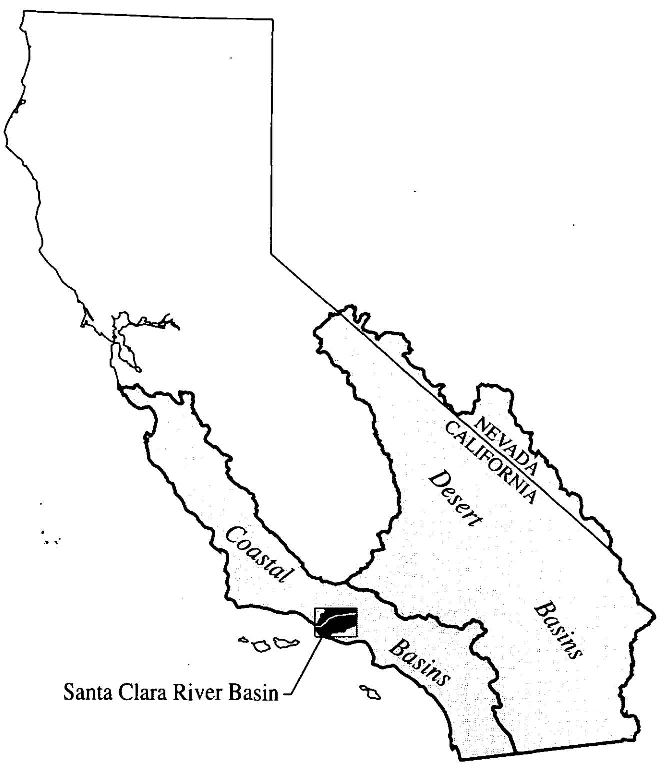
U.S. Department of the Interior
U.S. Geological Survey

Evaluation of Surface-Water/Ground-Water Interactions in the Santa Clara River Valley, Ventura County, California

Water-Resources Investigations Report 98-4208

REGIONAL AQUIFER-SYSTEM ANALYSIS



Southern California Basins

Prepared in cooperation with the
UNITED WATER CONSERVATION DISTRICT

USGS
science for a changing world

Evaluation of Surface-Water/Ground-Water Interactions in the Santa Clara River Valley, Ventura County, California

By Eric G. Reichard, Steven M. Crawford, Katherine Schipke Paybins, Peter Martin, Michael Land, *and* Tracy Nishikawa

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98–4208

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UNITED WATER CONSERVATION DISTRICT

Sacramento, California
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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CONVERSION FACTORS, ABBREVIATIONS, WATER-QUALITY INFORMATION, VERTICAL DATUM, AND WELL-NUMBERING SYSTEM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Abbreviations:

GIS	Geographic information system
PVC	Polyvinyl chloride
RASA	Regional Aquifer-System Analysis
TU	Tritium unit
USGS	U.S. Geological Survey
UWCD	United Water Conservation District

Water-Quality Information

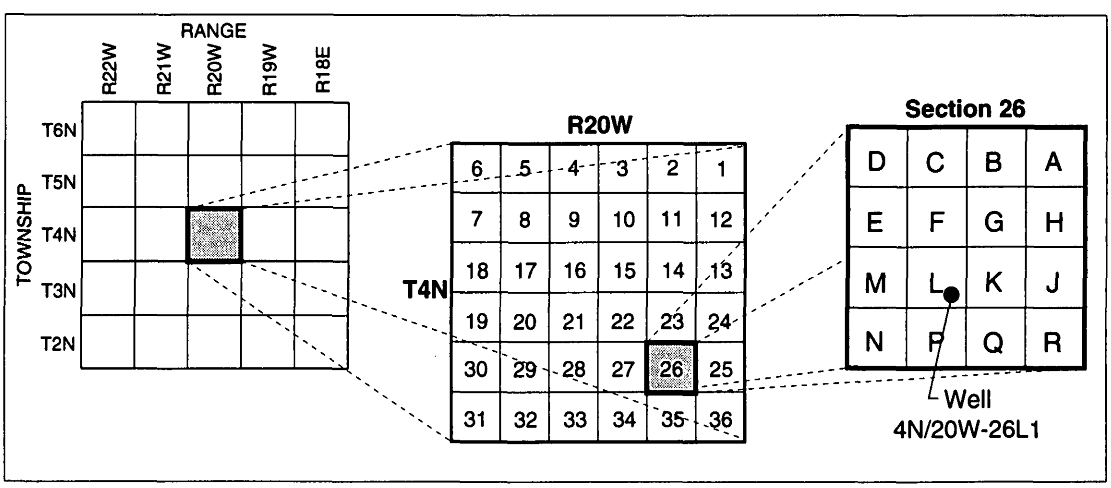
Specific conductance is given in microsiemens per centimeter at 25 degrees Calsius (µS/cm at 25°C). Concentrations of chemical constituents in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/L)

Vertical Datum

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Well-Numbering System

Wells are identified and numbered according to their location in the rectangular system for the subdivision of public lands. Identification consists of the township number, north or south; the range number, east or west; and the section number. Each section is divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with "A" in the northeast corner of the section and progressing in a sinusoidal manner to "R" in the southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. In California, there are three base lines and meridians; Humboldt (H), Mount Diablo (M), and San Bernardino (S). All wells in the study area are referenced to the San Bernardino base line and meridian (S) Well numbers consist of 15 characters and follow the format 004N020W26L001S. In this report, well numbers are abbreviated and written 4N/20W-26L1. The following diagram shows how the number for well 4N/20W-26L1 is derived.



Well-numbering diagram

EVALUATION OF SURFACE-WATER/GROUND-WATER INTERACTIONS IN THE SANTA CLARA RIVER VALLEY, VENTURA COUNTY, CALIFORNIA

By Eric G. Reichard, Steven M. Crawford, Katherine Schipke Paybins, Peter Martin, Michael Land, *and* Tracy Nishikawa

ABSTRACT

The interactions of surface water and ground water along the Santa Clara River in Ventura County, California, were evaluated by analyzing river-discharge and water-quality data and geohydrologic information collected by the U.S. Geological Survey between 1993 and 1995 for the Piru, Fillmore, and Santa Paula subbasins. Measurements of discharge and water quality were made at multiple locations along the Santa Clara River and its tributaries at eight different time periods during different releases from Lake Piru. Geologic, hydraulic, and water-quality data were collected from three new multiple-completion ground-water monitoring wells. These data, together with data collected as part of the U.S. Geological Survey Southern California Regional Aquifer-System Analysis (RASA) study, were analyzed in order to quantify rates and locations of ground-water recharge and discharge within the river, characterize the correlation of recharge and discharge rates with ground-water conditions and reservoir releases, and better characterize the three-dimensional ground-water flow system.

Analysis of the data indicates that the largest amount of ground-water recharge from the river consistently occurs in the Piru subbasin. Some ground-water recharge from the river may occur in the upper part of the Fillmore subbasin. Increases in sulfate concentrations indicate that increases in flow at the lower ends of the Piru and Fillmore subbasins result from high-sulfate ground-water discharge. Increases in flow in the lower part of the Santa Paula subbasin are not accompanied by significant sulfate increases. Several sets of regressions indicate possible correlation between net flow changes in the river and depths to ground water and release rates from Lake Piru. These statistical relations may be of use for evaluating alternative Lake Piru release strategies.

Data on the stable isotopes of hydrogen and oxygen from the ground-water monitoring wells that were installed as part of this investigation were used to distinguish between zones affected by recharge from the Santa Clara River and zones affected by recharge from local precipitation. Tritium data from a new multiple-completion monitoring site indicate that near the river in the upper Santa Paula subbasin, recent (post-1950) recharge water is not present at depths greater than about 350 feet below land surface. Water-level and lithologic data from the monitoring site indicate that the river and the Shallow aquifer have only limited hydraulic connection to the underlying aquifers at this location. Water-level data from the Shallow aquifer and from an in-stream drive point were used in an analytic model to estimate hydraulic properties governing stream–aquifer interactions in the upper Santa Paula subbasin. Hydraulic conductivities in all the USGS monitoring wells were estimated on the basis of slug tests.

INTRODUCTION

This report provides an analysis of the interaction of surface water and ground water along the Santa Clara River in Ventura County (fig. 1). Because the Santa Clara River is the main source of recharge to ground water in Ventura County, improved understanding of stream–aquifer interactions along the river and its tributaries is important to water managers. To address this need, a study was done in cooperation with the United Water Conservation District (UWCD). As part of the study, surface-water and ground-water data were collected and analyzed in order to quantify rates and locations of ground-water recharge and discharge within the river; to characterize the correlation between ground-water recharge and discharge rates, ground-water conditions, and reservoir releases; and to better characterize geohydrologic properties relevant to surface-water/ground-water interaction.

The authors thank UWCD for its support of this study and Doug Maurer, David Morgan, Steven Bachman, Paul Barlow, Tony Buono, Peter Dal Pozzo, Robert Fleck, Randy Hanson, Clark Londquist, Robert Meyer, Keith Prince, and Ken Turner for their comments and reviews. The editing of Jerrald Woodcox, the illustrations of Rudolph Contreras, the layout of Jim Baker, and the field and office work of Greg Mendez, Michael Kuster, and Daniel Swope are gratefully acknowledged. The authors thank Juan Rico and Norman Wilkinson, City of Santa Paula, for providing drill sites.

DESCRIPTION OF STUDY AREA

The Santa Clara River is in the Santa Clara–Calleguas Hydrologic Unit in southern California (fig. 1) and has a drainage area of approximately 2,000 mi^2. Average precipitation ranges from 14 in/yr at Port Hueneme (fig. 1) to as much as 25 in/yr in the mountains to the north and east. The focus of this study was on surface-water/ground-water interactions along the Santa Clara River within Ventura County. In this predominantly agricultural area, the river flows through five ground-water subbasins: Piru, Fillmore, Santa Paula, the Montalvo Forebay of the Oxnard Plain, and Mound.

The UWCD operates two facilities in the area: Lake Piru and the Freeman Diversion (see figure 1). Lake Piru—on Piru Creek, a tributary to the Santa Clara River—is operated to collect water in the wet winter months and release water during the late summer and autumn. River water diverted at the Freeman Diversion is used for artificial recharge at the Saticoy and El Rio spreading grounds in the Oxnard Plain and for direct delivery to water users within the Oxnard Plain and Pleasant Valley (fig. 1). The water-management issues of concern for this study relate to surface-water/ground-water interactions along the Santa Clara River system between these two facilities. Therefore, the discussion in this report deals mostly with the Piru, Fillmore, and Santa Paula subbasins. Average annual flow at the U.S. Geological Survey (USGS) gage on Piru Creek, which is just downstream from Lake Piru (see site 6 in figure 1) during the past 40 years has been about 40 ft^3/s. Controlled releases have ranged from 100 to 350 ft^3/s. Other major tributaries that flow into the Santa Clara River within the three subbasins are Sespe Creek and Santa Paula Creek. Mean annual streamflow in the Santa Clara River at the Freeman Diversion has been about 255 ft^3/s during the past 40 years (R.T. Hanson, USGS, written commun., 1997). An estimated average of 85 ft^3/s can be diverted annually through the Freeman facilities (Steven Bachman, UWCD, written commun., 1996).

Geology

The lithologic units of most significance for ground-water supply in the Santa Clara–Calleguas Hydrologic Unit are the Santa Barbara Formation of late Pliocene to early Pleistocene age, the San Pedro Formation of early Pleistocene age, deposits of late Pleistocene age, and deposits of Holocene age. These units overlie partly consolidated and consolidated rocks of Tertiary and older age (California Department of Water Resources, 1956).

The Santa Barbara Formation overlies consolidated rocks of Tertiary age in most of the Santa Clara River Valley and consists of marine sandstone, siltstone, mudstone, and shale (Weber and others, 1973). The formation is as much as 5,000 ft thick in the Ventura area (Yerkes and others, 1987). Because the formation mostly consists of low-permeability sediments and contains water of poor quality in most of the study area (Turner, 1975), it is not considered an important source of ground water.

The San Pedro Formation overlies the Santa Barbara Formation in most of the Santa Clara River Valley and is as much as 5,000 ft thick in the vicinity of

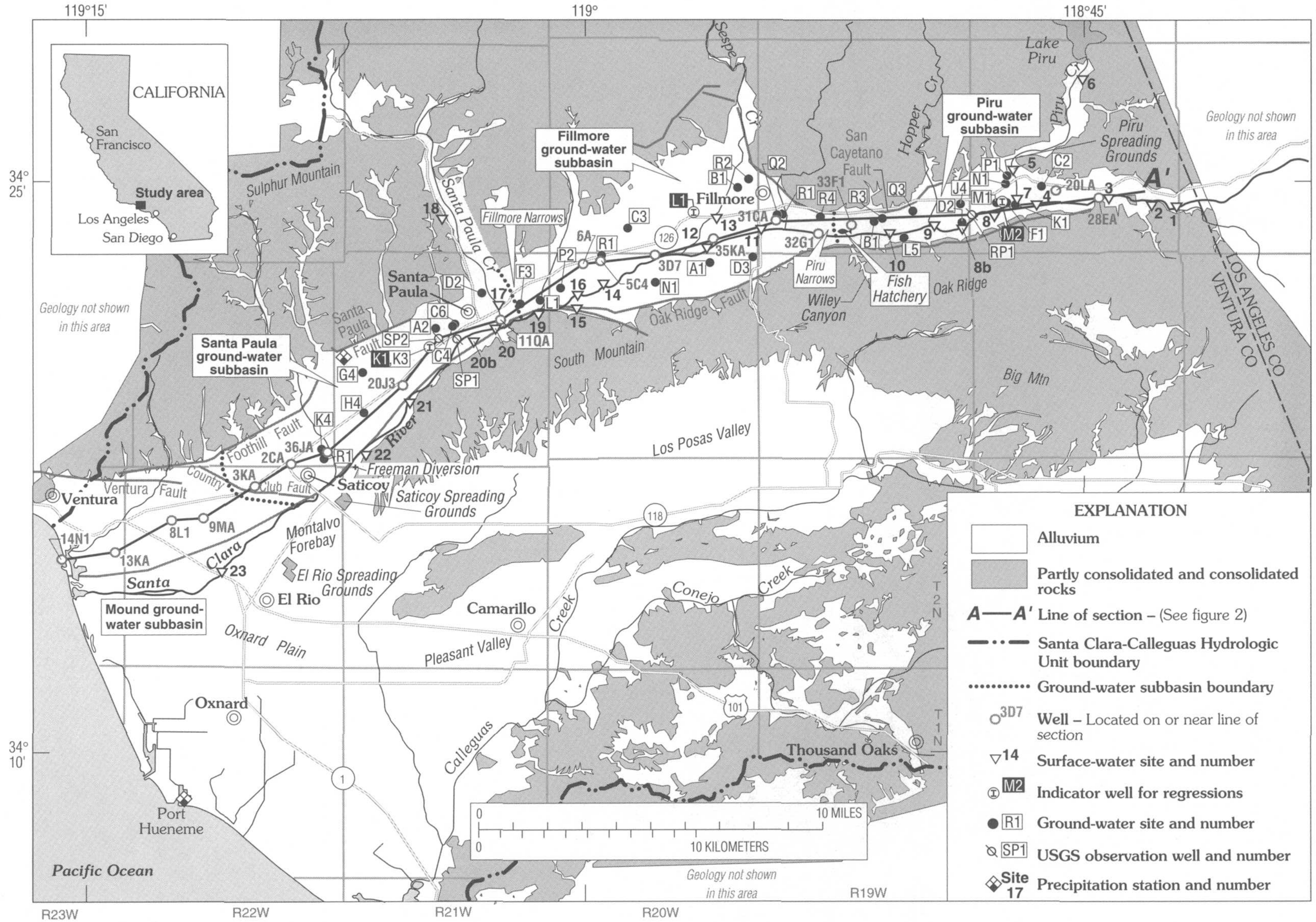


Figure 1. Surface-water and ground-water sampling sites in the study area, Santa Clara River basin, Ventura County, California.

Santa Paula (Bailey and Jahns, 1954). The lower part of the formation consists of weakly indurated very fine sand to medium-grained fossiliferous sand with occasional gravel layers of shallow marine origin. Dibblee (1992) separated these deposits and placed them in a formation he designated "Las Posas Sand." The Las Posas Sand reaches a miximum thickness of more than 2,000 ft in the Santa Clara River Valley (Dibblee, 1992). The upper part of the San Pedro Formation consists of lenticular layers of sand, gravel, silt, and clay. Age estimates for the lower and upper parts of the San Pedro Formation are 600,000 and 200,000 yr B.P., respectively (Yerkes and others, 1987). Large-scale sea-level fluctuations during that period resulted in the deposition of continuous, laterally extensive coarse-grained materials above erosional unconformities. These coarse basal units potentially are a major source of water to wells.

The deposits of late Pleistocene age unconformably overlie the San Pedro Formation and contain a coarse-grained basal unit in most of the Santa Clara–Calleguas Hydrologic Unit (Turner, 1975; Weber and others, 1973). These deposits, which are generally less folded than are underlying older deposits, are described by Turner (1975) as being of continental and shallow marine origin, but are considered to be of alluvial origin in the Santa Clara River subbasins (California Department of Water Resources, 1975). The deposits of late Pleistocene age are, in turn, overlain by alluvial and fluvial deposits of Holocene age. The basal sand and gravel units within these deposits, which were laid down by the ancestral Santa Clara River at the end of the last glacial stage (approximately 10,000 yr B.P.), range in thickness from 10 to 200 ft.

The greatest thickness of unconsolidated deposits in the Santa Clara–Calleguas Hydrologic Unit occurs in the Santa Clara River subbasins. The San Pedro Formation is exposed in the hills to the north of the Santa Paula and Mound subbasins. In the Fillmore and Piru subbasins, the ground-water system is bounded by non-water-bearing Tertiary deposits that have been thrust over the San Pedro Formation along the San Cayetano Fault, a north-dipping reverse fault (fig. 1) (California Department of Water Resources, 1975). The Oak Ridge Fault, a south-dipping reverse fault, closely parallels the base of South Mountain. The non-water-bearing Tertiary deposits that are thrust up along the fault plane bound the Piru, Fillmore, and Santa Paula ground-water subbasins (Dibblee, 1991, 1992). Another south-dipping reverse fault, the Country Club Fault, forms the boundary between the Santa Paula and Mound subbasins (California Department of Water Resources, 1975). Ground-water modeling done as part of the USGS RASA study indicates that the Country Club Fault causes some restriction of ground-water flow between the two subbasins (R.T. Hanson, USGS, written commun., 1997).

Two structural features of importance for surface-water/ground-water interaction are the Piru and Fillmore Narrows (see figure 1). Constrictions in the width of the unconsolidated deposits at these locations can cause ground water to discharge to the Santa Clara River.

Aquifers

Five major aquifers have been identified by previous investigators in the Santa Clara–Galleguas Hydrologic Unit (table 1): the Shallow and Oxnard aquifers within the alluvial deposits of Holocene age, the Mugu aquifer within the deposits of late Pleistocene age, the Hueneme aquifer within the upper part of the San Pedro Formation, and the Fox Canyon aquifer within the basal part of the San Pedro Formation (California Department of Water Resources, 1956; Turner, 1975). In this report, aquifers have been defined on the basis of analysis and correlation of lithologic and geophysical data collected as part of this study and the USGS RASA study. In this report, the Hueneme aquifer is separated into upper and lower parts. In wells, the lower Hueneme aquifer is differentiated from the upper Hueneme aquifer by longer drill times, indicating more consolidated materials. A generalized cross section through the Santa Clara River Valley is shown in figure 2. The Shallow aquifer, which consists of sand and gravel along the Santa Clara River, extends from the land surface to a depth of approximately 60 to 80 ft.

Table 1. Lithologic units and aquifers in the study area

Geologic series	Lithologic unit	Aquifers
Holocene	Alluvial deposits	Shallow Oxnard
Upper Pleistocene	Alluvial and shallow marine deposits	Mugu
Lower Pleistocene	San Pedro Formation–Las Posas Sand	Hueneme (upper and lower) Fox Canyon

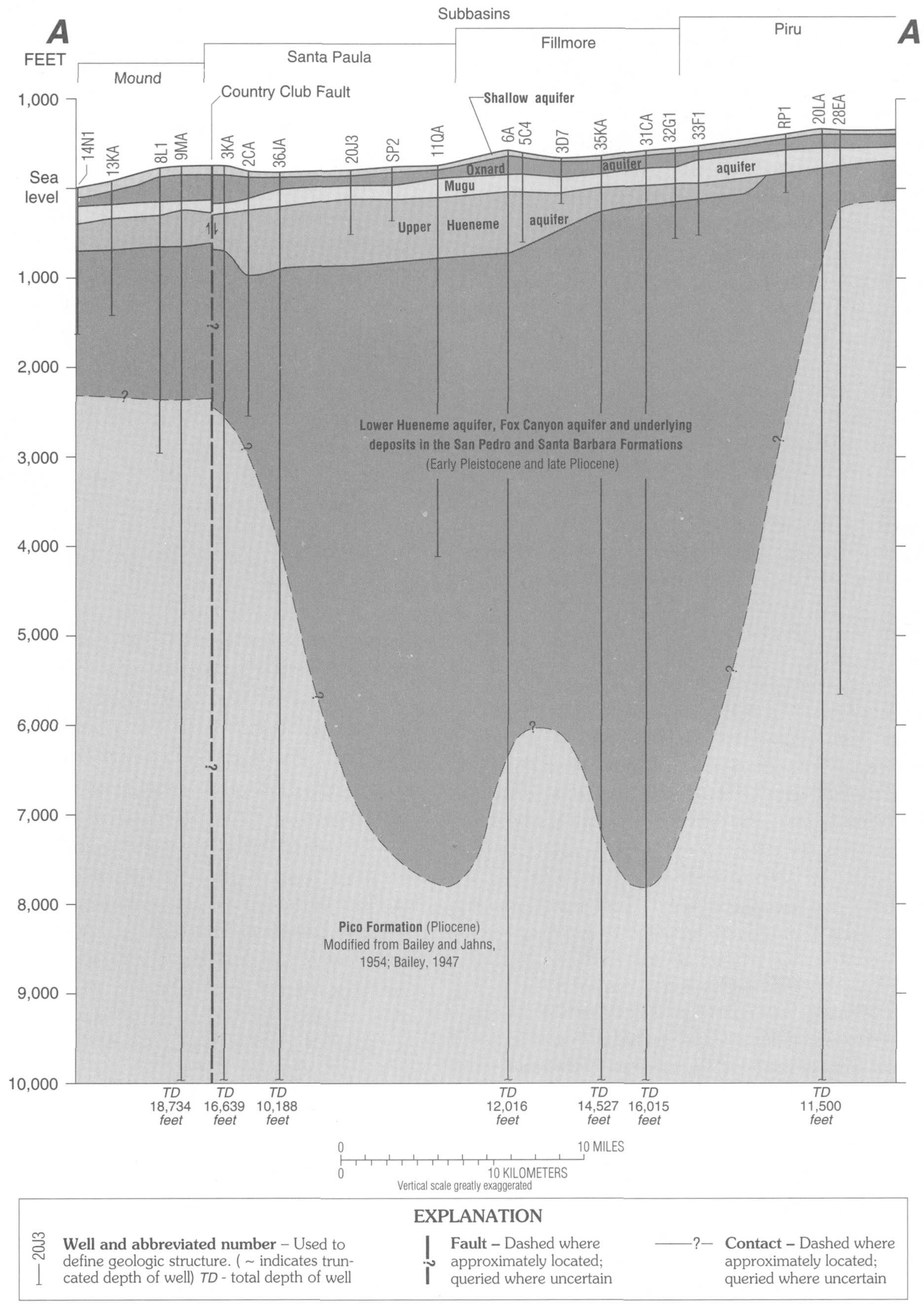


Figure 2. Generalized geohydrologic section through the Santa Clara River basin, Ventura County, California.

