head of 0 feet msl, representing average sea level, No correction for seawater density was included, but it could be incorporated in future model modifications. All GHG cells are assigned a conductance of 90,000 square feet per day. This conductance is equivalent to a seabed hydraulic conductivity of 1 foot per day and thickness of 1 foot for the cells with length and width dimensions of 300 feet each. These conductance values are reasonable estimates, and were not modified during calibration.

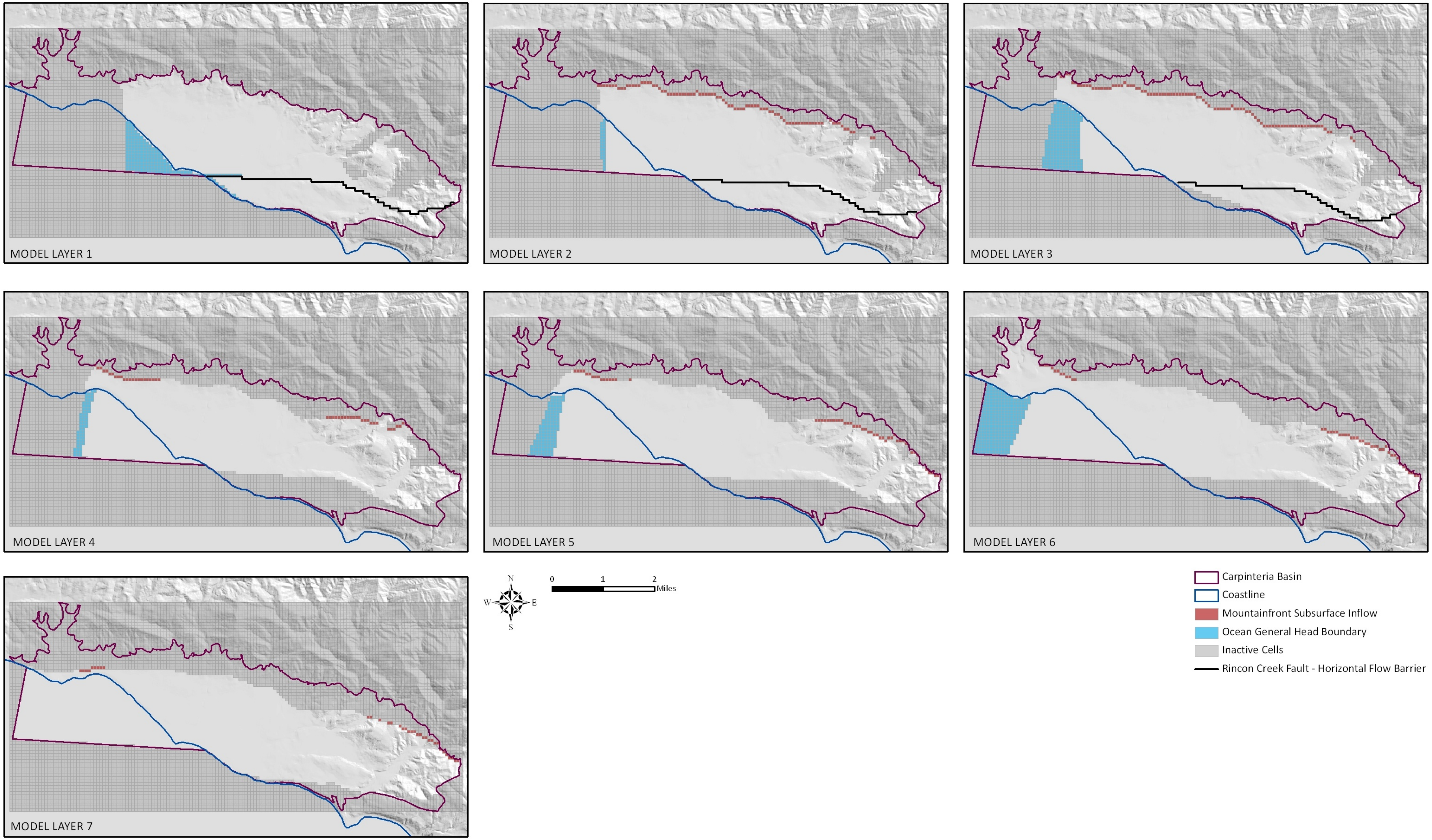


Figure 6: Model Boundary Conditions

2.5.3 MOUNTAIN FRONT SUBSURFACE INFLOW

Subsurface inflow from the mountain front is represented as defined fluxes using MODFLOW's well (WEL) package (Harbaugh, 2005). The flux is added using injection wells which are located in cells adjacent to the northern bedrock from just east of El Toro Canyon to the eastern boundary of the model. The top of the injection wells are located in Layer 2; and the wells extend down to a depth of 500 feet (Figure 6). The injection wells were removed from Layer 1 because parts of Layer 1 dried out during initial simulations using MODFLOW-2005.

2.5.4 RINCON CREEK FAULT

The Rincon Creek Fault separates Storage Units 1 and 2. The fault has an approximately 50° from horizontal southward dip. As a result, both horizontal and vertical barriers to flow are implemented in the model. MODFLOW's horizontal flow barrier (HFB) package (Harbaugh, 2005) is used to add barriers to horizontal flow between Storage Units 1 and 2. To represent the southward dip, the HFB barriers occur farther south for deeper layers (Figure 7). A hydraulic characteristic representing hydraulic conductivity divided by barrier thickness is assigned to each barrier. The barrier thickness is assumed to be 1 foot and the hydraulic conductivity of the HFB barrier was adjusted during calibration.

The barrier to vertical flow between the underlying Storage Unit 1 and the overlying Storage Unit 2 was implemented using the quasi-3D confining bed option in MODFLOW's Layer-Property Flow (LPF) package (Harbaugh, 2005). The quasi-3D confining bed option implements a semi-confining layer underneath a layer. This semi-confining layer is assigned a vertical hydraulic conductivity and thickness that provide resistance to flow between the layer and the underlying layer. The thickness of the semi-confining layer is assigned as 1 foot and the vertical hydraulic conductivity was adjusted during calibration.

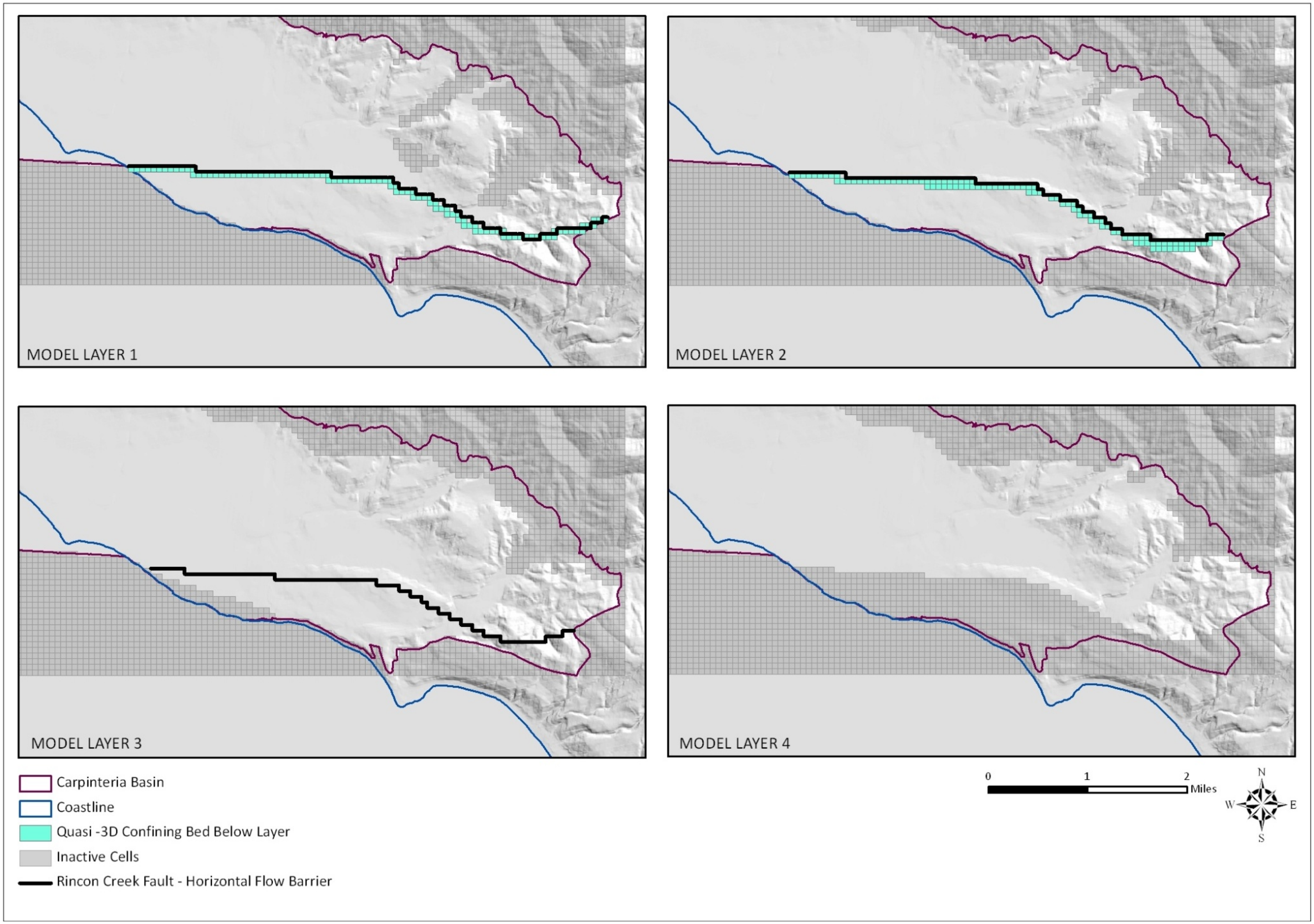


Figure 7: Horizontal Flow Barriers and Quasi-3D Confining Bed Option Representing Rincon Creek Fault

2.6 MODEL WATER BUDGET

The annual water budget developed for the conceptual model (PWR Inc., 2011) is implemented in the regional groundwater model using MODFLOW recharge, well, and multi-node well packages with annual stress periods (Table 1). The confined area deep percolation from precipitation that is shown on Table 1 is less than the corresponding values in the conceptual model. This reduction in confined area recharge was implemented during calibration to better match the measured groundwater elevations.

The recharge (RCH) package is used to define percolation of precipitation, percolation of irrigation water, streambed percolation, and extraction by phreatophytes. The well (WEL) package is used to define subsurface inflow at the northern boundary. The multi-node well (MNW2) package is used to simulate extraction by groundwater pumping. Flows to and from the ocean boundary are calculated by the model.

2.6.1 RECHARGE PACKAGE

The MODFLOW recharge package adds a specified amount of water to the model's top active layer. Twelve recharge zones are defined for the model (Figure 8). Each zone represents a combination of recharge components that occur in the cells making up the zone. For example, cells with streambed percolation also have extraction by phreatophytes from the stream as well as percolation of precipitation and irrigation water because the stream does not cover the entire cell. Table 2 shows the combinations of recharge components assigned to each zone. The sum of the recharge components for a cell in each zone is divided by the uniform cell area of 90,000 square feet to calculate recharge in feet per day for input in the recharge package. Individual recharge components are discussed below.

Table 1: Annual Water Budget Implemented in Model (acre-feet)

MODFLOW Package	**Recharge**					**Well**	**Total Inflow**	**Recharge**	**Multi-Node Well**		**Total Outflow**
	Unconfined Area				**Confined Area**						
	Deep Percolation from Precipitation	**Deep Percolation from Irrigation Water**		**Streambed Percolation**	**Deep Percolation from Precipitation**	**Mountain-front Subsurface Inflow**		**Extraction by Phreato-phytes**	**Groundwater Pumpage**		
Water Year		**Delivered**	**Pumped**						**CVW**	**Private**	
1985	391	58	190	57	121	869	1,687	100	1,836	949	2,901
1986	4,198	80	208	866	1,300	1,100	7,752	100	2,032	1,041	3,173
1987	30	90	186	91	9	683	1,089	100	2,363	932	3,395
1988	731	103	213	112	226	988	2,374	100	2,342	1,065	3,507
1989	0	116	304	26	0	585	1,031	100	2,984	1,520	4,604
1990	0	246	398	4	0	509	1,157	100	3,413	1,990	5,503
1991	1,634	166	452	758	506	1,100	4,616	100	3,014	2,261	5,375
1992	4,174	140	433	1,026	1,293	1,100	8,166	100	1,560	2,165	3,825
1993	5,499	177	484	1,434	1,703	1,100	10,398	100	1,261	2,422	3,783
1994	278	184	564	352	86	822	2,286	100	1,307	2,818	4,225
1995	5,487	162	478	1,746	1,699	1,100	10,672	100	1,291	2,389	3,793
1996	1,401	162	502	894	434	1,100	4,493	100	1,557	2,510	4,188
1997	862	192	487	958	267	1,030	3,796	100	1,317	2,437	3,873
1998	5,467	149	486	1,744	1,693	1,100	10,638	100	575	2,428	3,129
1999	0	292	598	434	0	569	1,893	100	340	2,990	3,446
2000	740	256	621	789	229	995	3,630	100	1,410	3,105	4,652
2001	1,692	205	652	1,096	524	1,100	5,269	100	185	3,259	3,560
2002	0	257	621	7	0	436	1,320	100	558	3,103	3,780
2003	2,293	245	545	521	710	1,100	5,415	100	402	2,723	3,235
2004	0	277	561	2	0	545	1,385	100	999	2,803	3,930
2005	5,366	289	412	1,657	1,662	1,100	10,487	100	1,152	2,060	3,312
2006	930	316	417	927	288	1,059	3,935	100	1,120	2,083	3,302
2007	0	410	501	9	0	405	1,325	100	1,418	2,507	4,025
2008	735	317	561	1,041	327	998	3,979	100	661	2,806	3,567

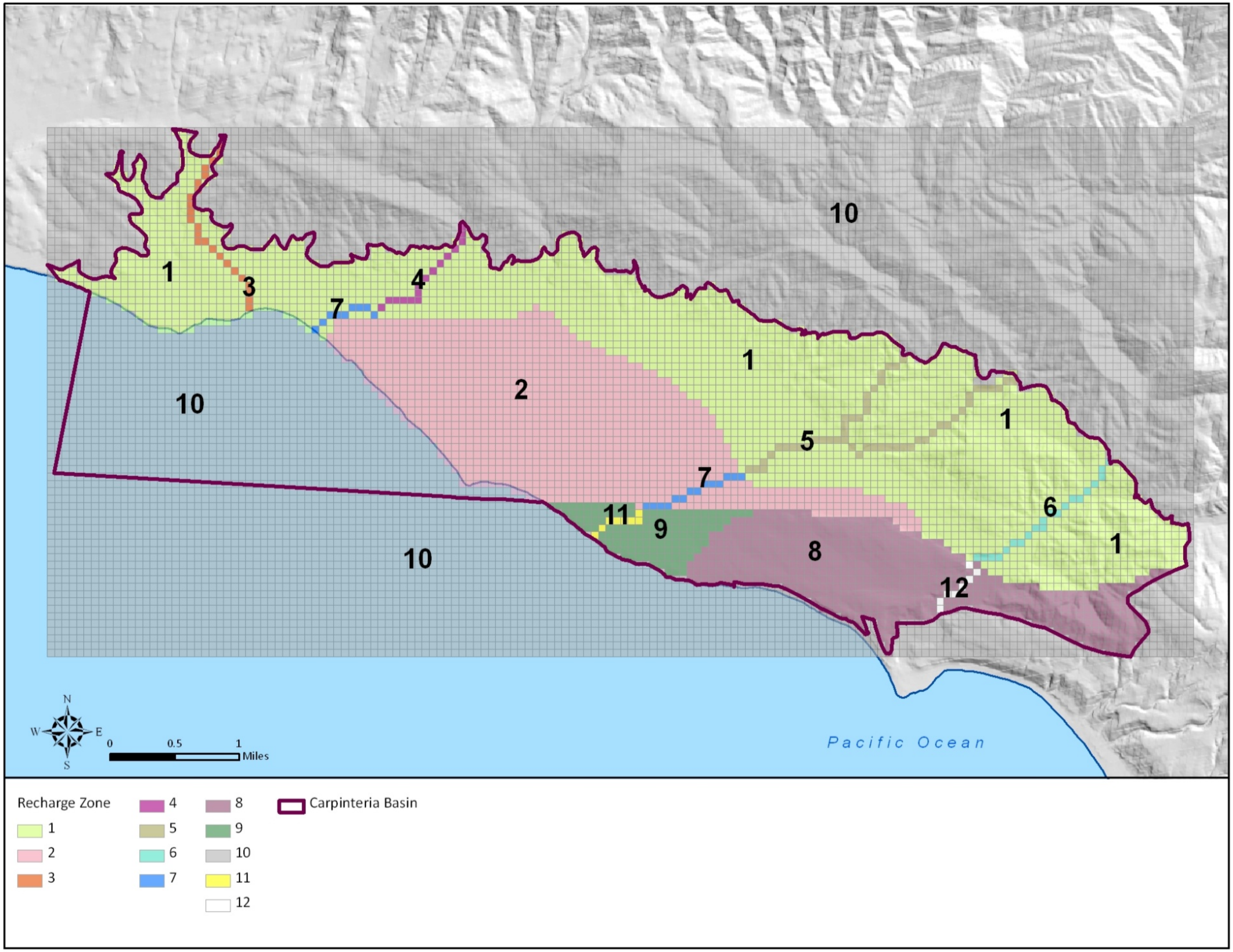


Figure 8: Recharge Zones

Table 2: Recharge Components Assigned to Zones

Recharge Zone	Number of Cells	Storage Unit 1 Percolation				Storage Unit 2 Percolation				Streams				
		Unconfined Area Precipitation	Irrigation Water		Confined Area Precipitation	Unconfined Area Precipitation	Irrigation Water		Confined Area Precipitation	El Toro Canyon	Arroyo Parida	Carpinteria-Gobernador	Rincon	Extraction by Phreato-phytes
			Delivered	Pumped			Delivered	Pumped						
1	2,231	X	X	X										
2	1,051				X									
3	24	X	X	X						X				X
4	16	X	X	X							X			X
5	53	X	X	X								X		X
6	21	X	X	X									X	X
7	23				X									X
8	571					X	X	X						
9	134								X					
10	7,092	Inactive Cells												
11	8								X					X
12	8					X	X	X					X	X

UNCONFINED AREA DEEP PERCOLATION FROM PRECIPITATION

Annual deep recharge of precipitation in the unconfined area (Figure 8) is summarized in Table 1. The annual recharge value is used to calculate areal recharge based on the number of cells in the unconfined area in Storage Unit 1 (2,345 cells) and Storage Unit 2 (579 cells) with a uniform cell size of 90,000 square feet. Based on falling hydrographs from wells in Storage Unit 2, less areal recharge from precipitation is assigned to Storage Unit 2 than Storage Unit 1. The deep percolation from precipitation that was removed from Storage Unit 2 was added to Storage Unit 1, so that the combined annual deep recharge in the unconfined areas of Storage Unit 1 and Storage Unit 2 is consistent with the conceptual model (PWR Inc., 2011). After moving percolation from Storage Unit 2 to Storage Unit 1, deep percolation from precipitation in Storage Unit 1 is approximately 25 times greater than the deep percolation from precipitation in Storage Unit 2 in the unconfined area. The areal recharge from precipitation in feet per day is added to zone totals for the recharge package.

PERCOLATION OF IRRIGATION RETURN WATER

Percolation of irrigation return water occurs over the unconfined area and does not occur in the confined area (Figure 8). The annual recharge values for pumped and delivered water are combined and used to calculate areal recharge based on the number of cells in the unconfined area in Storage Unit 1 (2,345 cells) and Storage Unit 2 (549 cells) with a the uniform cell size of 90,000 square feet. Based on hydrographs from wells in Storage Unit 2, less recharge is assumed for Storage Unit 2 than Storage Unit 1. The total recharge of irrigation return flow is distributed between Storage Unit 1 and Storage Unit 2 such that areal recharge from return flow in Storage Unit 1 is approximately 25 times the areal recharge from return flow in Storage Unit 2. The areal recharge from return flow in feet per day is added to zone totals for the recharge package.

CONFINED AREA DEEP PERCOLATION OF PRECIPITATION

Although recharge from confined area precipitation was not included in the original conceptual model, it is important to add it into the numerical model. The original conceptual model balances for all groundwater in the basin regardless of location: the groundwater model must account for water at every unique location in the model. Therefore, even small amounts of recharge from precipitation in the confined area should be accurately modeled. As discussed in the model results section of this report, much of the precipitation that infiltrates into the confined zone likely flows out to the ocean rather than percolate into deeper aquifer layers.

Annual deep recharge of precipitation in the confined area (Figure 8) is summarized in Table 1. As discussed above, hydrographs from wells in Storage Unit 2 suggested that less recharge from precipitation be assigned to Storage Unit 2 than Storage Unit 1. Deep percolation from precipitation in the confined area in Storage Unit 1 is consistent with initial estimates developed by PWR Inc. (2011). Deep percolation from precipitation in the confined area of Storage Unit 2 is reduced from the initial estimates. Unlike deep percolation in the unconfined zone, the reduction in confined zone deep percolation in Storage Unit 2 was not added to Storage Unit 1. This is because there is no total confined zone recharge number in the conceptual model that we needed to match. Areal recharge is based on the number of cells in the confined area in Storage Unit 1 (1,074 cells) and Storage Unit 2 (142 cells) with a uniform cell size of 90,000 square feet. The areal recharge in feet per day is added to zone totals for the recharge package.

STREAMBED PERCOLATION

Streambed percolation occurs below portions of El Toro Canyon Creek, Arroyo Parida, Carpinteria Creek, Gobernador Creek, and Rincon Creek within the unconfined area of the basin. Portions of all creeks occur in Storage Unit 1, while only Rincon Creek is in Storage Unit 2. Santa Monica and Franklin Creeks are concrete-lined from the bedrock boundary to El Estero and do not contribute recharge to the basin. Streambed percolation was added to the recharge package to ensure that the defined flux was added to the highest active layer.

Table 1 shows the annual streambed percolation for each creek system provided by PWR Inc. (2011). The annual percolation is divided by the number of cells in the unlined portion of each creek system and uniform cell area of 90,000 square feet to calculate the amount of stream percolation in feet per day to add to zone totals for the recharge package.

EXTRACTION BY PHREATOPHYTES

Table 1summarizes the annual estimates for extraction of water by phreatophytes along stream channels. This water budget component is applied to the 153 cells underlying lined and unlined portions of the El Toro Canyon Creek, Arroyo Parida, Carpinteria Creek, Gobernador Creek, and Rincon Creek. The annual extraction is divided by the number of these cells and uniform cell area of 90,000 square feet to calculate the amount of extraction by phreatophytes in feet per day to subtract to zone totals for the recharge package.

Table 3: Annual Streambed Percolation (acre-feet)

Number of Cells	24	16	53	29
Water Year	**El Toro Canyon**	**Arroyo Parida**	**Carpinteria-Gobernador**	**Rincon**
1985	5	5	26	20
1986	55	42	567	201
1987	12	13	62	3
1988	15	16	74	8
1989	2	3	12	9
1990	0	0	2	2
1991	40	32	508	178
1992	77	56	656	236
1993	133	93	883	325
1994	41	43	207	60
1995	175	121	1,056	393
1996	59	45	583	208
1997	68	50	618	221
1998	175	121	1,055	393
1999	50	53	252	78
2000	44	35	525	185
2001	86	63	695	252
2002	1	1	3	2
2003	8	11	376	126
2004	0	0	1	1
2005	163	113	1,007	374
2006	63	47	601	215
2007	1	1	4	3
2008	79	58	665	240

2.6.2 WELL PACKAGE

MOUNTAIN FRONT SUBSURFACE INFLOW

As discussed in Section 2.5.3, mountain front subsurface inflow at the northern boundary is implemented using specified flow cells in the MODFLOW well (WEL) package. This package specifies the injection rate for specific cells for each stress period. The total annual mountain front subsurface inflow shown in Table 1 is areally distributed based on the area of the watersheds contributing inflow (Figure 9) (PWR Inc., 2011). Inflow from each watershed is distributed equally across the watershed contact. For each model row and column that receives mountain front recharge, the inflow is distributed vertically proportional to thickness of layers between Layer 2 and the deepest layer that is above a depth of 500 feet. The resulting inflow for each cell in cubic feet per day is added for each annual stress period to the well package file.

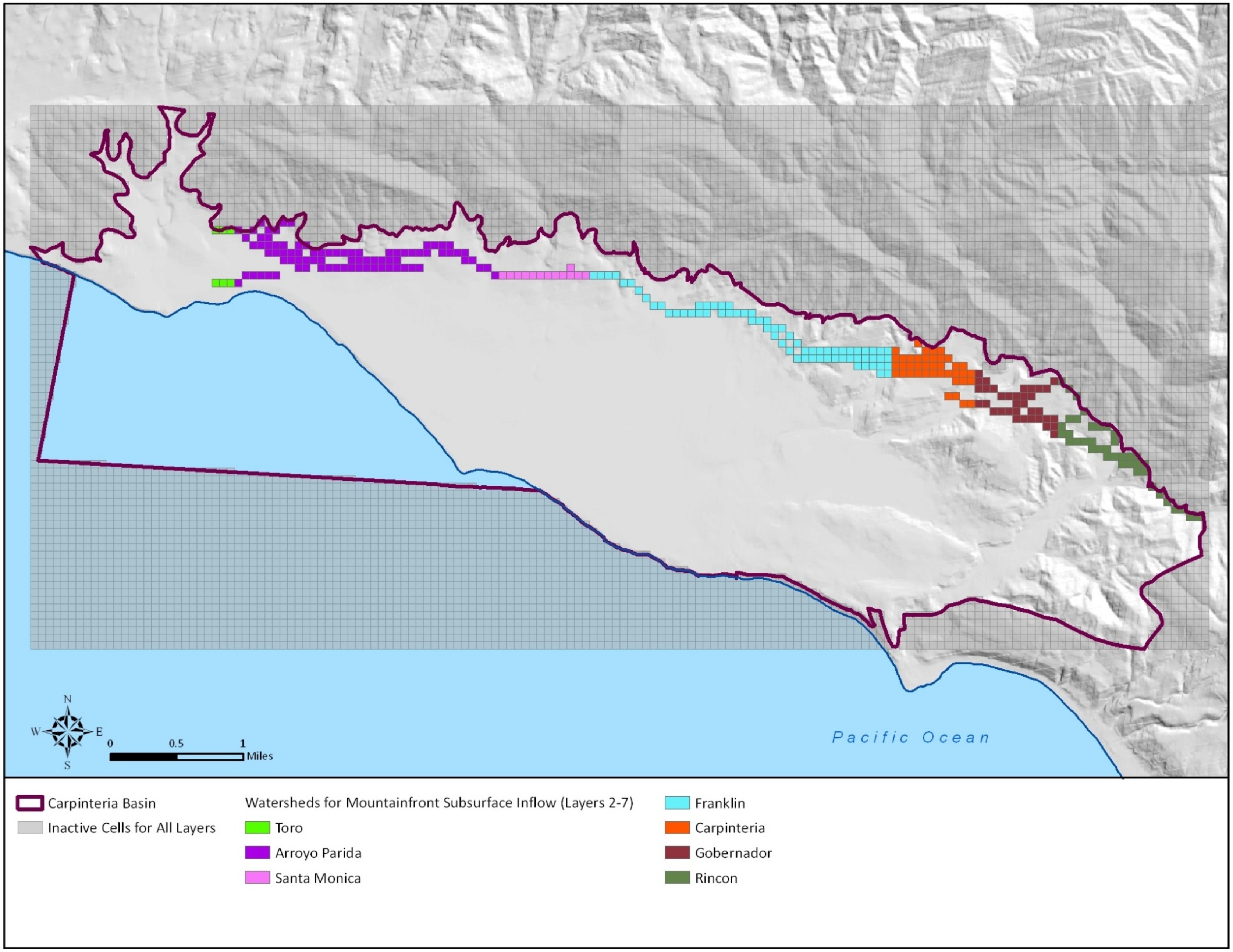


Figure 9: Mountainfront Subsurface Inflow Watersheds

Table 4: Watershed Areas and Contact Boundaries

Watershed	Area	% Total	West Model Column	East Model Column	Number of Columns
El Toro Canyon	1,587	7.1%	25	27	3
Arroyo Parida	2,027	9.1%	28	62	35
Santa Monica	2,220	9.9%	63	74	12
Franklin	2,135	9.6%	75	114	40
Carpinteria	3,046	13.6%	115	125	11
Gobernador	4,465	20.0%	126	136	11
Rincon	6,865	30.7%	137	155	19

2.6.3 MULTI-NODE WELL PACKAGE

GROUNDWATER PRODUCTION

The multi-node well package was used to simulate both municipal and private well pumping. Table A- 1 in Appendix A shows the annual groundwater pumping for Carpinteria Valley Water District (CVWD) and private wells compiled and estimated by PWR Inc. (2011). Four of the five CVWD wells have multiple screen intervals. The fifth CVWD well, 27F2, has a 346 foot long screen that spans Model Layers 4 to 7. Fourteen of the 174 private wells are known to have multiple screen intervals; and 44 of those wells are known to have a screen longer than 100 feet (Appendix A, Table A- 2). With MODFLOW's multi-node well package (MNW2), specific screen interval elevations are input to the groundwater model (Konikow et al., 2009). Using the Theim option, the package calculates the layer flow distribution for each well based on transmissivity and an assumed well radius of 0.5 feet. The option to constrain pumping if groundwater levels fall below the bottom of the lowest screen is also implemented. Table A- 3 in Appendix A shows the estimated screen intervals and basis for estimates.

113 of the private wells do not have known screen information. For most of these wells, screen intervals are estimated using known screen intervals from nearby pumping wells. For some of the wells, estimated screen intervals are adjusted based on observed groundwater levels at nearby monitoring well.

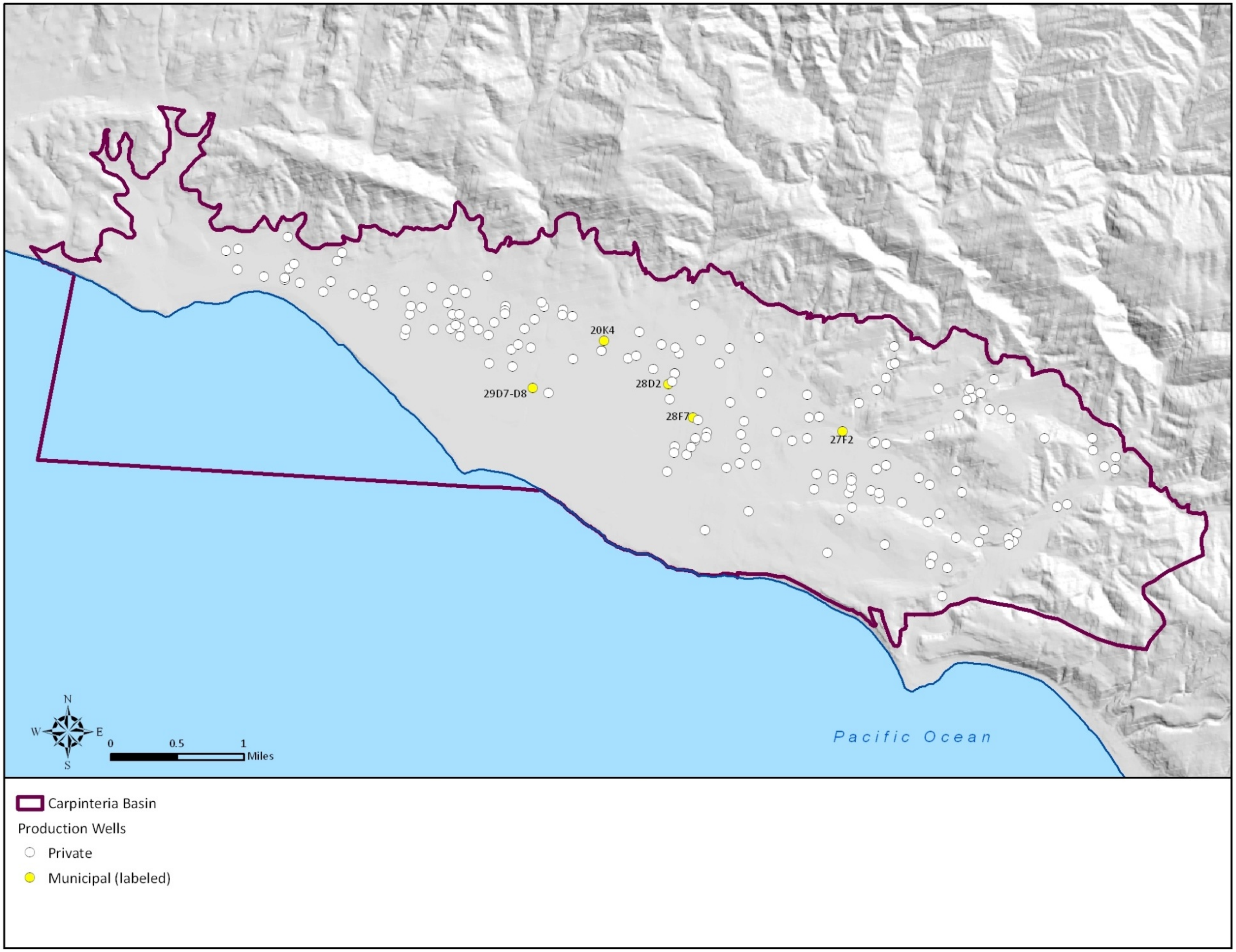


Figure 10: Location of Production Wells Used in Model

SECTION 3
MODEL CALIBRATION

3.1 APPROACH

Calibrating the Carpinteria groundwater flow model involved successive attempts to match model simulated groundwater elevations to measured data for the calibration period. The model was considered calibrated when simulated results matched the measured data within an acceptable measure of accuracy, and when successive calibration attempts did not notably improve the calibration statistics. Calibration was conducted by varying relatively uncertain and sensitive parameters over a reasonable range of values. The following parameters were varied during model calibration:

- Horizontal hydraulic conductivity,
- Vertical hydraulic conductivity using vertical anisotropy,
- Specific storages, and
- Rincon Creek Fault conductance using horizontal flow barrier hydraulic characteristic and quasi-3D confining bed hydraulic conductivity.
- Spatial distribution of areal recharge
- Spatial distribution of mountain front recharge

3.2 CALIBRATION PERIOD

The calibration period was based on the data set provided by PWR Inc. (2011). The data set included water budget data and groundwater elevation data for calibration. The calibration period is Water Year 1985 to Water Year 2008, or October 1, 1984 to September 30, 2008.

3.3 STRESS PERIODS

Stress periods define a time period in the groundwater model over which hydraulic stresses such as pumping and recharge are held constant. Stress period selection depends on the model objectives and the time frame of interest. The primary objective of the model is to assist with multi-year groundwater management strategies. Consistent with the water budget data set (Section 2.6) based on annual flow totals, annual stress periods are used for the model.

3.4 PILOT POINT METHOD FOR MODEL CALIBRATION

A pilot point approach, rather than a zoned conductivity approach, was used to distribute aquifer parameters during calibration. The pilot point approach results in smoothly varying hydraulic conductivity and specific storage fields. Doherty (2003) describes the methodology for the use of pilot points in groundwater model calibration. Using this method, the values of aquifer hydraulic properties are estimated at the locations of a number of points spread throughout the model domain. Hydraulic properties are then assigned to the model grid through spatial interpolation from those points (Doherty, 2007). Spatial interpolation from pilot points to the finite difference grid defines a hydraulic property array on a cell-by-cell basis. Regularization, a geostatistical method that constrains heterogeneity, is also used. Using pilot points with regularization eliminates the need to guess where unmapped heterogeneity might exist: the calibration process informs where heterogeneity exists.

Prior to estimating any hydraulic parameters, the pilot points were selected manually based on following criteria (Doherty, 2002):

1) More pilot points were placed where there are more data;
2) Pilot points were placed between data points in order to calibrate to head differences between wells;
3) Pilot points were placed in between wells and outflow boundaries.
4) Pilot points were placed to eliminate big gaps between adjacent pilot points;

For the model, 20-50 pilot points were selected for each layer. The plotted pilot points are created for horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage. The locations of the pilot points for each layer are shown on Figure 11. The pilot points in Storage Unit 1 and Storage Unit 2 were treated as separate groups of pilot points to avoid spatial interpolation of hydrogeologic parameters across the Rincon Creek Fault.

The use of pilot point methodology results in over 1,000 parameter values that can be varied in the calibration. PEST software and its Singular Value Decomposition (SVD)-assist functionality (Watermark Numerical Computing, 2004) was used to help update the full set of parameter values and improve the calibration.

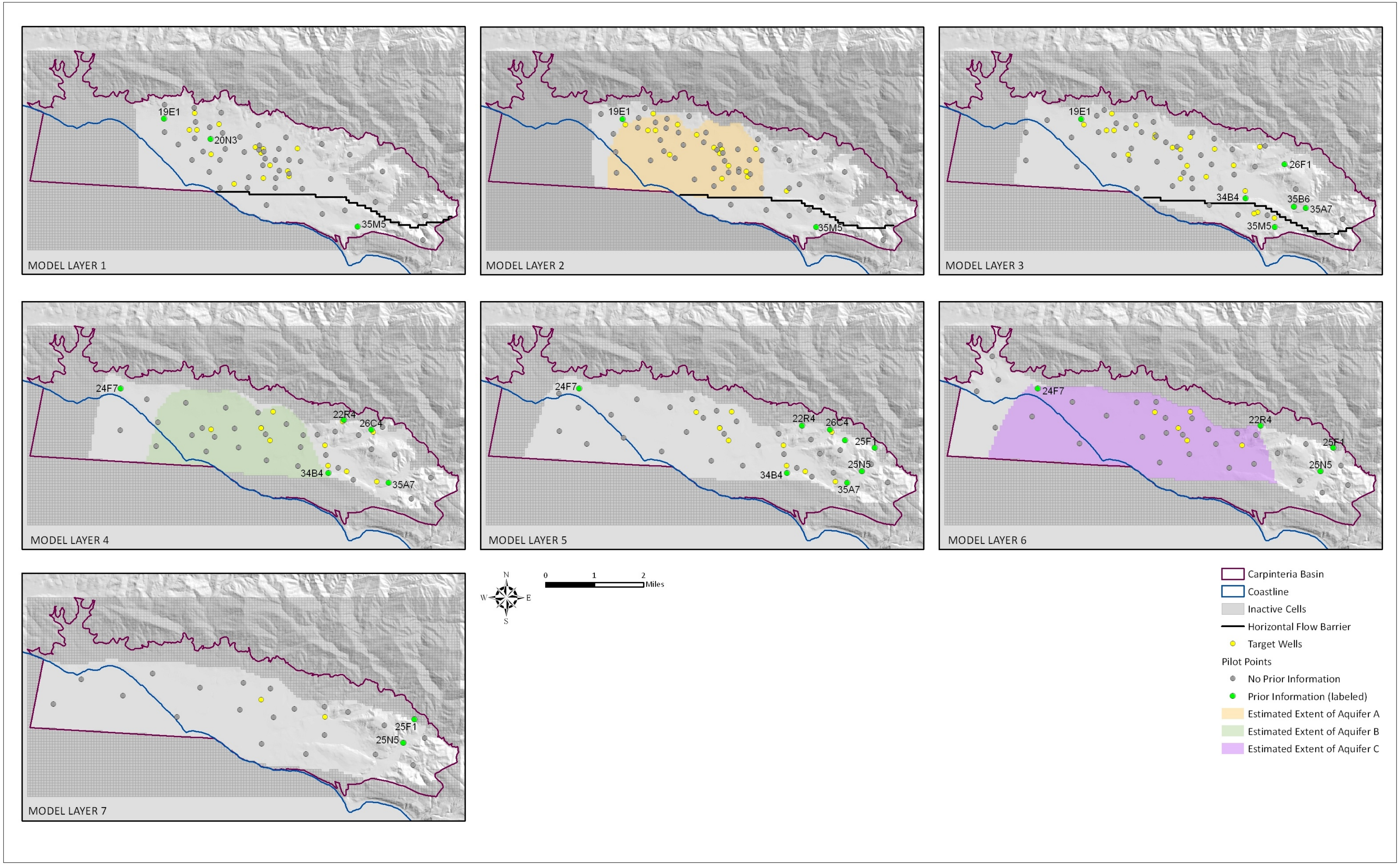


Figure 11: Pilot Point and Target Observation Well Locations

3.5 INITIAL HYDROGEOLOGIC PARAMETERS

Initial values for horizontal hydraulic conductivity are assigned based on pumping test data. Based on these data, average horizontal hydraulic conductivities were estimated for the A, B, C aquifers, and the unconfined areas outside the aquifers. For pilot points within the estimated extents of A (Model Layer 2), B (Model Layer 4), and C (Model Layer 6) aquifers as shown on Figure 11, initial values were based on the average horizontal hydraulic conductivity of the aquifer. For pilot points in aquitard layers or in the unconfined area outside the estimated aquifer extents within Storage Unit 1, initial values were based on representative horizontal hydraulic conductivities estimated for those areas from pumping test data. Within Storage Unit 2, initial values were based on values used for geologically similar layers in Storage Unit 1 with an adjustment for assumed differences. Layers 1 and 2 are geologically similar across the fault, while Storage Unit 2's Layer 3 and Storage Unit 1's Layer 7 both represent the Santa Barbara Formation. Table 5 shows the initial horizontal hydraulic conductivity used for different areas of each layer. One reason calibration was expected to change these layer-specific values from pumping test estimates is that the pumping tests were conducted at wells screened in multiple layers and represent bulk horizontal hydraulic conductivities. Besides establishing these initial values, the estimated aquifer extents are not used during calibration with pilot points as discussed in Section 3.4.

Table 5: Initial Hydraulic Conductivity Values for Each Model Layer

Layer	**Storage Unit**	**Aquifer**	**Horizontal Hydraulic Conductivity**	**Vertical Hydraulic Conductivity**
			feet/day	
1	1		1.0	0.01
1	2		2.0	0.2
2	1 (confined area)	A	14.0	1.4
2	1 (unconfined area)		0.5	0.01
2	2		1.4	0.014
3	1		0.5	0.01
3	2		2.5	0.025
4	1 (confined area)	B	13.3	1.33
4	1 (unconfined area)		0.5	0.01
5	1		0.2	0.01
6	1 (confined area)	C	11.6	1.16
6	1 (unconfined area)		2.0	0.01
7	1		2.5	0.01

Initial values for vertical hydraulic conductivity were based on a vertical anisotropy of 10:1 for pilot points within the estimated extents of the A, B, and C aquifers, and the alluvial Layer 1 of Storage Unit 2. For pilot points in aquitard layers, areas outside the estimated aquifer extents, and Layers 2 and 3 of Storage Unit 2, vertical anisotropies of 20:1 to 250:1 were assigned with a minimum vertical hydraulic conductivity of 0.01 feet per day.

All pilot points were assigned an initial specific storage value of 1 x 10^{-5}. The specific yield was set to 0.12 for the model and not varied during calibration.

The Rincon Creek Fault was assumed to be less of a barrier in Layer 1 than in Layers 2 and 3. The vertical barriers to flow between Layers 1 and 2 and between Layers 2 and 3 represented by the quasi-3D confining layers were assumed to be equivalent to the horizontal barriers to flow in Layers 2 and 3, respectively. A barrier thickness of 1 foot was assumed for both the horizontal flow barriers and the quasi-3D confining layers. The initial value for the Layer 1 horizontal flow barrier hydraulic conductivity was 1 foot per day. Initial values for the horizontal flow barrier hydraulic conductivity for Layers 2 and 3 were 10^{-4} feet per day. Therefore, initial values for the vertical conductivity of the quasi-3D confining layers were assigned 10^{-4} feet per day. During calibration, the conductivities of the horizontal flow barriers in Layers 2 and 3 were maintained as equivalent to the conductivities of the overlying quasi-3D confining layers.

3.6 CALIBRATION RESULTS

3.6.1 MODEL PARAMETER MODIFICATIONS

Model parameters were adjusted during model calibration to improve the model's ability to simulate known conditions. Calibration of the model consisted of modifying the distribution and magnitude of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific storage values using the pilot point method discussed above. The final distributions of the aquifer parameter values are shown for each of the five model layers in Figure 12 through Figure 14. These parameter distributions do not necessarily match the mapped distribution of aquifers and aquitards because they are based on different data sets. The mapped aquifers and aquitards are based on geologic observations from scattered boreholes. The parameter distributions in Figure 12 through Figure 14 are parameters necessary to simulate observed water level changes. While geology influences these parameters, they are not necessarily distributed similarly.

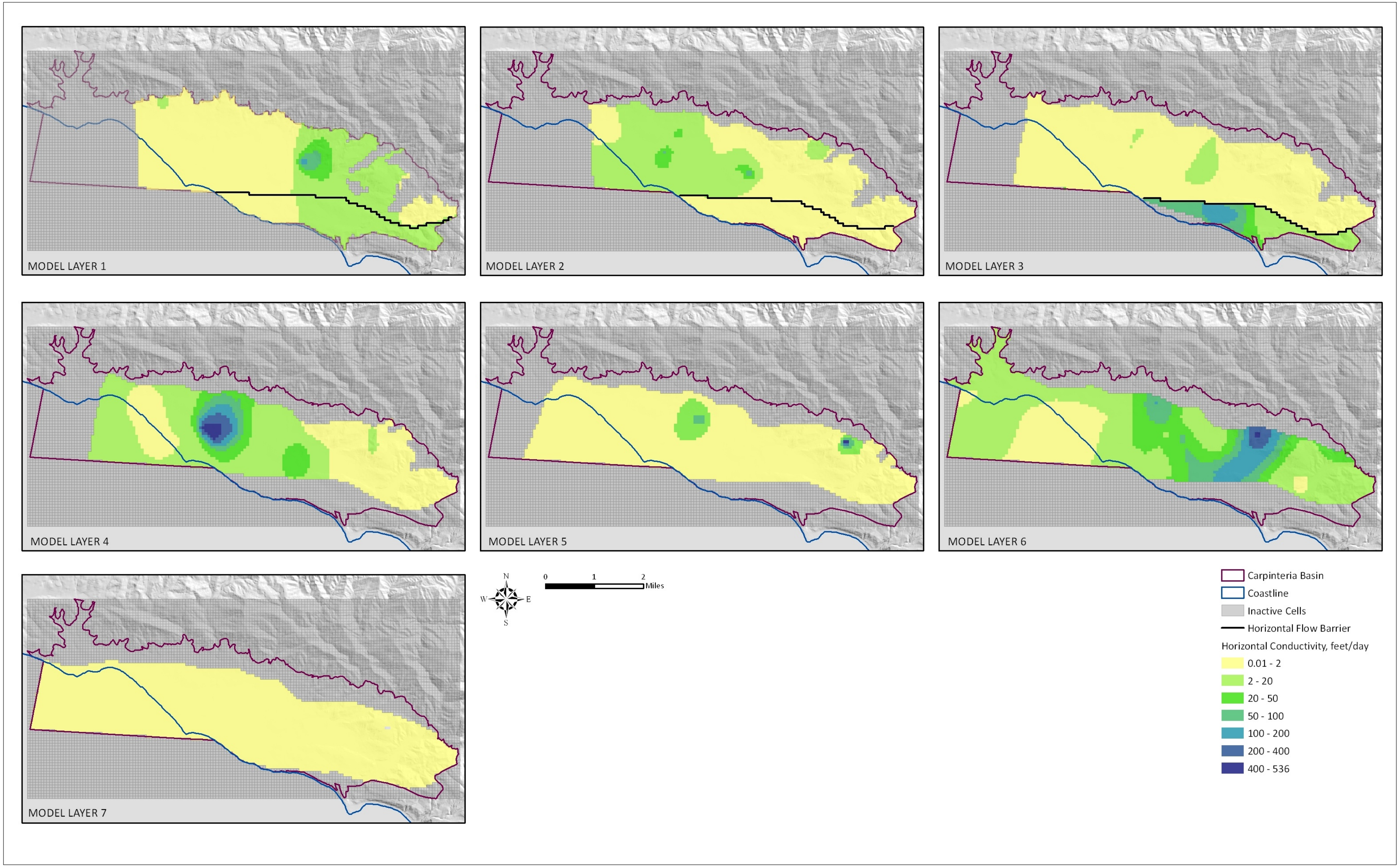


Figure 12: Final Distribution of Horizontal Hydraulic Conductivity by Layer

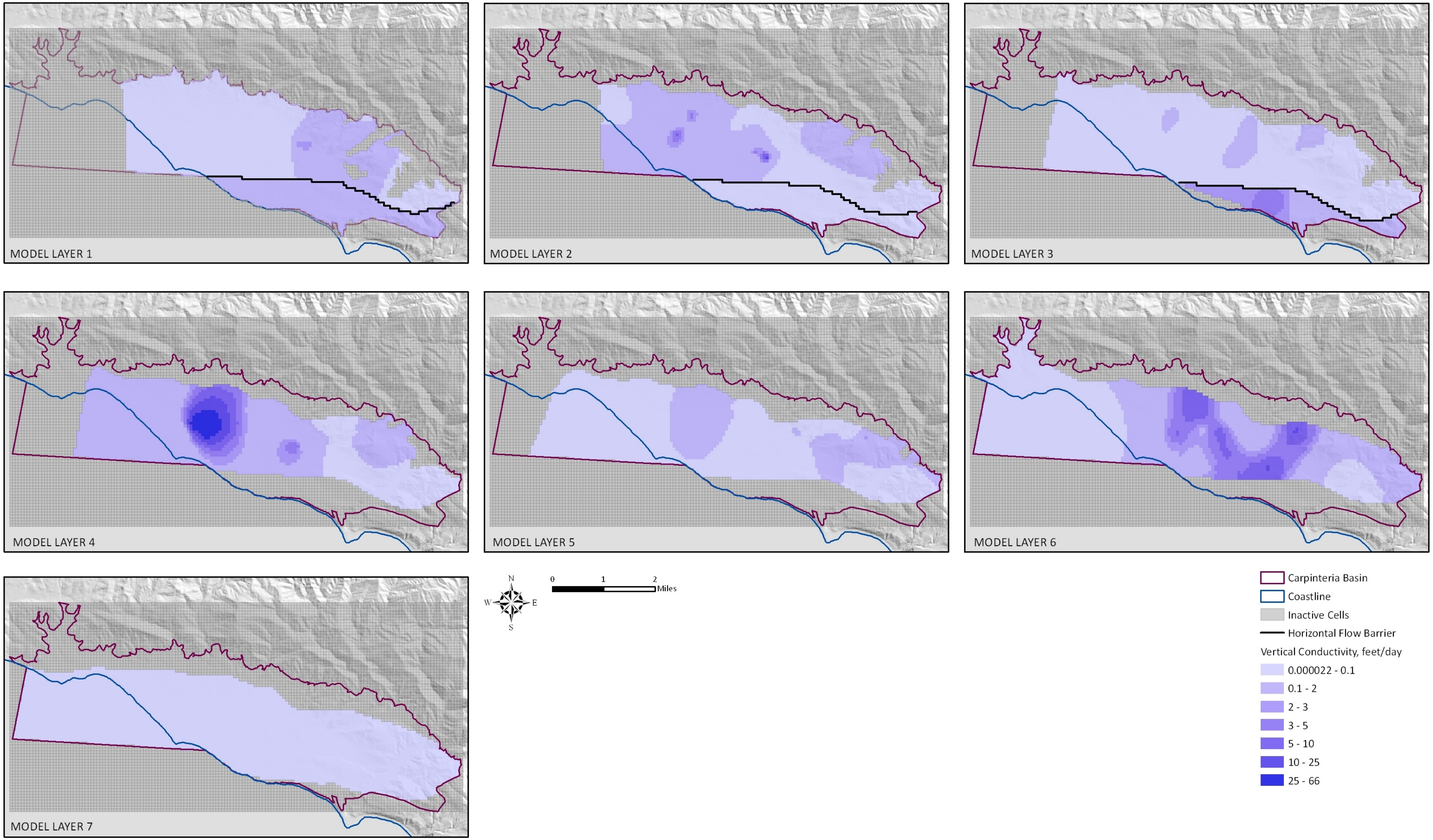


Figure 13: Final Distribution of Vertical Hydraulic Conductivity by Layer

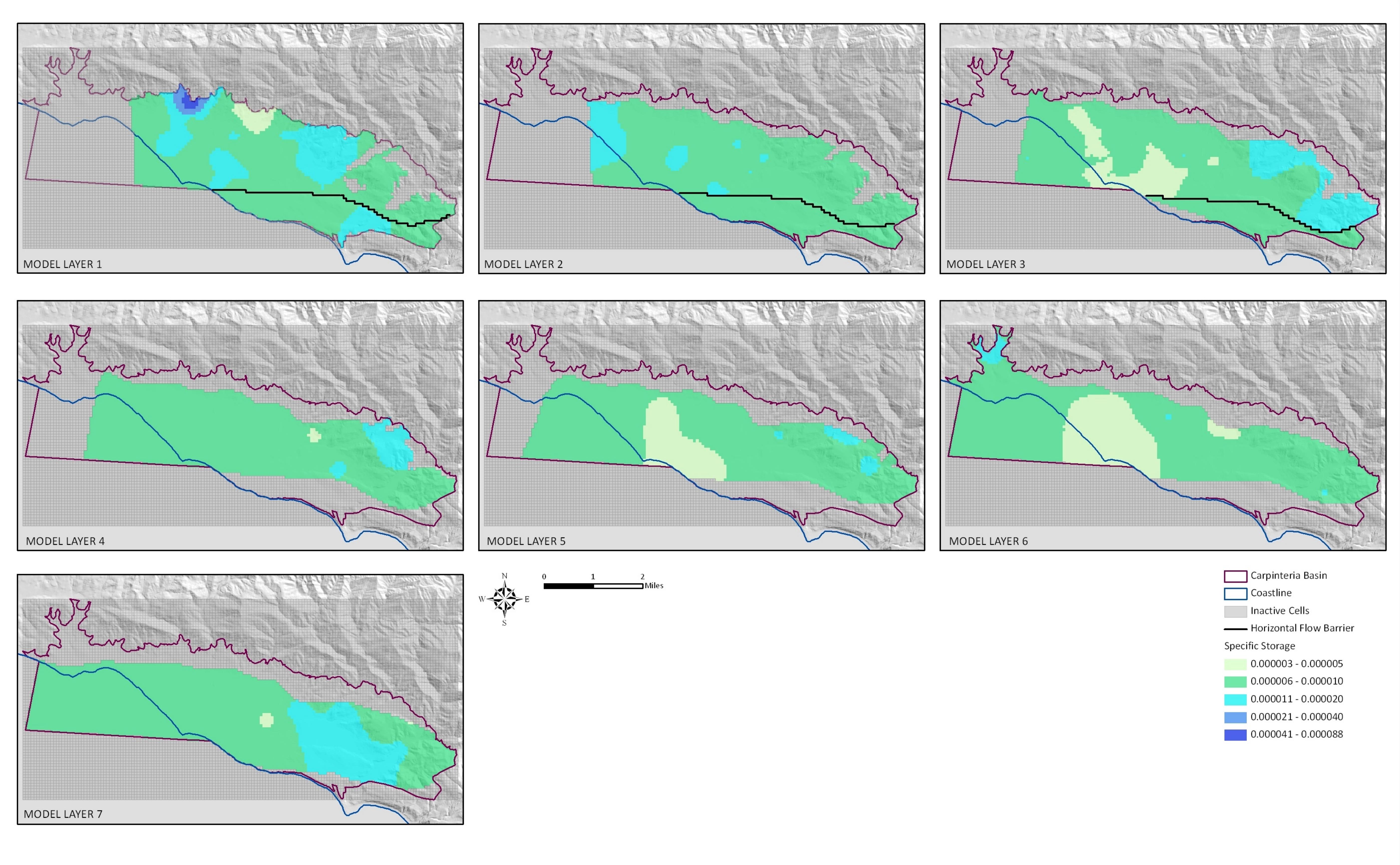


Figure 14: Final Distribution of Specific Storage by Layer

Figure 12 shows locations of relatively high hydraulic conductivity in layers 4 and 6. These are localized conductivities that are greater than the average values; and were necessary for calibrating local groundwater elevations.