The Oxnard aquifer, which consists of the basal sand and gravel deposits of Holocene age, extends to a depth of approximately 150 to 200 ft below land surface. The Mugu aquifer, which consists of the basal part of the upper Pleistocene deposits, extends from about 200 ft below land surface to about 350 ft. The upper Hueneme, lower Hueneme, and Fox Canyon aquifers underlie the Mugu aquifer throughout most of the Santa Clara River Valley. The combined thickness of these aquifers ranges from less than 500 ft in the eastern Piru subbasin to more than 8,000 ft in the Fillmore and Santa Rosa subbasins (fig. 2).

In the Piru subbasin, there appears to be no confining unit between the Oxnard aquifer and the overlying Shallow aquifer. As described later in this report, data from USGS monitoring well SP1 indicate that, near the Santa Clara River in the northern part of the Santa Paula subbasin, the Shallow aquifer is underlain by a thick clay layer, and the Oxnard aquifer seems to be absent. Data from a second USGS monitoring well, SP2, indicate that, away from the river in the northern part of the Santa Paula subbasin, the Oxnard aquifer is present but the Shallow aquifer is predominantly clay and has limited hydraulic connection to the Oxnard aquifer. In the southern part of the Santa Paula subbasin, the present river channel lies south of the Oak Ridge Fault, where the Shallow aquifer overlies older (late Pliocene to early Pleistocene) deposits adjacent to South Mountain (Law/Crandall, Inc., 1993). Hence, interaction between the Shallow aquifer and the Oxnard aquifer is limited.

Supply wells in the Piru, Fillmore, and Santa Paula subbasins draw water from multiple aquifers. Flowmeter data indicate that wells perforated in both the Oxnard and Mugu aquifers tend to derive most of their water from the Oxnard aquifer. In the Santa Clara subbasins, where the deposits that form the Mugu aquifer are relatively coarse, wells perforated in both the Mugu and Hueneme aquifers tend to derive most of their water from the Mugu aquifer (R.T. Hanson, USGS, oral commun., 1997). Because of the extreme thickness of the San Pedro Formation, wells are generally not drilled deeper than the Hueneme aquifer, which is in the upper part of the San Pedro Formation.

The geographic information system (GIS) developed as part of the USGS RASA project (Predmore and others, 1997) was used to roughly quantify the relative amounts of ground water pumped from different depths within the aquifer system. The following results are based on data from pumped wells in 1993 for which perforation data are available (which accounts for only about 60 percent of the total pumpage in the three subbasins) and on the assumption that the top of the perforated interval of a well is an indicator of where water is being drawn from. About 15 percent of the pumpage came from wells with tops of perforations 100 ft below land surface or shallower (considered to generally represent the Shallow aquifer); about 50 percent came from wells with tops of perforations between 100 and 200 ft below land surface (considered to generally represent the Oxnard aquifer); about 20 percent came from wells with tops of perforations between 200 and 350 ft below land surface (considered to generally represent the Mugu aquifer); and about 15 percent came from wells with tops of perforations deeper than 350 ft (considered to generally represent the Hueneme aquifer).

PREVIOUS WORK

Densmore and others (1992) measured discharge and several chemical constituents and properties of water at 23 locations along the Santa Clara River and its tributaries during four different periods in 1991—including a period of zero release from Lake Piru (see fig. 1) that was considered to represent base flow, and periods with releases of 100, 272, and 391 ft^3/s. For the zero-release condition, the only flow in the river was the result of discharging ground water at the Fillmore Narrows at the lower end of the Fillmore subbasin. This water was characterized by high specific conductance (2,000 μS/cm) and high sulfate concentration (800 mg/L). For the 100- and 272-ft^3/s releases, all the release water infiltrated into the ground-water system (or was diverted) before reaching the Freeman Diversion. Only for the 391-ft^3/s release did water flow all the way to the diversion.

Mass-balance computations on sulfate concentrations and stable isotopes of oxygen and hydrogen suggested that ground-water discharge at the Fillmore Narrows increased with increasing release rates. Thus, increased upstream infiltration may have led to increased discharge at the lower end of the Fillmore subbasin.

APPROACH

The data-collection efforts in this study, which supported and expanded the efforts of Densmore and others (1992), had three main components: (1) measurements of discharge and water quality were made at the same locations (as those of Densmore and others, 1992) along the Santa Clara River and its tributaries during several different time periods and under different flow conditions regulated by releases from Lake Piru; (2) geologic and hydraulic data were collected and water-quality samples were collected and analyzed from three multiple-completion ground-water monitoring wells installed during this study; and (3) water levels were continuously monitored at these wells and in drive points in the Santa Clara River near two of the wells. These data, together with data collected as part of the USGS RASA study (see Izbicki and others, 1995), were analyzed in order to quantify rates and locations of ground-water recharge and discharge within the river, to characterize the correlation between recharge and discharge rates and ground-water conditions and reservoir releases, and to better characterize the geohydrologic properties relevant to the interaction of ground water and surface water.

An additional set of tasks completed as part of this project involved conducting, analyzing, and modeling a dye-tracer test. The goal of the tracer test was to test some of the inferred recharge/discharge processes discussed in this report and to develop estimates of travel times, velocities, dispersion, and stream-channel characteristics. The results of this work are described by Paybins and others (1998) and Nishikawa and others (1999). Dye-test results indicated that, during a controlled release of approximately 170 ft^3/s from Lake Piru, the mean travel time from Lake Piru to the Freeman Diversion was approximately 18 hours. This provides useful information on the time required for transient effects to propagate downstream.

ANALYSIS OF SURFACE-WATER DATA

In this study, the discharge measurements and water-quality sampling and analysis were repeated eight times during 1993–95 at the same locations measurements were made and sampling was done in 1991 by Densmore and others (1992). Two of the eight sets of data were collected under zero-release conditions and six were collected during releases. Flow and water-quality results (focusing on sulfate and the stable isotopes of hydrogen and oxygen) are described and compared with those of Densmore and others (1992) in the sections that follow. There is an important difference in conditions between the data-collection periods of the two studies: conditions during the 1993–95 measurements were much wetter than those in 1991.

Flow Measurements

The results of flow measurements for all eight sets of data collected during this study are given in Appendix 1. Discussion in this report focuses on the sites on Piru Creek and the Santa Clara River between Lake Piru (site 6) and the Freeman Diversion (site 22), sites which are influenced by releases from Lake Piru. Discharge and sulfate concentrations for these sites are shown in figure 3. Measurement of changes in sulfate concentrations in surface water along the river are important because they can provide information on the possible sources of inflow to the river.

Two of the data sets—for the periods August 15–20, 1993 (fig. 3*A*), and July 25–August 2, 1994 (fig. 3*E*)—were collected during zero-release (base-flow) conditions. The other six data sets were collected during releases from Lake Piru: August 24, 1993 (fig. 3*B*); August 30–September 15, 1993 (fig. 3*C*); October 26–30, 1993 (fig. 3*D*); September 19–24, 1994 (fig. 3*F*); October 25–27, 1994 (fig. 3*G*); and October 10–13, 1995 (fig. 3*H*).

Sources of Error and Uncertainty in Flow Measurements

There are several sources of error and uncertainty associated with the flow measurements made as part of this study. It is extremely important to keep these in mind when interpreting the results. In spite of the presence of multiple sources of possible errors, however, it is possible to analyze the data and to draw preliminary inferences, particularly regarding patterns of flow changes that are present in multiple data sets. Clearly, additional follow-up data collection is essential to test these inferences.

One source of error is in the flow measurements themselves. Flow measurements were made using guidelines outlined by Carter and Davidian (1968).

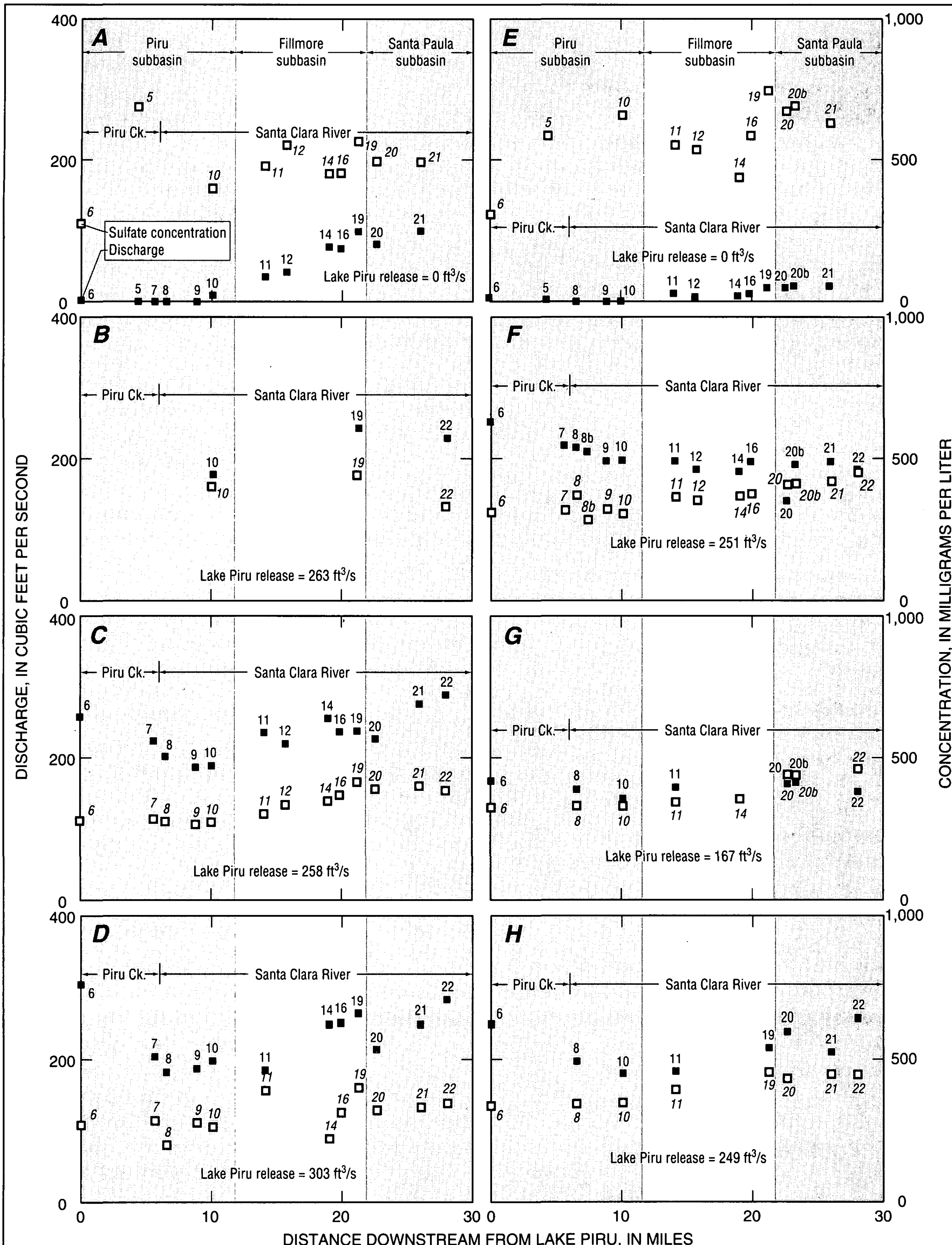


Figure 3. Discharge measurements and sulfate concentrations at surface-water monitoring sites in the Santa Clara River basin, Ventura County, California. ***A***, August 15–20, 1993. ***B***, August 24, 1993. ***C***, August 30–September 15, 1993. ***D***, October 26–30, 1993. ***E***, July 25–August 2, 1994. ***F***, September 19–24, 1994. ***G***, October 25–27, 1994. ***H***, October 10–13, 1995.

Most measurements were rated as good-to-fair, indicating possible errors of 5 to 8 percent. Therefore, some of the apparent changes in flow along the river may not be significant.

A second source of possible error is in unmeasured inflows to and outflows from the river. These could include diversions, tributaries, and return flows. There are likely several small unmeasured diversions along the course of the river (Peter Dal Pozzo, UWCD, oral commun., 1997). A fish hatchery between sites 10 and 11 pumps large amounts of water (on the order of 10,000 acre-ft/yr) from the lowermost end of the Piru subbasin. Some of this water may drain back into the river at the upper end of the Fillmore subbasin as return flow.

A third source of error is that each set of discharge measurements were made over a period of days, during which time conditions may have changed. Of particular importance were potential changes in Lake Piru release rates. Average daily flow values measured at the USGS gage at site 6 are given in table 2. As can be seen, there is some variability in these values for most of the measurement periods. For each period, depending on when measurements at individual sites were made, some of the changes in flow between sites may be the result of changes in releases, not inflows or outflows along the river.

Flow Changes in the Piru Subbasin

As shown in Appendix 1, for all data-collection periods, all flow entering the Piru subbasin from Los Angeles County to the east at site 1 infiltrates (or is diverted) before it reaches site 4, just upstream from Piru Creek (see figure 1). Data from the two zero-release periods, August 15–20, 1993 (fig. 3*A*), and July 25–August 2, 1994 (fig. 3*E*), show zero river flow in the middle part of the subbasin (sites 8 and 9). In both zero-release periods there is flow at site 10, the lowermost site in the Piru subbasin and increased flow

Table 2. Releases from Lake Piru and diversions at Piru spreading grounds during data-collection periods

[ft^3/s, cubic feet per second; —, no data]

Data-collection period	Date	Release from Lake Piru (ft^3/s)	Diversion at Piru spreading grounds (ft^3/s)
Aug. 24, 1993	8/23	263	—
	8/24	263	—
Aug. 30–Sept. 15, 1993	8/29	248	—
	8/30	248	—
	8/31	248	—
	9/1	248	—
	9/2	248	—
	9/3	242	—
	9/4	245	—
	9/5	251	—
	9/6	246	—
	9/7	251	—
	9/8	250	—
	9/9	250	—
	9/10	251	—
	9/11	241	—
	9/12	251	—
	9/13	254	—
	9/14	260	—
	9/15	262	—
Oct. 26–30, 1993	10/25	286	55
Oct 26–30, 1993	10/26	286	53
	10/27	282	57
	10/28	286	56
	10/29	293	56
	10/30	302	62
Sept. 19–24, 1994	9/18	273	—
	9/19	267	—
	9/20	241	—
	9/21	241	—
	9/22	241	—
	9/23	208	—
	9/24	197	—
Oct. 25–27, 1994	10/24	174	—
	10/25	174	3
	10/26	174	—
	10/27	174	—
Oct. 10–13, 1995	10/9	213	—
	10/10	219	—
	10/11	240	—
	10/12	248	—
	10/13	248	—

at site 11, the uppermost site in the Fillmore subbasin. This increase in flow seems to be due to ground-water discharge at the Piru Narrows. For the periods during releases, figures 3*C*, *D*, *F*, *G*, and *H* all show consistent decreasing flow from Lake Piru (site 6) downstream through site 8 (Torrey Road). This result is consistent with the conclusion of Densmore and others (1992) that during releases from Lake Piru, ground-water recharge always occurs in the middle part of the Piru subbasin. The data collected during releases also show generally increasing flow associated with the Piru Narrows. For the three data sets during releases with measurements at both sites 9 and 10, one shows an increase in flow (fig. 3*D*) and two show constant flow (figs. 3*C*,*F*). For the five data sets during releases with measurements at both sites 10 and 11, three show increases in flow (figs. 3*C*, *G*, and *H*), one shows constant flow (fig. 3*F*), and one shows decreasing flow (fig. 3*D*). As mentioned in the prior discussion of possible errors and uncertainties, flow changes between sites 10 and 11 may be affected by fish hatchery operation.

Flow Changes in the Fillmore Subbasin

In the Fillmore subbasin, there is some evidence of decreasing flow—indicating ground-water recharge—in the upper part of the subbasin (between sites 11 and 12). Three of the four data sets with measurements at both sites 11 and 12 (figs. 3*C*, *E*, and *F*) show flow decreases; the fourth (fig. 3*A)* shows a flow increase, however. In general, there appears to be an overall increase in flow between the upper part of the Fillmore subbasin (sites 11 and 12) and the lower part (sites 16 and 19). The increases in flow between sites 12 and 14 are likely the result of shallow, low-sulfate ground-water discharge associated with Sespe Creek. The increases in flow between sites 14 and 19 are likely due to ground-water discharge associated with the Fillmore Narrows.

The data are inconclusive regarding the processes occurring between the lower end of the Fillmore subbasin (site 19) and the upper end of Santa Paula subbasin (site 20). Of the five data sets with measurements at both sites, three show flow decreases (figs. 3*A*, *C*, and *D*), one shows an increase (fig. 3*H*), and one shows no change (fig. 3*E*). Along this reach, there is a small amount of inflow from Santa Paula Creek (see site 17 in Appendix 1) as well as an ungaged diversion (Peter Dal Pozzo, UWCD, oral commun., 1997). Measurements for September 19–24, 1994 (fig. 3*F*), show a very large decrease in flow between sites 16 and 20 (no measurement was made at site 19). However, an additional measurement was made just downstream from site 20 at site 20b, which is adjacent to the USGS monitoring well SP-1. Measured flow at site 20b (191 ft^3/s) was back up to nearly the same rate as that at site 16 (195 ft^3/s). This may be the result of water that was diverted upstream from site 20 reentering the river.

Flow Changes in the Santa Paula Subbasin

Data generally indicate an increase in flow in the Santa Paula subbasin between sites 20 and 22. As described earlier, the Shallow aquifer in this part of the Santa Clara River directly overlies Tertiary deposits. As is discussed later in the "Surface-Water-Quality Measurements" section, no significant increases in sulfate concentrations occur along this reach (see figure 3 and Appendix 1). Therefore, unlike at the Piru and Fillmore Narrows, this flow increase seems not to be caused by discharge of high-sulfate ground water. It is possible that this flow increase in the lower Santa Paula subbasin results from the discharge of ground water from the Shallow aquifer system that has sulfate concentrations similar to those in the river.

Regression Analyses of Flow Measurements

Regression analyses (table 3; Appendix 2) were used to quantify the relations between ground-water recharge to and discharge from the river with respect to Lake Piru releases and ground-water conditions. Net flow changes in each subbasin and total river flow at site 22 (Freeman Diversion) were regressed against releases from Lake Piru (site 6) and depths to water at indicator wells.

Net flow changes were computed for the Piru subbasin [defined as the difference between flow at Lake Piru (site 6) and flow at the upper end of the Fillmore subbasin (site 11)]; for the Fillmore subbasin [defined as the difference between flow at the upper end of the Fillmore subbasin (site 11) and flow at the upper end of the Santa Paula subbasin (site 20)]; and for the Santa Paula subbasin [defined as the difference between flow at the upper end of the Santa Paula subbasin (site 20) and flow upstream of the Freeman diversion (site 22)] for five sets of flow measurements

Table 3. Results of regression analyses

[Regression equation and method: OLS, ordinary least-squares regression; IWLS, iteratively weighted least-squares regression. Dependent variable, in cubic feet per second: *Lp*, net flow loss in Piru subbasin; *Lf*, net flow loss in Fillmore subbasin; *Lsp*, net flow loss in Santa Paula subbasin; *F*, flow at site 22 in Santa Clara River upstream of Freeman Diversion. Regression coefficients for independent variables: *R*, release from Lake Piru, in cubic feet per second; *G1*, depth, in feet, to water at Piru subbasin indicator well, 4N/18W-20M2; *G2*, depth, in feet, to water at Fillmore subbasin indicator well, 4N/20W-26L1; *G3*, depth, in feet, to water at Santa Paula subbasin indicator well, 3N/21W-16K1. <, actual value is less than value shown]

Regression equation and method	Regression statistics	Dependent variable	Regression coefficients for independent variables		Constant	R^2
1a -- OLS		*Lp*	0.71*R*	1.25*G1*	–188	0.95
	Standard error		.16	.39	38.1	
	t-ratio		4.46	3.24	–4.93	
	P-value		.022	.048	.016	
1b -- IWLS		*Lp*	.70*R*	1.46*G1*	–203	1.00
	Standard error		.05	.12	11.9	
	t-ratio		14.33	11.49	–17.0	
	P-value		.0007	.0013	.0004	
2a -- OLS		*Lf*	.08*R*	3.75*G2*	–204.9	.72
	Standard error		.28	2.00	75.7	
	t-ratio		.29	1.87	–2.71	
	P-value		.7914	.1577	.0734	
2b -- IWLS		*Lf*	–.04*R*	5.09*G2*	–244.0	.999
	Standard error		.01	.11	4.07	
	t-ratio		–3.21	48.05	–59.8	
	P-value		.049	<.0001	<.0001	
3a -- OLS		*Lsp*	–.28*R*	3.61*G3*	–122.7	.34
	Standard error		.22	2.94	128.4	
	t-ratio		–1.27	1.23	–.96	
	P-value		.274	.287	.393	
3b -- IWLS		*Lsp*	–.28*R*	3.41*G3*	–112.6	.34
	Standard error		.22	2.84	124.2	
	t-ratio		–1.28	1.20	–.91	
	P-value		.270	.296	.416	
4a -- OLS		*F*	.49*R*	–3.52*G1*	280.8	.99
	Standard error		.11	.20	26.5	
	t-ratio		4.62	–17.68	10.59	
	P-value		0.0099	<.0001	.0005	
4b		*F*	.42*R*	–3.45*G1*	292.9	1.00
	Standard error		.01	.03	2.97	
	t-ratio		32.13	–113.26	98.49	
	P-value		<.0001	<.0001	<.0001	

made during releases in this study (excluding the partial data set for August 24, 1993) and for two sets of flow measurements made during releases in 1991 reported by Densmore and others (1992). These net flow changes are shown in figure 4. Flow-change computations for the 1991 data sets are incomplete because of missing data.