Calibrating the Rincon Creek Fault consisted of modifying the equivalent hydraulic conductivity of the horizontal flow barrier and quasi-3D confining layers. Uniform values were used for each layer. The conductivities of the horizontal flow barrier in layers 2 and 3 were kept equal to the overlying quasi-3D confining layers. Calibration resulted in the equivalent hydraulic conductivity for layer 1 of 0.79 feet per day. Calibration resulted in the equivalent hydraulic conductivities for layers 2 and 3 of 1×10^{-6} feet per day.

3.6.2 GROUNDWATER ELEVATION CALIBRATION

Flow model calibration is commonly evaluated by comparing simulated water elevations with observed groundwater elevations from monitoring and production wells. Hydrographs of simulated groundwater elevations should generally match the trends and fluctuations observed in measured hydrographs. Furthermore, the average errors between observed and simulated groundwater elevations should be relatively small and unbiased. The target well locations used for calibration of the regional groundwater flow model are shown in Figure 15. The target wells were selected based on data availability for both groundwater levels and screen intervals. For wells screened over multiple model layers, simulated groundwater levels in each of the layers are weighted by layer transmissivity and averaged before comparing with measured data.

Example maps of simulated piezometric surfaces are displayed on Figure 16 and Figure 17. The maps show results from the relatively low 1990, which was a year with relatively low water levels; and results from 2008, the last year of the simulation. The maps show results from model layers 1, 2, 4, and 6, representing the overlying alluvium, Aquifer A, Aquifer B, and Aquifer C. Hydrographs showing both observed and simulated groundwater elevations are shown in Figure 18 through Figure 25. These example hydrographs were chosen to demonstrate the model's accuracy in various parts of the Carpinteria Groundwater Basin. The hydrographs show that the model accurately simulates both the magnitude of groundwater fluctuations and trends observed in monitoring well data.

Figure 25 shows that calibration in Storage Unit 2 is not as good as calibration in Storage Unit 1. Additional refinement of the conceptual model, in particular the water budget, will be required to improve calibration in this area south of the Rincon Creek Fault.