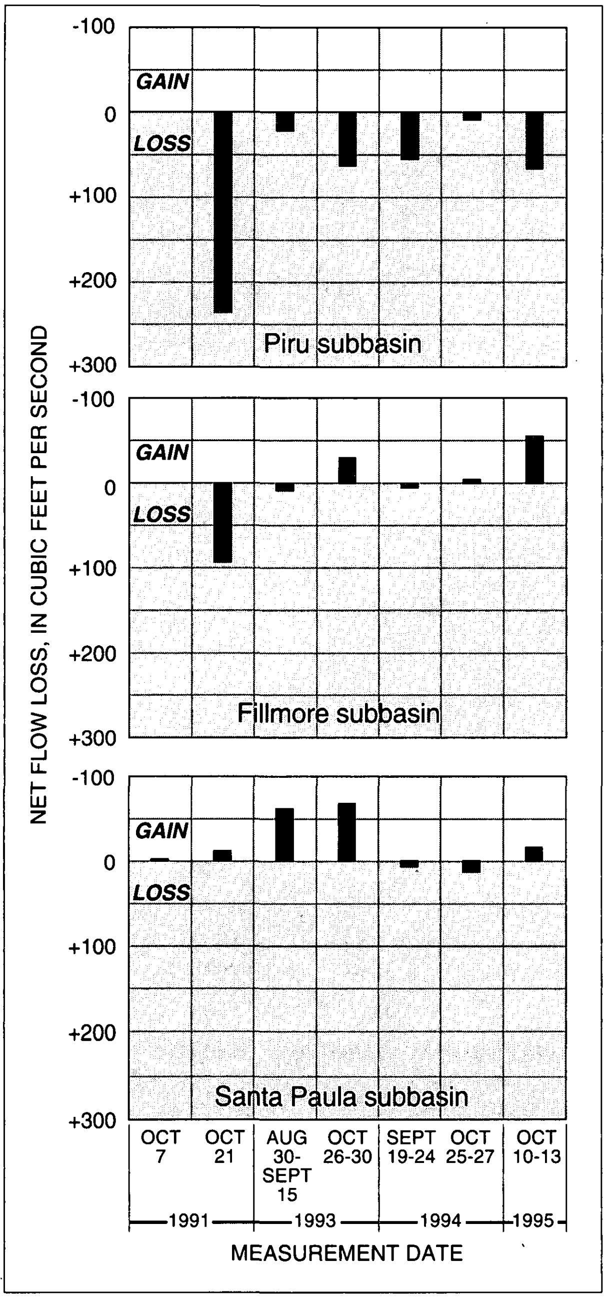


Figure 4. Net flow loss in the Piru, Fillmore, and Santa Paula subbasins, Santa Clara River basin, Ventura County, California.

Depths to ground water, measured during or close to the flow-measurement period, at wells used for long-term monitoring by UWCD in the three subbasins were used as an indicator of overall ground-water conditions for the subbasins. These indicator wells are not meant to represent the hydraulic conditions in the aquifer at the river; they simply provide a gross quantitative indication of the antecedent ground-water conditions for the releases. The indicator wells, shown in figure 1, are 4N/18W-29M2 for the Piru subbasin (well depth of 142 ft below land surface with an unknown perforated interval), 4N/20W-26L1 for the Fillmore subbasin (perforated from 100 ft to 397 ft below land surface), and 3N/21W-16K1 for the Santa Paula subbasin (perforated from 105 ft to 220 ft below land surface). Long-term hydrographs for these three wells, along with precipitation and cumulative departure curves for precipitation stations at Santa Paula and Port Hueneme (see figure 1), are shown in figure 5. Conditions during 1991–95 ranged from near-historical-low ground-water levels in 1991 to near-historical-high levels in 1993–94. The three indicator wells show different amplitudes of water-level fluctuations. Water levels during the period 1990–95 fluctuated about 110 ft in the Piru subbasin well, 4N/18W-29M2, and about 35 ft in the Fillmore subbasin well, 4N/20W-26L1, and the Santa Paula subbasin well, 3N/21W-16K1.

Net streamflow loss (change) in each subbasin was regressed against release from Lake Piru and depth to ground water at the indicator well (as calculated in table 3, losses are positive numbers, gains are negative). Total flow in the Santa Clara River upstream from the Freeman Diversion (site 22) was then regressed against release from Lake Piru and depth to ground water at the Piru subbasin indicator well. The Piru well was used for this regression because it has the largest fluctuations in depth to water. Ideally, one might want to use a combination of wells in all subbasins for a regression analysis. However, the small number of data sets precluded adding additional variables to the regression.

The data used for these regressions are tabulated in Appendix 2 and are shown graphically in figures 6 and 7. For the October 1993 data, the net flow losses in the Piru subbasin and total flow upstream from the Freeman Diversion were adjusted for the diversions at the Piru spreading grounds. Six to seven data sets were used for each regression.

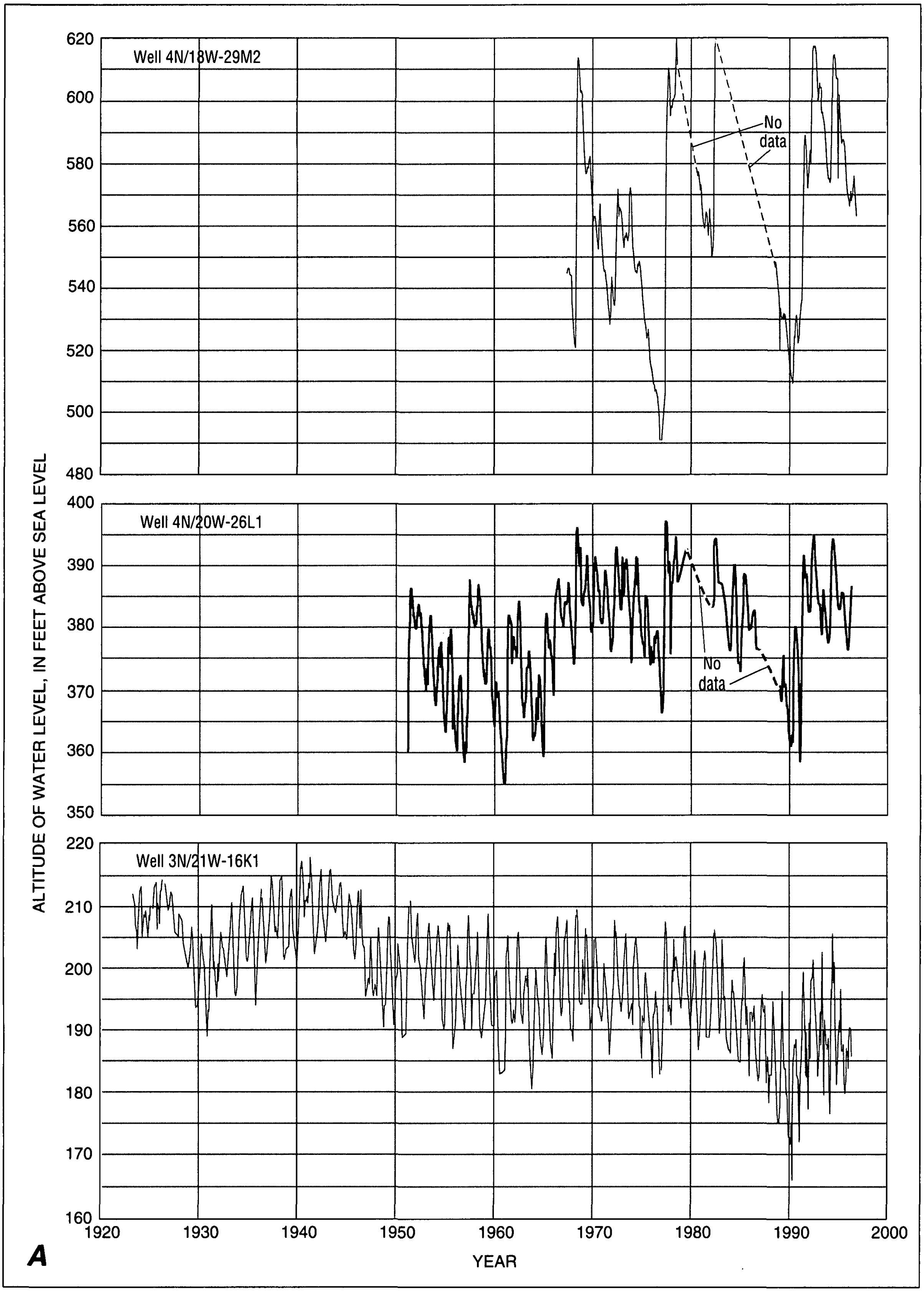


Figure 5. Hydrographs for selected wells *(A)*, observed-precipitation and calculated-cumulative-departure curves for precipitation stations at Santa Paula and Port Hueneme *(B)*, Santa Clara River basin, Ventura County, California

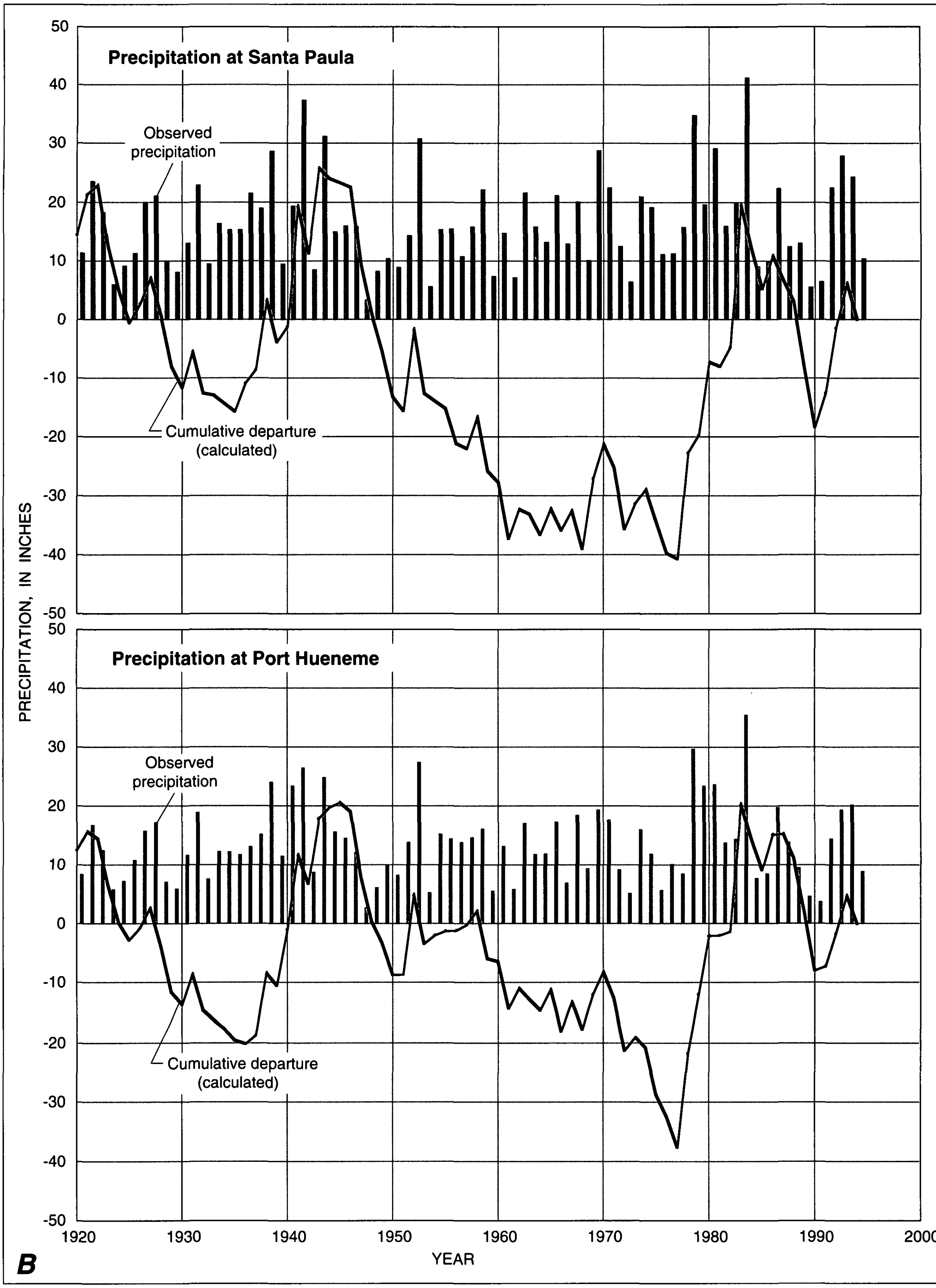


Figure 5.—Continued.

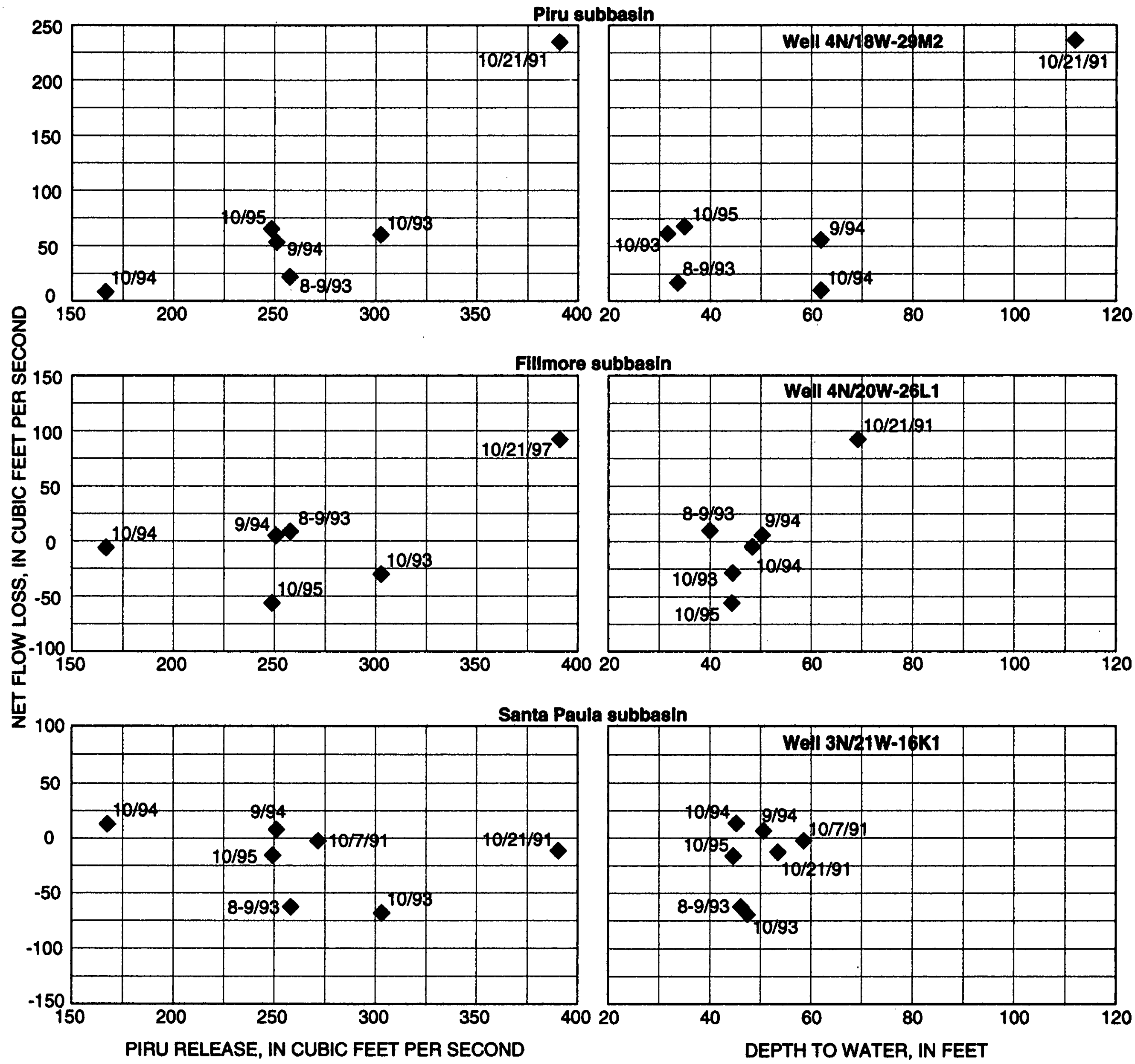


Figure 6. Net flow loss in Piru Creek and the Santa Clara River in the Piru, Fillmore, and Santa Paula subbasins as a function of release from Lake Piru and as a function of depth to ground water, Santa Clara River basin, Ventura County, California. (Negative net flow losses are gains in streamflow.)

Extreme caution is required in drawing implications from the regressions. First, the regressions are based on a very small number of data points. Second, as described earlier, there are multiple sources of uncertainty and potential error in all the data. Third, statistical correlation does not prove causation. Finally, the regression results are not valid outside the range of data used for the analysis.

The results of the regressions for the four dependent variables—flow loss in the Piru subbasin, *Lp*; flow loss in the Fillmore subbasin, *Lf*; flow loss in the Santa Paula subbasin, *Lsp*; and flow at site 22, upstream from the Freeman Diversion, *F*—are given in table 3. For each dependent variable, two regression methods were applied: ordinary least-squares (OLS) regression, and an iteratively weighted least-squares regression (IWLS). IWLS is a robust regression method, which is considered appropriate for data sets in which outliers may have a large influence on regression results (Helsel and Hirsch, 1992). The

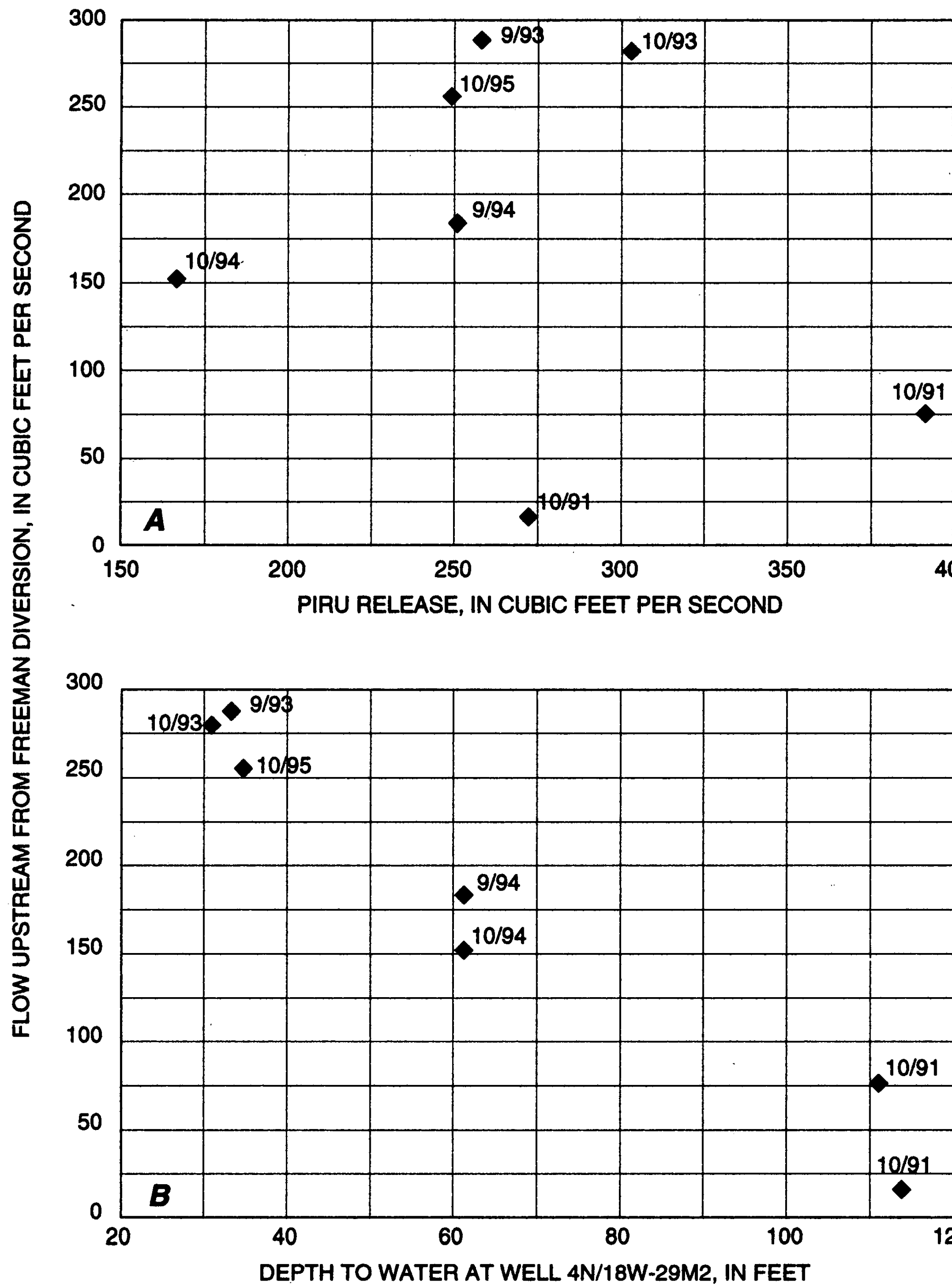


Figure 7. Flow in the Santa Clara River upstream from the Freeman Diversion (site 22) as a function of release from Lake Piru ***(A)***, and as a function of depth to ground water at well 4N/18W-29M2 ***(B)***, Santa Clara River basin, Ventura County, California.

specific weighting function used in the IWLS is the bisquare weight estimator (Mosteller and Tukey, 1977).

Regression equations 1a and 1b in table 3 indicate that net flow loss in the Piru subbasin (*Lp*) seems to be statistically well explained by the quantity released from Lake Piru (*R*) and the depth to ground water (*G1*) at indicator well 4N/18W-29M2. Note that the OLS regression results (1a) are very similar to the IWLS regression results (1b). As one would expect, flow loss (recharge) is positively correlated with both release from Lake Piru and depth to ground water. Because the Piru subbasin consistently has the largest net flow loss (see figures 3 and 4), this statistical relation may be useful in estimating or predicting net flow losses and ground-water recharge along the Santa Clara River.

Regression equation 2a in table 3, which applies OLS, indicates that net flow loss in the Fillmore subbasin (*Lf*) is not as well correlated with the quantity of water released from Lake Piru (*R*) and the depth to ground water (*G2*) at indicator well 4N/20W-26L1. The t-ratio for the coefficient on *R* indicates that the coefficient is not significant. Regression equation 2b, which uses IWLS, yields a larger coefficient on depth to ground water. Note that the IWLS regression applies zero weights to the August–September 1993 and the October 1995 data. As can be seen in figure 6, there is a strong apparent linear relation between net flow change in the Fillmore subbasin and depth to ground water if these two data points are excluded.

Regression equations 3a and 3b in table 3 show that net flow loss in the Santa Paula subbasin (*Lsp*) is not statistically well explained by the quantity released from Lake Piru (*R*) or the depth to ground water (*G3*) at indicator well 3N/21W-16K1. The R^2 values and the t-ratios are low in both the OLS (3a) and the IWLS (3b) regressions. In contrast to the other two subbasins, flow loss in the Santa Paula subbasin is negatively correlated with release from Lake Piru. In other words, in the Santa Paula subbasin where flows are generally increasing (see figures 3 and 4), the flow increases appear to be positively correlated with Lake Piru releases (see figure 6).

Regression equations 4a and 4b in table 3 show that flow (*F*) in the Santa Clara River upstream from the Freeman Diversion (site 22) is statistically well explained by the quantity released from Lake Piru (*R*) and the depth to ground water (*G1*) at the Piru subbasin indicator well 4N/18W-29M2. Regression coefficients computed by the OLS (4a) are very similar to those computed by the IWLS (4b). Because the dependent variable is flow, rather than flow loss, it is negatively correlated with depth to ground water. In this case, the depth to ground water apparently explains most of the statistical correlation. The R^2 value and the t-ratios for equation 4a are higher than those for the individual OLS regressions relating net changes in three subbasins (regressions equations 1a, 2a, and 3a). The regressions for the individual subbasins apparently do not account for the interaction between the subbasins, whereas equation 4a integrates over the three subbasins and may better account for water moving through the Shallow aquifer under and near the river channel. A plot of flow (fig. 7*A*) upstream from the Freeman Diversion (site 22) against release from Lake Piru clearly shows two data populations. The five points grouped on the upper part of the graph are from the five data sets for 1993–95. The two data points on the lower right part of the graph are from two data sets from 1991, the dry period in which ground-water levels were much lower.

Surface-Water-Quality Measurements

For all flow measurements, specific conductance was measured in the field. In addition, grab samples were collected and analyzed for sulfate and chloride in the USGS laboratory in San Diego, California, using an ion chromatograph (non-suppressed single column) to separate numerous dissolved ions. Subsequent quantification was by means of conductance and UV absorption. Selected samples were analyzed for stable isotopes of hydrogen and oxygen in the USGS Isotope Fractionization Project in Reston, Virginia, using hydrogen- and CO_2 -equilibration techniques (see Gonfiatini, 1984, and Coplen, 1994). Techniques used for handling and preserving all surface-water samples are discussed in detail by Izbicki and others (1995). All water-quality data from surface-water samples are given in Appendix 1. Discussion in this section will focus on sulfate and stable-isotope data.

Sulfate

Changes in sulfate concentration along the river can provide information on stream/ground-water interaction because the native ground water generally has high sulfate concentrations relative to those of local precipitation and runoff. Concentrations in samples collected from USGS monitoring wells ranged from 270 to 680 mg/L. In many other wells in the Santa Clara subbasins, sulfate concentrations are greater than 500 mg/L (see Izbicki and others, 1995). Izbicki (USGS, written commun., 1997) suggests that these high sulfate concentrations could be due to dry-period accumulation and subsequent wet-period dissolution of sulfate in evaporite minerals. Runoff from the adjacent mountains tends to have lower sulfate concentrations. For example, concentrations in all samples from Santa Paula Creek, site 18, were less than 220 mg/L (see Appendix 1). Increases in flow owing to ground-water discharge can therefore be distinguished from increases owing to tributary inflow. Care must be taken, however, because some higher values of sulfate concentrations have been measured in small tributaries at the lowermost end of the Santa Paula subbasin (Peter Dal Pozzo, UWCD, written commun., 1997).

Sulfate concentrations for samples collected during each of the eight flow-measurement periods for sites on Piru Creek and the Santa Clara River between Lake Piru (site 6) and the Freeman Diversion (site 22) are shown in figures 3*A–H*. Sulfate concentrations for all sites are given in Appendix 1.

With the exception of the July 25–August 2, 1994, data set (fig. 3*E*), sulfate concentrations generally increase between the lower part of the Piru subbasin (site 10) and the upper part of the Fillmore subbasin (site 11). Sulfate concentrations also appear to be higher at the lower end of the Fillmore subbasin (site 19) and at the upper end of the Santa Paula subbasin (site 20). As noted previously in the discussion of the flow measurements, the increasing sulfate concentrations at the lower ends of the Piru and Fillmore subbasins are consistent with discharge of high-sulfate ground water at the downstream narrows of each subbasin. The relatively constant sulfate concentrations in the Santa Paula subbasin between sites 20 and 22 (see figure 3) indicate that the measured flow increases in this reach do not result from high-sulfate ground-water discharge or from low-sulfate local runoff. It is possible that these flow increases are due to discharge of ground water with moderate sulfate concentrations (400 to 500 mg/L), similar to those measured in USGS monitoring well SP1-5 (3N21W -15G5) in the Shallow aquifer near the river.

For the two zero-release data sets, (figs. 3*A, E*), a decrease in sulfate concentration occurs between sites 12 and 14 in the Fillmore subbasin, likely reflecting discharge of low-sulfate, shallow ground water associated with Sespe Creek. Similarly, all data sets with measurements at both sites 19 and 20 (figs. 3*A, C, D, E*, and *H*) show decreases in sulfate concentration between the sites, possibly owing to discharge of low-sulfate, shallow ground water associated with Santa Paula Creek.

As mentioned previously, Densmore and others (1992) measured discharge and sulfate concentrations during base flow at the lower end of the Fillmore subbasin. Using mass-balance computations, they concluded that there seemed to be an increase in ground-water discharge during the release. Similar mass-balance computations were made in this study for both 1993 and 1994 releases to determine if ground-water discharge increased in the Piru and Fillmore Narrows during releases. Computations were made at the sites with the most consistently high sulfate concentrations: site 11 at the upper end of the Fillmore subbasin and site 19 at the lower end of the Fillmore subbasin. For site 11, the mass-balance computations both overestimate and underestimate the sulfate concentrations. For site 19, the sulfate concentrations during August 30–September 15, 1993, and October 26–30, 1993, releases were slightly higher (3 percent and 4 percent) than concentrations from mass-balance computations. No measurement was made during the September 19–24, 1994, period. Because of the small differences for site 19 and the inconsistencies for site 11, the possibility of increased ground-water discharge at the Piru and Fillmore Narrows resulting from releases (and the associated increased upstream recharge) during this period can not be confirmed.

In addition to the "snapshot" measurement of flow and concentration made by the USGS, the UWCD collected more-frequent samples of the diverted water from the Freeman Diversion (site 22); these samples were analyzed by the USGS for chloride and sulfate. Temporal trends in sulfate and chloride concentration (fig. 8) show that there is an inverse relation between flow measured at the gage at the intake of Freeman Diversion and both sulfate and chloride concentrations; the highest concentrations occur during low flows. As was noted by Densmore and others (1992), ground water, which is higher in sulfate and chloride concentrations than is local runoff, contributes a higher percentage of the flow in the Santa Clara River at the Freeman Diversion at lower flow rates.

Sulfate concentration was measured at several sites that are not shown in figure 3: sites 1–3, upstream from the confluence of Piru Creek and the Santa Clara River; sites 17 and 18 on Santa Paula Creek; and site 23, downstream from the Freeman Diversion. These results are given in Appendix 1. Sulfate concentrations increased between sites 1 and 3. The reason for this increase in sulfate concentration is not certain. One possible explanation is return flow of pumped ground water. The flow measurements given in Appendix 1 consistently show a net decrease in flow between sites 1 and 3 (decreasing flow between sites 1 and 2, and a slight increase between sites 2 and 3) and no remaining flow at site 4. Note that there is a known, but unmeasured, diversion upstream from site 2. Also shown in Appendix 1 is the previously noted low sulfate concentration at site 18 on Santa Paula Creek, slightly higher values downstream at site 17, and

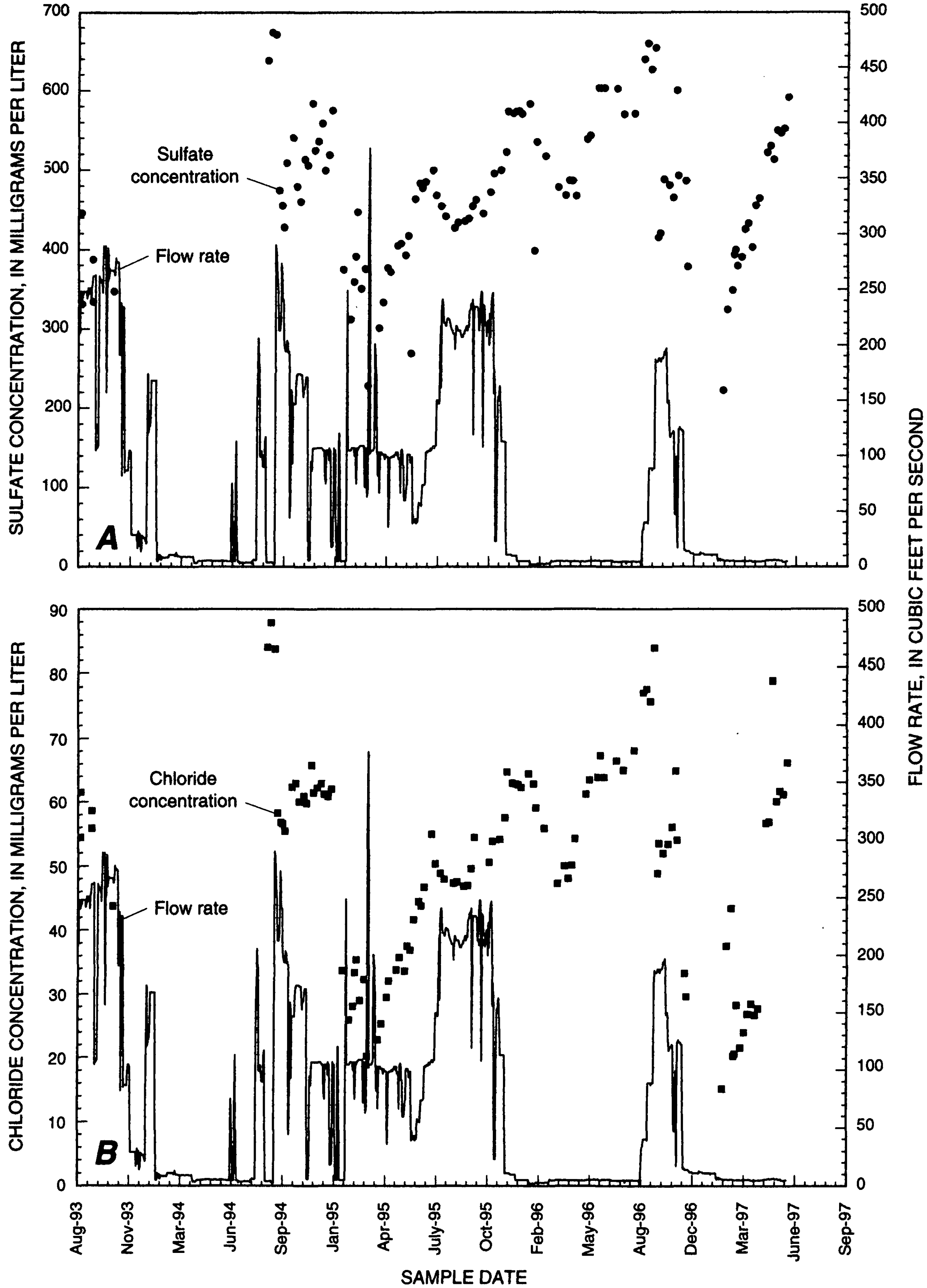


Figure 8. Sulfate concentration and flow rate *(A)*, and chloride cincentration and flow rate *(B)*, at the Freeman Diversion (site 22), 1993–97, Santa Clara River basin, Ventura County, California.

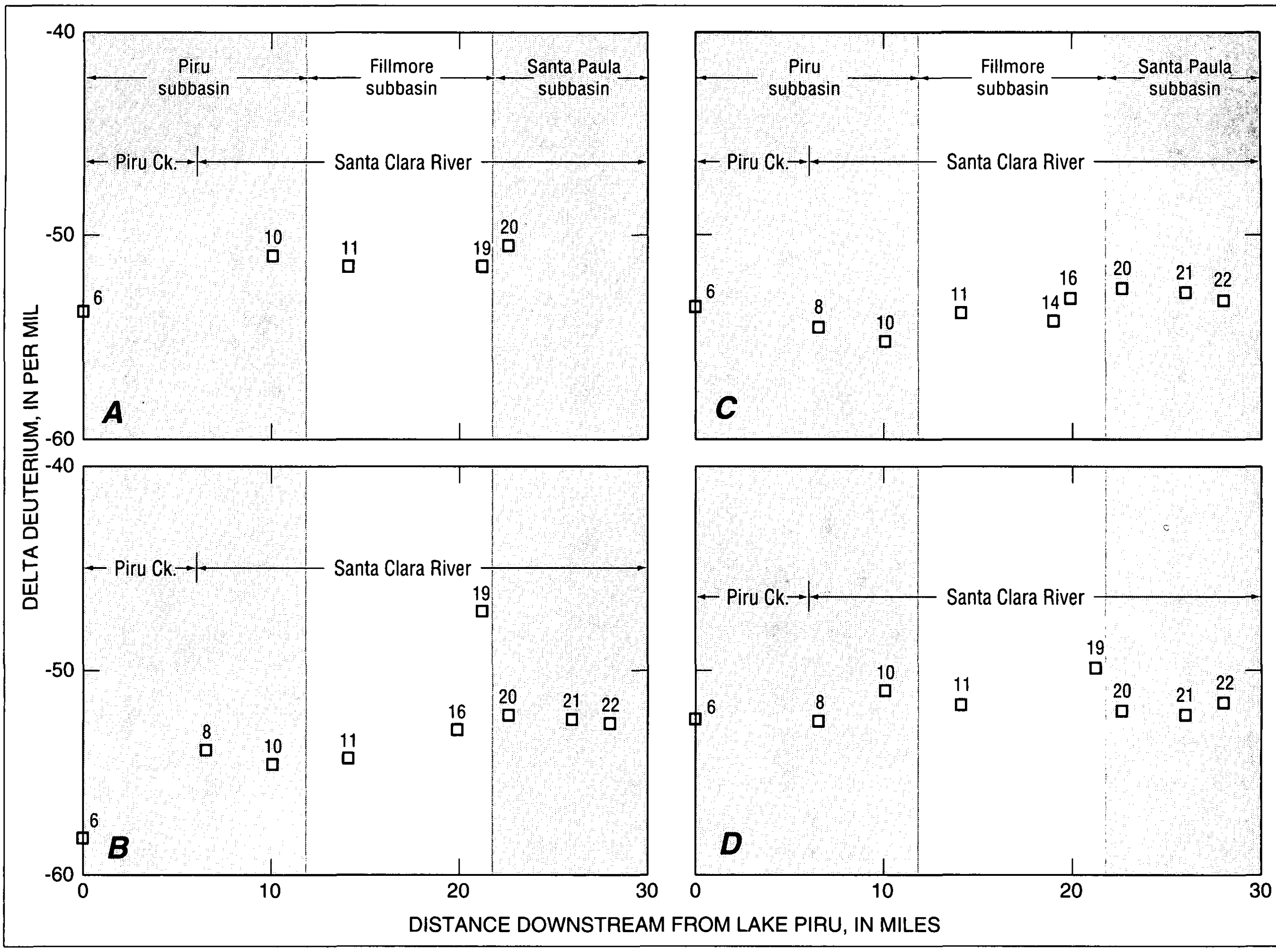


Figure 9. Delta deuterium (δD) composition at surface-water monitoring sites in the Santa Clara River basin, Ventura County, California. ***A,*** August 15–20, 1993; ***B,*** October 26–30, 1993; ***C,*** September 19–24, 1994; ***D,*** October 10–13, 1995.

extremely high sulfate concentrations for the very low flows sampled at site 23, downstream from the Freeman Diversion.

Stable Isotopes of Hydrogen and Oxygen

Oxygen-18 and deuterium are stable isotopes of oxygen and hydrogen. These isotopes are heavier than the common oxygen-16 and hydrogen isotopes. The isotopic composition of water is generally expressed in terms of per mil (parts per thousand) differences from the composition of ocean water. These differences are referred to as "delta oxygen-18" ($\delta^{18}O$) and "delta-deuterium" (δD).Water that has less deuterium than does ocean water will have a negative δD value. Various factors can produce different isotopic signatures in water (see Mazor, 1991; Gat and Gonfiantini, 1981). For example, water that originated as precipitation at higher altitudes or at cooler temperatures would tend to be isotopically lighter (more negative).

Shown in figures 9*A–D* are the δD values for selected river sites for four of the sampling periods. As can be seen in figure 9 and Appendix 1, most of the samples from the Santa Clara River and from Piru Creek have δD values of -52 to -58 per mil. The $\delta^{18}O$ values during the release sampling periods were lighter (generally -7 per mil and lighter) than the $\delta^{18}O$ values measured during the 1991 sampling described by Densmore and others (1992) (heavier than -7 per mil in the Piru and Fillmore subbasins). This difference indicates that water in the reservoir in 1993–95 apparently underwent less evaporation than in 1991, a drought year. Only one set of δD and $\delta^{18}O$ analyses were made during a zero-release period: August 15–20,

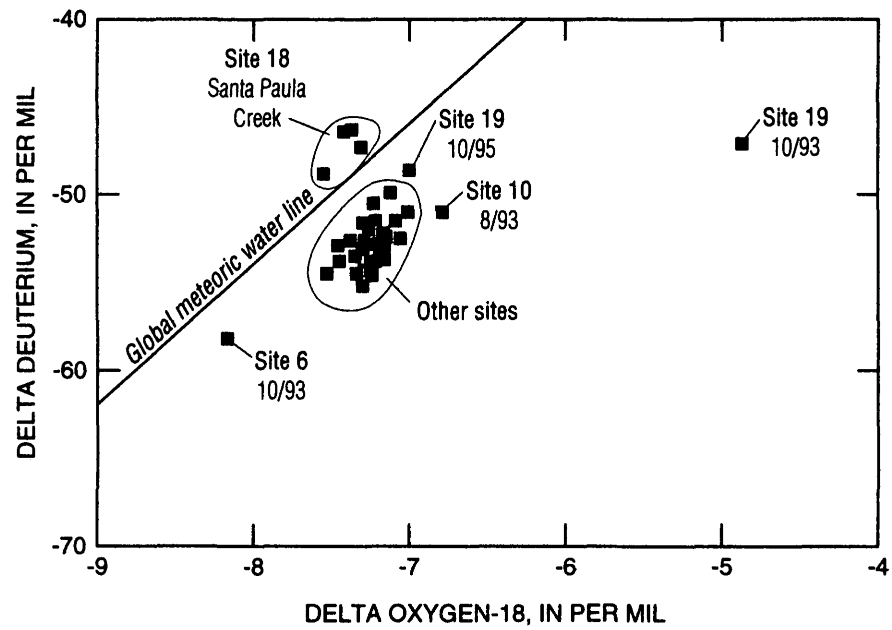


Figure 10. Delta deuterium (δD) as function of delta oxygen-18 ($\delta^{18}O$) in surface water, Santa Clara River basin, Ventura County, California.

1993. (fig 9*A*). Comparison of the δD values for that period with those during the subsequent release period, October 26–30, 1993 (fig. 9*B*), indicates that δD values were lighter (more negative) during the release. Note that the δD value of the release water (site 6) shown in fig. 9*B* is the lightest of all the surface-water values. The δD data also provide some evidence of heavier (less negative) water at the lower end of the Fillmore subbasin (sites 16 and 19).

Because most precipitation originates from evaporation of seawater, the $\delta^{18}O$ and δD values of precipitation are linearly correlated and can be plotted along a line called the meteoric water line (fig. 10) (see Izbicki, 1996; Mazor, 1991). As one moves up the meteoric water line, one moves from lighter water (more negative $\delta^{18}O$ and δD values) to heavier water (less negative $\delta^{18}O$ and δD values). The isotopic composition of samples relative to each other and to the meteoric water line provides information on source and evaporative history of the water. In figure 10, the δD values are plotted against the $\delta^{18}O$ values for surface water in the Santa Clara River subbasins, along with the global meteoric water line. All the values, except those from Santa Paula Creek (site 18) fall below the global meteoric water line, apparently along a regional meteoric water line. Water from Santa Paula Creek (site 18), which has δD values ranging from -49 to -46 per mil and $\delta^{18}O$ values ranging from -7.6 to -7.3 per mil (see Appendix 1), lies above the meteoric line. This water originates as local precipitation or local runoff at lower altitudes than those at which the water in Lake Piru originated and is therefore isotopically heavier (less negative).

ANALYSIS OF GROUND-WATER DATA

In order to better characterize the interaction of surface water and ground water along the Santa Clara River, three multiple-well monitoring sites were completed in the Santa Paula and Piru subbasins (see figure 1) as part of this study. In this section, data collected from these three sites are summarized. Information is presented on the construction and lithology of the sites, hydraulic-conductivity estimates, the relation of ground-water levels to stream stage, and water quality. Also presented are water-quality data collected from existing wells in the study area as part of the USGS RASA study.

Description of USGS Multiple-Well Monitoring Sites

The location of the three USGS multiple-well monitoring sites is shown in figure 1. Sites SP1 and

SP2 are located at the upstream end of the Santa Paula subbasin: SP1 is adjacent to the river (approximately 300 ft from the main channel) and SP2 is approximately 4,000 ft west of the river. Site RP1 is in the upper part of the Piru subbasin, about 8,000 ft downstream from the confluence of Piru Creek and the Santa Clara River. The geophysical logs, lithologic descriptions, and well-construction diagrams for the monitoring sites are shown in figures 11–13. The determination of which aquifer is tapped by each well was based on lithologic and geophysical data, along with other data analyzed as part of the USGS RASA study.