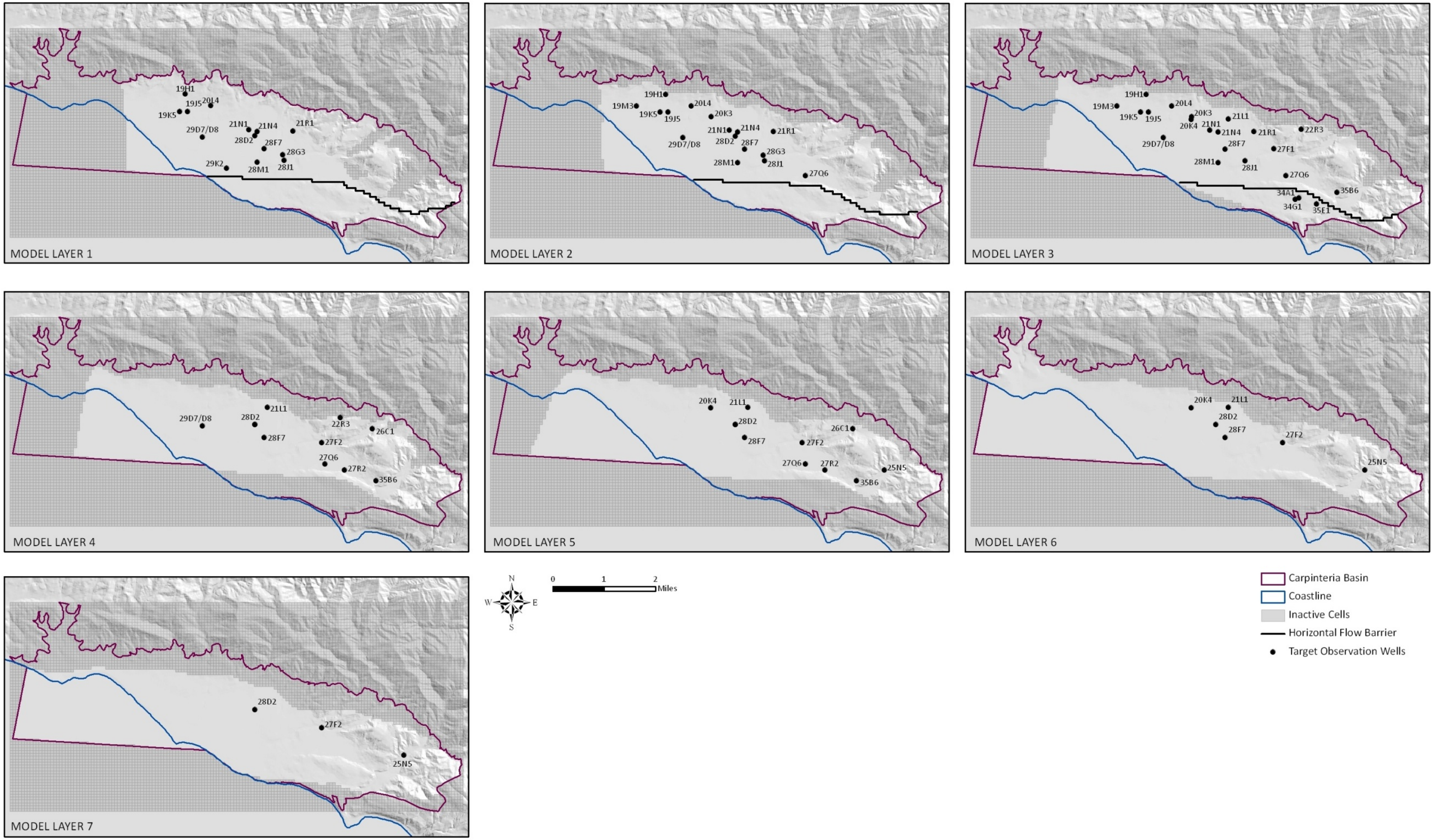


Figure 15: Observation Well Locations by Layer Used for Calibration

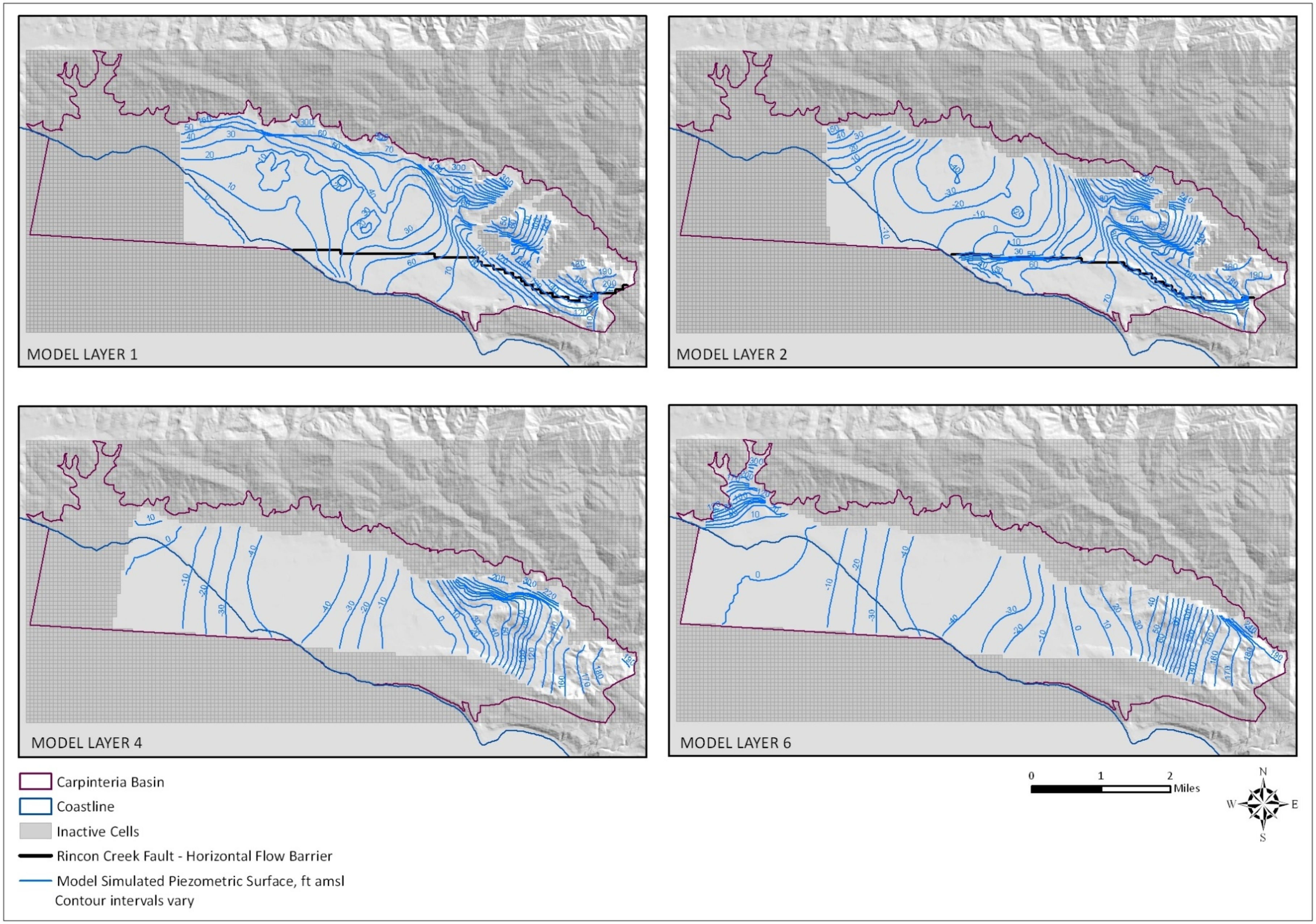


Figure 16: Simulated Piezometric Surfaces – 1990

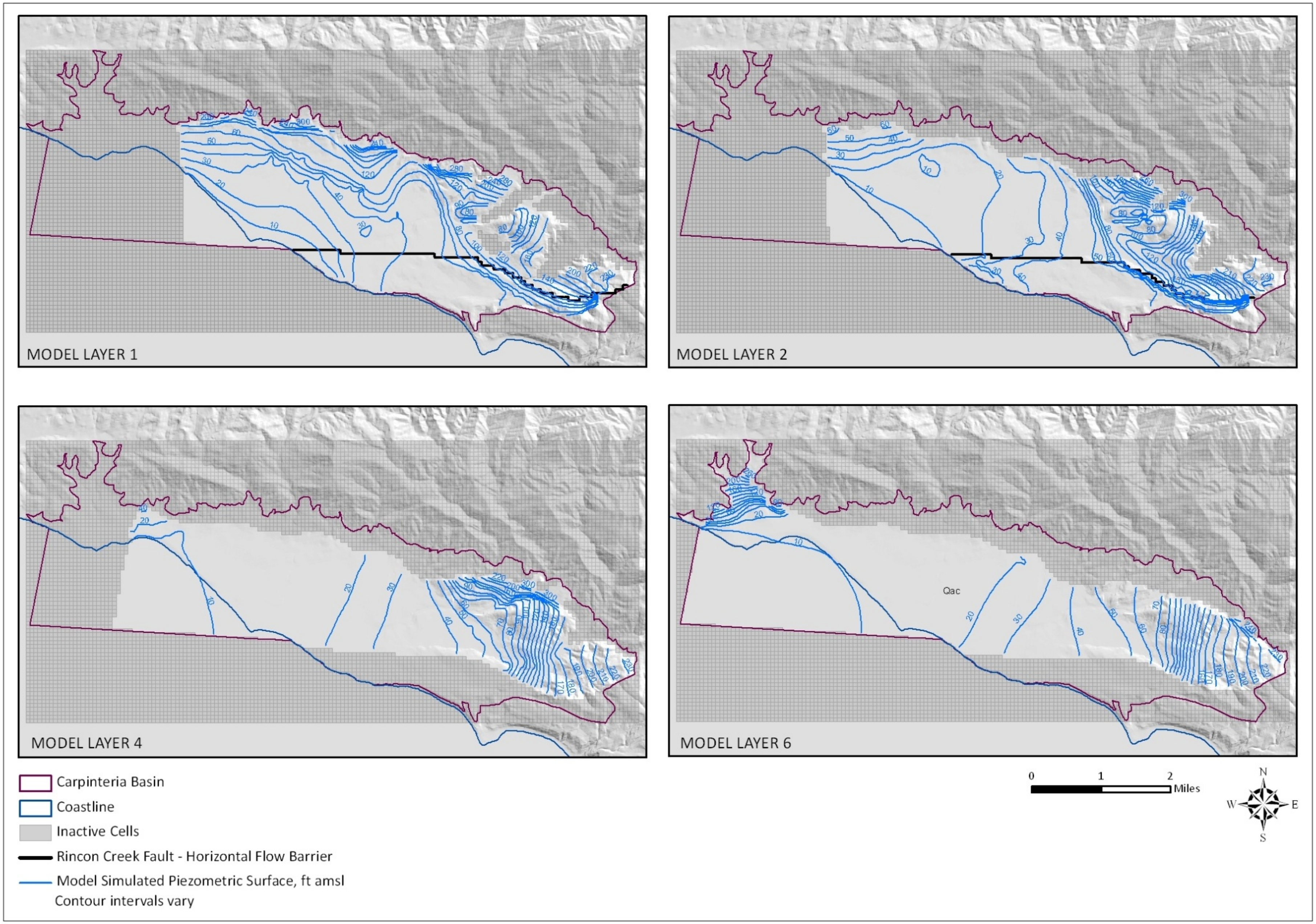


Figure 17: Simulated Piezometric Surfaces - 2008

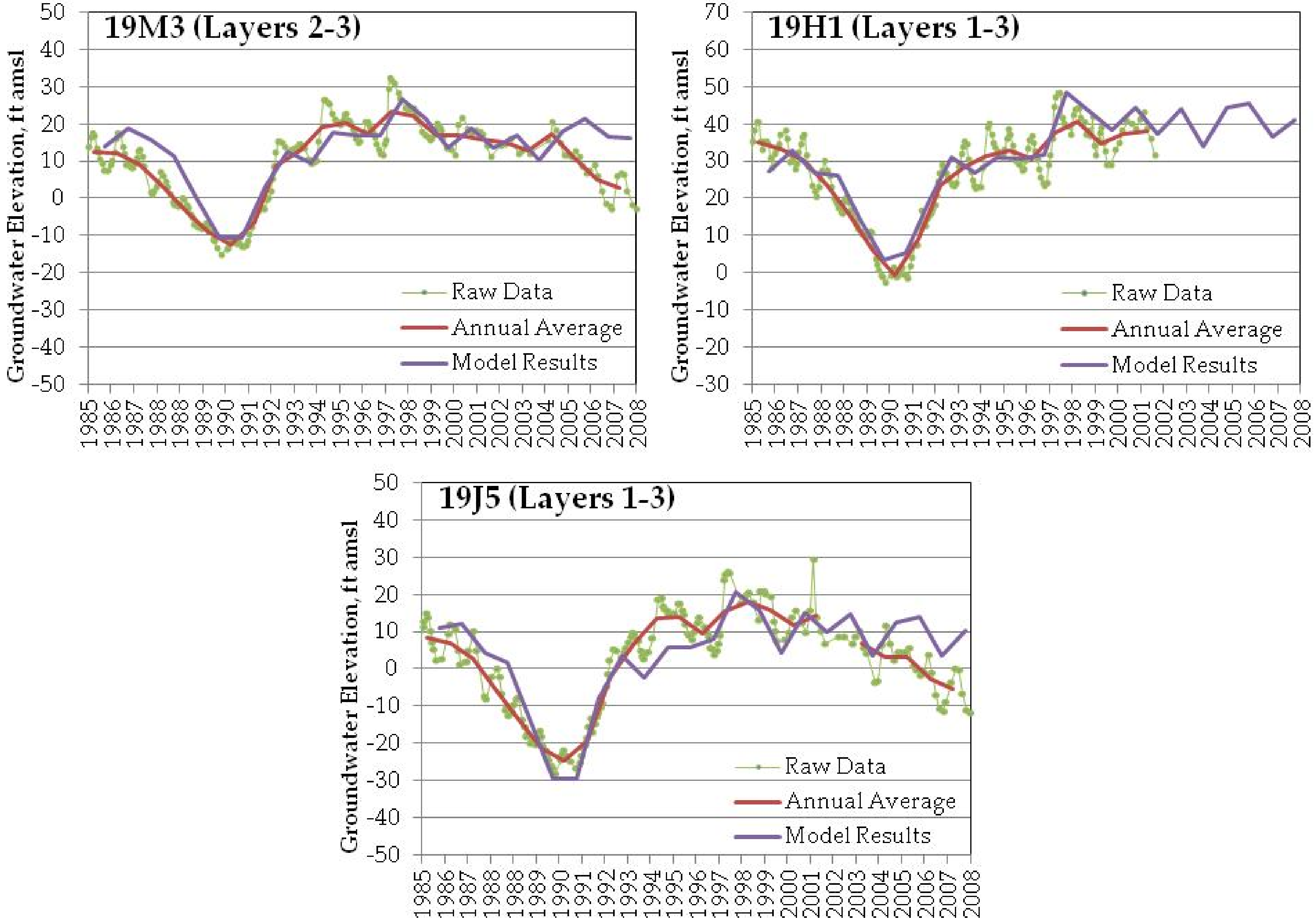


Figure 18: Calibration Hydrographs - Section 19

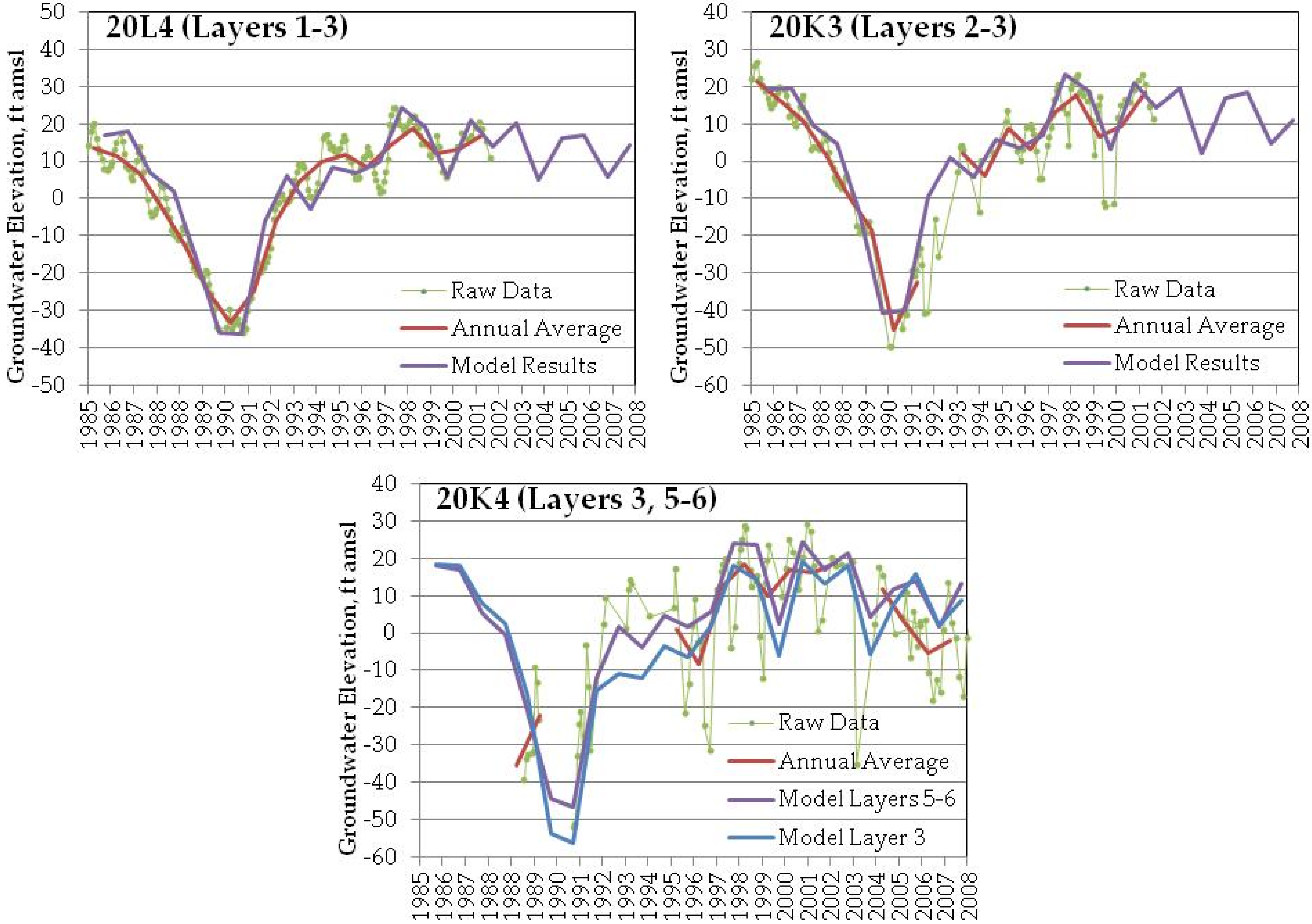


Figure 19: Calibration Hydrographs – Section 20

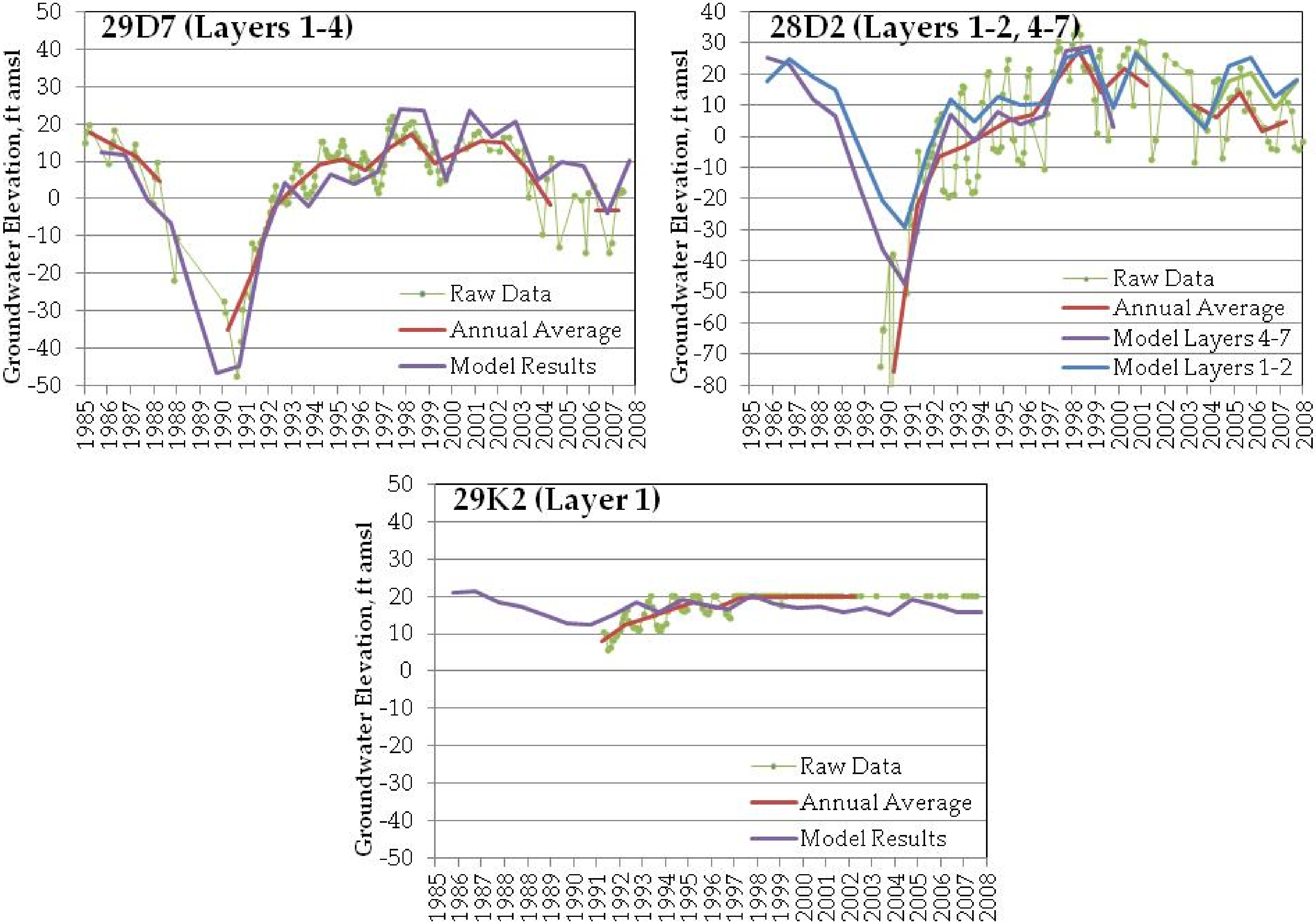


Figure 20: Calibration Hydrographs - Sections 29 and 28

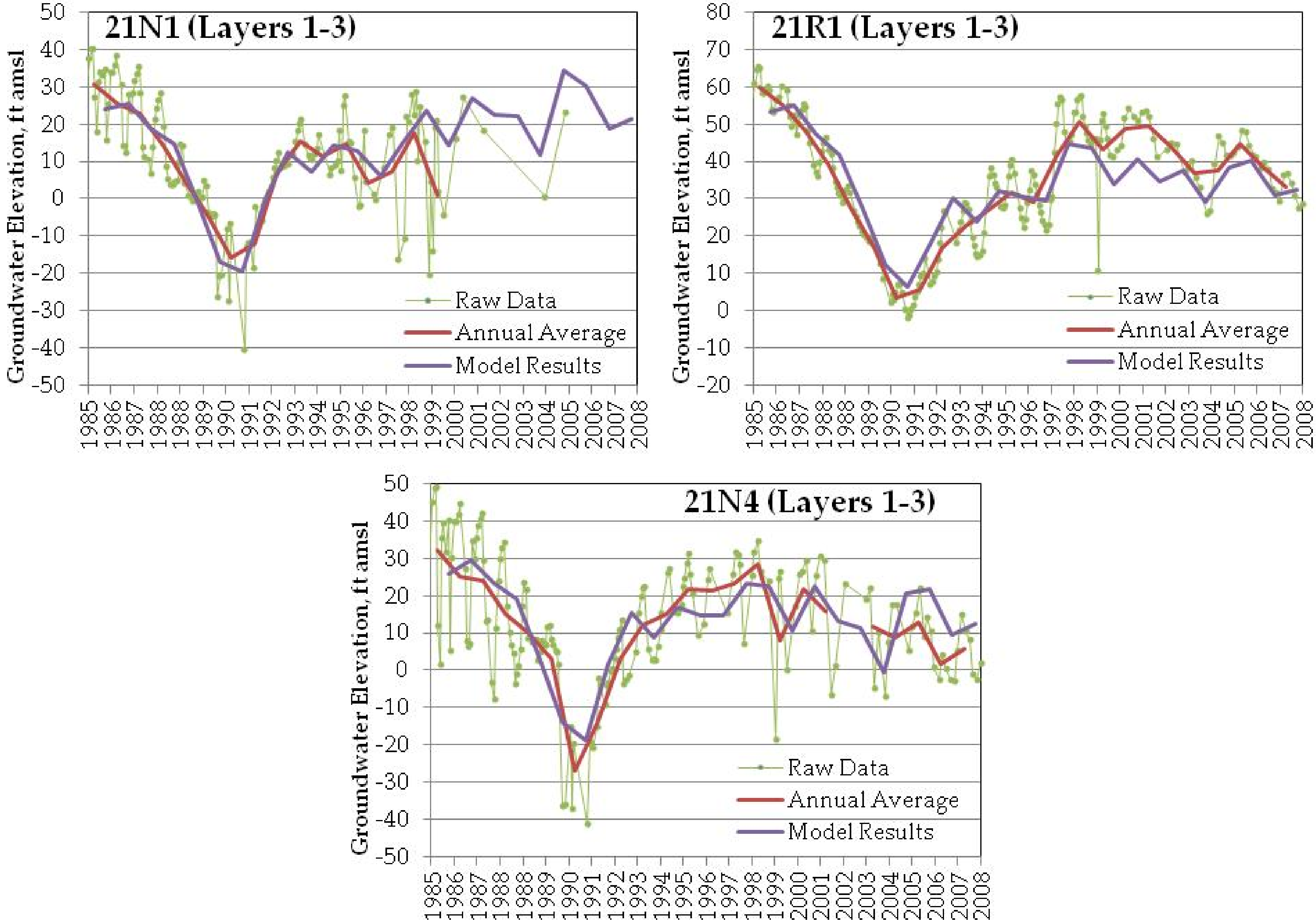


Figure 21: Calibration Hydrographs -Section 21

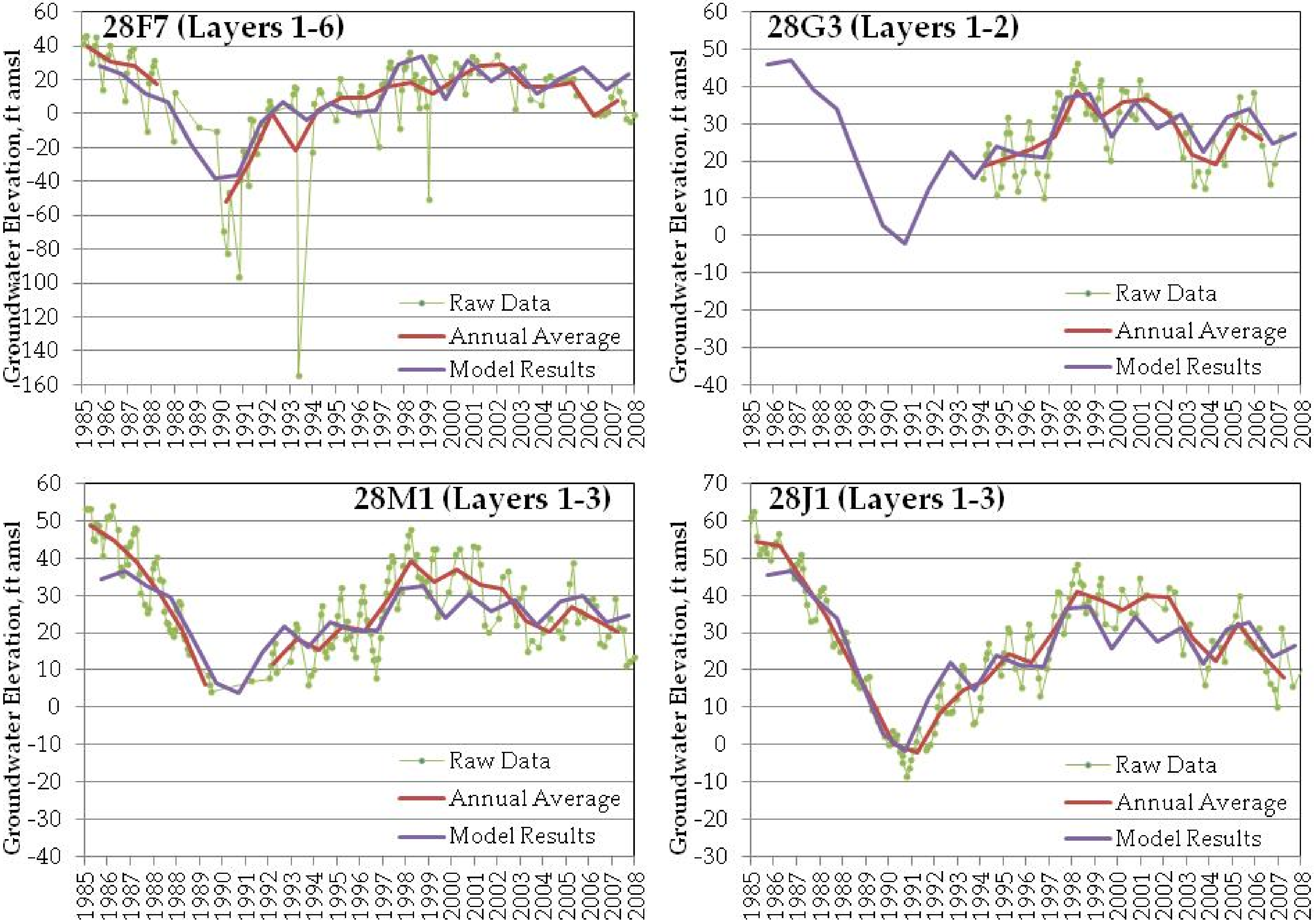


Figure 22: Calibration Hydrographs - Section 28

]

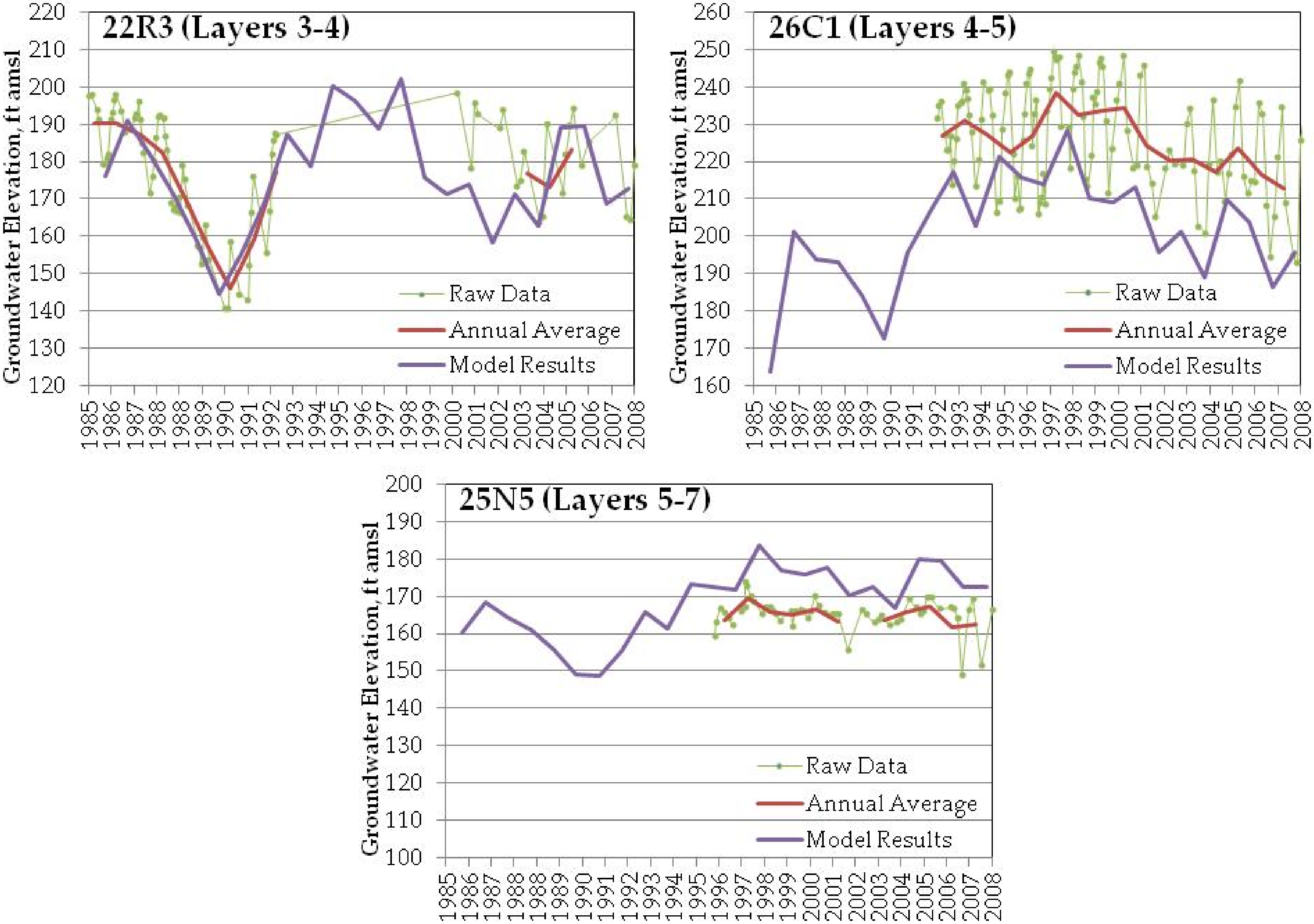


Figure 23: Calibration Hydrographs - Sections 22, 25, and 26

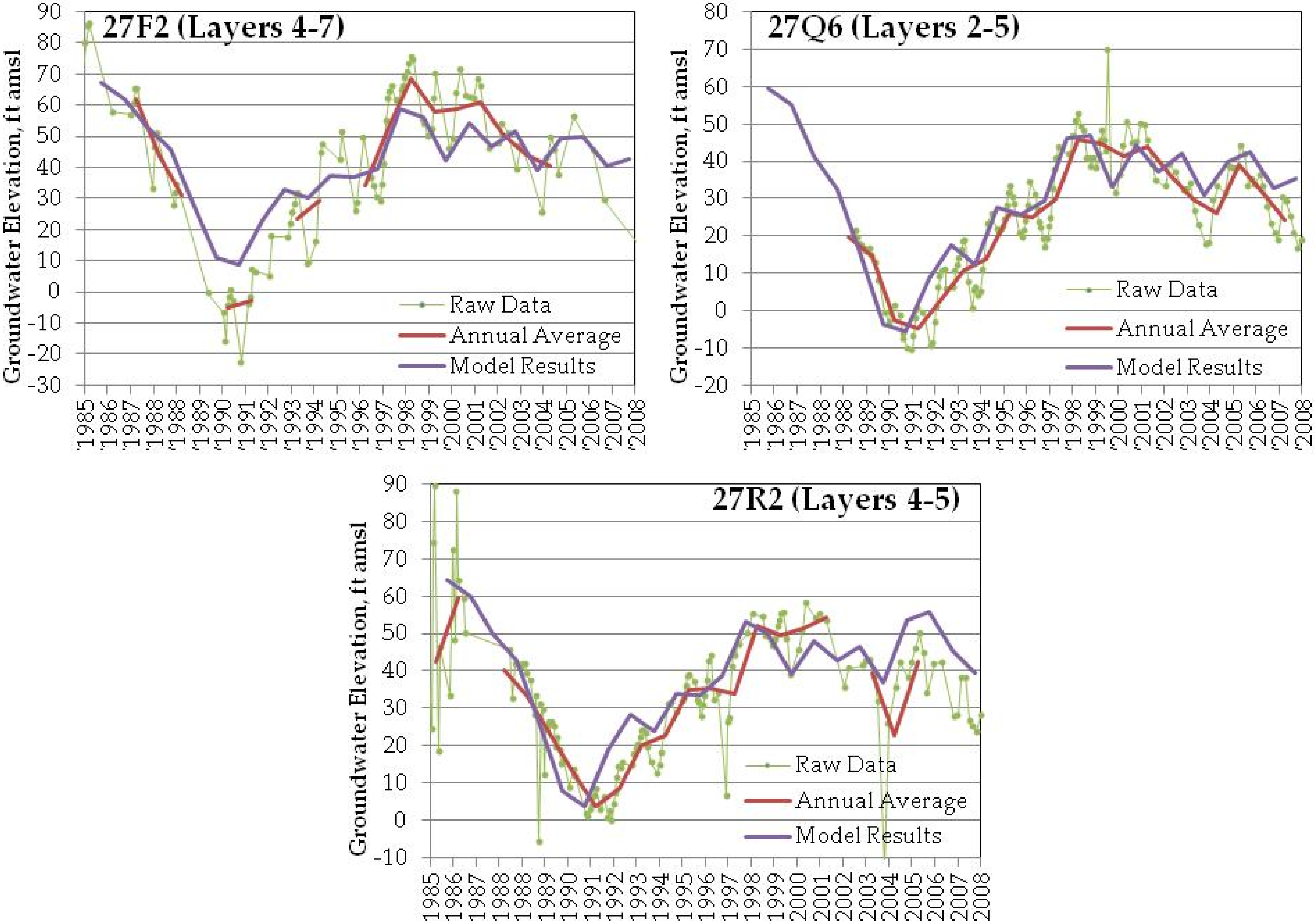


Figure 24: Calibration Hydrographs – Section 27

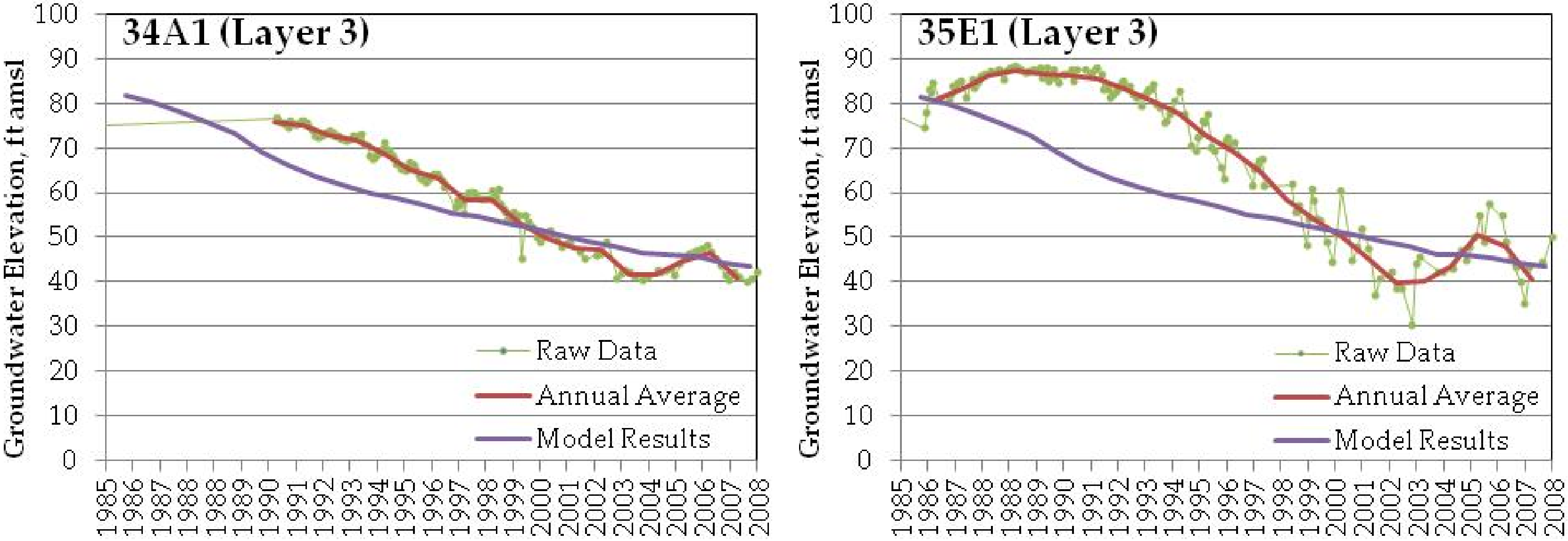


Figure 25: Calibration Hydrographs – Sections 34 and 35 (Storage Unit 2)

Various graphical and statistical methods can be used to demonstrate the magnitude and potential bias of the calibration errors. Calibration statistics compare simulated groundwater elevations with annual average observed groundwater elevations because the model uses annual stress periods. Figure 26 shows all simulated groundwater elevations plotted against observed annual averages for all the entire calibration period. Results from an unbiased model will scatter around a 45º line on this graph. If the model has a bias such as exaggerating or underestimating groundwater level differences, the results will diverge from this 45º line. The line drawn on Figure 26 demonstrates that the results lie close to a 45º line, suggesting that the model results are not biased towards overestimating or underestimating average groundwater level differences.

Figure 26 also includes various statistical measures of calibration accuracy. The four statistical measures used to evaluate calibration are the mean error (ME), the mean absolute error (MAE), the standard deviation of the errors (STD), and the root mean squared error (RMSE). The mean error is the average error between measured and simulated groundwater elevations for all data on Figure 26,

$$ME = \frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i$$

Where h_m is the measured groundwater elevation, h_s is the simulated groundwater elevation, and n is the number of observations.

The mean absolute error is the average of the absolute differences between measured and simulated groundwater elevations.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|h_m - h_s\right|_i$$

The standard deviation of the errors is one measure of the spread of the errors around the 45º line in Figure 26. The population standard deviation is used for these calculations.

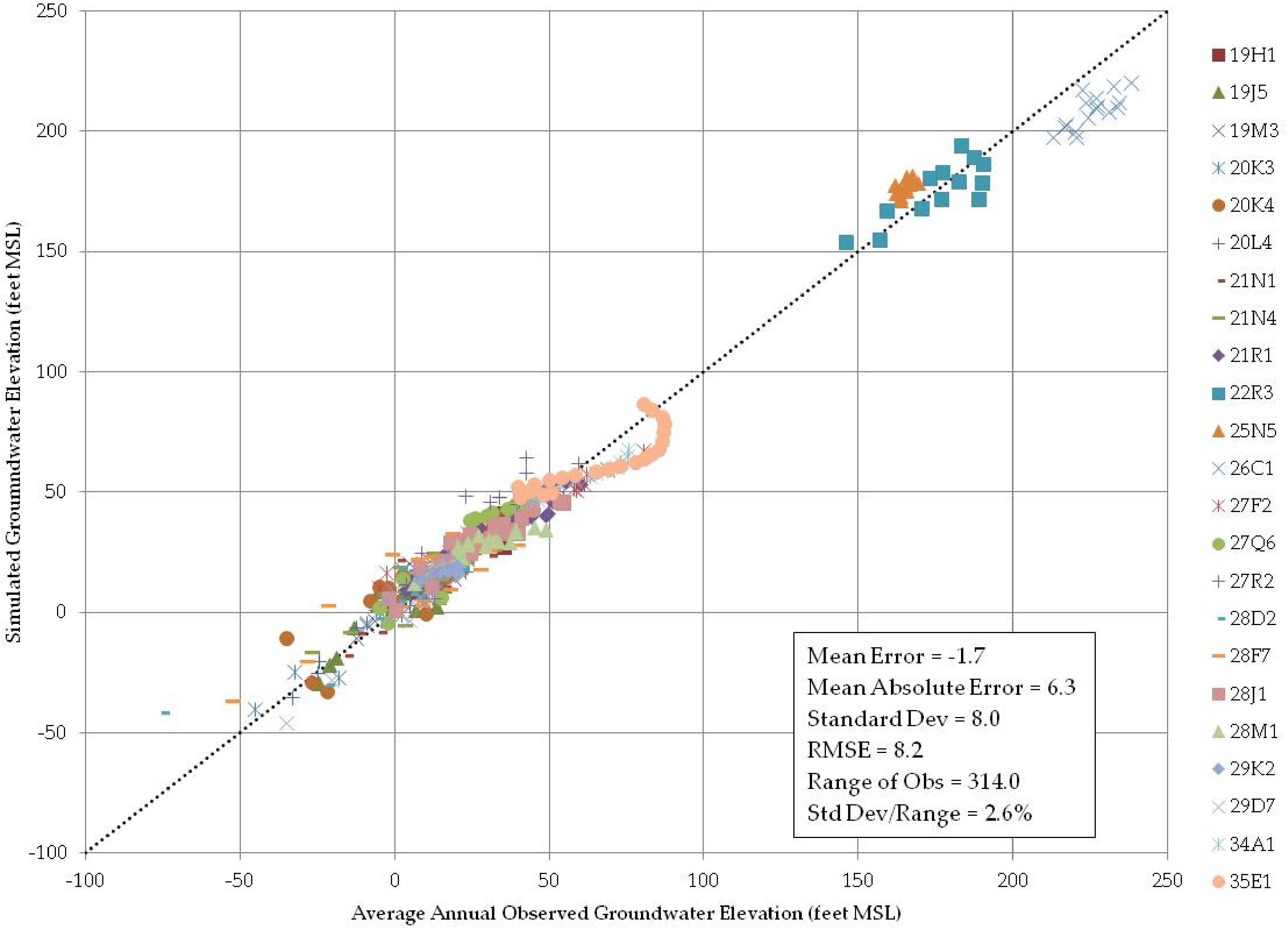
$$STD = \sqrt{\frac{n\sum_{i=1}^{n}(h_m - h_s)_i^2 - \left(\sum_{i=1}^{n}(h_m - h_s)\right)_i^2}{n^2}}$$

The RMSE is similar to the standard deviation of the error. It also measures the spread of the errors around the 45º line in Figure 26 and is calculated as the square root of the average squared errors.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_m - h_s\right)_i^2}$$

As a measure of successful model calibration, Anderson and Woessner (1992) state that the ratio of the spread of the errors to the total head range in the system should be small to ensure that the errors are only a small part of the overall model response. As a general rule, the standard deviation of errors should be less than 10% of the total head range in the model. The standard deviation of 8.0 is approximately 2.6% of the total head range of 314 feet. A second general rule that is occasionally used is that the mean error should be less than 5% of the total head range in the model. The mean error of -1.7 is approximately 0.5% of the total head range. Therefore, on average, the model errors are within an acceptable range.

A second graph used to evaluate bias in model results is show Figure 27. This figure is a graph of observed groundwater elevations versus model residual (simulated elevation minus observed elevation). Results from a non-biased simulation will appear as a cloud of data points clustered around the zero model residual line. Results that do not cluster around the zero residual line show potential model bias. Results that display a trend instead of a random cloud of points may suggest additional model bias. The results plotted on Figure 27 show that the calibrated model results are generally unbiased.