Site SP1 consists of five separate 2-inch-diameter polyvinyl chloride (PVC) wells installed with perforations at the following intervals below land surface: (1) 660–680 ft, (2) 520–540 ft, (3) 370–390 ft, (4) 260–280 ft, and (5) 60–80 ft (see figure 11). A zone of gravel and gravelly sand, the Shallow aquifer, is present in the upper 90 ft of the well (SP1-5 is perforated in this zone). This coarse zone is underlain by approximately 120 ft of clay. Below the clay, from approximately 230 ft to 400 ft, is a second zone of predominantly coarse materials, which is the Mugu aquifer (wells SP1-3 and SP1-4 are perforated in the lower and upper parts, respectively, of this zone). Below 400 ft is the upper Hueneme aquifer. Well SP1-2 is perforated in a coarse zone, indicated by the driller's log and the resistivity logs, that extends from 460 to 540 ft below land surface. Well SP1-1 is perforated in the lowermost zone of the monitoring site (540 ft to 700 ft); on the basis of the driller's log and the geophysical logs, this zone consists of intervals of moderately coarse materials separated by thin clay layers. Note that the Oxnard aquifer, which normally is present between the Shallow aquifer and the Mugu aquifer (table 1), is not present at this site.

During the drilling of SP1, a 3-foot core was taken (from 131 to 134 ft below land surface) within the thick clay zone (which extends from 100 ft to 220 ft below land surface) below well SP1-4 and above well SP1-5. To help determine the depositional environment of this clay zone, water extracted from the core was analyzed for its strontium 87-86 ($^{87}Sr/^{86}Sr$) ratio, which was determined to be 0.70956. As discussed by Izbicki and others (1994), the $^{87}Sr/^{86}Sr$ ratio of ground water in the Santa Clara–Calleguas Hydrologic Unit appears to approximate the average $^{87}Sr/^{86}Sr$ ratio of the sediment within which the water is found. Izbicki and others (1994) noted that the Santa Clara River watershed is underlain by rocks of Precambrian age in which $^{87}Sr/^{86}Sr$ is greater than the value that they report for current seawater (0.70912). Water in wells completed in Santa Clara River alluvial deposits have $^{87}Sr/^{86}Sr$ ratios of 0.710 or greater and thus is clearly different from the water extracted from the core. The lower $^{87}Sr/^{86}Sr$ value in the water sampled from the core may indicate that the source material and age of the clay are different from those of the overlying and underlying alluvial materials. Alternatively, the lower $^{87}Sr/^{86}Sr$ value in the water sampled from the core may simply reflect the lower permeability of the clay deposits and the longer residence time of the water that they contain. The longer residence time would allow the water to come closer to equilibrium with the sediment. In order to more fully assess the implications of these $^{87}Sr/^{86}Sr$ results from the core, it would be necessary to determine the $^{87}Sr/^{86}Sr$ values in the sediment itself (Robert Fleck, USGS, oral commun., 1997).

Monitoring-site SP2, approximately 4,000 ft west of site SP1 (see figure 1) consists of four 2-inch PVC wells perforated at the following intervals: (1) 530–550 ft, (2) 290–310 ft, (3) 150–170 ft, and (4) 60–70 ft (see figure 12). The upper 100 ft, the Shallow aquifer, is predominantly clay but includes several thin coarse zones; well SP2-4 is perforated in the thickest of these zones. Below the Shallow aquifer, from 100 ft to 260 ft, is the Oxnard aquifer, in which well SP2-3 is perforated. The Mugu aquifer, which extends from 260 ft to 350 ft below land surface, is composed of materials that are somewhat finer grained than those of the overlying Oxnard aquifer; well SP2-2 is perforated in this zone. Below 350 ft is the upper Hueneme aquifer; well SP2-1 is perforated in this zone.

Monitoring-site RP1 is located in the Piru subbasin, adjacent to the river, about 8,000 ft downstream from the confluence of Piru Creek and the Santa Clara River (see figure 1). Five wells were installed at the following intervals below land surface: (1) 590–610 ft, (2) 310–330 ft, (3) 220–240 ft, (4) 140–160 ft, and (5) 50–70 ft (see figure 13). No well-defined clay zones were identified. The entire upper 540 ft is coarse material (gravelly sand). The driller's log and the geophysical logs indicate that the upper 70 ft, the Shallow aquifer, is coarse and contains considerable gravel; well RP1-5 is perforated in this zone. The underlying Oxnard aquifer, which extends to a depth of approximately 180 ft, is coarse and also contains considerable gravel; well RP1-4 is perforated

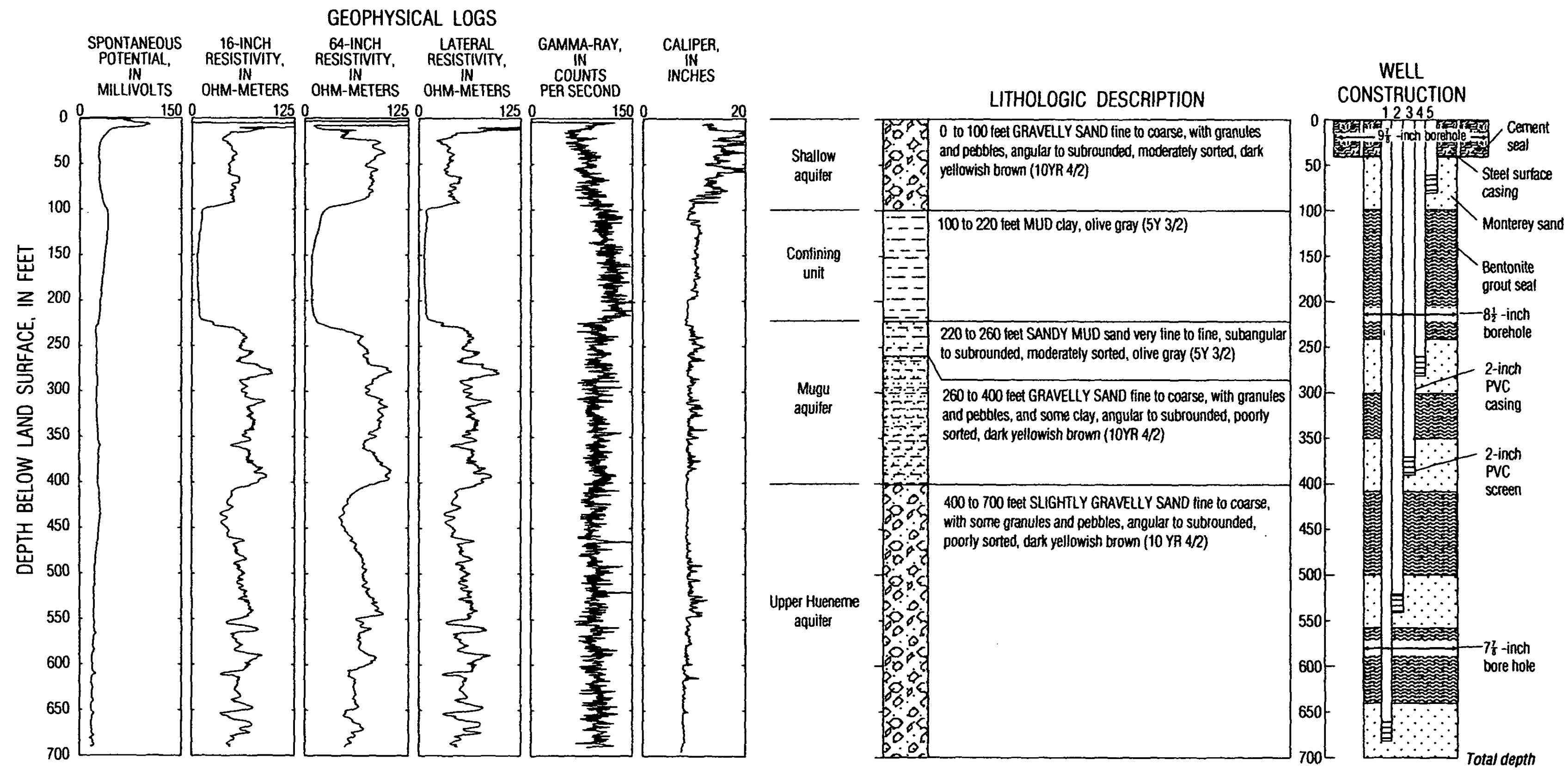


Figure 11. Geophysical logs, lithologic description, and well-construction diagram for multiple-well monitoring site SP1 (wells 3N/21W-15G1,2,3,4,5) in the Santa Clara River basin, Ventura County, California. From Densmore and others, 1996.

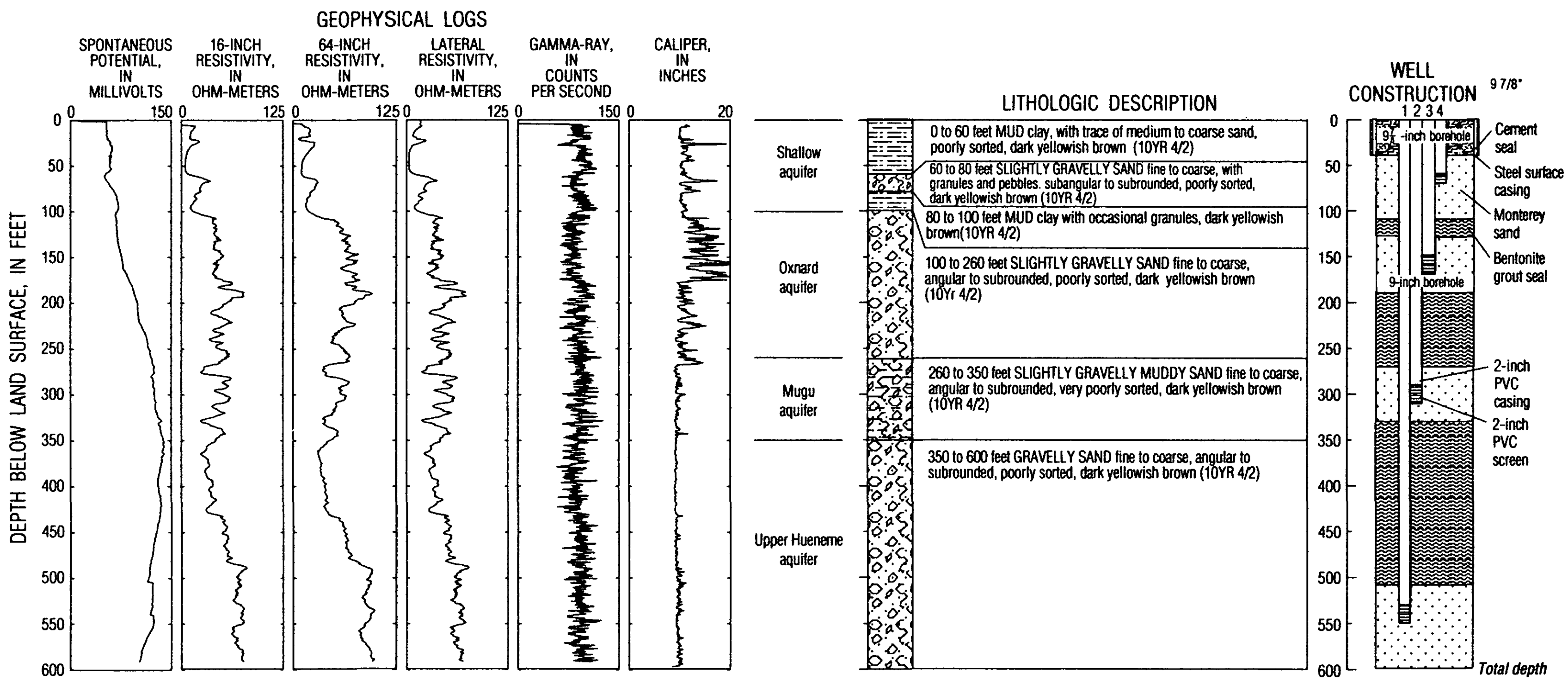


Figure 12. Geophysical logs, lithologic description, and well-construction diagram for multiple-well monitoring site SP2 (wells 3N/21W-16H5,6,7,8) in the Santa Clara River basin, Ventura County, California. From Densmore and others, 1996.

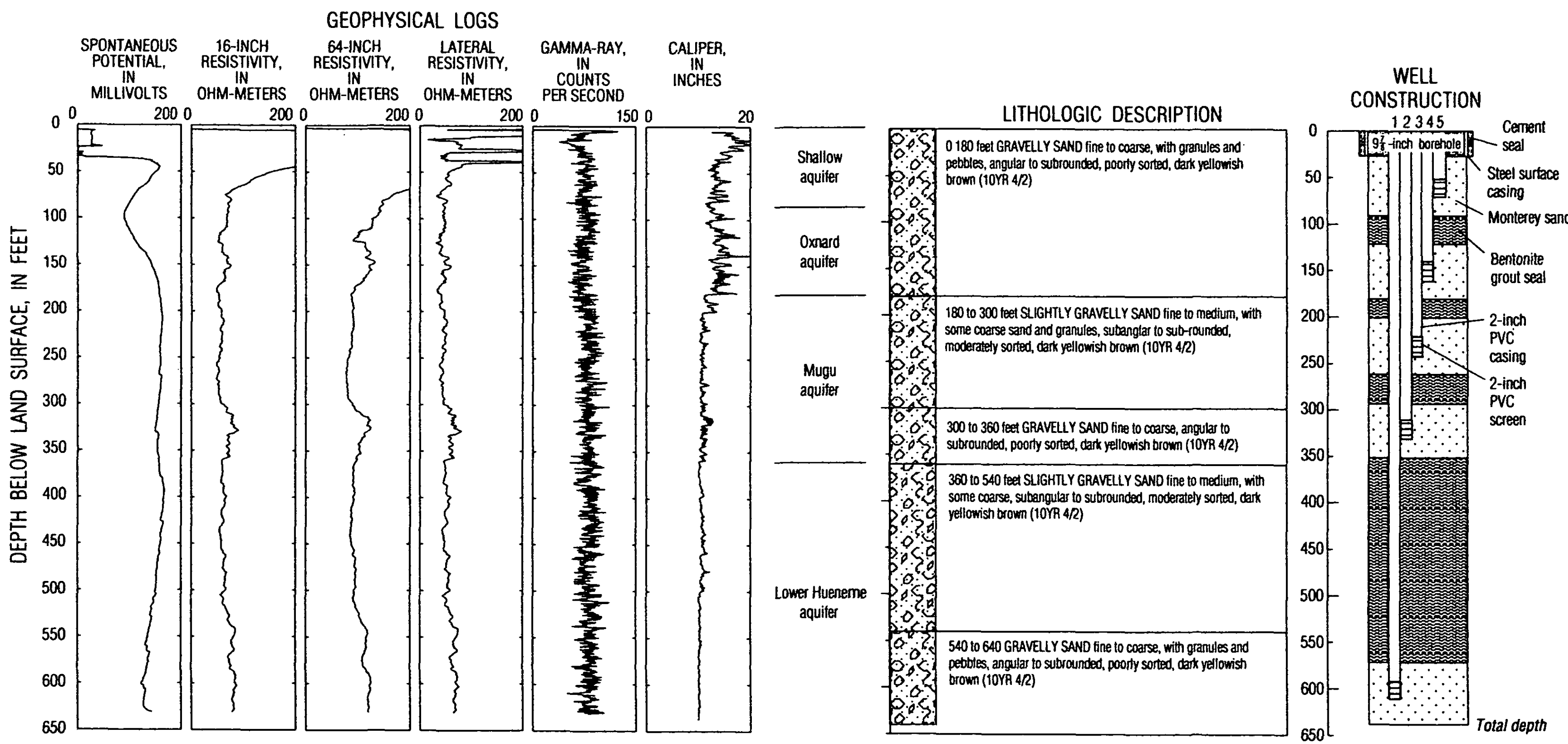


Figure 13. Geophysical logs, lithologic description, and well-construction diagram for multiple-well monitoring site RP1 (wells 4N/18W-31D3,4,5,6,7) in the Santa Clara River basin, Ventura County, California. From Densmore and others, 1996.

in this zone. The Mugu aquifer extends from 180 ft to 360 ft below land surface; wells RP1-2 and RP1-3 are perforated in the lower and upper parts, respectively, of this zone. The lower Hueneme aquifer begins at a depth of approximately 360 ft below land surface; well RP-1 taps this zone. The upper Hueneme aquifer, which is normally present below the Mugu aquifer, is not present at this site. The upper part of the San Pedro Formation was either eroded or never deposited at this location. On the basis of drilling times and geophysical logs at this site, the materials of the lower Hueneme aquifer are more consolidated than the materials in the overlying aquifers.

Hydraulic-Conductivity Estimates

Slug tests were done at the three multiple-completion monitoring sites in order to help quantify geohydrologic properties affecting the interaction of ground water and surface water and to provide information for the regional ground-water modeling conducted as part of the USGS RASA program. At least one and as many as eight tests were done for each of the 14 wells, and the results are given in Appendix 3. Data from all wells except RP1-1 and SP2-4 were analyzed using the method of Kipp (1985); data from RP1-1 and SP2-4 were analyzed using the method of Cooper and others (1967). As pointed out by Cooper and others (1967), estimates of storage coefficient(S) from slug-test data are problematic because the determined value of S is extremely sensitive to the choice of the matching type curve. Therefore, hydraulic conductivities were estimated for two specified values of specific storage (1.0E-4 and 1.0E-6). As shown in Appendix 3, geometric mean estimates of hydraulic conductivity in the Shallow aquifer were 45, 85, and 35 ft/d at SP1-5, SP2-4, and RP1-5, respectively. Geometric mean estimates of hydraulic conductivity in the Oxnard aquifer were 100 and 33 ft/d in SP2 -3 and RP1-4, respectively. Geometric mean estimates of hydraulic conductivity in the Mugu aquifer were 68, 18, 26, 17, and 30 ft/d in SP1-3, SP1-4, SP2-2, RP1-2, and RP1-3, respectively. Geometric mean estimates of hydraulic conductivity in the upper Hueneme aquifer were 58, 15, and 24 ft/d in SP1-1, SP1-2, and SP2-1, respectively. The geometric mean estimate of hydraulic conductivity in the lower Hueneme aquifer was 7 ft/d.

Ground-Water Levels and Relation to Stream Stage

The three multiple-well monitoring sites were instrumented with transducers and data loggers. Transducers were installed in all wells at monitoring sites SP1 and SP2 and in wells RP1-1, RP1-2, and RP1-5 at monitoring site RP1. Water levels for each of three monitoring sites for the period July 1994 to October 1996 are shown in figure 14. Also shown in figure 14 are measured heads in drive points that were installed in the bed of the Santa Clara River near monitoring sites SP1 and RP1. The purpose of these drive points, which also were instrumented with transducers and data loggers, was to provide a quantitative estimate of the changes in stream stage. As shown in figure 14*A*, water levels in SP1-5, the shallowest well, were approximately 15 ft higher and responded very differently than water levels in the four deeper wells. These differences indicate that the thick clay layer at this site acts as a confining zone that limits the hydraulic connection between the Shallow aquifer and the underlying aquifers. Water levels in SP1-5 appear to respond exclusively to changes in stream stage. Water levels in the four deeper wells at SP1 also show a response to changes in stream stage, but appear to be dominated by seasonal pumping patterns.

As at site SP1, water levels in SP2-4, the shallowest well at monitoring site SP2, are consistently higher than those in the three deeper wells (see figure 14*A*). Unlike at SP1-5, water levels in SP2-4 show a response to seasonal pumping patterns.

At site RP1, all three instrumented wells respond similarly, with water levels in RP1-1 (the deepest well) being slightly lower than those in RP1-2 and RP1-5 (the shallowest well). As described earlier, well RP1-1 was installed in the lower Hueneme aquifer in materials that are more consolidated than those in the overlying aquifers. During the data-collection period, water-level fluctuations in all the RP1 (Piru subbasin) wells were considerably larger than those in the Santa Paula subbasin wells. Recall (fig. 5) that the long-term monitoring well for the Piru subbasin, 4N/18W-29M2, also showed greater amplitude of water-level fluctuations than did the long-term monitoring wells in the Fillmore and Santa Paula subbasins.

Data were collected from the two in-stream drive points for brief periods. The instrumentation at the site near RP1 functioned only intermittently, and it was not possible to complete any quantitative analysis of the stream–aquifer interaction at this location. Ground-

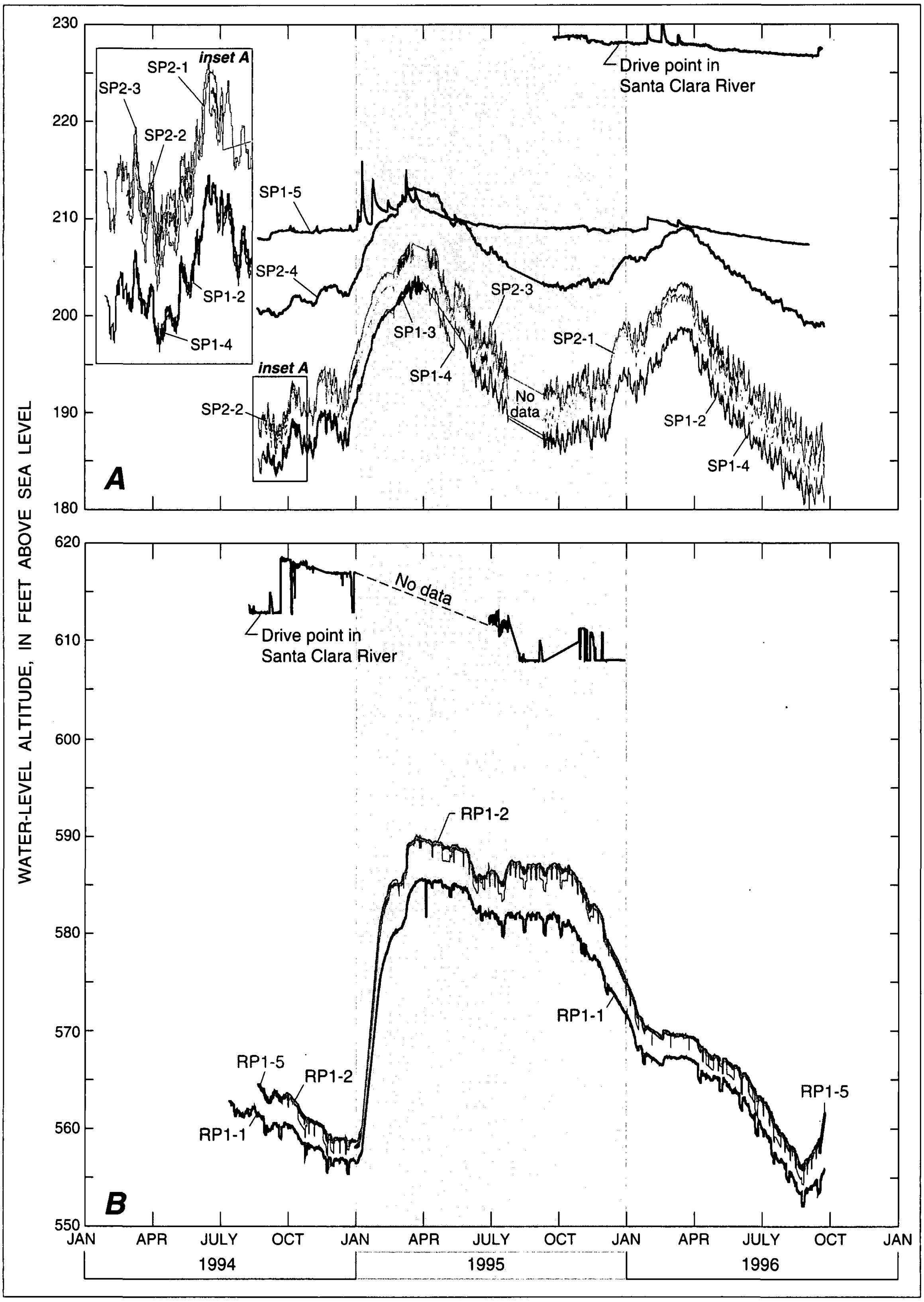


Figure 14. Water level in drive points in the Santa Clara River and in monitoring wells at sites SP1 and SP2 *(A)*, and at site RP1 *(B)*, 1994–96, Santa Clara River basin, Ventura County, California.

water-level data for well SP1-5 and the water-level data from the adjacent in-stream drive point were analyzed using an analytic model recently developed by Barlow and Moench (1998). The model, based on the assumption of a semi-infinite, water-table aquifer bounded by a fully penetrating river, considers two-dimensional, cross-sectional flow and uses the convolution technique to predict ground-water-level fluctuations caused by a continuously varying river stage. The model uses a Laplace transform solution for a problem similar to that solved by Neuman (1981, eqs. 1–6), with the additional consideration of a semipervious streambank.