Mean Error = -1.7
Mean Absolute Error = 6.3
Standard Dev = 8.0
RMSE = 8.2
Range of Obs = 314.0
Std Dev/Range = 2.6%

Figure 26: Simulated versus Observed Groundwater Elevation

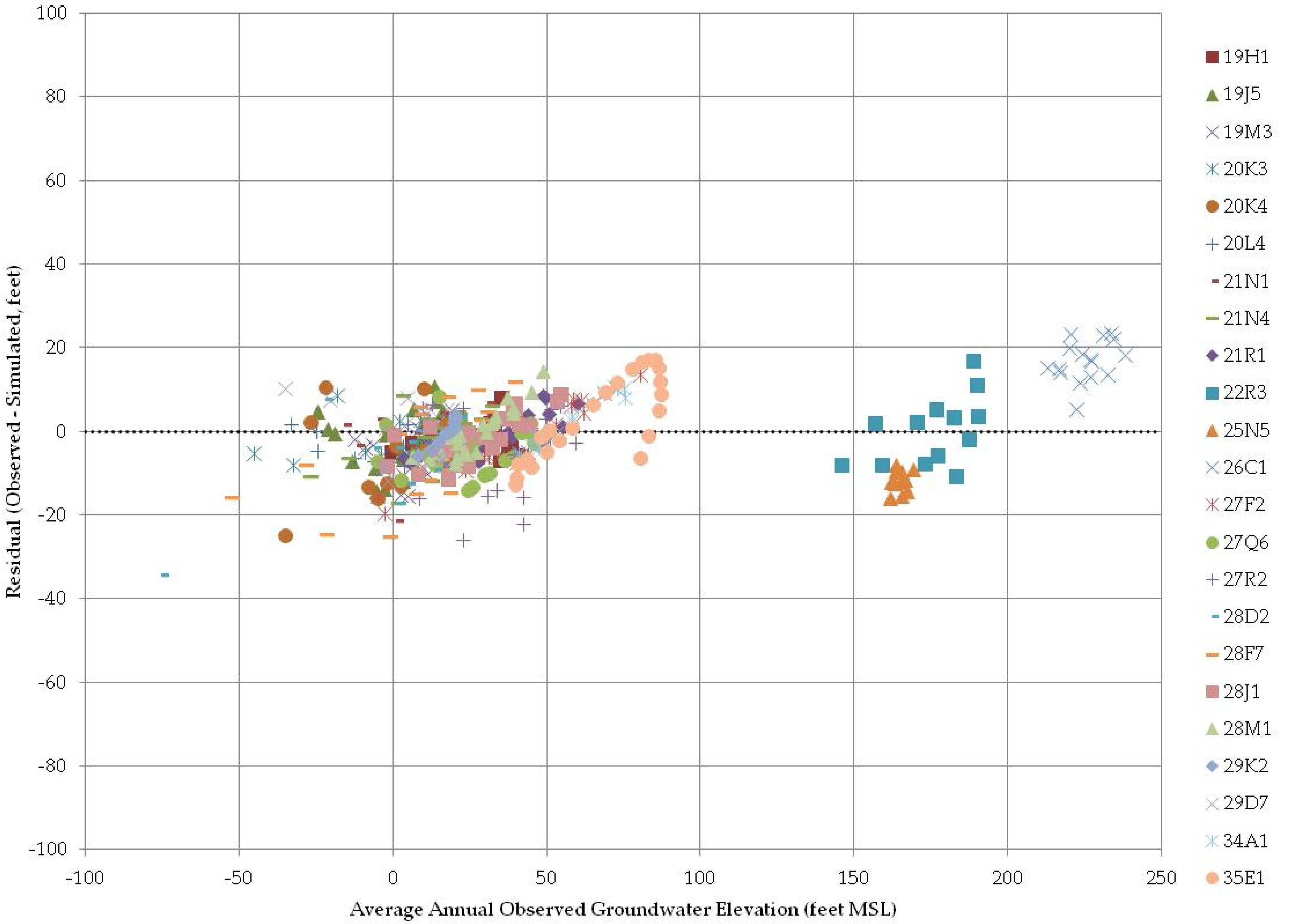


Figure 27: Model Residual versus Observed Groundwater Elevations

3.6.3 CALIBRATION RESULTS COMPARED TO AQUIFER TEST ESTIMATES

Horizontal hydraulic conductivity estimates from aquifer tests outside of the estimated aquifer extents were included in the calibration process. The hydraulic conductivities at the test locations were allowed to vary if needed to match observed groundwater levels. Table 6 shows the calibrated conductivities at these locations compared to aquifer test estimates. The calibrated conductivities are unique in each model layer the well, while the aquifer test conductivities represent bulk estimates for all layers screened by the wells.

At some wells such as 22R4 and 25F1, the calibrated model has large vertical differences in hydraulic conductivity. As mentioned in Section 3.7.1, these localized high conductivities that are greater than the average values were necessary for calibrating nearby, local groundwater elevations that are in discrete layers.

Table 6: Pilot Point Horizontal Hydraulic Conductivities at Aquifer Test Locations

Well	**Layer**	**Horizontal Hydraulic Conductivity (feet/day)**	
		Aquifer Test Estimate	**Model**
19E1	1	1.93	1.01
	2		2.62
	3		0.81
20N3	1	0.87	0.13
22R4	4	0.94	0.04
	5		0.02
	6		357.73
24F7	4	1.57	2.52
	5		0.17
	6		2.98
25F1	5	1.55	0.58
	6		61.06
	7		0.02
25N5	5	0.80	0.28
	6		5.95
	7		0.01
26B1	5	1.59	7.60
26C4	4	0.78	4.18
	5		0.01
26F1	3	0.45	0.27
34B4	3	0.14	0.01

Well	Layer	Horizontal Hydraulic Conductivity (feet/day)	
		Aquifer Test Estimate	Model
	4		3.83
	5		0.08
35A7	3	1.00	0.04
	4		0.36
	5		0.17
35B6	3	2.66	0.11
35M5	1	0.50	2.10
	2		1.02
	3		10.77

3.7 SIMULATED WATER BUDGET

Figure 28 through Figure 31 show the model's water budget output compared to the water budget provided by PWR Inc. (2011) and presented in Section 2.6. Figure 28 shows that simulated mountain front subsurface inflow matches the totals in Table 1. For recharge zones, Figure 29 through Figure 31 show the recharge components discussed in Section 2.6.1. The total of all estimated recharge components are compared to the simulated recharge in Figure 29 through Figure 31. The total net estimated recharge values are represented by the grey line; and they combine both recharge inflows and extraction by phreatophytes. The simulated flows are shown with the yellow lines, and they match total estimated inputs for each recharge zone. Simulated flows for injection wells and recharge match input because MODFLOW-NWT does not result in dry cells that would prevent flows from being added or subtracted as input for those cells.

Figure 28 shows total net model extraction by the multi-node well package because inflows to the model occur in some cells from inter-nodal flow within a well. Simulated net model extraction by multi-node wells is less than the groundwater pumping totals in Table 1 and **Error! Reference source not found.** by an annual average of approximately 10% because pumping constraints are implemented in the multi-node well package. If groundwater levels in a well node fall below the lowest well screen, extraction from the well node is eliminated.

Outflow to the ocean general head boundary is completely dependent on simulated heads. Figure 28 shows that the model simulates an average of 410 acre-feet per year of outflow to the ocean. The outflow to the ocean estimated by PWR Inc. averaged 79 acre-feet per year for the 24-year simulation period. Therefore the model simulates approximately 330 acre-feet per year more outflow to the ocean than is estimated by PWR Inc. (2011). We assume the difference in outflow results from the confined zone recharge that was not included in the PRW Inc. conceptual model. The additional confined zone recharge averages approximately 545 acre-feet per year. Therefore, approximately 330 acre-feet per year of the 545 acre feet of recharge (60%) flows to the ocean, and 215 acre-feet per year (40%) adds to the basin recharge,

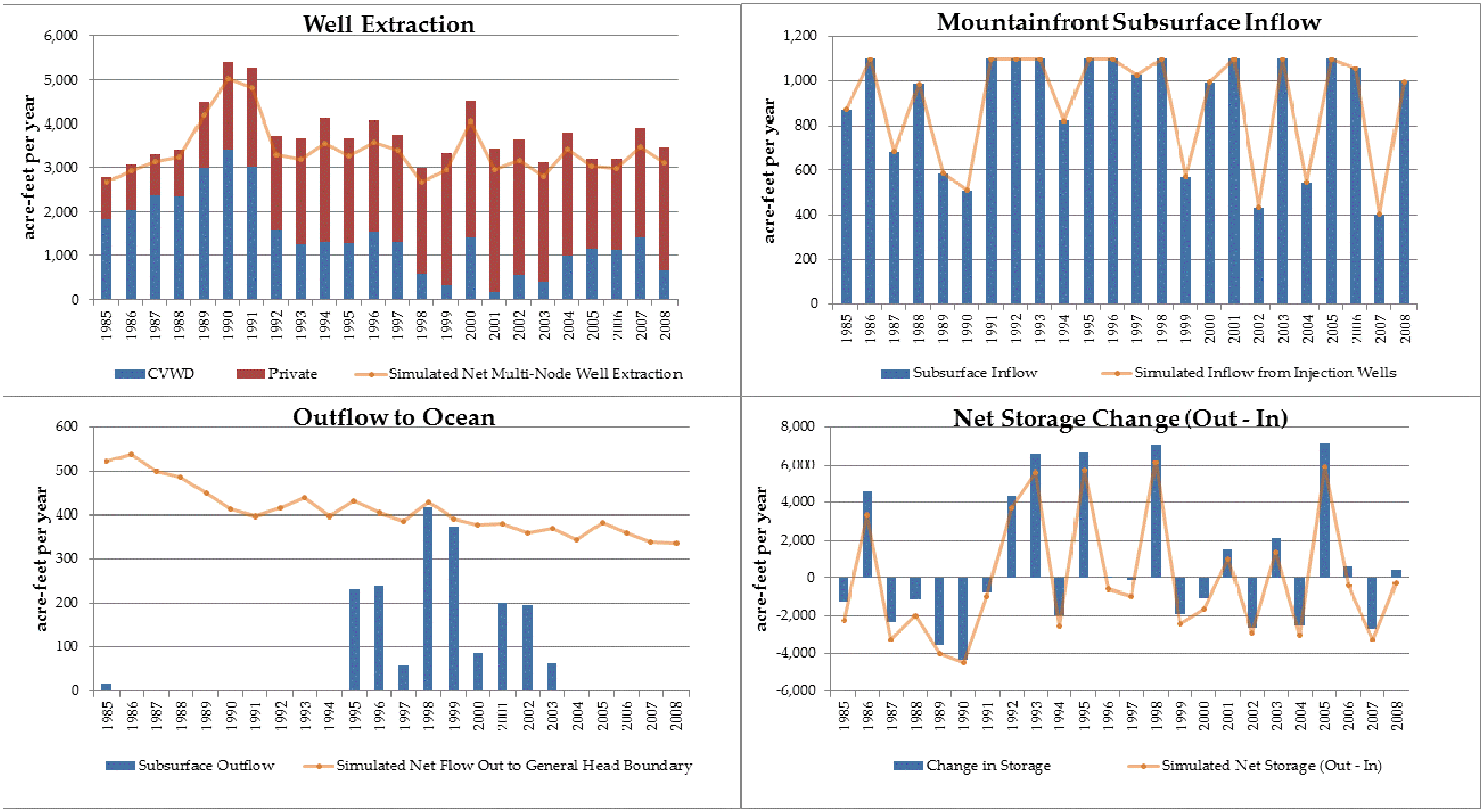


Figure 28: Simulated Water Budget for Non-Recharge Components

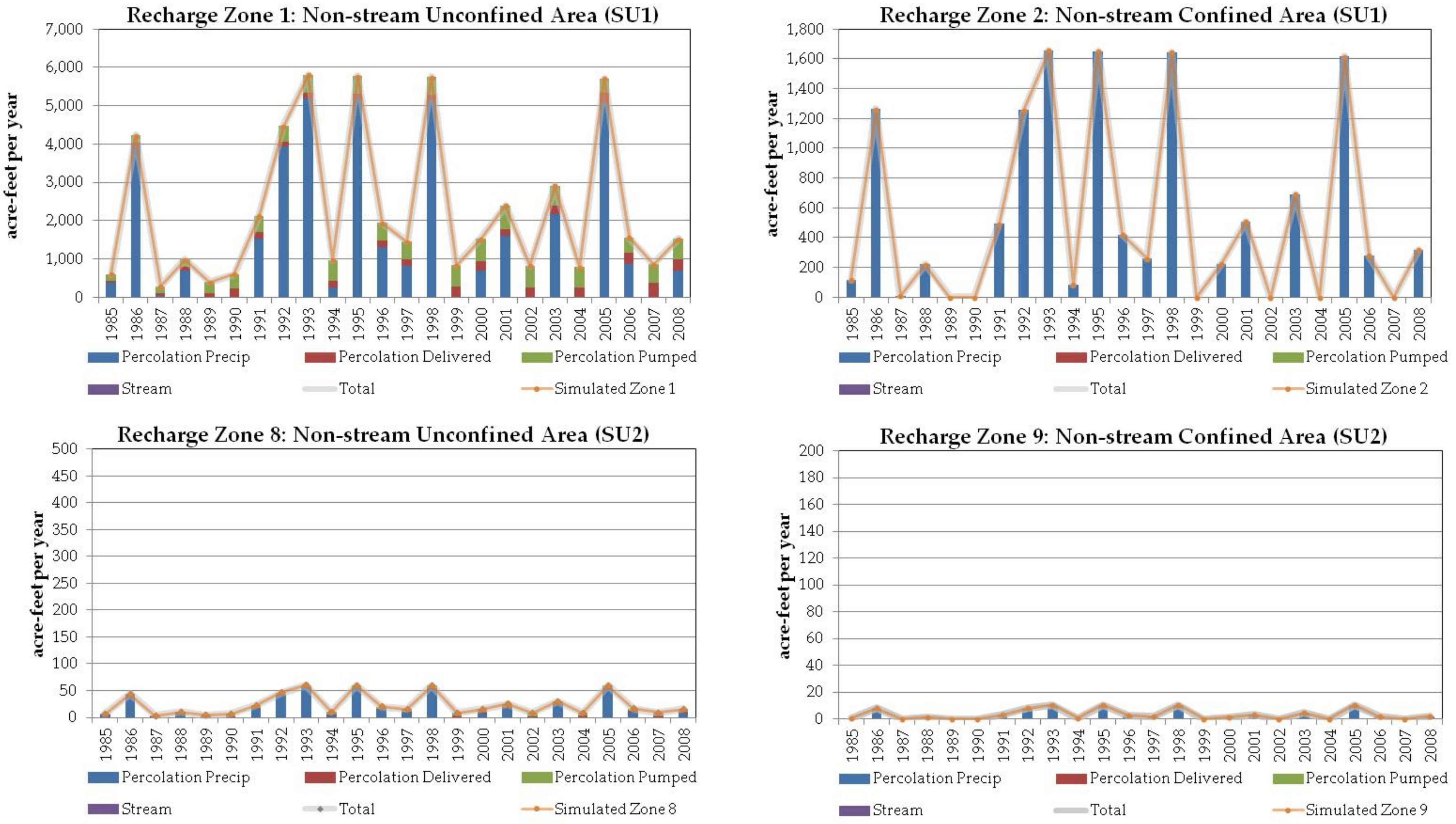


Figure 29: Simulated Water Budget for Recharge Zones with no Streams

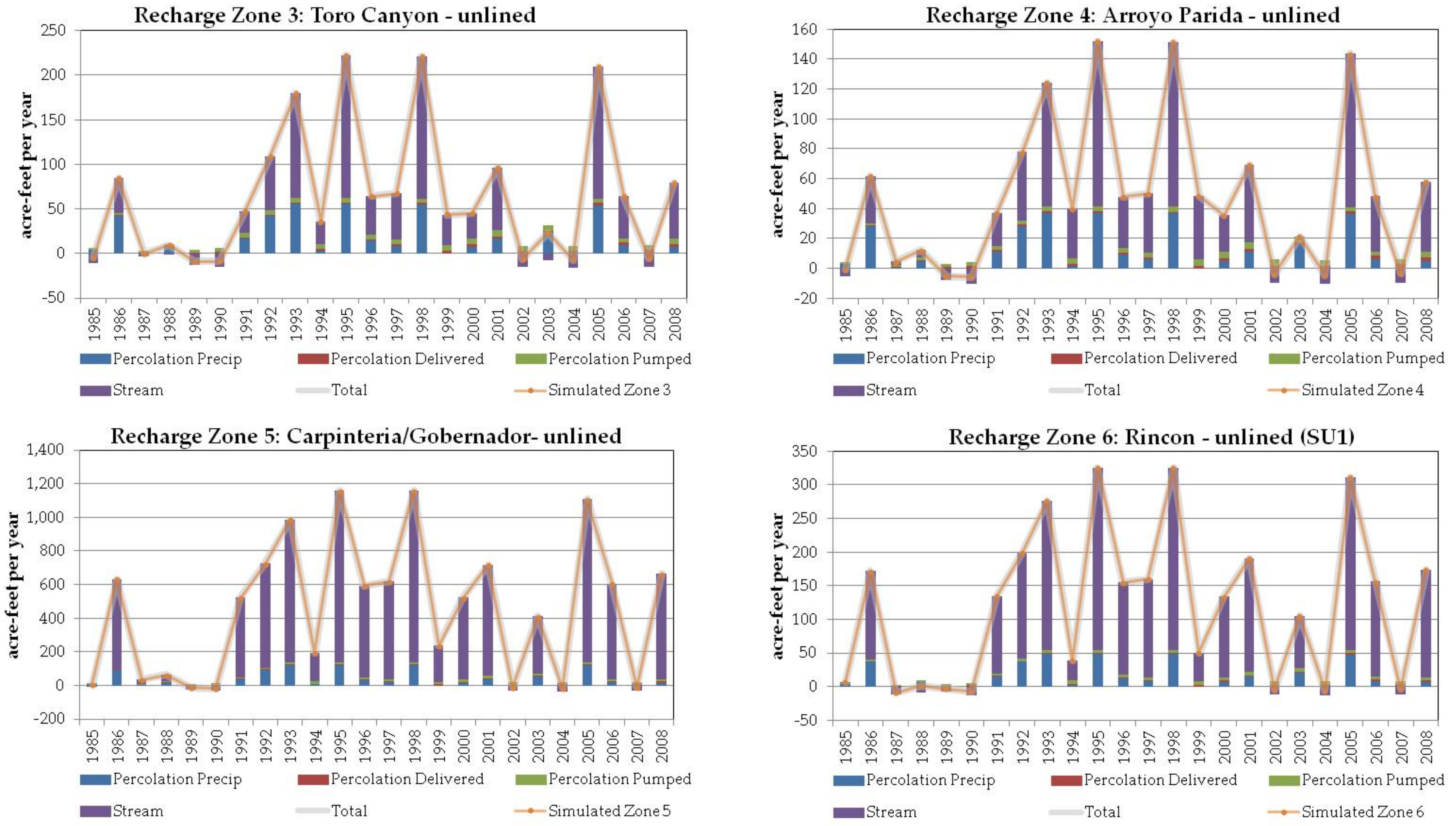
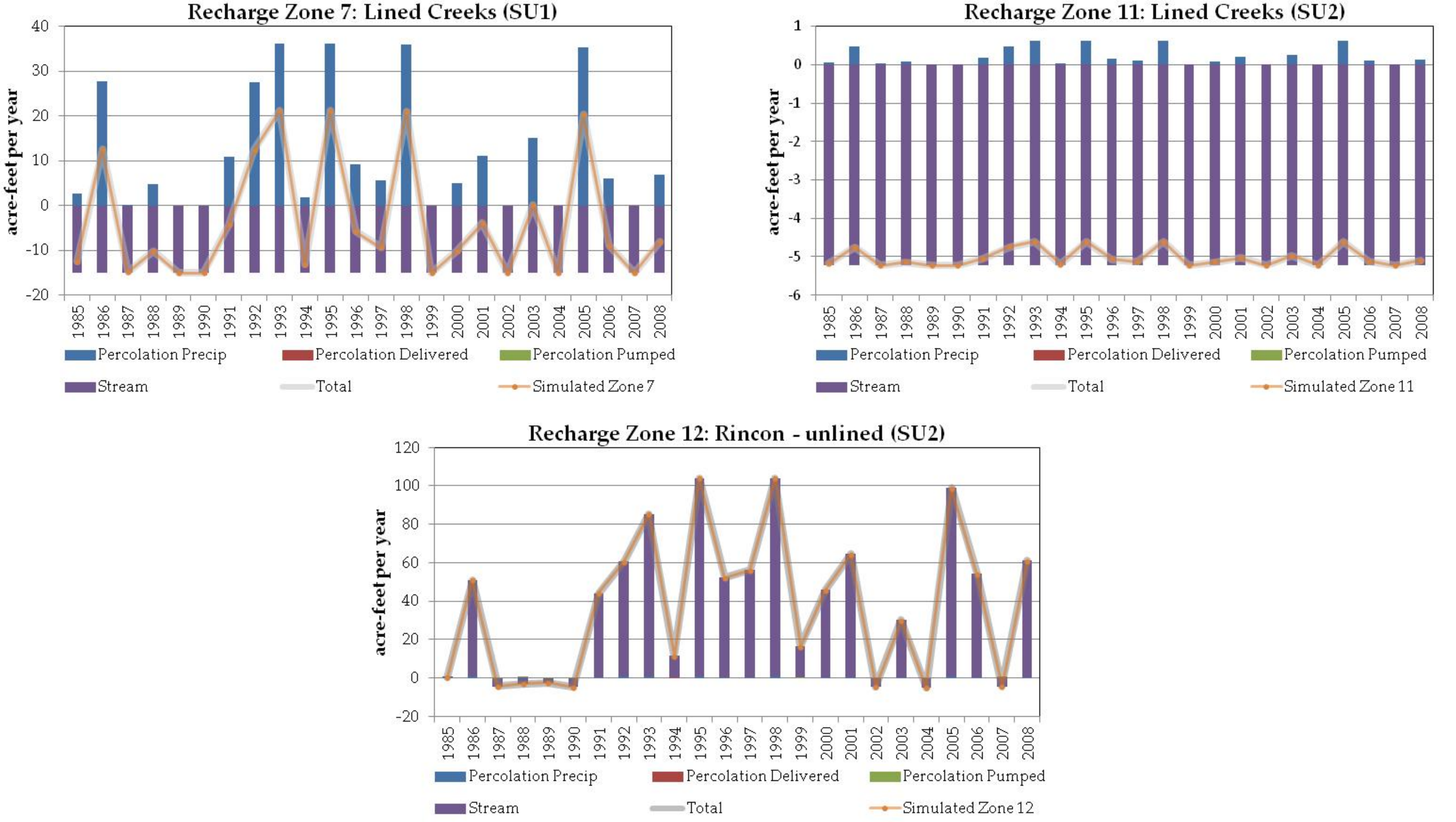


Figure 30: Simulated Water Budget for Recharge Zones with Unlined Creeks in Storage Unit 1


Recharge Zone 7: Lined Creeks (SU1)

Recharge Zone 11: Lined Creeks (SU2)

Recharge Zone 12: Rincon - unlined (SU2)

Figure 31: Simulated Water Budget for Recharge Zones with Lined Creeks and Storage Unit 2 Creeks

SECTION 4
PREDICTIVE MODELING

The calibrated Carpinteria Basin groundwater model, described in Section 3 was used to estimate the effects of five general water management strategies and scenarios. The five management strategies and scenarios included:

- Pumping during an extended drought,
- Pumping to meet increased water demands,
- Implementing Aquifer Storage and Recovery (ASR),
- Adding supplemental wells to the Carpinteria Valley Water District’s existing well field, and
- Recharging additional water through stream beds.

Each scenario is designed to provide general guidance on the groundwater impacts of the strategy. These scenarios can be refined and combined in the future to develop more accurate assessments of groundwater management strategies. Results from each scenario are compared to results from a base simulation that represents the calibrated model. Groundwater elevation and groundwater storage data are analyzed to assess the effectiveness or impact of each scenario. These results will help us evaluate the model’s ability to represent the basin, as well as its predictive capabilities. A description and brief discussion of the scenarios and their results are discussed below.

4.1 SCENARIO 1: EXTENDED DROUGHT

Scenario 1 simulates an extended eight-year drought by adding two additional years to the original 1985-1990 (six-year) drought. This was accomplished by repeating the 1990 pumping and recharge values for two additional years, resulting in a 26-year model. Pumping values throughout the eight-year drought were modified from the original 1985 through 1990 values to account for expected changes in pumping demand due to depletion of surface water supplies. The pumping schedules in subsequent years remain equivalent to the calibration model. Recharge in this scenario was changed to reflect the extended drought conditions, with the 1990 values repeated for two additional years. The year 1990 was repeated because it was the last year with a less than normal precipitation.

Figure 32 and Figure 33 show representative hydrographs comparing the results of the base simulation and results from the extended drought simulation. The hydrographs produced for this scenario depict extremely low groundwater levels during the period of extended drought. Additionally, they suggest a lack of recovery after the drought ends. As shown in Figure 32 and Figure 33, twelve years after drought conditions have subsided (model year 2004), the significantly decreased groundwater levels persist. This reveals the basin's inability to quickly recover from the increased pumping and decreased recharge associated with droughts.

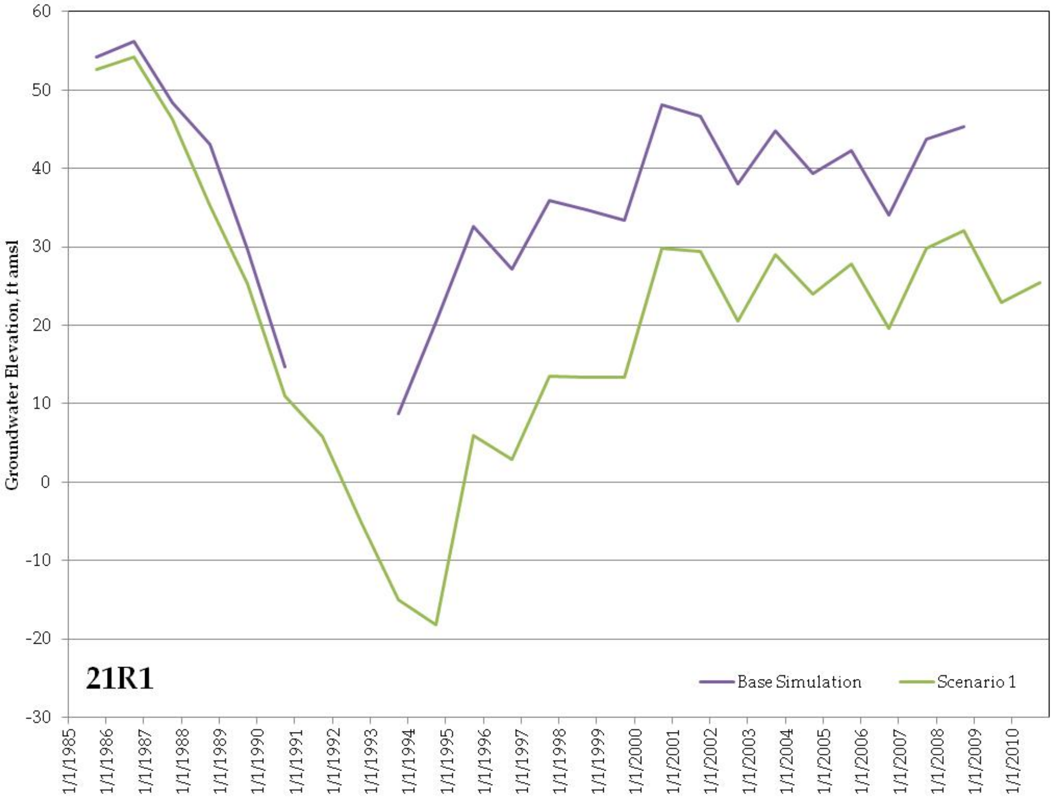


Figure 32: Scenario 1 Hydrograph of Well 21R1

Figure 33: Scenario 1 Hydrograph of Well 28J1

The six-year drought in Scenario 1 causes a substantial decrease in groundwater storage over the modeled period (Figure 34). Extended drought conditions deplete storage and the basin fails to recover, even years after conditions return to normal.