The model was applied to data from SP1-5 and the in-stream drive point for an 8-day storm period in March 1996. Although not all the assumptions of the analytic model are met for these data, the analyses yielded some potentially useful preliminary results. The best match between measured and calculated ground-water levels was found for the following set of parameters: horizontal hydraulic conductivity (Kx) of 60 ft/d, vertical conductivity (Kz) of 6 ft/d, specific storage (Ss) of 1.0 E-05/ft, and a specific yield of 0.01–0.02 (Paul Barlow, USGS, written commun., 1997). A streambed leakance value of 0.011 (which represents a 1-foot-thick streambed with a hydraulic conductivity of 6 ft/d) was used. The calculated water-level response was very sensitive to the specific-yield value and the Kz/Kx ratio. The rapid response of water levels in SP1-5 indicates good hydraulic connection between the river and the aquifer over relatively large horizontal distances (300 ft) and suggests that the assumption of a fully penetrating river may be appropriate for this analysis. The Kz/Kx ratio of 0.1 indicates substantial anisotrophy. The low estimated value for specific yield would suggest that the system is locally confined. This result is surprising, given the absence of clay in materials encountered when drilling the upper 90 ft of SP1 (see figure 11); the low value may indicate the possible presence of a shallow confining layer(s) immediately beneath the river.

Ground-Water-Quality Measurements

Water-quality samples were collected and analyzed from the three USGS multiple-completion monitoring sites (see Appendix 4). The results from these analyses, along with relevant ground-water-quality data collected as part of the southern California RASA (Izbicki and others, 1995), are presented below. Emphasis is on sulfate, the stable isotopes of hydrogen and oxygen, tritium, and carbon-14. The methods used for sample collection, handling, preservation, and analysis are described in detail by Izbicki and others (1995). Construction information for the USGS wells is shown in figures 11–13. Construction information for the non-USGS wells is given in Appendix 5.

Sulfate

Sulfate concentrations (fig. 15; App. 4) in the study area generally ranged from 400 to 600 mg/L, although some concentrations were as high as 1,000 mg/L. As was described in the sections on surface-water data, sulfate concentrations provide an indicator of sources of discharge to the Santa Clara River. There are several interesting aspects of the sulfate results for the USGS ground-water monitoring sites. First, the sulfate concentration in the water extracted from the core in the upper clay zone in SP1 was 3,000 mg/L (see Appendix 4), indicating that this zone is a possible source of the generally high sulfate concentrations in ground water. Second, as suggested in the section "Analysis of Surface-Water Data," increases in streamflow in the lower part of the Santa Paula subbasin may be due to discharge of ground water from the Shallow aquifer, in which sulfate concentrations (well SP1-5, for example) are similar to that in the river. Third, sulfate concentrations for the three shallowest wells at the RP1 site (RP1-3, RP1-4, and RP1-5) are among the lowest in the study area, apparently reflecting the effects of regular recharge from the Santa Clara River.

Stable Isotopes of Hydrogen and Oxygen

Delta deuterium (δD) and delta oxygen-18 (δ^{18}O) values in samples from selected wells in the study area are shown on the map in figure 16. Izbicki (1996, fig. 4) presents δD values for the entire Santa Clara-Calleguas Hydrologic Unit. According to Izbicki, δD values in water from most wells in the Santa Clara Valley are less (more negative) than -50 per mil, indicating that the water in these wells was recharged by the Santa Clara River. As can be seen in figure 16, wells with δD values greater (less negative) than -50 per mil (including SP2-1, the deepest well at monitoring site SP2) tend to be north of the river in the Santa Paula and lower Fillmore subbasins; these heavier δD values reflect recharge from local runoff from the lower altitude mountains to the north.

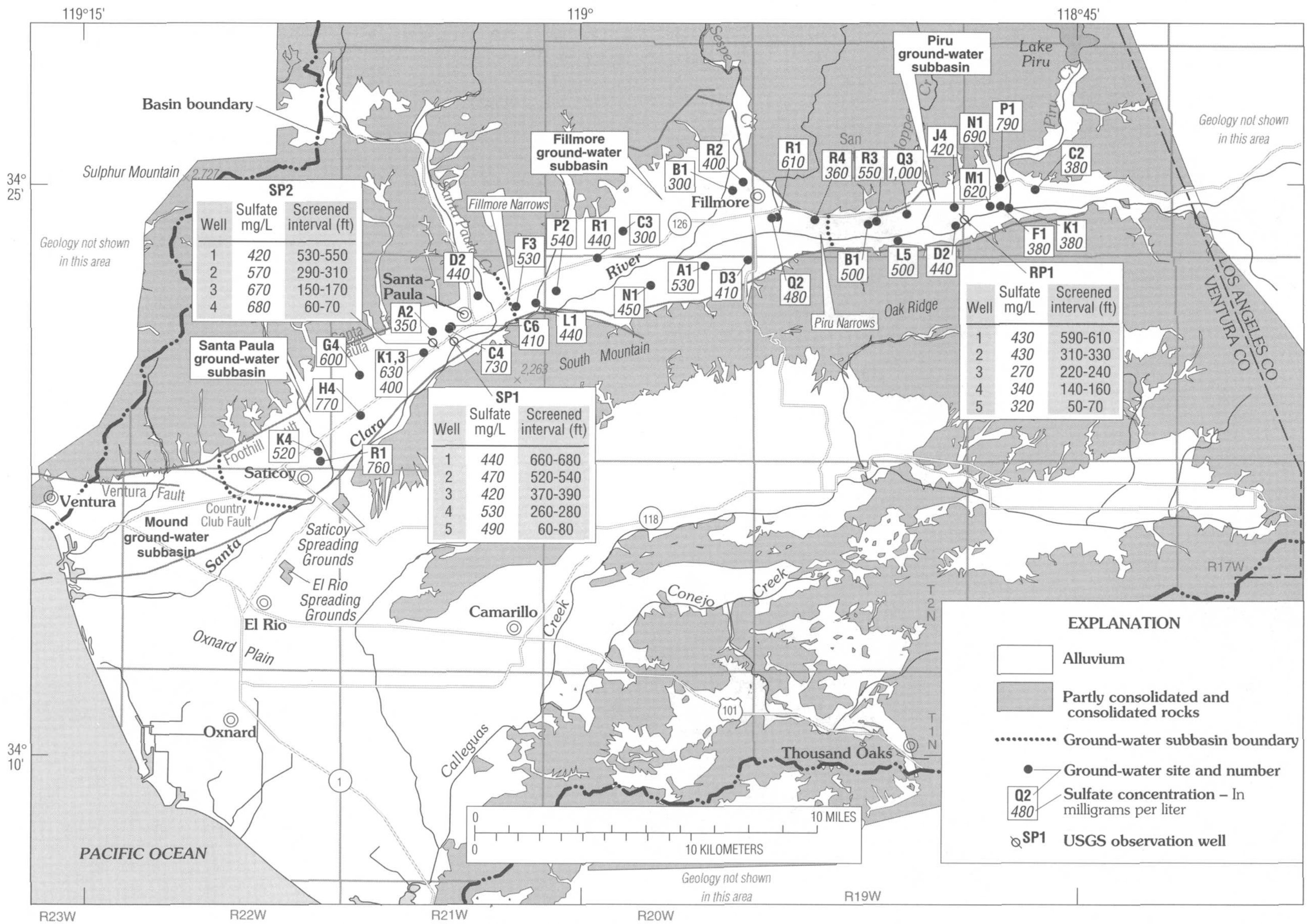


Figure 15. Sulfate concentrations, Santa Clara River basin, Ventura County, California.

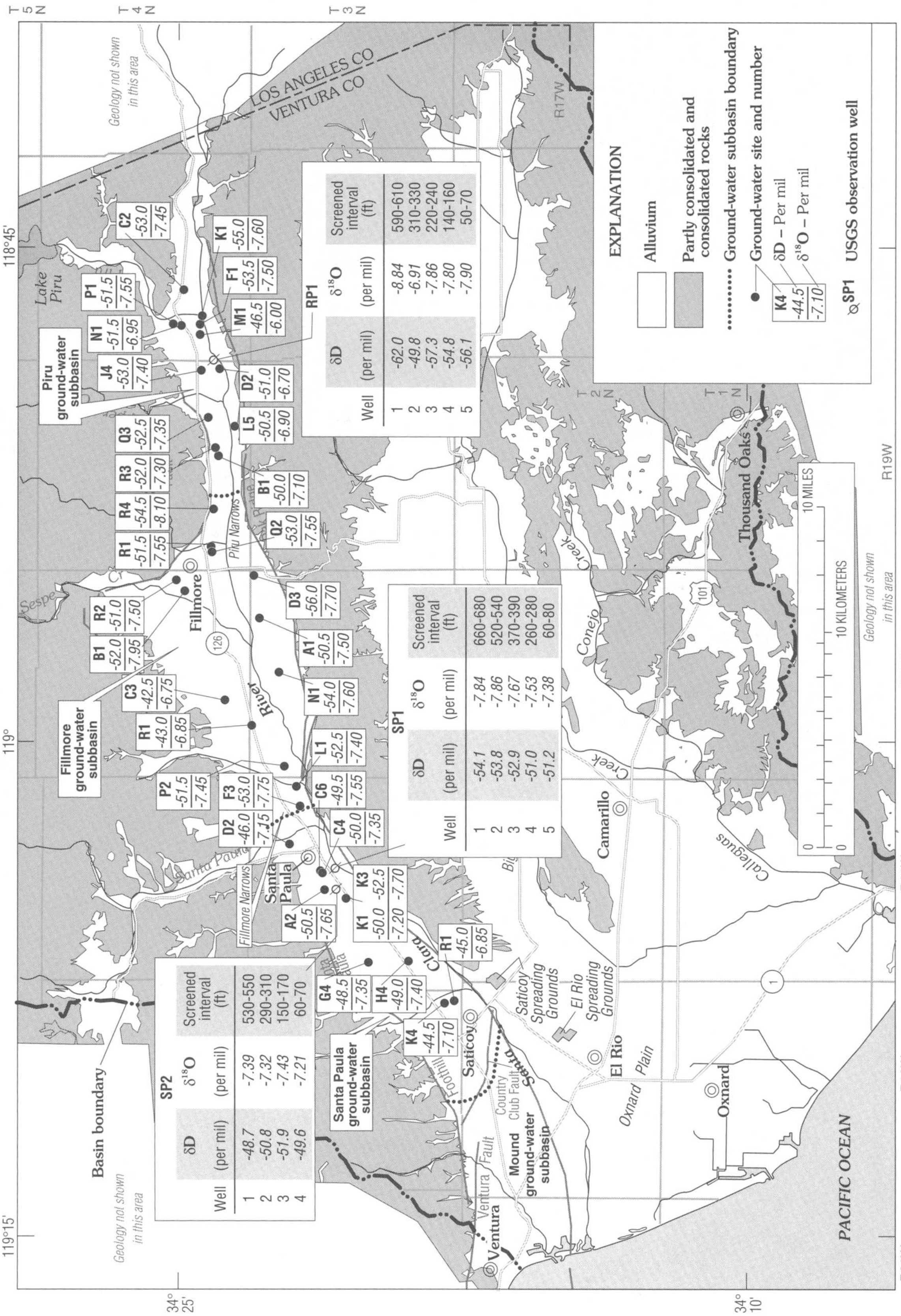


Figure 16. Delta deuterium (δD) and delta oxygen-18 ($\delta^{18}O$) values in samples from selected wells, Santa Clara River basin, Ventura County, California.

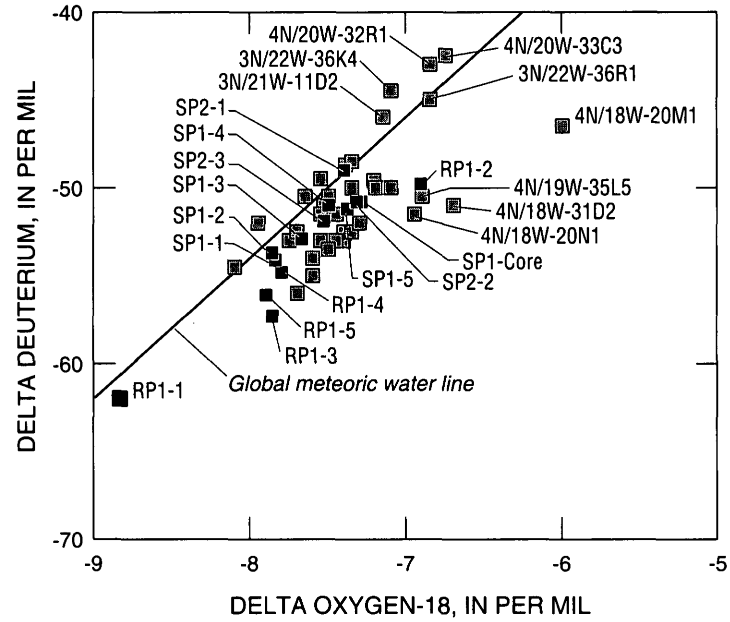


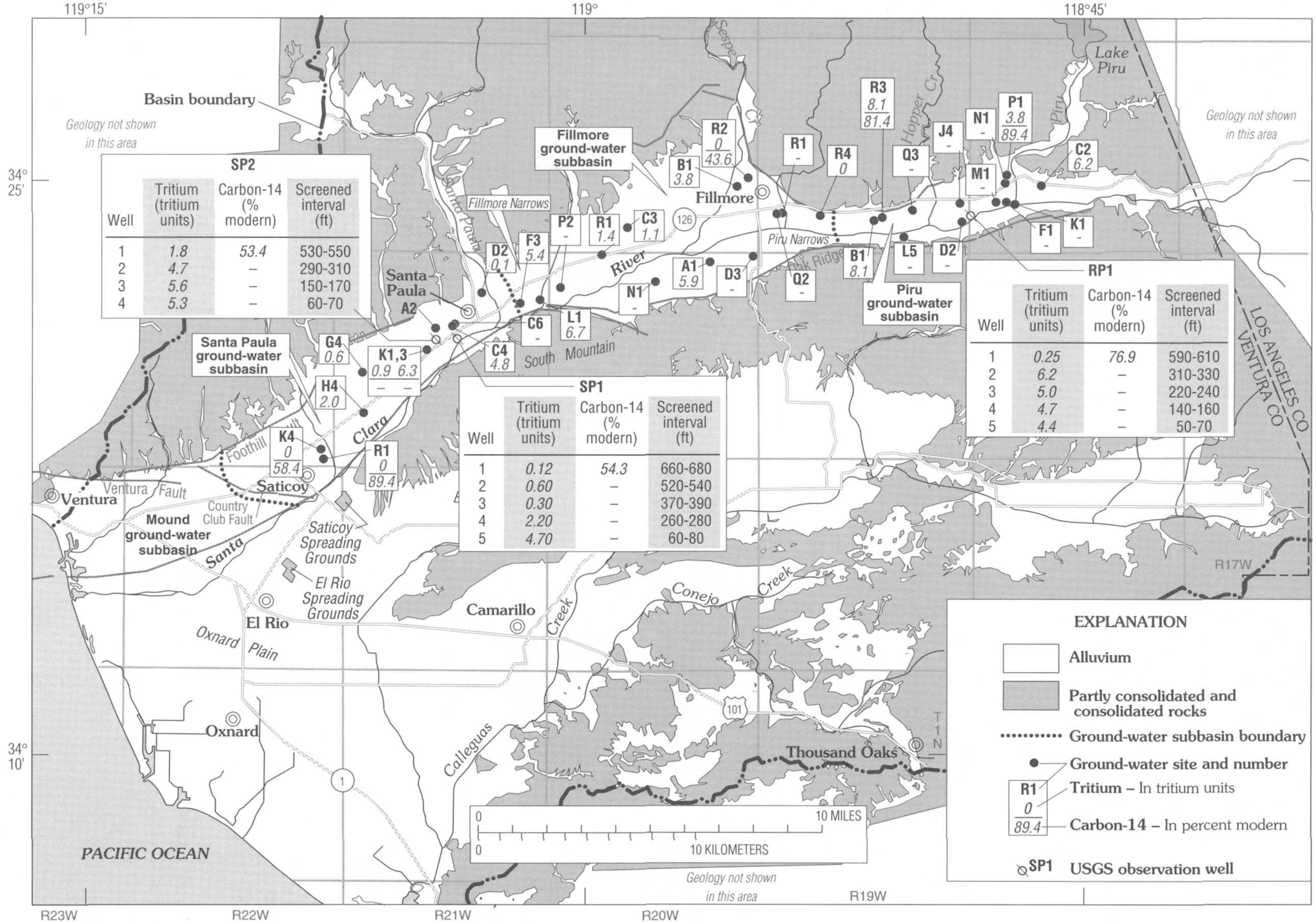
Figure 17. Delta deuterium (δD) as a function of delta oxygen-18 ($\delta^{18}O$) in water from wells, Santa Clara River basin, Ventura County, California.

A plot of δD as a function of $\delta^{18}O$ for ground-water samples in the Piru, Fillmore, and Santa Paula subbasins is shown in figure 17. This figure is analogous to figure 10, which is a plot of δD as a function of $\delta^{18}O$ in surface-water samples. As shown in figure 17, samples from most wells in the area, including most of the USGS monitoring wells, plot below the global meteoric water line, in a manner similar to that of samples from the Santa Clara River (see figure 10). Again, all wells with δD and $\delta^{18}O$ values that plot on or above the meteoric water line—including SP2-1, the deepest well at monitoring site SP2—are north of the Santa Clara River in the Santa Paula and lower Fillmore subbasins. Water from the core taken from the upper clay zone at monitoring site SP1 has an isotopic signature (fig. 17) very similar to that of water from the wells that are perforated above (SP1-5) and below the clay (SP1-4).

The $\delta^{18}O$ and δD data plotted in figure 17 also indicate that there are three different isotopic signatures in samples from monitoring site RP1. Water from well RP1-1, which is perforated in the lower Hueneme aquifer, is the lightest (most negative) of all the ground-water samples. Water from wells RP1-3, RP1-4, and RP1-5 is somewhat heavier (less negative). Water from well RP1-2, perforated in the basal zone of the Mugu aquifer, is the heaviest of the samples from the 14 wells in the USGS monitoring sites (in terms of $\delta^{18}O$). As can be seen by comparing figures 17 and 9, the sample from the Santa Clara River at site 10 during zero-release conditions, August 15–20, 1993, has an isotopic signature similar to that of RP1-2. This suggests that the discharging ground water at the Piru Narrows may include water from this permeable basal zone. Samples from several other Piru subbasin wells that appear to draw water from the same interval as RP1-2 have a similar isotopic signature (fig. 17). These other wells include 4N/18W-20N1 (perforated from 220 ft to 441 ft), 4N/18W-31D2 (perforated from 220 ft to 500 ft, and 4N/19W-35L5 (total depth of 302 ft). A sample from well 4N/18W-20M1 (total depth of 397 ft), which is located very near to RP1, is the heaviest (in terms of $\delta^{18}O$) of all the ground-water samples.

Tritium and Carbon-14

Tritium, the heavy isotope of hydrogen, can be a useful tool for estimating the age of ground water that was recharged less than about 50 years ago. The atmospheric testing of nuclear weapons released large quantities of tritium into the atmosphere beginning in 1952. As discussed by Izbicki (1996), ground water in the study area in which tritium concentrations are less than the detection limit of 0.3 tritium unit (TU) (referred to as "tritium dead" water) is interpreted as having recharged prior to 1952. Ground water with tritium concentrations greater than this is interpreted as recharge that occurred after 1952. As stated by Izbicki (1996) and shown in figure 18, detectable tritium is



SP2

Well	Tritium (tritium units)	Carbon-14 (% modern)	Screened interval (ft)
1	1.8	53.4	530-550
2	4.7	–	290-310
3	5.6	–	150-170
4	5.3	–	60-70

SP1

Well	Tritium (tritium units)	Carbon-14 (% modern)	Screened interval (ft)
1	0.12	54.3	660-680
2	0.60	–	520-540
3	0.30	–	370-390
4	2.20	–	260-280
5	4.70	–	60-80

RP1

Well	Tritium (tritium units)	Carbon-14 (% modern)	Screened interval (ft)
1	0.25	76.9	590-610
2	6.2	–	310-330
3	5.0	–	220-240
4	4.7	–	140-160
5	4.4	–	50-70

Figure 18. Tritium and carbon-14 values in samples from selected wells, Santa Clara River basin, Ventura County, California.

present in samples from most of the sampled wells in the Santa Clara Valley. At the three USGS multiple-completion monitoring sites, tritium concentrations clearly exceeded the detection limit in 10 of the 14 wells. Samples from the deepest well at RP1 (RP1-1) and the three deepest wells at SP1 (SP1-1, SP1-2, and SP1-3) all had tritium concentrations near or below the detection limit. These four wells apparently have received little recent recharge. As just discussed, RP1-1, which is perforated in the lower Hueneme aquifer, also has a unique isotopic signature (see figure 17). The fact that water from SP1-1, SP1-2, and SP1-3 appears to be "tritium dead" indicates that, even though the monitoring site is located about 300 ft from the Santa Clara River, very little recent river water has reached these lower zones. Apparently, the clay zone (see figure 11) greatly restricts the vertical movement of water from the Shallow aquifer at this location.

Carbon-14 can be a useful tool for estimating the age of older ground water (see Mazor, 1991). Izbicki (1996) describes how carbon-14, together with carbon-13/12 ratios ($\delta^{13}C$), was used to estimate ground-water ages throughout the Santa Clara–Calleguas Hydrologic Unit. Unadjusted carbon-14 values, measured as percent modern carbon, are shown in figure 18. For this study, carbon-14 and $\delta^{13}C$ values were determined for water from the deepest well in each of the three monitoring sites: SP1-1, SP2-1, and RP1-1. As can be seen from figure 18 and Appendix 4, SP1-1 and SP2-1 have very similar values for carbon-14 (54 percent modern carbon and 53 percent modern carbon, respectively) and for $\delta^{13}C$ (-13.4 and -13.1, respectively). Using these data, Izbicki (1996) estimated the age of water in these wells to be 300 to 400 years old. The fact that tritium is above the detection limit in water from well SP2-1 (see figure 18) raises the possibility that, although the well was extensively developed by air lifting, this measured tritium may be the result of residual drilling fluids.

Results from the carbon isotope analysis for RP1-1 are 77 percent modern carbon and a $\delta^{13}C$ value of -0.8. These values differ considerably from those for water from SP1-1 and SP2-1 and indicate that water in RP1-1 probably is significantly younger (recharged more recently). Another noticeable difference between the RP1 site and the SP1 and SP2 sites is the dissolved-oxygen concentration. All five wells at RP1 have at least one dissolved-oxygen concentration value that is 3 mg/L or greater (see Appendix 4). In contrast, the dissolved-oxygen concentration in all wells at SP1 and SP2 was less than 0.5 mg/L. Both the carbon and dissolved-oxygen data seem consistent with the fact that the Piru subbasin is located at the upper end of the flow system where there has been continuous ground-water recharge from the river.

MANAGEMENT IMPLICATIONS OF SURFACE-WATER/GROUND-WATER INTERACTIONS

The information provided by the surface-water and ground-water data described in this report has potential implications for water management in the area. The repeated measurements of discharge and water quality at different sites along the Santa Clara River and its tributaries, under different releases from Lake Piru and under different antecedent ground-water conditions, allow improved characterization of recharge and (or) discharge processes in different reaches. The simple regressions indicate that it may be possible to estimate net flow losses in individual subbasins on the basis of release rates from Lake Piru and depths to ground water at indicator wells. On a more aggregated scale, it also may be possible to estimate available flow at the Freeman Diversion on the basis of Lake Piru release rates and depths to ground water at indicator wells. These kinds of simple relations could aid water managers in predicting the total flow availability at Freeman Diversion that would result from different Lake Piru release strategies. This information could be useful for identifying strategies that are "most efficient" in terms of transmitting the most Lake Piru water downstream to the Freeman Diversion and, incorporating the inverse relation between flow and sulfate and chloride concentrations (fig. 8), for predicting likely sulfate concentrations at the Freeman Diversion. Because of the small number of observations on which the regressions are based and the multiple sources of error and uncertainty, however, great caution must be taken in drawing implications from the regression results.

Additional data would be required to confirm the apparent relation between net flow changes, Lake Piru release rates, and depths to ground water. Additional data sets at the sampling sites described in this report, along with better quantification of diversions, would be useful. To reduce the potential sources of error and uncertainty, it would be desirable to collect all measurements on a single day during a period of constant release from Lake Piru. Continued monitoring of the USGS multiple-completion sites and installation of new monitoring sites in the Fillmore subbasin and in the lower Santa Paula subbasin also would be helpful. These additional data would enable testing of some of the hypotheses presented in this report. Finally, more detailed modeling of the interaction of surface water and ground water could be of value in the study area. As part of the USGS RASA study, a two-layer (representing the upper and lower aquifer systems) ground-water model that incorporates stream routing is being developed (R.T. Hanson, USGS, written commun., 1998). A one-dimensional riverflow and transport model also was developed to model the dye-tracer test done as part of this study (Paybins and others, 1998; Nishikawa and others, 1999). Extending the RASA model to simulate the Shallow aquifer, linking it to the riverflow and transport model, and applying optimization techniques as was done in the Oxnard Plain (Reichard, 1995) could provide improved tools to evaluate water-management scenarios.

SUMMARY AND CONCLUSIONS

Surface-water-discharge and water-quality data, together with geohydrologic data, were compiled and analyzed in order to gain an improved understanding of the ground-water system and stream–aquifer interactions along the Santa Clara River in Ventura County, California.

During 1993–95, eight sets of discharge and water-quality measurements were made at different locations along the Santa Clara River. Two of the data sets were collected during base flow (zero release from Lake Piru); the remaining data sets were collected during different releases from Lake Piru. The data show consistent decreases in flow in Piru Creek from Lake Piru to the confluence of Piru Creek and the Santa Clara River and in the Santa Clara River from this confluence to the lower part of the Piru subbasin. Flow generally increases between the lower end of the Piru subbasin and the upper end of the Fillmore subbasin. An increase in sulfate concentration indicates that this increase in flow represents discharge of high-sulfate ground water associated with the Piru Narrows. In the Fillmore subbasin, there are consistent increases in flow in the lower part. As in the Piru subbasin, increases in sulfate concentration indicate that the flow increases represent high-sulfate ground-water discharge. Most of the data sets show increasing flow in the lower part of the Santa Paula subbasin. There are no significant increases in sulfate concentration associated with increases in flow in the lower part of the Santa Paula subbasin; the source of this water flux may be the Shallow aquifer near the river. Time-series data for sulfate concentration at the Freeman Diversion illustrate the relation between lower flows and higher sulfate concentrations at the Freeman Diversion: at lower flows, a higher percentage of the downstream flow is from high-sulfate ground-water discharge.

Several regressions were computed in order to statistically analyze the correlation of net flow changes in the individual subbasins with Lake Piru release rates and ground-water conditions. Because these regressions were based on a very small number of data sets, and because of the multiple sources of uncertainty and potential errors in the data, the results must be interpreted very cautiously. Regressions indicate that net flow change in the Piru subbasin can be statistically explained by the quantity released from Lake Piru and depth to ground water at an indicator well. Net flow changes in the Fillmore subbasins are somewhat less well explained by the joint effects of reservoir release and ground-water conditions. For the Fillmore subbasin, the regression coefficient for release from Lake Piru is not statistically significant. Flow changes in the Santa Paula subbasin are not well explained statistically by the Lake Piru release and depth to ground water.

An additional regression was computed to evaluate the joint effects of reservoir release and ground-water conditions on the overall ground-water recharge and discharge summed over all three subbasins. Measured flow in the Santa Clara River upstream from the Freeman Diversion was regressed against release from Lake Piru and depth to ground water at an indicator well. Results indicate that a relation exists between flow at the Freeman Diversion and both reservoir release and ground-water conditions. This relation has potential value for water-management decisions, particularly because of the inverse relation between flow at the Freeman Diversion and sulfate concentration.

Ground-water data from USGS multiple-completion monitoring sites installed during this study and from existing wells were analyzed. Analysis of slug-test data yielded estimates of hydraulic conductivities ranging from 35 to 85 ft/d in the Shallow aquifer, 33 to 100 ft/d in the Oxnard aquifer, 17 to 68 ft/d in the Mugu aquifer, and 15 to 58 ft/d in the upper Hueneme aquifer, and an estimate of 7 ft/d in the lower Hueneme aquifer. Analysis of water levels from the USGS wells, together with data from in-stream drive points, provided additional information on stream–aquifer relations. At site SP1, water levels in the Shallow aquifer are very closely tied to river stage and show little response to pumping. Water levels in the deeper wells appear to be dominated by pumping. At site RP1, all five wells responded in a similar manner. During the entire data-collection period, water-level fluctuations in all the RP1 (Piru subbasin) wells were larger than those in the Santa Paula subbasin wells. An analytic model of stream–aquifer interaction applied to water-level data from SP1-5 and the in-stream drive point yielded estimates of storage properties and the ratio of vertical to horizontal hydraulic conductivity.

Analysis of ground-water-quality data on the concentrations of sulfates, the stable isotopes of hydrogen and oxygen, tritium, and carbon provided some insight into the ground-water flow system and the interaction between ground water and surface water. Sulfate concentrations in the regional ground-water system generally ranged from 400 to 600 mg/L, although some concentrations were as high as 1,000 mg/L. Ground water that contains very high concentrations of sulfate appears to be associated with discharge to the river at the Piru and Fillmore Narrows. Ground water from the Shallow aquifer, with moderate sulfate concentrations, may be the source of discharge to the river in the lower part of the Santa Paula subbasin.

Isotopic data provide information on the source and age of water. The δD and $\delta^{18}O$ data indicate that samples from most wells, including most of the wells at the USGS monitoring sites, have δD values less (more negative) than -50 and plot below the global meteoric water line. The samples with values greater (less negative) than -50 and which plot above the global meteoric water line (SP2-1, the deepest well at monitoring site SP2, for example) probably reflect recharge from local precipitation. Unlike most sampled wells in the study area, the deepest well at site RP1 and the three deepest wells at site SP1 have tritium levels that are near or below the detection limit. The SP1 data indicate little vertical movement of water from the Shallow aquifer to the lower aquifers near the river in the upper Santa Paula subbasin.

The results from this study have potential water-management implications. In particular, the suggested correlation of flow losses and flow at the Freeman Diversion with releases from Lake Piru and ground-water conditions may have utility for scheduling Lake Piru releases. Additional ground-water and surface-water data collection is needed to confirm the apparent relations described in this report.

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APPENDIX

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California

[ft^3/s, cubic feet per second, µS/cm, microsiemens per centimeter; mg/L milligrams per liter; SC, specific conductance; Cl, chloride dissolved; SO_4, sulfate dissolved, N-NO_3, nitrate, dissolved as N, dD, delta deuterium, $d^{18}O$, delta oxygen-18; —, no data]

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	N-NO_3 (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: August 15–20. 1993								
1	Santa Clara River at County Line	8/20/93	47.7	1,204	100	277	5	—	—
2	Santa Clara River downstream from Camulos Ranch	8/16/93	36.3	1,304	104	311	5.3	—	—
3	Santa Clara River near Piru	8/16/93	42.1	1,370	107	334	5.5	—	—
4	Santa Clara River upstream from Piru Creek	8/17/93	0	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	8/17/93	3	914	48	276	.7	-53.7	-7.16
5	Piru Creek at Piru	8/17/93	1.2	1,840	82	690	1	—	—
7	Piru Creek at mouths	8/17/93	0	—	—	—	—	—	—
8	Santa Clara River at Torrey Road	8/17/93	0	—	—	—	—	—	—
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	8/17/93	0	—	—	—	—	—	—
10	Santa Clara River at Cavin Road	8/17/93	10	1,209	78	399	2.4	-51	-6.79
11	Santa Clara River at Chambersburg	8/17/93	36.2	1,334	62	477	2	-51.5	-7.09
12	Santa Clara River near Bardsdale	8/17/93	42.8	1,460	67	551	3.2	—	—
13	Sespe Creek at Route 126	8/18/93	13	950	36	322	.5	-52.9	-7.46
14	Santa Clara River upstream frm Richardson Diversion	8/18/93	78.2	1,232	48	450	2.3	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	8/18/93	76.0	1,289	50	452	2.9	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	8/16/93	100	1,468	57	564	3.5	-51.5	-7.22
18	Santa Paula Creek near Santa Paula	8/16/93	12	689	12	178	.4	-46.3	-7.37
17	Santa Paula Creek at bridge for 126	8/16/93	8	765	20	198	.4	—	—
20	Santa Clara River at bridge for South Mountain Road	8/15/93	82.2	1,426	49	493	2.9	-50.5	-7.23
20b	Santa Clara River at Palm Avenue (SP1)	—	—	—	—	—		—	—
21	Santa Clara River near Haines	8/16/93	101	1,446	59	491	2.4	—	—
22	Santa Clara River at Freeman Diversion	—	—	—	—	—	—	—	—
23	Santa Clara River at Montalvo	8/15/93	.12	2,990	—	—	—	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	$N\text{-}NO_3$ (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
		Measurement period: August 24, 1993							
1	Santa Clara River at County Line	—	—	—	—	—	—	—	—
2	Santa Clara River downstream from Camulos Ranch	—	—	—	—	—	—	—	—
3	Santa Clara River near Piru	—	—	—	—	—	—	—	—
4	Santa Clara River upstream from Piru Creek	—	—	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	—	—	—	—	—	—	—	—
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	—	—	—	—	—	—	—	—
8	Santa Clara River at Torrey Road	—	—	—	—	—	—	—	—
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	—	—	—	—	—	—	—	—
10	Santa Clara River at Cavin Road	8/24/93	179	976	33	399	1.1	—	—
11	Santa Clara River at Chambersburg	—	—	—	—	—	—	—	—
12	Santa Clara River near Bardsdale	—	—	—	—	—	—	—	—
13	Sespe Creek at Route 126	—	—	—	—	—	—	—	—
14	Santa Clara River upstream frm Richardson Diversion	—	—	—	—	—	—	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	—	—	—	—	—	—	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	8/24/93	244	1,270	61	439	2.2	—	—
18	Santa Paula Creek near Santa Paula	—	—	—	—	—	—	—	—
17	Santa Paula Creek at bridge for 126	—	—	—	—	—	—	—	—
20	Santa Clara River at bridge for South Mountain Road	—	—	—	—	—	—	—	—
20b	Santa Clara River at Palm Avenue (SP1)	—	—	—	—	—	—	—	—
21	Santa Clara River near Haines	—	—	—	—	—	—	—	—
22	Santa Clara River at Freeman Diversion	8/24/93	230	1,290	54	331	2.8	—	—
23	Santa Clara River at Montalvo	—	—	—	—	—	—	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	$N\text{-}NO_3$ (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: August 30–September 15, 1993								
1	Santa Clara River at County Line	8/30/93	44.4	1,198	103	291	6.5	—	—
2	Santa Clara River downstream from Camulos Ranch	8/30/93	33.7	1,255	105	318	6.2	—	—
3	Santa Clara River near Piru	8/30/93	41.4	1,330	109	358	6	—	—
4	Santa Clara River upstream from Piru Creek	8/30/93	0	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	8/31/93	258	882	49	281	.7	—	—
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	8/31/93	224	880	50	287	.6	—	—
8	Santa Clara River at Torrey Road	8/31/93	202	892	49	278	.6	—	—
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	8/31/93	187	986	49	268	.6	—	—
10	Santa Clara River at Cavin Road	9/1/93	189	892	50	276	.7	—	—
11	Santa Clara River at Chambersburg	9/1/93	236	943	53	305	.9	—	—
12	Santa Clara River near Bardsdale	9/1/93	220	1,026	55	337	1.1	—	—
13	Sespe Creek at Route 126	9/1/93	10	886	39	316	.4	—	—
14	Santa Clara River upstream frm Richardson Diversion	9/1/93	256	990	55	350	2.5	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	9/2/93	237	1,050	54	371	1.5	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	9/3/93	238	1,126	58	417	1.9	—	—
18	Santa Paula Creek near Santa Paula	9/2/93	9	696	14	185	.3	—	—
17	Santa Paula Creek at bridge for 126	9/2/93	5	750	24	216	.4	—	—
20	Santa Clara River at bridge for South Mountain Road	9/2/93	227	1,125	52	392	1.6	—	—
20b	Santa Clara River at Palm Avenue (SP1)	—	—	—	—	—	—	—	—
21	Santa Clara River near Haines	9/2/93	276	1,167	59	403	1.6	—	—
22	Santa Clara River at Freeman Diversion	9/15/93	289	1,130	59	387	1.5	—	—
23	Santa Clara River at Montalvo	9/2/93	.21	3,310	144	1,810	9.7	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	N-NO_3 (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
Measurement period: October 26–30, 1993									
1	Santa Clara River at County Line	10/30/93	37.6	1,290	97	234	5.8	—	—
2	Santa Clara River downstream from Camulos Ranch	10/30/93	—	—	—	—	—	—	—
3	Santa Clara River near Piru	10/30/93	44	1,400	109	358	6.2	—	—
4	Santa Clara River upstream from Piru Creek	10/30/93	0	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	10/30/93	303	—	55	272	.5	-58.2	-8.17
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	10/29/93	204	960	45	287	.8	—	—
8	Santa Clara River at Torrey Road	10/29/93	182	940	49	201	.6	-53.9	-7.25
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	10/29/93	187	920	56	280	.4		
10	Santa Clara River at Cavin Road	10/27/93	198	937	48	265	.6	-54.6	-7.24
11	Santa Clara River at Chambersburg	10/27/93	185	1,035	53	392	1.2	-54.3	-7.29
12	Santa Clara River near Bardsdale	—	—	—	—	—	—	—	—
13	Sespe Creek at Route 126	10/27/93	5	1,002	42	306	.6	—	—
14	Santa Clara River upstream frm Richardson Diversion	10/27/93	249	1,038	56	223	1.4	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	10/28/93	251	1,080	51	315	1.5	-52.9	-7.16
19	Santa Clara River 1.4 miles upstream from South Mountain Road	10/28/93	263	1,181	41	402	1.8	-47.1	-4.87
18	Santa Paula Creek near Santa Paula	10/29/93	6	714	12	114	.5	-48.8	-7.55
17	Santa Paula Creek at bridge for 126	10/26/93	2	803	31	188	.7	—	—
20	Santa Clara River at bridge for South Mountain Road	10/27/93	214	1,121	65	323	1.8	-52.2	-7.18
20b	Santa Clara River at Palm Avenue (SP1)	—	—	—	—	—	—	—	—
21	Santa Clara River near Haines	10/28/93	249	1,160	58	333	1.8	-52.4	-7.21
22	Santa Clara River at Freeman Diversion	10/26/93	282	1,240	44	347	1.9	-52.6	-7.38
23	Santa Clara River at Montalvo	10/26/93	.16	3,330	130	1,650	8.8	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	$N-NO_3$ (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: July 25–August 2, 1994								
1	Santa Clara River at County Line	8/1/94	30.5	1,173	102	307	6.5	—	—
2	Santa Clara River downstream from Camulos Ranch	7/29/94	17.9	1,463	102	352	5.7	—	—
3	Santa Clara River near Piru	8/1/94	23.4	1,638	107	404	5.1	—	—
4	Santa Clara River upstream from Piru Creek	—	—	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	7/25/94	5.46	1,096	46	309	.2	—	—
5	Piru Creek at Piru	7/26/94	2.88	1,704	67	586	0	—	—
7	Piru Creek at mouth	—	—	—	—	—	—	—	—
8	Santa Clara River at Torrey Road	—	—	—	—	—	—	—	—
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	—	—	—	—	—	—	—	—
10	Santa Clara River at Cavin Road	7/26/94	.33	1,871	24	658	0	—	—
11	Santa Clara River at Chambersburg	7/26/94	11.2	1,500	57	553	1.3	—	—
12	Santa Clara River near Bardsdale	7/27/94	6.32	1,423	57	536	.8	—	—
13	Sespe Creek at Route 126	—	—	—	—	—	—	—	—
14	Santa Clara River upstream frm Richardson Diversion	7/27/94	7.67	1,370	44	438	1.7	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	7/28/94	11	1,728	58	586	2.7	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	7/27/94	19.3	1,998	66	745	3.1	—	—
18	Santa Paula Creek near Santa Paula	8/2/94	3.57	882	18	203	.1	—	—
17	Santa Paula Creek at bridge for 126	7/28/94	.74	1,372	55	388	1.2	—	—
20	Santa Clara River at bridge for South Mountain Road	7/27/94	19.4	1,880	61	672	2.2	—	—
20b	Santa Clara River at Palm Avenue (SP1)	7/28/94	21.9	1,850	63	691	2	—	—
21	Santa Clara River near Haines	7/28/94	21.7	1,920	87	630	1.7	—	—
22	Santa Clara River at Freeman Diversion	—	—	—	—	—	—	—	—
23	Santa Clara River at Montalvo	8/2/94	.06	3,900	129	1,755	4.9	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	$N\text{-}NO_3$ (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: September 19–24, 1994								
1	Santa Clara River at County Line	9/19/94	32.1	1,380	115	310	5.9	-54.5	-7.53
2	Santa Clara River downstream from Camulos Ranch	9/20/94	23.8	1,483	118	363	5.4	—	—
3	Santa Clara River near Piru	9/19/94	24.2	1,536	117	419	5.7	—	—
4	Santa Clara River upstream from Piru Creek	—	—	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	9/20/94	251	962	47	315	.2	-53.5	-7.35
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	9/20/94	218	972	48	323	.1	—	—
8	Santa Clara River at Torrey Road	9/20/94	215	978	47	375	.1	-54.5	-7.34
8b	Santa Clara River at Powell Road (RP1)	9/21/94	209	1,006	48	289	.1	—	—
9	Santa Clara River near Wiley Canyon	9/21/94	196	1,033	48	326	.1	—	—
10	Santa Clara River at Cavin Road	9/21/94	197	1,026	47	310	.04	-55.2	-7.3
11	Santa Clara River at Chambersburg	9/21/94	196	1,083	52	369	.3	-53.8	-7.22
12	Santa Clara River near Bardsdale	9/22/94	184	1,112	50	357	.3	—	—
13	Sespe Creek at Route 126	—	—	—	—	—	—	—	—
14	Santa Clara River upstream frm Richardson Diversion	9/22/94	181	1,120	49	372	.4	-54.2	-7.25
16	Santa Clara River 2.6 miles upstream from South Mountain Road	9/22/94	195	1,144	51	380	.4	-53.1	-7.3
19	Santa Clara River 1.4 miles upstream from South Mountain Road	—	—	—	—	—	—	—	—
18	Santa Paula Creek near Santa Paula	9/24/94	2.66	888	21	213	.2	-47.3	-7.31
17	Santa Paula Creek at bridge for 126	9/24/94	.18	1,010	47	312	.8		
20	Santa Clara River at bridge for South Mountain Road	9/22/94	140	1,234	51	413	.6	-52.6	-7.29
20b	Santa Clara River at Palm Avenue (SP1)	9/23/94	191	1,258	52	416	.7	—	—
21	Santa Clara River near Haines	9/23/94	195	1,282	56	424	.8	-52.8	-7.22
22	Santa Clara River at Freeman Diversion	9/23/94	184	1,297	57	455	.9	-53.2	-7.19
23	Santa Clara River at Montalvo	9/24/94	.076	4,140	146	2,020	.7	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	N-NO_3 (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: October 25–27, 1994								
1	Santa Clara River at County Line	—	—	—	—	—	—	—	—
2	Santa Clara River downstream from Camulos Ranch	—	—	—	—	—	—	—	—
3	Santa Clara River near Piru	—	—	—	—	—	—	—	—
4	Santa Clara River upstream from Piru Creek	—	—	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	10/26/94	167		56	324	0	—	—
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	—	—	—	—	—	—	—	—
8	Santa Clara River at Torrey Road	10/25/94	155		57	330	0	—	—
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	—	—	—	—	—	—	—	—
10	Santa Clara River at Cavin Road	10/27/94	142		56	329	0	—	—
11	Santa Clara River at Chambersburg	10/25/94	158		57	343	.3	—	—
12	Santa Clara River near Bardsdale	—	—	—	—	—	—	—	—
13	Sespe Creek at Route 126	—	—	—	—	—	—	—	—
14	Santa Clara River upstream frm Richardson Diversion	10/27/94			57	354	.2	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	—	—	—	—	—	—	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	—	—	—	—	—	—	—	—
18	Santa Paula Creek near Santa Paula	—	—	—	—	—	—	—	—
17	Santa Paula Creek at bridge for 126	—	—	—	—	—	—	—	—
20	Santa Clara River at bridge for South Mountain Road	10/25/94	163		57	440	.8	—	—
20b	Santa Clara River at Palm Avenue (SP1)	10/26/94	165		57	438	.8	—	—
21	Santa Clara River near Haines	—	—	—	—	—	—	—	—
22	Santa Clara River at Freeman Diversion	10/27/94	152	—	—	—	—	—	—
23	Santa Clara River at Montalvo	—	—	—	—	—	—	—	—