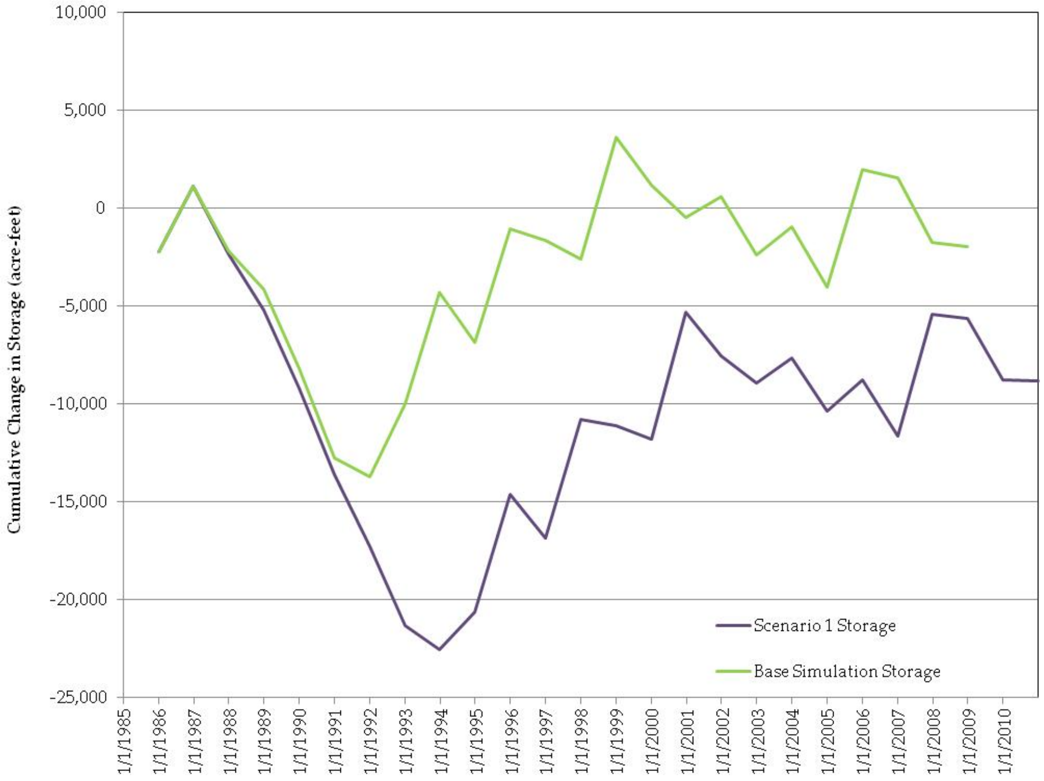


Figure 34: Scenario 1 Cumulative Change in Storage

4.2 SCENARIO 2: INCREASED GROUNDWATER DEMANDS

Scenario 2 involves increasing pumping rates of all wells proportionally in order to model the effects of increased demand. An annual demand increase of 940 acre-feet per year was simulated based on predicted development (residential, commercial, and agricultural) for the year 2030. No changes were made to baseline recharge values. While there are various means for obtaining additional supplies to meet increased demand, this scenario assumes that groundwater will fulfill all additional supply requirements.

Figure 35 and Figure 36 show representative hydrographs comparing the measured groundwater elevation data, results of the base simulation, and results from the increased demand simulation. The produced hydrographs for Scenario 2 depict a significant decrease in groundwater levels throughout the basin as a result of increased pumping demands. The decrease is especially significant during the height of the drought period (1990-1992) as shown in Figure 35 and Figure 36.

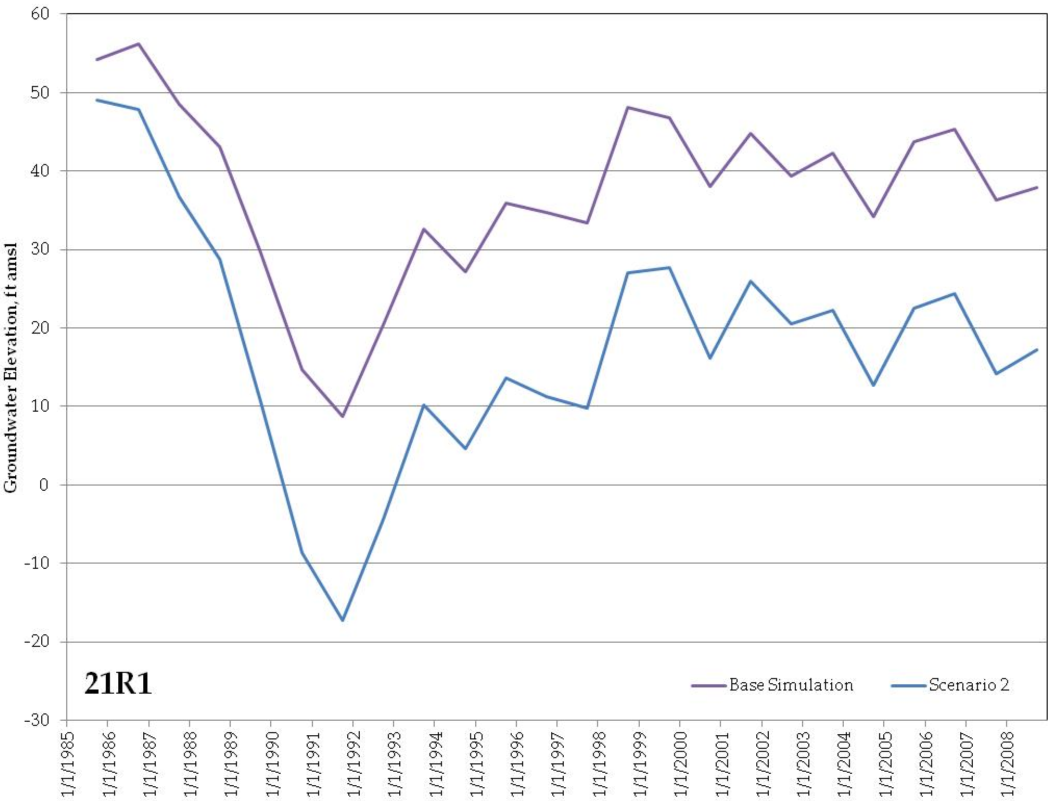


Figure 35: Scenario 2 Hydrograph of Well 21R1

Figure 36: Scenario 2 Hydrograph of Well 28J1

Scenario 2 results in a decrease in groundwater storage due to increased pumping (Figure 37). The loss of groundwater storage is most significant during the six-year drought. After the drought, storage values remain consistently below the base simulation for the remainder of the simulation. This increased demand has a significant effect on the overall groundwater storage in the basin.

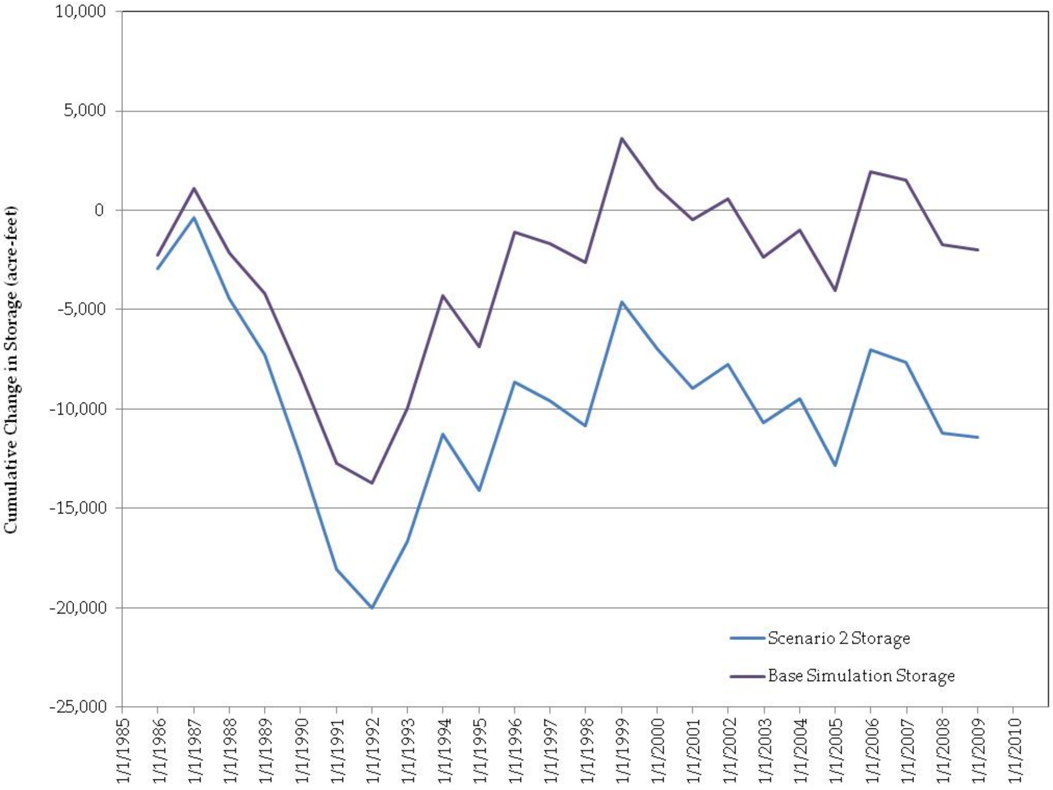


Figure 37: Scenario 2 Cumulative Change in Storage

4.3 SCENARIO 3: AQUIFER STORAGE AND RECOVERY

Scenario 3 simulates converting two existing City of Carpinteria wells to ASR wells. The ASR recharge water is derived from Cachuma Lake surplus. A portion of the winter flows that historically spilled from Cachuma Lake are routed to the two ASR wells. The two wells are assumed to operate at maximum injection rates of 450 and 565 gallons per minute (gpm). There was no surplus Cachuma Lake water available for recharge in 16 of the 24 simulated years. During the eight years when surplus Cachuma Lake water was available, the amount of water recharged ranged between 275 afy and 815 afy. Depending on the magnitude of initial pumping yields, some years resulted in a net annual reduction of pumping, while others resulted in a net gain or true injection.

Two wells designated to receive the injection are 29D7 and 28D2 (the Headquarters and El Carro #2 Wells, respectively). Their resulting hydrographs are shown on Figure 38 and Figure 39. The hydrographs show increased groundwater levels in some years, but the increase appears to be temporary, returning to normal after a couple of years. However, there does seem to be a slight overall shift in all wells, depicting a subtle basin-wide groundwater level increase due to increased recharge.

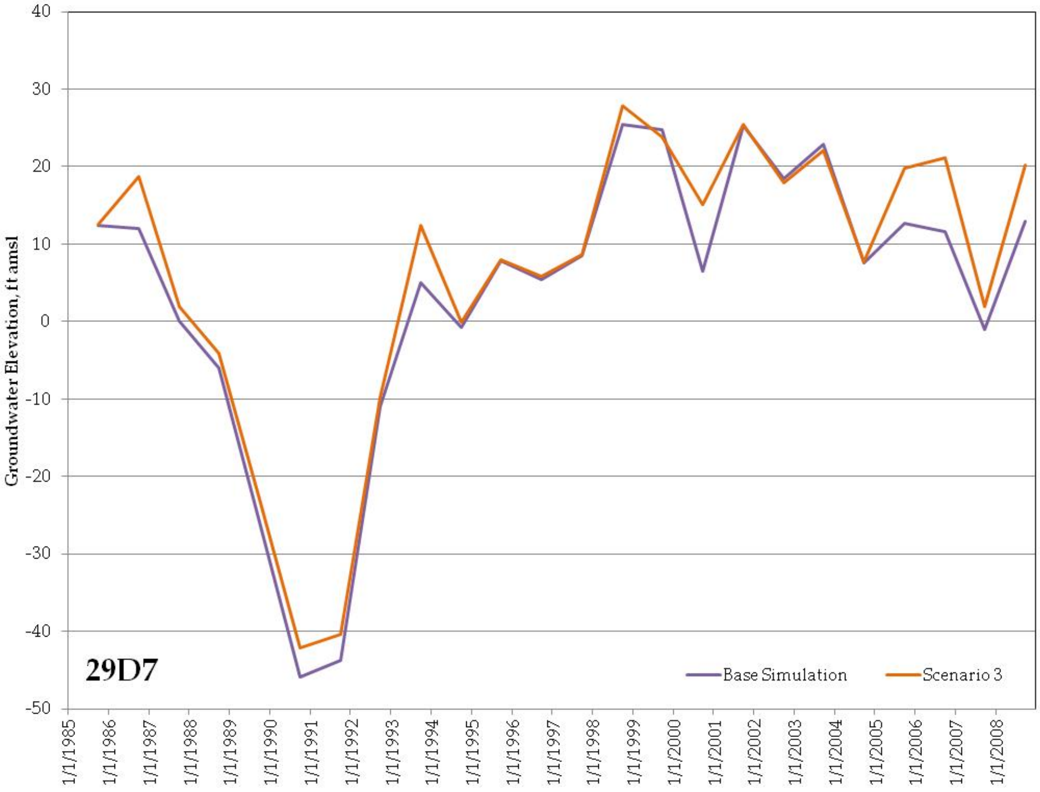


Figure 38: Scenario 3 Hydrograph of Well 29D7

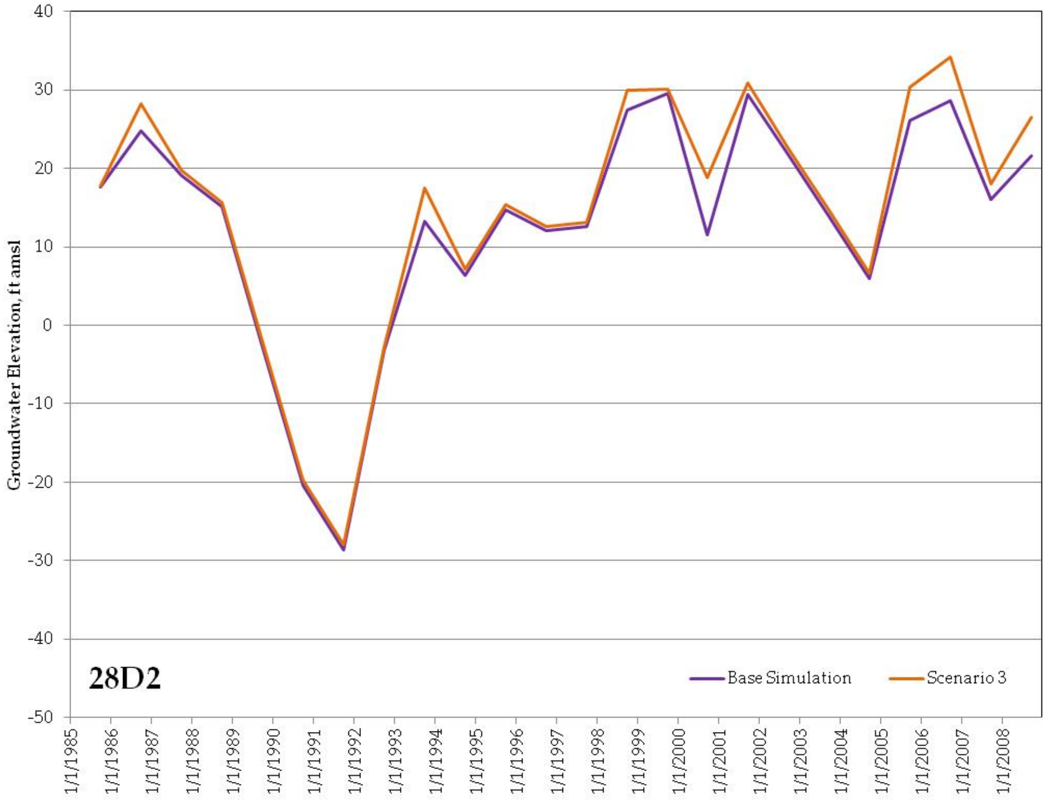


Figure 39: Scenario 3 Hydrograph of Well 28D2

Scenario 3 results in a slight increase in total basin storage through time as expected (Figure 40). While this change does not become visible immediately, the second half of the model run reveals a clear increase, one that appears to persist through time. While the hydrographs for this scenario depict the groundwater level increases as temporary; the storage graph shows that the ASR water remains in storage in the basin. Although a total of 4,520 acre-feet of water could have been recharged through the two wells; after accounting for pumping rate reductions due to low water levels the model only recharged a total of 2,460 acre-feet of surplus Cachuma Lake water over the 24 year simulation period. Of this recharged water, 1,760 acre-feet, or 71% remain in the basin at the end of the simulation. Much of the lost recharge is likely due to outflow to the ocean. If the full 4,520 acre-feet were recharged, we could expect an increase of 3,210 acre-feet of water in the basin by the end of the simulation. The 3,210 acre-feet of increased storage should be used as the benefit from implementing the ASR program.

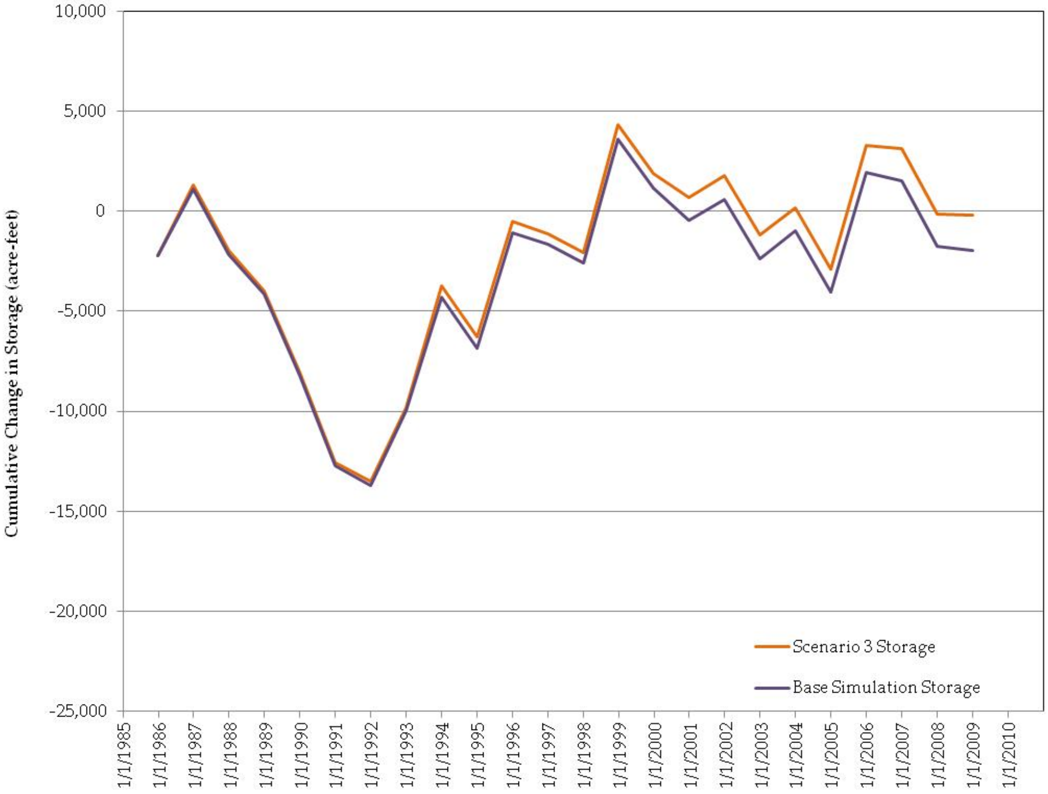


Figure 40: Scenario 3 Cumulative Change in Storage

4.4 SCENARIO 4: ADD A SUPPLEMENTAL WELL AND MAINTAIN THE CURRENT NET EXTRACTION

Scenario 4 redistributes Carpinteria Valley Water District pumping by adding an additional well into the model, located near the Carpinteria Reservoir. The purpose of this new well is to redistribute pumping and reduce local drawdown. The 750 gpm pumping capacity of this new well was proportionally redistributed from existing wells, with total pumping remaining the same. The new well subtracted pumping from following wells: 29D7-D8, 27F2, 28F7, 20K4, and 28D2.

The resulting hydrographs are shown on Figure 41 through Figure 45. These hydrographs show slight recharge trends in wells far away from the new well. Yet the redistributed pumping does not appear to have a significant effect on the District wells, despite the fact that their pumping rates have decreased. The only noticeable difference in groundwater level of well 29D7-D8, 27F2, and 28F7 occurs during the drought years, where the redistributed pumping scheme appears to alleviate the effects of drought conditions.

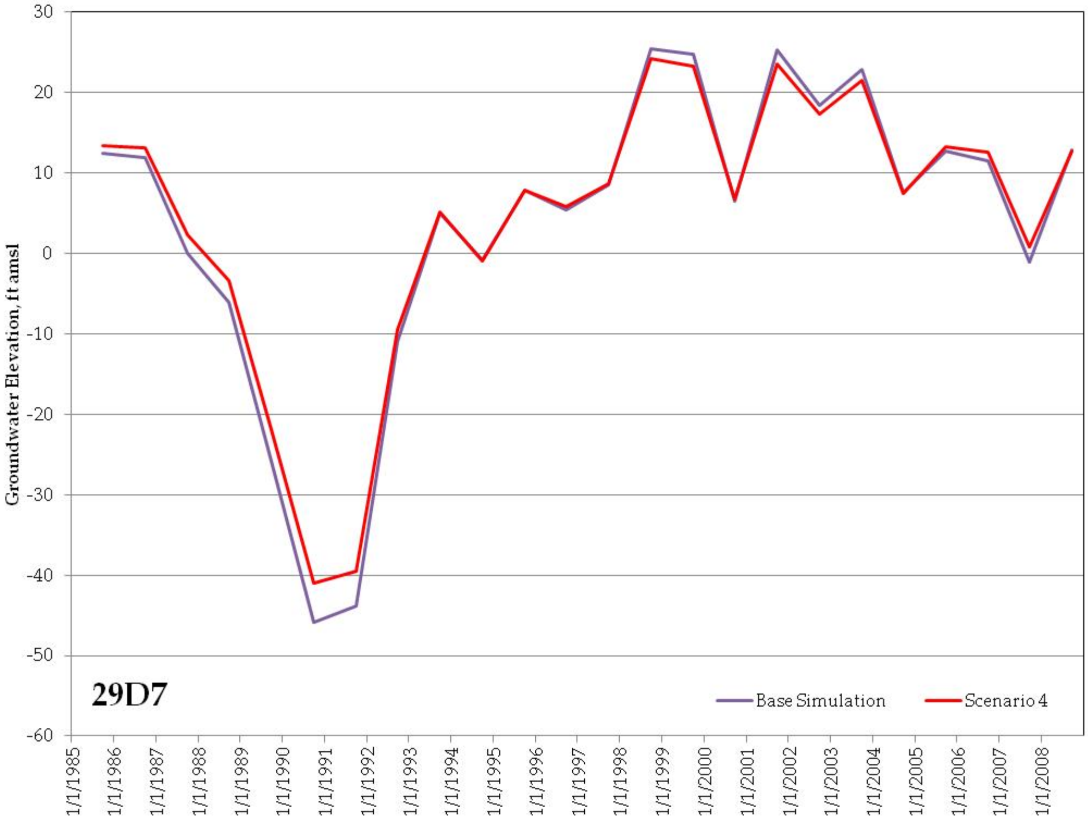


Figure 41: Scenario 4 Hydrograph of Well 29D7

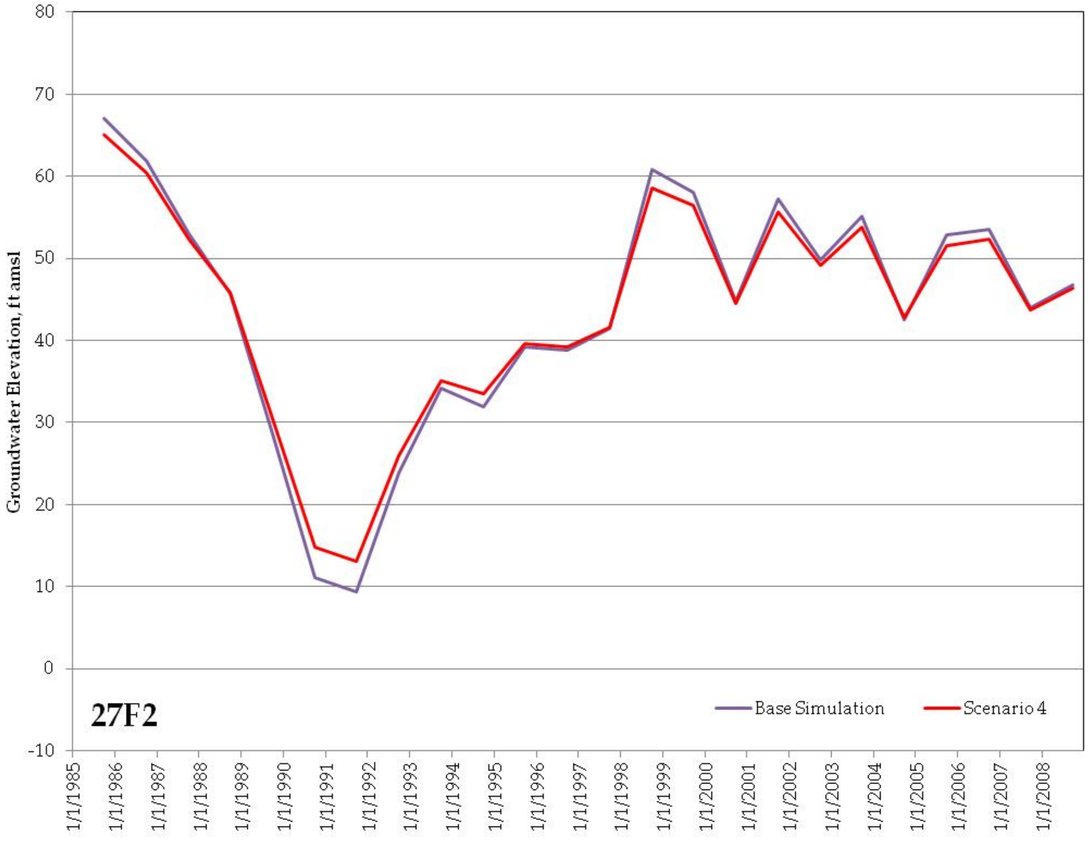


Figure 42: Scenario 4 Hydrograph of Well 27F2

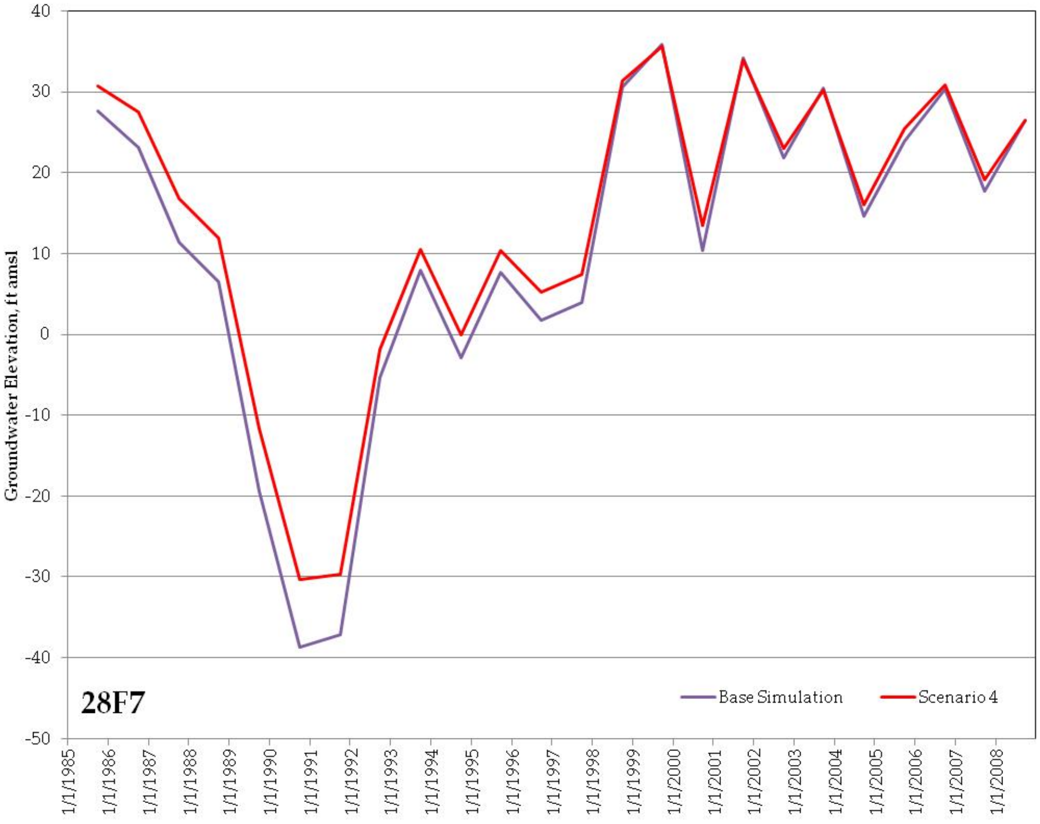


Figure 43: Scenario 4 Hydrograph of Well 28F7

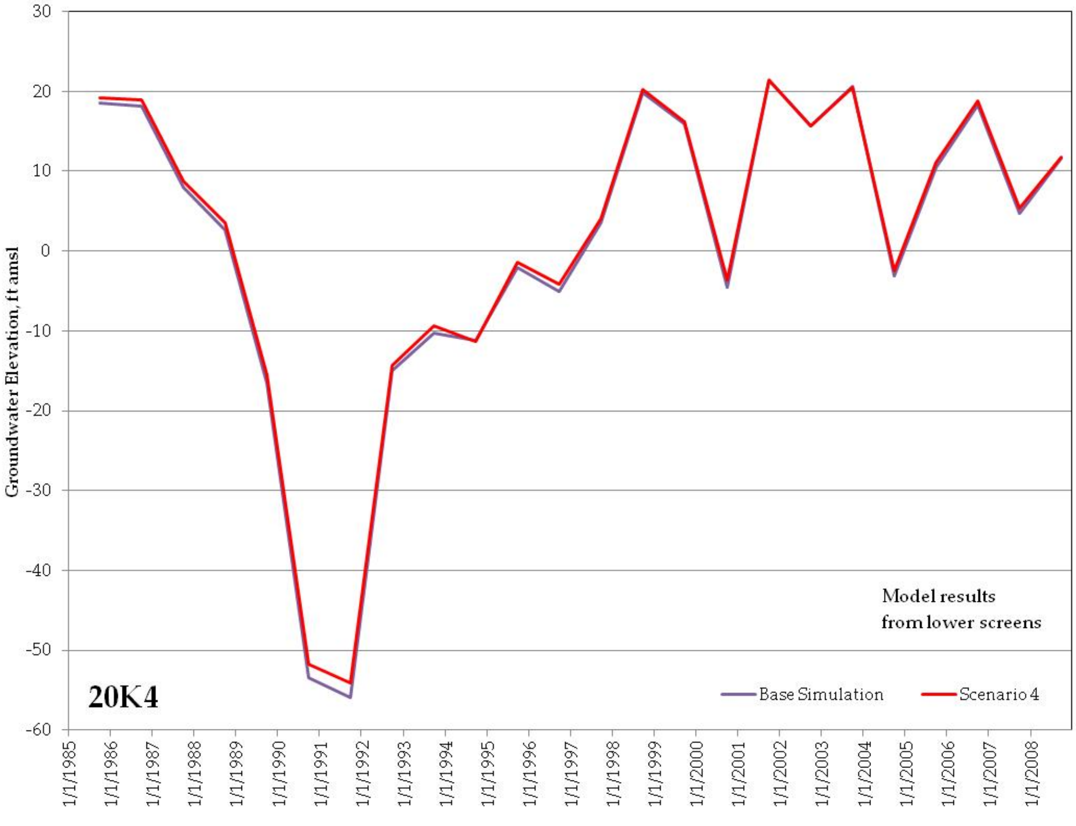


Figure 44: Scenario 4 Hydrograph of Well 20K4

Figure 45: Scenario 4 Hydrograph of Well 28D2

Scenario 4 does not result in any change in basin storage (Figure 46). This is expected because it involves no net loss or gain in pumping, only a shift in pumping from one area of the basin to another. Scenario 4 storage data are identical to the calibration storage data throughout the course of the model.

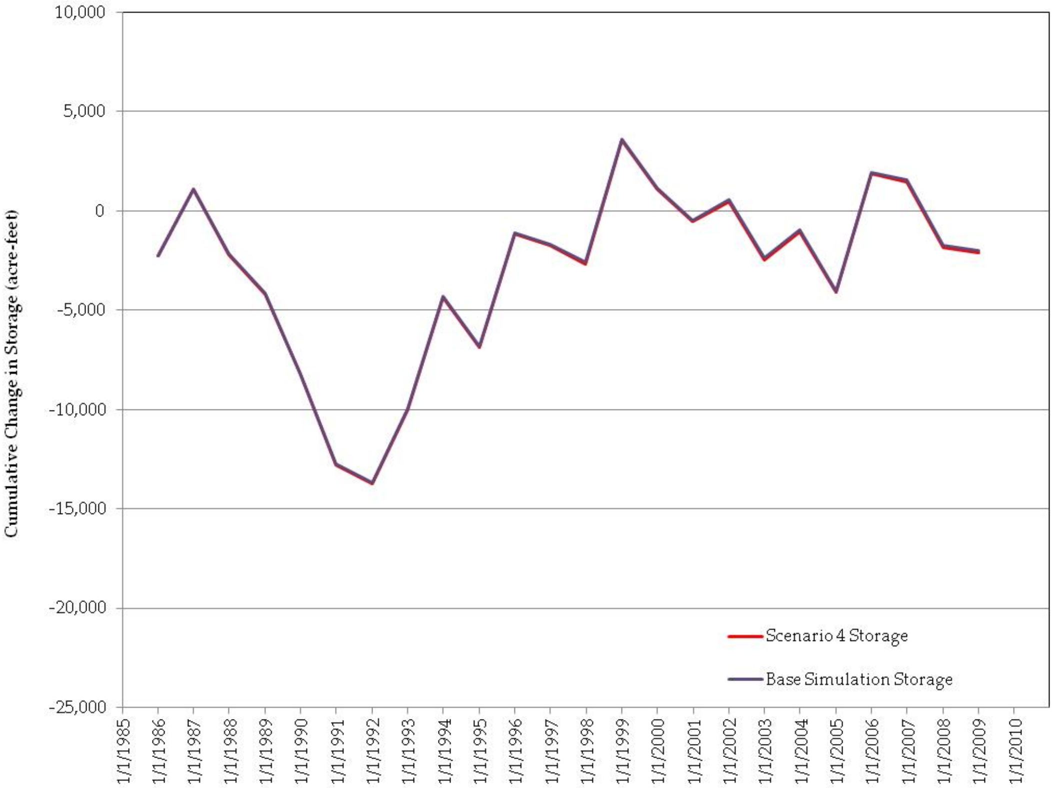


Figure 46: Scenario 4 Cumulative Change in Storage

4.5 SCENARIO 5: RECHARGE DUE TO "DE-LINING" OF CREEKS

This scenario adds new recharge to the model along Santa Monica Creek and Franklin Creek. The two creeks were lined with concrete in 1974. Since being lined, the streambeds no longer contribute to the recharge of the basin. This simulation models the recharge that would occur had the channels not been channelized. The annual increase in recharge due to de-lining Santa Monica Creek and Franklin Creek ranges between 0.4 acre-feet in the driest year, to 520 acre-feet in the wettest year. The average annual increase in recharge is 165 acre-feet per year.

The resulting hydrographs are shown on Figure 47 and Figure 48. These hydrographs show that the Scenario 5 results are similar to the calibrated model hydrographs during drought times. However, the added recharge affects groundwater levels more significantly during periods of normal rainfall and recharge.

Figure 47: Scenario 5 Hydrograph of Well 28G3

Figure 48: Scenario 5 Hydrograph of Well 29D7

Scenario 5 results in the most significant increase in basin storage of all the modeled scenarios (Figure 49). The recharge added by de-lining of creeks has basin-wide storage effects, not just local ones. Approximately 3,940 acre-feet of water are recharged through Santa Monica and Franklin Creeks during the 24-year simulation. Of this amount, approximately 2,930 acre-feet, or 74%, remain in the basin at the end of the simulation.

Figure 49: Scenario 5 Cumulative Change in Storage

SECTION 5

INFORMATION GAINED FROM THE GROUNDWATER MODEL AND RECOMMENDATIONS FOR FUTURE MODEL DEVELOPMENT

The Carpinteria Basin groundwater model has provided substantial new information about how groundwater flows in the Carpinteria Basin. Particular lessons learned from the groundwater model include:

- Recharge from precipitation in the confined zone adds approximately 545 acre-feet per year to the basin. Approximately 330 acre-feet per year of the 545 acre feet of recharge (60%) flows to the ocean, and 215 acre-feet per year (40%) adds to the basin recharge,
- Basin recharge is not equally distributed. In particular, the recharge in Storage Unit 2 is less than the recharge in Storage Unit 1.
- Mountain front recharge is not equally distributed across the northern basin boundary. Distributing mountain front recharge in proportion to upslope drainage area provided better calibration.
- Approximately 71% of water injected through ASR wells can be expected to remain in the basin over long time periods
- Approximately 74% of additional stream percolation derived from de-lining Santa Monica and Franklin creeks can be expected to remain in the basin over long time periods.

The level of development of the Carpinteria Basin model is appropriate to provide general guidance of impacts from groundwater scenarios discussed in Section 4. If more accurate assessments of groundwater scenarios or evaluation of different scenarios are required, the following model enhancements should be considered.

- Implement quarterly stress periods to represent seasonal variation. The model uses annual stress periods and does not reflect seasonal changes in groundwater levels. If the evaluation of groundwater scenarios requires predictions of seasonal changes, shorter stress periods will be required. For example, quarterly stress periods could more accurately reflect extraction and injection periods in the aquifer storage and recovery Scenario 3 discussed in Section 4.3;

- Refine conceptual model and water budget for Storage Unit 2. If groundwater scenarios involve activity in Storage Unit 2, the model should be refined in this area. The calibration for Storage Unit 2 is not as good as the calibration in Storage Unit 1;
- Implement stream routing package for stream percolation from creeks. The model uses the recharge package to implement the defined flux of stream percolation. If local impacts from stream percolation need to be evaluated more accurately, a stream routing package will simulate the percolation flux based on streamflow and groundwater levels as opposed to evenly distributing flux along creek length as currently implemented. This could be important in a more detailed evaluation of recharge from creek "de-lining" in Scenario 5;
- Evaluate effect of pumping constraints in model-node well package on simulation results. If simulated groundwater levels fall below the lowest well screens, the model limits well extraction. As a result, simulations may not result in the full extraction required by different scenarios. A more accurate assessment may require modifying pumping inputs to result in desired extraction; and
- Perform uncertainty analysis on the calibrated model. The uncertainty of model predictions can be evaluated by varying model parameters that results in an acceptable level of calibration. This analysis could be useful to assess the probability groundwater scenarios will meet management objectives.

SECTION 6
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APPENDIX A:
Well Data

Table A- 1: Annual Production by Well (acre-feet)

Well ID		Well Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CVWD	29D7-D8	SY / HQ	905	851	1079	1158	1273	1198	666	318	0	0	0	0	0	0	0	0	0	0	0	113	496	925	1127	499
	27F2	SMILLIE	292	333	291	275	288	359	202	210	261	134	226	190	146	1	100	160	41	73	15	138	92	194	164	162
	28F7	LYONS	639	848	993	909	1423	1449	878	408	564	908	751	1015	1025	405	0	555	108	471	117	344	341	0	127	0
	20K4	HIGH SCHOOL	0	0	0	0	0	407	512	139	436	265	314	352	146	169	169	327	25	4	0	256	223	0	0	0
	28D2	EL CARRO	0	0	0	0	0	0	756	485	0	0	0	0	0	0	71	368	11	10	270	148	0	0	0	0
Private	19E1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.2	22.4	17.7	12.5	14.7	23.2	23.5	0.0	0.0	0.0	0.0	0.0	0.0	31.1	23.1	7.2	47.7
	19F1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.4	1.8	0.8	1.1	1.0	1.1	0.8	0.5	1.3
	19F3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19G1		0.0	1.2	0.0	0.0	9.2	5.8	6.2	6.1	7.0	10.9	7.9	8.8	8.9	5.0	13.0	13.5	15.1	15.1	1.2	0.0	2.1	3.9	0.0	0.0
	19G3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	11.9	10.5	10.6	7.6	9.6	8.1	1.0	0.0	10.3
	19H1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.9	21.1	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19J1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	15.5	25.4	23.3	19.0	19.0	18.9	18.5	17.3	18.4	15.0	12.4	25.8	25.3
	19J2		19.3	20.7	34.8	16.6	24.1	25.6	21.8	0.0	22.7	0.0	19.5	21.6	19.1	18.3	49.5	49.5	49.4	49.0	45.5	50.4	38.1	34.4	50.2	47.7
	19J5		11.7	12.7	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19J6		16.4	20.6	0.0	12.5	19.2	17.1	14.8	55.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19J7		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.1	35.0	0.0	14.5	13.5	13.2	17.9	17.9	17.9	17.9	16.6	18.5	14.3	14.3	17.8	17.8
	19K1		10.6	0.0	0.0	0.0	0.0	0.0	0.0	9.8	5.3	5.3	3.0	3.5	1.1	0.5	1.0	1.0	2.8	0.2	0.0	0.0	0.0	0.0	0.4	0.3
	19K2		0.0	0.0	0.0	5.0	21.1	30.6	26.5	26.0	0.0	0.0	0.0	15.2	0.0	0.0	18.7	19.8	22.5	24.3	23.6	21.2	21.1	21.6	16.3	20.4
	19K3		25.7	31.5	27.2	8.5	11.9	16.6	18.8	20.1	21.4	34.6	17.0	0.0	19.7	22.7	21.5	24.1	31.8	30.9	30.1	24.4	23.8	20.9	1.3	5.1
	19K5		0.0	0.0	0.0	0.0	0.0	2.7	10.7	9.8	11.6	13.3	10.3	11.4	10.7	9.6	13.7	12.4	11.6	8.0	10.9	13.1	10.0	10.5	13.8	12.7
	19K6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	3.4	3.9	1.0	3.9	3.2	5.0	4.7	0.0	2.2
	19K7		15.2	17.4	15.2	18.7	0.0	0.0	0.0	0.0	14.0	21.6	0.0	0.0	21.9	38.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19K8		0.0	0.0	13.0	32.4	44.0	34.1	44.4	18.6	21.0	22.0	17.1	19.0	6.4	6.2	10.2	10.2	10.2	10.2	9.5	10.5	8.1	8.1	10.7	10.1
	19K9		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6	8.5	34.2	31.4	4.6	0.0	2.5	8.6	9.2	8.4	8.7	7.6	1.0	1.4	0.0	3.3
	19L1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.4	26.8	25.0	21.8	22.4	4.4	0.0	0.0	0.0
	19L2		0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	14.9	18.3	28.6	29.6	23.8	19.0	0.6	0.0	8.2
	19M1		0.0	0.0	0.0	11.0	16.6	17.3	14.3	13.1	14.7	16.1	10.5	11.8	13.0	12.2	16.5	16.5	16.5	16.5	15.3	17.0	12.6	12.6	16.5	15.8
	19M2		31.3	22.3	0.0	15.1	17.0	22.0	0.0	0.0	0.0	0.0	30.3	0.0	0.0	0.0	17.1	16.9	18.8	21.2	21.3	17.8	15.5	15.1	10.0	13.3
	19M3		9.3	9.5	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0
	19M4		0.0	0.0	0.0	6.5	6.7	5.4	26.1	9.4	1.0	0.0	0.0	28.1	31.0	22.1	23.0	23.0	23.0	23.0	22.0	20.1	10.0	10.2	0.0	6.7
	19R1		0.0	0.0	0.0	0.0	23.6	39.4	40.4	12.6	31.5	37.7	38.1	35.8	57.3	45.1	27.8	30.4	34.5	34.7	30.9	27.7	12.0	8.0	5.1	13.7
	19R2		0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.0	9.3	34.8	7.6	8.5	7.7	9.4	0.0	29.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	20J2		0.0	10.4	0.0	2.8	35.5	52.5	55.9	102.9	41.8	69.1	0.0	0.0	34.6	0.0	35.1	0.0	59.8	47.4	62.7	58.0	0.0	0.0	8.2	74.8
	20K1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.2	16.7	28.2	22.5
	20L1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	6.8	9.6	10.7	7.0	8.0	16.2	15.8	15.3	12.9	27.1	30.1	19.0	16.2	21.1	25.1
	20L2		23.1	19.3	13.0	26.4	36.9	46.9	46.7	31.6	15.4	35.8	57.9	54.7	51.7	81.8	101.5	99.5	101.6	99.1	93.3	85.0	81.4	85.5	58.2	63.2

Well ID		Well Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	20L3		0.0	17.4	35.7	60.4	29.0	65.5	47.5	3.3	42.9	54.2	28.9	29.8	44.5	32.4	45.5	45.8	44.0	37.9	34.8	43.7	38.4	38.7	0.0	43.5
	20M1		0.0	0.0	0.0	0.0	0.0	0.0	36.8	8.0	15.1	20.6	10.3	11.9	0.0	7.0	3.8	6.9	9.3	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Private	20M3		14.1	30.5	42.3	52.6	66.3	70.2	62.9	62.9	63.3	156.1	71.1	70.4	67.6	61.5	90.6	90.9	91.1	90.9	87.9	86.5	81.2	80.8	73.3	83.0
	20M4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.4	0.0	0.0
	20M6		6.9	0.0	0.0	0.0	1.8	1.8	1.8	1.4	1.6	1.7	1.3	1.4	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	20N1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	10.5	11.9	10.8	11.2	9.1	8.6	8.3	7.8	9.7
	20N2		0.0	1.6	0.0	0.0	2.7	2.9	2.1	0.0	2.2	2.7	1.9	2.1	1.9	0.0	2.5	2.6	2.6	2.5	2.3	2.6	1.9	1.9	2.7	2.6
	20N3		0.0	0.0	10.5	0.0	0.0	0.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	8.8	4.3	11.2	5.9	9.7	9.5	10.1
	20P1		16.9	14.8	25.6	28.1	41.1	42.3	43.6	35.0	31.6	26.5	56.4	52.5	52.3	52.4	55.3	56.1	56.1	55.0	52.5	48.7	0.0	0.0	37.5	46.1
	20Q1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5	19.8	20.8	20.1	20.3	19.4	0.0	0.0	7.3	14.5
	20Q2		0.0	0.0	0.0	0.0	0.0	36.0	0.7	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	8.0
	20Q3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.2	0.0	22.2	23.6	26.4	15.9	10.4	8.8	0.5	1.1	3.2	9.7
	20R4		15.7	31.3	46.3	37.0	38.5	22.2	13.3	0.0	21.7	0.0	69.0	65.4	2.3	56.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	21F1		0.0	0.0	0.0	0.0	0.0	0.0	12.9	9.6	21.6	18.6	8.7	13.1	8.5	14.0	0.0	0.0	11.9	4.2	7.6	7.6	4.8	0.0	5.4	3.5
	21J1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	56.0	0.0
	21L1		0.0	0.0	0.0	0.0	0.0	0.0	11.5	13.6	27.8	107.0	78.6	77.9	125.1	67.3	84.5	79.3	76.2	74.1	72.3	73.8	65.5	68.0	0.0	61.0
	21N1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	1.4	23.8	40.5	9.0	3.3	2.4	0.0	9.3	7.6	2.0	1.3	2.7	4.8
	21N2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.3	15.7	21.2	25.2	28.0	31.8	22.6	22.6	25.0	26.4
	21N3		0.0	0.0	0.0	0.0	0.0	0.0	23.3	5.6	6.7	14.5	11.2	10.7	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	21N4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	21N5		0.0	0.0	0.0	0.0	0.0	19.2	42.1	43.9	42.1	61.5	43.5	49.1	43.5	26.7	54.7	52.4	54.3	52.1	22.8	22.5	8.5	7.9	8.4	26.7
	21N6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.4	24.8	0.0	23.8	23.3	0.0	62.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	21Q1		12.8	0.0	0.0	0.0	0.0	74.9	1.3	7.8	13.0	27.3	52.5	49.3	50.0	33.1	32.2	32.6	32.0	30.6	29.3	27.8	26.2	26.9	10.8	26.7
	21Q2		0.0	0.0	0.0	0.0	0.0	0.0	68.6	58.5	2.3	39.5	72.6	73.3	74.6	79.4	65.1	66.9	68.9	49.7	70.9	83.7	64.8	64.9	90.9	87.2
	21R1		5.3	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.0	33.1	33.1	31.9	30.9	34.1	30.6	30.2	41.3	39.2
	22R2		0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.6	77.6	77.6	77.6	43.8	52.3	43.3	43.3	55.1	52.8
	22R3		0.0	0.0	0.0	8.2	12.8	13.1	10.2	9.2	10.9	12.9	9.7	10.9	10.1	9.1	28.3	28.7	28.1	27.6	8.5	7.6	1.2	3.0	12.1	11.7
	22R4		41.0	45.3	55.7	61.2	89.8	83.3	80.7	80.6	87.0	2.6	0.0	0.0	141.9	117.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	22R5		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	12.2	17.2	9.0	0.9	3.8	0.0	0.9	14.4	0.0
	23A1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	4.8	0.0	1.2	0.0	0.0	0.0	0.0
	23A2		0.0	0.0	0.0	0.0	0.0	0.0	24.6	22.7	17.7	15.0	18.6	20.4	7.1	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	23H7		0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	14.5	9.6	7.8	7.8	2.1	4.3	0.0	3.4	0.0	0.0	5.1	5.0	0.0	4.6	1.7	2.8
	23Q1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	7.7	7.7	7.7	3.6	4.0	2.3	0.7	6.4	7.5
	24A1		0.0	0.0	0.0	0.0	0.0	7.9	0.0	12.7	23.4	24.3	14.0	16.3	14.0	16.4	10.5	13.3	13.5	13.5	24.5	16.3	4.3	4.2	11.2	12.8
	24B2		0.0	0.0	0.0	0.0	0.0	0.0	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	5.1	0.0	0.0	2.3	0.0
	24C1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	9.6	8.3	5.3	0.0	0.0	4.7	4.3	0.0	2.5
	24C4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	10.2	10.3	10.2	9.4	10.5	8.1	8.0	10.9	10.2
	24E3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.9	31.9	31.4	25.5	0.0	0.0	0.0	0.0	2.4	3.7

Well ID		Well Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	24F1		0.0	0.0	0.0	0.0	0.0	0.0	4.2	4.8	7.2	8.3	7.2	8.0	7.4	44.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24F3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.1	24.9	25.3	25.3	23.8	21.2	16.4	17.4	2.2	10.7
	24F4		74.8	118.9	75.4	14.8	34.8	68.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24F8		0.0	0.0	0.0	0.0	0.0	0.0	35.2	42.0	86.5	36.1	14.6	14.6	6.3	24.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Private	24G1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.4	34.6	40.0	38.0	35.0	31.5	0.0	0.0	19.8	29.5
	24G2		0.0	0.0	0.0	0.0	0.0	21.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9	26.3	26.7	26.4	25.4	22.4	20.2	20.6	7.2	14.8
	24H1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	22.6	23.7	16.6	0.0	0.0	0.0	0.0	0.0	1.7
	24H2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.3	0.5	0.5	0.0	0.2	0.1
	24H3		109.3	37.6	0.0	45.2	50.7	54.8	46.8	36.5	36.3	43.0	4.7	4.2	0.0	8.3	5.2	12.8	14.0	8.2	6.9	5.5	0.0	0.0	0.0	0.0
	24H4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	11.1	13.1	12.3	9.6	24.8	55.5	41.7	53.4	50.9	51.3	46.6	0.0	0.0	0.0	10.5
	25F1		0.0	0.0	0.0	0.0	0.0	37.4	51.0	49.8	71.2	64.1	52.2	55.0	51.5	41.0	68.9	68.8	68.6	63.0	77.1	84.1	62.8	56.6	73.2	69.7
	25K1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.1	29.9	30.9	29.4	11.1	12.5	9.9	9.5	31.7	30.1
	25L2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	5.7	5.7	5.7	5.3	5.9	4.6	4.6	6.0	5.7
	25L4		0.0	37.2	16.0	20.7	29.3	31.1	30.3	26.3	29.8	33.0	28.9	31.8	29.6	27.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	25L7		19.7	17.1	16.8	24.0	35.2	39.2	31.7	26.1	30.1	27.1	15.6	18.2	14.1	9.2	36.4	41.8	41.0	41.7	38.4	26.5	17.6	27.3	39.2	39.0
	25N1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0
	25N4		0.0	0.0	0.0	0.0	0.0	10.6	23.4	22.4	22.5	18.5	14.9	14.9	16.4	17.4	3.0	3.0	3.0	2.8	2.9	3.3	2.6	2.6	3.4	3.2
	26B1		0.0	0.0	0.0	0.0	0.0	3.1	6.1	3.2	3.6	1.9	2.9	2.9	2.0	1.9	1.0	0.9	1.5	0.6	2.1	2.2	3.0	1.6	0.0	1.1
	26B2		12.9	34.5	20.3	39.1	43.7	47.2	43.4	49.4	63.1	61.4	37.4	38.0	44.4	40.9	51.1	51.7	52.2	50.3	48.9	29.0	45.4	46.8	42.5	43.3
	26B3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.4
	26C1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	26C3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	10.9	10.9	10.9	10.1	11.2	0.0	0.0	0.0	0.0
	26C4		37.6	28.6	42.9	49.4	81.5	76.3	71.6	72.0	40.6	169.7	133.2	146.9	0.0	12.9	78.6	78.6	78.6	78.6	45.6	55.0	0.0	0.0	0.0	0.0
	26C6		9.8	8.2	13.0	14.0	22.0	19.7	17.0	13.6	16.2	16.0	12.1	13.6	12.1	10.3	15.8	16.0	16.5	14.5	15.3	17.5	10.2	14.6	18.5	17.5
	26C7		10.0	6.6	5.0	6.6	11.1	15.5	12.5	12.5	13.7	17.4	13.6	15.1	14.0	11.6	5.8	5.8	5.8	5.8	5.3	5.9	48.0	48.0	63.7	60.4
	26C8		29.6	32.4	36.2	34.2	50.7	51.4	43.2	40.0	45.0	47.8	37.3	41.3	38.4	37.1	46.7	46.3	47.2	44.7	41.9	45.7	34.4	52.8	48.6	52.4
	26D1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	26E1		0.0	0.0	0.0	0.0	0.0	10.5	22.5	25.8	26.4	18.0	16.0	16.3	15.0	8.9	12.6	11.8	18.7	14.7	30.6	33.1	28.1	27.0	38.2	32.8
	26F1		0.0	0.0	0.0	0.0	0.0	6.1	16.3	32.5	29.2	30.9	24.3	26.7	25.0	24.2	36.0	36.8	36.8	36.7	34.1	38.0	29.3	29.3	38.7	36.5
	26H1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	8.8	3.5	2.0	3.4	4.7
	26L1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0
	26N1		0.0	0.0	0.0	10.8	0.0	14.3	3.9	21.7	20.8	23.8	20.4	20.7	18.7	20.4	23.6	23.4	23.7	23.9	10.2	10.3	10.1	8.4	12.8	11.8
	26N2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	1.2	0.6	3.7	5.4	4.1	2.3
	26N3		0.0	0.0	0.0	0.0	0.0	0.0	21.2	18.9	24.5	31.3	23.1	24.3	22.7	19.6	23.0	22.2	23.6	21.5	27.4	26.4	19.6	18.6	28.4	26.3
	26P2		0.0	0.0	0.0	0.0	0.0	4.5	5.5	6.3	6.5	6.4	5.7	5.7	5.1	6.6	6.7	6.7	6.7	6.7	9.1	10.0	0.0	0.0	0.0	0.0
	27B2		6.0	6.6	0.0	7.2	35.9	31.5	29.6	27.1	30.4	29.5	29.8	34.9	28.6	28.7	10.9	10.9	10.9	10.9	10.1	11.2	8.7	9.6	11.4	10.8
	27B3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	11.6	15.2	12.2	13.5	12.4	10.6	5.6	3.3	5.8	5.8	5.3	5.8	8.3	8.4	21.8	20.2
	27D1		0.0	0.0	0.0	0.0	0.0	0.0	40.4	47.6	52.8	61.9	55.9	55.8	59.9	52.4	62.4	62.3	63.6	62.3	69.8	64.6	73.3	72.2	54.1	70.5

Well ID		Well Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	27E1		38.8	39.8	26.9	59.1	92.8	50.5	80.0	39.7	44.5	47.8	37.1	41.2	38.4	36.7	52.2	52.0	52.1	52.0	48.5	53.9	41.6	41.6	55.2	51.8
	27E2		53.9	44.8	75.8	20.2	46.7	47.4	40.4	37.4	42.0	44.0	0.0	0.0	60.2	34.7	82.4	82.3	82.3	82.0	71.8	79.9	65.7	65.6	86.0	81.8
	27F1		11.1	79.9	23.6	50.4	102.9	69.2	134.5	127.1	178.6	187.1	143.0	157.9	129.2	128.3	112.1	170.8	190.3	175.9	164.5	166.7	129.6	127.2	168.9	159.2
	27F3		0.0	0.0	0.0	0.0	0.0	0.0	11.8	11.0	12.9	14.7	11.2	12.4	11.7	10.5	12.9	12.9	12.8	12.9	11.9	13.3	10.2	10.2	11.4	12.7
	27G1		14.7	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.4	26.6	26.5	26.5	12.7	14.1	10.8	21.4	27.9	26.3
	27G4		0.0	0.0	17.1	18.4	27.2	26.1	22.3	19.7	22.6	25.6	20.0	22.1	20.6	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Private	27H1		0.0	0.0	0.0	0.0	0.0	1.7	2.0	0.0	0.0	4.6	4.7	5.3	5.1	3.2	9.4	9.1	7.7	3.3	2.4	5.0	3.8	3.6	5.3	6.0
	27J1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	12.9	7.4	9.0	6.8	7.6	7.7	17.2	18.6
	27K1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5	20.4	20.4	20.4	18.8	20.8	16.3	16.2	21.5	20.3
	27L1		0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5	0.0
	27L2		18.9	37.1	30.1	68.7	84.5	83.1	36.3	27.5	30.9	32.4	89.9	99.6	38.7	61.7	13.2	17.8	17.8	17.2	16.5	18.3	14.2	13.5	0.0	17.6
	27L3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.0	40.6	44.5	34.4	38.2	36.5	33.5	74.3	74.3	74.5	74.4	54.6	60.2	23.7	23.6	77.7	73.9
	27P1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	8.0	7.9	6.9	7.2	8.0	6.1	5.8	6.8	6.9
	27Q1		22.7	23.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	27Q2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.5	41.7	41.7	41.7	25.0	27.8	21.4	42.8	43.4	38.3
	27Q6		0.0	0.0	26.0	28.1	23.0	36.8	26.7	32.4	36.5	38.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	27Q7		0.0	0.0	0.0	0.0	0.0	0.0	36.4	40.9	44.9	51.8	39.0	43.5	39.5	36.5	30.1	29.2	23.9	21.4	17.7	19.6	17.1	14.0	17.2	14.7
	27Q8		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	34.0	30.9	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	27R2		43.0	41.8	45.3	42.7	44.8	53.4	51.3	40.3	41.0	45.3	37.9	37.1	25.3	32.8	35.9	30.3	33.4	27.9	31.6	28.9	0.0	0.0	0.0	30.3
	27R4		0.0	0.0	0.0	2.6	2.8	6.6	14.5	13.8	20.6	21.3	11.4	12.2	0.0	0.0	18.1	18.8	19.2	18.7	0.0	1.4	0.0	0.0	0.0	0.0
	27R5		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	28A1		0.0	0.0	0.0	0.0	0.0	14.2	51.7	51.6	59.1	52.2	31.4	33.4	34.8	37.2	2.2	2.1	2.4	2.3	3.1	3.3	2.4	2.5	3.6	3.4
	28B1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1	13.7	11.7	11.2	10.2	7.0	9.6
	28D1		48.5	13.9	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	2.5	5.1	3.7	0.0	0.0	0.0
	28D3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	3.2	3.4	3.3	6.3	6.3	0.0	0.0	10.2	9.3
	28F11		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.5	16.1	23.7	23.7	23.8	23.8	22.3	24.9	19.1	19.1	25.2	23.9
	28F2		0.0	0.0	0.0	1.4	7.7	31.3	44.9	46.2	52.1	57.9	0.0	0.0	0.0	0.0	36.7	36.7	36.6	36.7	34.1	37.9	53.4	77.4	57.7	56.2
	28F3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.9	49.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	28F5		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	11.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	28F6		0.0	0.0	0.0	0.0	0.0	0.0	14.4	0.0	14.8	16.6	0.0	0.0	0.0	0.0	15.9	16.0	16.0	16.2	15.0	16.7	12.8	12.8	16.9	16.0
	28G2		0.0	0.0	0.0	0.0	0.0	21.7	11.3	0.0	24.9	37.4	36.4	34.8	31.1	32.7	3.0	1.8	0.2	0.0	0.0	4.0	0.0	0.0	0.0	0.0
	28G3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.5	26.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	28H1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.0	38.3	40.1	31.3	34.6	32.2	31.6	41.8	41.8	41.8	41.8	38.9	43.2	33.3	36.7	43.9	41.5
	28J1		49.1	47.4	39.2	46.5	64.8	68.1	57.0	49.4	61.0	66.3	54.2	59.9	53.8	50.1	61.9	62.4	62.4	62.0	58.5	65.3	50.7	50.8	67.1	63.3
	28J2		0.0	0.0	13.0	0.0	0.0	0.0	29.1	0.0	0.0	0.0	17.7	0.0	0.0	0.0	12.5	11.6	11.2	10.2	3.1	6.1	7.7	7.4	8.0	7.3
	28K2		0.0	0.0	0.0	0.0	0.0	7.9	21.2	19.8	20.8	22.1	0.0	19.6	18.7	18.4	21.0	21.0	20.4	20.9	19.1	21.3	16.7	16.7	22.0	19.4
	28K3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	46.7	46.5	43.7	42.4	41.8	44.8	52.8	51.9	54.5	52.8	52.1	46.6	46.4	39.0	45.8
	28L1		16.7	18.1	19.5	20.9	30.4	29.0	25.2	26.1	29.7	31.6	30.6	33.6	31.6	30.6	35.1	35.2	35.2	35.2	26.7	29.7	22.9	22.9	37.1	35.1

Well ID		Well Name	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	28L3		0.0	0.0	0.0	0.0	0.0	6.8	1.0	0.5	1.1	5.4	0.0	0.0	0.0	0.0	0.5	0.7	0.7	0.3	0.6	0.9	0.7	0.7	0.9	0.9
	28L4		0.0	0.0	2.5	3.9	10.8	7.1	11.9	17.8	10.2	13.6	22.8	25.4	10.4	9.2	13.4	13.4	13.4	13.3	12.1	13.4	10.1	10.1	13.5	12.7
	28M1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	3.2	0.0
	28M5		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1.1	4.9	5.1	1.1	0.0	0.9	0.0	0.0	3.4
	29A2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	4.3	7.5	6.7
	33A1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.1	0.5	0.3	0.3	0.0	0.0	0.4	0.3
	33C1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	10.5	4.5	11.1	4.7	2.5	4.9	0.0	0.0
	34A1		0.0	0.0	0.0	0.0	0.0	6.5	9.2	7.3	8.6	11.5	9.1	10.0	9.2	8.8	12.3	12.0	12.2	11.7	4.9	6.3	5.1	4.4	8.1	6.8
Private	34B1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.4	42.9	43.2	43.5	14.3	17.0	11.4	10.7	21.2	24.1
	34B4		0.0	0.0	0.0	0.0	0.0	22.7	34.2	31.4	33.8	34.7	26.8	29.5	25.6	24.8	0.0	7.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0
	34F2		0.0	0.0	0.0	0.0	18.2	20.8	20.1	13.9	11.1	1.9	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	35A6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4
	35B1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	4.0	3.9	3.8	3.4	3.5	2.6	1.8	2.8	2.6
	35B4		0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.1	4.7	5.3	4.2	4.3	4.3	3.5	4.1	4.1	4.3	4.0	5.3	6.6	4.8	5.0	6.7	7.1
	35B5		0.0	0.0	0.0	0.0	0.0	9.9	9.3	28.8	30.1	32.7	27.8	30.2	28.9	18.0	36.0	35.9	35.9	35.8	12.5	17.4	13.3	12.8	21.8	23.2
	35B6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	24.7	25.7	22.2	22.7	24.6	18.4	30.1	30.1	31.7	31.6	42.2	46.4	37.3	37.3	51.0	48.9
	35C1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.0	58.2	58.1	56.8	13.3	14.5	10.6	10.2	47.0	49.9
	35C3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
	35D1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5	20.8	17.9	20.4	21.0	23.6	17.2	18.0	24.8	23.0
	35E1		24.9	26.0	23.6	15.3	0.0	24.7	25.1	39.8	32.1	2.6	14.5	16.3	50.9	0.0	43.7	43.7	43.7	43.7	36.5	44.0	28.4	27.5	35.5	32.0
	35E2		22.0	12.3	12.8	13.7	20.3	20.6	18.9	17.5	19.5	20.1	29.8	31.2	16.3	15.1	0.0	0.0	0.0	10.6	0.0	0.0	0.0	0.0	0.0	0.0
	35E3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.9	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0
	35F1		0.0	0.0	1.1	0.0	0.0	18.6	23.4	0.0	0.0	0.0	0.0	0.0	0.0	10.7	15.7	11.2	13.4	0.0	5.4	9.4	6.0	1.6	0.0	9.3
	35M1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.3	0.0	0.0	0.0	3.1	3.9	3.9	3.9	0.0	0.2	0.2	0.1	0.1	3.0	2.9

Table A- 2: Known Screen Intervals for Pumping Wells

Well ID		Surface Elevation	Screen 1 Elevation		Screen 2 Elevation		Screen 3 Elevation		Screen 4 Elevation		Screen 5 Elevation	
			Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
		feet amsl										
CVWD	29D7-D8	41	-276	-307	-317	-318	-528	-569	-719	-750	-850	-897
	27F2	136.5	-318.5	-664.5								
	28F7	70.5	-239.5	-279.5	-329.5	-349.5	-419.5	-859.5	-1069.5	-1,109.5	-1,139.5	-1,159.5
	20K4	52.2	-302.8	-362.8	-562.8	-592.8	-652.8	-672.8	-692.8	-712.8	-772.8	-832.8
	28D2	60.6	-223.4	-267.4	-793.4	-853.4	-1,033.4	-1,133.4				
Private	19E1	71.7	-48.3	-328.3								
	26E1	340.9	-9.1	-259.1								
	35E2	249.5	-144.5	-243.5								
	19J7	72.4	-107.6	-227.6	-247.6	-407.6						
	19L2	66.4	-123.6	-213.6	-263.6	-363.6						
	19R2	63.7	-96.3	-216.3								
	20J2	58.4	-56.6	-76.6	-116.6	-196.6	-216.6	-314.6				
	20M1	107.1	7.1	-104.9								
	20N3	65.2	-54.8	-246.8								
	20Q3	47.1	-268.9	-858.9								
	20R4	48.9	-71.1	-201.1								
	21F1	101.8	-40.67	-348.2								
	21J1	129.2	-247.27	-640.8								
	21L1	85.6	-279.4	-646.4								
	21N4	65.4	5.4	-340.6								
	21N5	63.1	-311.9	-816.9								
	21N6	72.5	-277.5	-357.5	-447.5	-657.5	-717.5	-817.5				
	21Q1	92.6	-147.4	-347.4	-367.4	-647.4						
	21R1	116.1	34.1	-299.9								
	22R4	243.3	51.3	-260.7								
	23H7	41.2	-58.8	-376.8								
	24B2	90.8	-93.46	-299.2								
	24G2	50.9	-159.1	-389.1								
	24H4	55.8	-184.2	-384.2	-564.2	-754.2						
	25F1	328.5	269.02	28.5								
	25L4	247.4	157.4	-102.6								
	25N4	192.1	107.1	-102.9								
	26B1	468.3	228.3	-83.7								
	26C4	291.6	161.6	-294.4								
	26C6	314.2	225.2	-102.8								
	26C7	276.6	195.6	-98.4								

Well ID		Surface Elevation	Screen 1 Elevation		Screen 2 Elevation		Screen 3 Elevation		Screen 4 Elevation		Screen 5 Elevation	
			Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
		feet amsl										
Private	26C8	270.7	126.7	-89.3								
	26D1	420.9	120.9	-49.1								
	26F1	291	111	-159								
	26L1	291.6	91.6	51.6	-48.4	-128.4						
	26N3	144.1	-75.9	-295.9								
	26P2	270.8	180.8	30.8	10.8	-79.2						
	27D1	135.5	-264.5	-724.5								
	27F1	124.1	-35.9	-155.9	-235.9	-297.9						
	27F2	136.5	-318.5	-664.5								
	27F3	123.7	23.7	-376.3								
	27G4	167.6	-82.4	-432.4								
	27H1	201.3	1.3	-318.7								
	27Q6	139.6	39.6	-440.4								
	27Q7	141.7	-5.3	-395.3								
	27R2	133.5	-161.5	-286.5								
	27R5	140.7	40.7	-159.3								
	28A1	101.4	-138.6	-238.6	-258.6	-478.6						
	28D3	60.6	-239.4	-279.4								
	28G3	89.7	-110.3	-210.3								
	28H1	105.2	-94.8	-394.8								
	28K2	82.8	-57.2	-417.2								
	28K3	71.5	-101.5	-301.5	-341.5	-421.5						
	34B4	178.9	118.9	98.9	-1.1	-21.1	-121.1	-221.1				
	34F2	163.5	78.5	-399.5								
	35B5	142.8	52.8	12.8	-17.2	-127.2						
	35B6	227.6	67.6	7.6	-12.4	-72.4	-112.4	-172.4	-252.4	-312.4		
	35B5	142.8	52.8	12.8	-17.2	-127.2						
	35B6	227.6	67.6	7.6	-12.4	-72.4	-112.4	-172.4	-252.4	-312.4		

Table 7: Estimated Screen Intervals for Private Pumping Wells

Table A- 3: Estimated Screen Intervals for Private Pumping Wells

Well ID		Estimated Screen Elevation		Estimate Basis	Nearby Observation Wells	Model Layer to Increase Drawdown
	Surface Elevation	Top	Bottom			
	feet amsl					
27E1	41	-421.97	-506.11	Observed GW Levels	27F2	4
35E1	136.5	-140	-250	Nearby PW Screens		
27E2	70.5	20	-260	Nearby PW Screens		
24E3	52.2	-180	-370	Nearby PW Screens		
35E3	60.6	-140	-250	Nearby PW Screens		
19F1	71.7	-125	-400	Nearby PW Screens		
19F3	340.9	-15	-300	Nearby PW Screens		
19G1	249.5	-10	-300	Nearby PW Screens		
19G3	72.4	-10	-300	Nearby PW Screens		
19H1	66.4	10	-300	Nearby PW Screens		
19J1	63.7	-10	-300	Nearby PW Screens		
19J2	58.4	-10	-300	Nearby PW Screens		
19J5	107.1	-100	-400	Nearby PW Screens		
19J6	65.2	-100	-400	Nearby PW Screens		
19K1	47.1	-100	-400	Nearby PW Screens		
19K2	48.9	-100	-400	Nearby PW Screens		
19K3	101.8	-100	-400	Nearby PW Screens		
19K5	129.2	-100	-400	Nearby PW Screens		
19K6	85.6	-100	-400	Nearby PW Screens		
19K7	65.4	-100	-400	Nearby PW Screens		
19K8	63.1	-100	-400	Nearby PW Screens		
19K9	72.5	-100	-400	Nearby PW Screens		
19L1	92.6	-100	-400	Nearby PW Screens		
19M1	116.1	-105	-400	Nearby PW Screens		
19M2	243.3	-130	-400	Nearby PW Screens		
19M3	41.2	-80	-400	Nearby PW Screens		
19M4	90.8	-120	-400	Nearby PW Screens		
19R1	50.9	-100	-350	Nearby PW Screens		
20K1	55.8	-50	-400	Nearby PW Screens		
20L1	328.5	-20	-400	Nearby PW Screens		
20L2	247.4	-20	-400	Nearby PW Screens		
20L3	192.1	-20	-400	Nearby PW Screens		
20M3	468.3	-30	-300	Nearby PW Screens		
20M4	291.6	-30	-300	Nearby PW Screens		

Well ID		Estimated Screen Elevation		Estimate Basis	Nearby Observation Wells	Model Layer to Increase Drawdown
	Surface Elevation	Top	Bottom			
	feet amsl					
20M6	314.2	0	-300	Nearby PW Screens		
20N1	276.6	-60	-330	Nearby PW Screens		
20N2	270.7	-40	-220	Nearby PW Screens		
20P1	420.9	-100	-250	Nearby PW Screens		
20Q1	291	-50	-350	Nearby PW Screens		
20Q2	291.6	-50	-350	Nearby PW Screens		
21N1	144.1	-60	-400	Nearby PW Screens		
21N2	270.8	-30	-350	Nearby PW Screens		
21N3	135.5	-280	-800	Nearby PW Screens		
21Q2	124.1	-100	-500	Nearby PW Screens		
22R2	136.5	150	-150	Nearby PW Screens		
22R3	123.7	140	-5	Nearby PW Screens		
22R5	167.6	305	299	Nearby PW Screens		
23A1	201.3	51	10	Nearby PW Screens		
23A2	139.6	50	30	Nearby PW Screens		
23Q1	141.7	306	302	Nearby PW Screens		
24A1	133.5	70	35	Nearby PW Screens		
24C1	140.7	94	86	Nearby PW Screens		
24C4	101.4	-50	-300	Nearby PW Screens		
24F1	60.6	-50	-300	Nearby PW Screens		
24F3	89.7	-60	-360	Nearby PW Screens		
24F4	105.2	-60	-360	Nearby PW Screens		
24F8	82.8	-60	-360	Nearby PW Screens		
24G1	71.5	-50	-300	Nearby PW Screens		
24H1	178.9	-200	-500	Nearby PW Screens		
24H2	163.5	-200	-500	Nearby PW Screens		
24H3	142.8	-200	-500	Nearby PW Screens		
25K1	227.6	240	210	Nearby PW Screens		
25L2	142.8	200	10	Nearby PW Screens		
25L7	227.6	275	270	Nearby PW Screens		
25N1	227.6	80	-120	Nearby PW Screens		
26B2	227.6	310	40	Nearby PW Screens		
26B3	227.6	260	60	Nearby PW Screens		
26C1	227.6	200	0	Nearby PW Screens		
26C3	227.6	150	80	Nearby PW Screens		
26H1	227.6	350	100	Nearby PW Screens		
26N1	227.6	-10	-400	Nearby PW Screens		

Well ID		Estimated Screen Elevation		Estimate Basis	Nearby Observation Wells	Model Layer to Increase Drawdown
	Surface Elevation	Top	Bottom			
	feet amsl					
26N2	227.6	-50	-350	Nearby PW Screens		
27B2	227.6	90	-200	Nearby PW Screens		
27B3	227.6	126.65	72.06	Observed GW Levels	27F2	2
27G1	227.6	125.69	71.82	Observed GW Levels	27F2	2
27J1	227.6	-40	-400	Nearby PW Screens		
27K1	227.6	-545.06	-581.99	Observed GW Levels	27Q6	6
27L1	227.6	-679.32	-745.73	Observed GW Levels	27Q6	6
27L2	227.6	-455.53	-523.27	Observed GW Levels	27Q6	4
27L3	227.6	-699.07	-764.66	Observed GW Levels	27Q6	6
27P1	227.6	-776.23	-868.14	Observed GW Levels	27Q6	6
27Q1	227.6	-648.29	-697.39	Observed GW Levels	27Q6	6
27Q2	227.6	-687.33	-732.5	Observed GW Levels	27Q6	6
27Q8	227.6	-648.29	-697.39	Observed GW Levels	27Q6	6
27R4	227.6	-591.43	-624.85	Observed GW Levels	27Q6	6
28B1	227.6	-50	-400	Nearby PW Screens		
28D1	227.6	-50	-400	Nearby PW Screens		
28F11	227.6	-50	-350	Nearby PW Screens		
28F2	227.6	-50	-350	Nearby PW Screens		
28F3	227.6	-50	-350	Nearby PW Screens		
28F5	227.6	-50	-350	Nearby PW Screens		
28F6	227.6	-50	-350	Nearby PW Screens		
28G2	227.6	-20	-300	Nearby PW Screens		
28J1	227.6	-50	-300	Nearby PW Screens		
28J2	227.6	-50	-300	Nearby PW Screens		
28L1	227.6	-50	-350	Nearby PW Screens		
28L3	227.6	-50	-350	Nearby PW Screens		
28L4	227.6	-50	-350	Nearby PW Screens		
28M1	227.6	-50	-350	Nearby PW Screens		
28M5	227.6	-50	-350	Nearby PW Screens		
29A2	227.6	-100	-360	Nearby PW Screens		
33A1	227.6	-200	-400	Nearby PW Screens		
33C1	227.6	-280	-400	Nearby PW Screens		
34A1	227.6	-310	-410	Nearby PW Screens		
34B1	227.6	-20	-280	Nearby PW Screens		
35A6	227.6	70	-120	Nearby PW Screens		
35B1	227.6	80	-80	Nearby PW Screens		
35B4	227.6	80	-80	Nearby PW Screens		

Well ID		Estimated Screen Elevation		Estimate Basis	Nearby Observation Wells	Model Layer to Increase Drawdown
	Surface Elevation	Top	Bottom			
	feet amsl					
35C1	227.6	60	-340	Nearby PW Screens		
35C3	227.6	50	-350	Nearby PW Screens		
35D1	227.6	25	-370	Nearby PW Screens		
35F1	227.6	-140	-250	Nearby PW Screens		
35M1	227.6	-140	-250	Nearby PW Screens		

GW = groundwater, PW = production well