Appendix 1. Discharge and water-quality data for surface-water monitoring sites, 1993–95, Ventura County, California—Continued

	Measurement sites	Date	Discharge (ft^3/s)	SC (µS/cm)	Cl (mg/L)	SO_4 (mg/L)	N-NO_3 (mg/L)	δD (per mil)	$\delta^{18}O$ (per mil)
	Measurement period: October 10–13, 1995								
1	Santa Clara River at County Line	10/10/95	28.4	1,362	110	317	7.5	-53.8	-7.45
2	Santa Clara River downstream from Camulos Ranch	—	—	—	—	—	—	—	—
3	Santa Clara River near Piru	—	—	—	—	—	—	—	—
4	Santa Clara River upstream from Piru Creek	—	—	—	—	—	—	—	—
6	Piru Creek below Santa Felicia Dam	10/13/95	249	1,024	32	335	0	-52.4	-7.15
5	Piru Creek at Piru	—	—	—	—	—	—	—	—
7	Piru Creek at mouth	—	—	—	—	—	—	—	—
8	Santa Clara River at Torrey Road	10/13/95	197	1,000	33	342	0	-52.5	-7.06
8b	Santa Clara River at Powell Road (RP1)	—	—	—	—	—	—	—	—
9	Santa Clara River near Wiley Canyon	—	—	—	—	—	—	—	—
10	Santa Clara River at Cavin Road	10/13/95	180	1,015	34	346	.06	-51	-7.01
11	Santa Clara River at Chambersburg	10/11/95	183	1,086	45	392	.9	-51.7	-7.25
12	Santa Clara River near Bardsdale	—	—	—	—	—	—	—	—
13	Sespe Creek at Route 126	—	—	—	—	—	—	—	—
14	Santa Clara River upstream frm Richardson Diversion	—	—	—	—	—	—	—	—
16	Santa Clara River 2.6 miles upstream from South Mountain Road	—	—	—	—	—	—	—	—
19	Santa Clara River 1.4 miles upstream from South Mountain Road	10/12/95	216	1,267	35	453	1.3	-49.9	-7.12
18	Santa Paula Creek near Santa Paula	10/11/95	6.8	763	13	196	.1	-46.4	-7.42
17	Santa Paula Creek at bridge for 126	—	—	—	—	—	—	—	—
20	Santa Clara River at bridge for South Mountain Road	10/13/95	239	1,230	35	431	1.3	-52	-7.26
20b	Santa Clara River at Palm Avenue (SP1)	—	—	—	—	—	—	—	—
21	Santa Clara River near Haines	10/12/95	210	1,284	40	446	1.4	-52.2	-7.17
22	Santa Clara River at Freeman Diversion	10/12/95	256	1,280	38	445	1.5	-51.6	-7.3
23	Santa Clara River at Montalvo	10/11/95	29	1,142	39	597	.8	-48.6	-7

Appendix 2. Input data for regression analyses

[ft^3/s, cubic feet per second; ft, feet. Bold-italic designations indicate regression-equation variables; —, no data]

Date	Piru release (ft^3/s) ***R***	Depth to water, 4N/18W-29M2, (ft) ***G1***	Depth to water, 4N/20W-26L1, (ft) ***G2***	Depth to water, 3N/21W-16K1, (ft) ***G3***	Mean diversion at Piru spreading grounds (ft^3/s)	Net flow loss, Piru subbasin (adjusted for diversion) (ft^3/s) ***Lp***	Net flow loss, Fillmore subbasin (ft^3/s) ***Lf***	Net flow loss, Santa Paula subbasin (ft^3/s) ***Lsp***	Flow in Santa Clara River upstream of Freeman Diversion (+diversion at Piru spreading grounds) (ft^3/s) ***F***
10/7/91	272	113.8	55.8	58.7	—	—	—	-2	16
10/21/91	391	111.2	69.4	53.5	—	235	93	-12	75
8/30–9/15/93	258	33.2	40.2	46.4	—	22	9	-62	289
10/26–30/93	303	30.9	44.6	47.7	57	61	-30	-68	339
9/19–24/94	251	61.4	50.5	50.5	—	55	5	7	184
10/25–27/94	167	61.5	48.5	45.2	—	9	-5	13	152
10/10–13/95	249	34.9	44.4	44.7	—	66	-56	-16	256

Appendix 3. Hydraulic-conductivity estimates from slug tests at ground-water monitoring sites, Ventura County, California

[ft below lsd, feet below land-surface datum; ft/d, foot per day; —, no data]

State well No.	Common name	Perforated interval (ft below lsd)	Aquifer	Storage coefficient	Method	Test number	Hydraulic conductivity (ft/d)	Geometric mean hydraulic conductivity (ft/d)
4N/18W-31D3	RP1-1	590 – 610	Lower Hueneme	2.0E-03	Cooper	u1	5.5	7
				2.0E-05	Cooper	u1	8.8	—
				2.0E-03	Cooper	u2	5.5	—
				2.0E-05	Cooper	u2	8.7	—
4N/18W-31D4	RP1-2	310 – 330	Mugu	2.0E-03	Kipp	d1, u2	21.7	17
				2.0E-05	Kipp	d1, u2	37.7	—
				2.0E-03	Kipp	d2	16.4	—
				2.0E-05	Kipp	d2	28.8	—
				2.0E-03	Kipp	u1, u3, d3	9.7	—
				2.0E-05	Kipp	u1, u3, d3	16.8	—
4N/18W-31D5	RP1-3	220 – 240	Mugu	2.0E-03	Kipp	d1	27.6	30
				2.0E-05	Kipp	d1	48.0	—
				2.0E-03	Kipp	u1	19.8	—
				2.0E-05	Kipp	u1	34.7	—
				2.0E-03	Kipp	u2	19.7	—
				2.0E-05	Kipp	u2	34.7	—
				2.0E-03	Kipp	d2	26.1	—
				2.0E-05	Kipp	d2	45.8	—
4N/18W-31D6	RP1-4	140 – 160	Oxnard	2.0E-03	Kipp	d2	32.1	33
				2.0E-05	Kipp	d2	56.3	—
				2.0E-03	Kipp	u1, u2, d1	23.1	—
				2.0E-05	Kipp	u1, u2, d1	40.8	—
4N/18W-31D7	RP1-5	50 – 70	Shallow	2.0E-03	Kipp	d1,d2, u1, u2	25.7	35
				2.0E-05	Kipp	d1,d2, u1, u2	46.9	—
3N/21W-15G1	SP1-1	660 – 680	Upper Hueneme	2.0E-03	Kipp	d1	38.4	58
				2.0E-05	Kipp	d1	63.0	—
				2.0E-03	Kipp	d2	72.0	—
				2.0E-05	Kipp	d2	114.6	—
				2.0E-03	Kipp	u1	42.2	—
				2.0E-05	Kipp	u1	68.9	—
				2.0E-03	Kipp	u2	37.8	—
				2.0E-05	Kipp	u2	62.1	—

Appendix 3. Hydraulic-conductivity estimates from slug tests at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Common name	Perforated interval (ft below lsd)	Aquifer	Storage coefficient	Method	Test number	Hydraulic conductivity (ft/d)	Geometric mean hydraulic conductivity (ft/d)
3N/21W-15G2	SP1–2	520 – 540	Upper Hueneme	2.0E-03	Kipp	d1,d2, u1, u2	11.6	15
				2.0E-05	Kipp	d1,d2, u1, u2	20.5	—
3N/21W-15G3	SP1–3	370 – 390	Mugu	2.0E-03	Kipp	u1	47.3	68
				2.0E-05	Kipp	u1	78.3	—
				2.0E-03	Kipp	u2	64.2	—
				2.0E-05	Kipp	u2	104.4	—
				2.0E-03	Kipp	d2	73.7	—
				2.0E-05	Kipp	d2	119.9	—
				2.0E-03	Kipp	d1	35.7	—
				2.0E-05	Kipp	d1	60.0	—
3N/21W-15G4	SP1–4	260 – 280	Mugu	2.0E-03	Kipp	d1,d2, u1, u2	13.1	18
				2.0E-05	Kipp	d1,d2, u1, u2	23.9	—
3N/21W-15G5	SP1–5	60 – 80	Shallow	2.0E-03	Kipp	d1,d2, u1, u2	34.1	45
				2.0E-05	Kipp	d1,d2, u1, u2	60.3	—
3N/21W-16H6	SP2–1	530 – 550	Upper Hueneme	2.0E-03	Kipp	d1, d2	16.5	24
				2.0E-05	Kipp	d1, d2	28.6	—
				2.0E-03	Kipp	u2	19.2	—
				2.0E-05	Kipp	u2	33.1	—
				2.0E-03	Kipp	u1	23.0	—
				2.0E-05	Kipp	u1	39.1	—
3N/21W-16H7	SP2–2	290 – 310	Mugu	2.0E-03	Kipp	d1	23.3	26
				2.0E-05	Kipp	d1	40.4	—
				2.0E-03	Kipp	d2	20.3	—
				2.0E-05	Kipp	d2	35.5	—
				2.0E-03	Kipp	u1	18.8	—
				2.0E-05	Kipp	u1	33.1	—
				2.0E-03	Kipp	u2	17.9	—
				2.0E-05	Kipp	u2	31.7	—
3N/21W-16H8	SP2–3	150 – 170	Oxnard	2.0E-03	Kipp	u1	98.0	100
				2.0E-05	Kipp	u1	160.8	—
				2.0E-03	Kipp	u2, d1	68.7	—
				2.0E-05	Kipp	u2, d2	114.4	—
3N/21W-16H9	SP2–4	60 – 70	Shallow	1.0E-03	Cooper	u2	67.9	85
				1.0E-05	Cooper	u2	106.7	—

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California

[Analysis for each sample is shown on one line on consecutive pages. ft, feet; lsd, land surface datum; µs/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; TU, tritium unit; <, actual value is less than value shown; —, no data]

State well No.	Common name	Station identification No.	Date	Water level, (ft below lsd)	Depth of well, total (ft)	Altitude of lsd (ft above sea level)
3N/21W-15G-CORE	SP-1 CORE	342034119040206	04-30-94	—	—	236
3N/21W-15G1	SP1-1	342034119040201	06-14-94	40.85	680	236
3N/21W-15G1		342034119040201	04-03-95	28.58	680	236
3N/21W-15G1		342034119040201	09-06-96	51	680	236
3N/21W-15G2	SP1-2	342034119040202	06-14-94	41.1	540	236
3N/21W-15G2		342034119040202	04-03-95	28.82	540	236
3N/21W-15G2		342034119040202	09-06-96	50	540	236
3N/21W-15G3	SP1-3	342034119040203	06-15-94	41.33	390	236
3N/21W-15G3		342034119040203	04-04-95	29.04	390	236
3N/21W-15G3		342034119040203	09-06-96	49.35	390	236
3N/21W-15G4	SP1-4	342034119040204	06-15-94	41.55	280	236
3N/21W-15G4		342034119040204	04-30-94	29.29	280	236
3N/21W-15G4		342034119040204	09-06-96	49.21	280	236
3N/21W-15G5	SP1-5	342034119040205	06-14-94	23.22	80	236
3N/21W-15G5		342034119040205	04-04-95	20.7	80	236
3N/21W-15G5		342034119040205	09-06-96	24.43	80	236
3N/21W-16H5	SP2-1	342035119044401	06-16-94	46.25	550	240
3N/21W-16H5		342035119044401	04-05-95	34.61	550	240
3N/21W-16H5		342035119044401	09-05-96	55.43	550	240
3N/21W-16H6	SP2-2	342035119044402	06-16-94	46.52	310	240
3N/21W-16H6		342035119044402	04-05-95	34.2	310	240
3N/21W-16H6		342035119044402	09-05-96	54.15	310	240
3N/21W-16H7	SP2-3	342035119044403	06-16-94	46.24	170	240
3N/21W-16H7		342035119044403	04-05-95	33.64	170	240
3N/21W-16H7		342035119044403	09-05-96	53.09	170	240
3N/21W-16H8	SP2-4	342035119044404	06-15-94	46.24	70	240
3N/21W-16H8		342035119044404	04-05-95	27.91	70	240
3N/21W-16H8		342035119044404	09-05-96	40.69	70	240
4N/18W-31D3	RP1-1	342335118484401	06-25-94	—	610	592
4N/18W-31D3		342335118484401	04-06-95	13.04	610	592
4N/18W-31D3		342335118484401	09-17-96	44.6	610	592
4N/18W-31D4	RP1-2	342335118484402	06-25-94	—	330	592
4N/18W-31D4		342335118484402	04-06-95	9	330	592
4N/18W-31D4		342335118484402	09-17-96	40.39	330	592
4N/18W-31D5	RP1-3	342335118484403	06-25-94	—	240	592
4N/18W-31D5		342335118484403	04-06-95	8.98	240	592
4N/18W-31D5		342335118484403	09-17-96	40.69	240	592
4N/18W-31D6	RP1-4	342335118484404	06-25-94	—	160	592
4N/18W-31D6		342335118484404	04-06-95	9.09	160	592
4N/18W-31D6		342335118484404	09-17-96	40.44	160	592
4N/18W-31D7	RP1-5	342335118484405	06-25-94	—	70	592
4N/18W-31D7		342335118484405	04-06-95	9.06	70	592
4N/18W-31D7		342335118484405	09-17-96	40.16	70	592

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Depth to top of sampled interval (ft below lsd)	Depth to bottom of sampled interval (ft below lsd)	Specific conductance, field (µS/cm)	Specific conductance, lab (µS/cm)	pH, field (standard units)	pH, lab (standard units)
3N/21W-15G-CORE	04-30-94	131	134	—	—	—	—
3N/21W-15G1	06-14-94	—	—	1,240	1,330	7.5	7.3
3N/21W-15G1	04-03-95	—	—	1,330	1,340	7.4	7.3
3N/21W-15G1	09-06-96	660	680	1,340	1,290	7.4	7.5
3N/21W-15G2	06-14-94	—	—	1,300	1,400	7.4	7.3
3N/21W-15G2	04-03-95	—	—	1,380	1,390	7.4	7.3
3N/21W-15G2	09-06-96	520	540	1,390	1,400	7.4	7.4
3N/21W-15G3	06-15-94	—	—	703	1,290	7.2	7.2
3N/21W-15G3	04-04-95	—	—	1,280	1,300	7.3	7.2
3N/21W-15G3	09-06-96	370	390	1,320	1,340	7.3	7.4
3N/21W-15G4	06-15-94	—	—	813	1,560	7.1	7.2
3N/21W-15G4	04-30-94	—	—	1,440	1,470	7.3	7.2
3N/21W-15G4	09-06-96	260	280	1,550	1,560	7.3	7.4
3N/21W-15G5	06-14-94	—	—	1,420	1,510	7.4	7.3
3N/21W-15G5	04-04-95	—	—	1,480	1,520	7.4	7.3
3N/21W-15G5	09-06-96	60	80	1,480	1,490	7.4	7.4
3N/21W-16H5	06-16-94	—	—	1,230	1,370	7.5	7.2
3N/21W-16H5	04-05-95	—	—	1,330	1,350	7.3	7.3
3N/21W-16H5	09-05-96	530	550	1,330	1,350	7.3	7.4
3N/21W-16H6	06-16-94	—	—	1,460	1,630	7.3	7.1
3N/21W-16H6	04-05-95	—	—	1,580	1,610	7.2	7.3
3N/21W-16H6	09-05-96	290	310	1,560	1,580	7.3	7.3
3N/21W-16H7	06-16-94	—	—	1,580	1,700	7.3	7.2
3N/21W-16H7	04-05-95	—	—	1,720	1,730	7.2	7.3
3N/21W-16H7	09-05-96	150	170	1,620	1,640	7.3	7.4
3N/21W-16H8	06-15-94	—	—	1,580	1,910	7.3	7.1
3N/21W-16H8	04-05-95	—	—	2,330	2,370	7.1	7.2
3N/21W-16H8	09-05-96	60	70	2,430	2,440	7.1	7.3
4N/18W-31D3	06-25-94	—	—	1,220	1,190	7.7	7.5
4N/18W-31D3	04-06-95	—	—	1,240	1,210	7.5	7.4
4N/18W-31D3	09-17-96	590	610	1,320	1,280	7.5	7.6
4N/18W-31D4	06-25-94	—	—	1,370	1,360	7.5	7.5
4N/18W-31D4	04-06-95	—	—	1,430	1,430	7.6	7.4
4N/18W-31D4	09-17-96	310	330	1,400	1,340	7.5	7.6
4N/18W-31D5	06-25-94	—	—	1,020	1,010	7.5	7.6
4N/18W-31D5	04-06-95	—	—	1,040	1,030	7.6	7.3
4N/18W-31D5	09-17-96	220	240	1,170	1,140	7.6	7.6
4N/18W-31D6	06-25-94	—	—	1,100	1,080	7.5	7.6
4N/18W-31D6	04-06-95	—	—	1,100	1,080	7.7	7.4
4N/18W-31D6	09-17-96	140	160	1,100	1,070	7.6	7.7
4N/18W-31D7	06-25-94	—	—	1,130	1,120	7.5	7.6
4N/18W-31D7	04-06-95	—	—	1,070	1,050	7.7	7.5
4N/18W-31D7	09-17-96	50	70	1,120	1,090	7.7	7.7

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Temperature, water (°C)	Temperature, air (°C)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
3N/21W-15G-CORE	04-30-94	—	—	—	—	—	—	—
3N/21W-15G1	06-14-94	19.0	—	—	150	41	97	4.5
3N/21W-15G1	04-03-95	19.0	27.0	—	140	41	94	4.9
3N/21W-15G1	09-06-96	20.0	—	.4	140	40	92	4.1
3N/21W-15G2	06-14-94	19.0	—	—	150	43	98	4.4
3N/21W-15G2	04-03-95	18.5	27.0	—	150	46	91	4.2
3N/21W-15G2	09-06-96	20.0	—	.4	150	43	87	4.1
3N/21W-15G3	06-15-94	19.5	—	—	150	39	83	3.0
3N/21W-15G3	04-04-95	18.0	22.0	—	140	40	79	3.2
3N/21W-15G3	09-06-96	19.5	—	.3	150	39	76	3.0
3N/21W-15G4	06-15-94	19.5	—	—	180	45	110	4.2
3N/21W-15G4	04-30-94	18.5	24.5	—	160	45	97	3.8
3N/21W-15G4	09-06-96	19.0	—	.4	180	49	100	3.5
3N/21W-15G5	06-14-94	17.5	—	—	150	50	110	4.9
3N/21W-15G5	04-04-95	17.5	22.0	—	150	53	110	3.9
3N/21W-15G5	09-06-96	19.0	—	.1	150	56	110	4.8
3N/21W-16H5	06-16-94	20.0	—	—	150	40	86	3.2
3N/21W-16H5	04-05-95	18.0	15.5	—	150	41	85	3.1
3N/21W-16H5	09-05-96	20.0	—	.4	150	38	79	3.0
3N/21W-16H6	06-16-94	20.0	—	—	230	48	110	3.4
3N/21W-16H6	04-05-95	19.5	20.5	—	190	47	100	3.1
3N/21W-16H6	09-05-96	20.5	—	.4	190	45	100	3.0
3N/21W-16H7	06-16-94	21.0	—	—	200	60	110	4.0
3N/21W-16H7	04-05-95	18.5	18.5	—	200	60	110	3.8
3N/21W-16H7	09-05-96	20.5	—	.2	190	52	100	3.6
3N/21W-16H8	06-15-94	21.0	—	—	180	59	160	3.6
3N/21W-16H8	04-05-95	19.5	21.0	—	190	80	240	3.6
3N/21W-16H8	09-05-96	21.0	—	.2	220	73	240	3.5
4N/18W-31D3	06-25-94	16.5	—	—	110	43	82	4.5
4N/18W-31D3	04-06-95	15.5	20.5	7.6	130	47	81	4.3
4N/18W-31D3	09-17-96	16.0	—	7.7	130	51	83	4.2
4N/18W-31D4	06-25-94	17.5	—	—	120	47	98	5.1
4N/18W-31D4	04-06-95	16.0	19.5	5.4	140	54	95	4.9
4N/18W-31D4	09-17-96	17.0	—	5.0	130	52	93	4.6
4N/18W-31D5	06-25-94	18.5	—	—	81	30	84	4.3
4N/18W-31D5	04-06-95	16.5	22.0	8.0	93	33	79	4.4
4N/18W-31D5	09-17-96	17.0	—	4.8	100	38	86	4.3
4N/18W-31D6	06-25-94	18.0	—	—	94	34	83	4.6
4N/18W-31D6	04-06-95	15.0	17.0	3.2	110	37	80	4.6
4N/18W-31D6	09-17-96	16.5	—	3.7	98	37	76	4.4
4N/18W-31D7	06-25-94	18.0	—	—	93	30	100	5.1
4N/18W-31D7	04-06-95	16.0	20.0	9.6	110	33	76	5.0
4N/18W-31D7	09-17-96	19.5	—	.6	110	38	68	4.8

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Alkalinity, filtered, fixed end-point titration (mg/L as $CaCO_3$)	Alkalinity, filtered, incremental titration (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Flouride, dissolved, (mg/L as F)
3N/21W-15G-CORE	04-30-94	—	—	—	3,000	220	—
3N/21W-15G1	06-14-94	220	219	228	440	44	.6
3N/21W-15G1	04-03-95	—	—	225	420	43	.6
3N/21W-15G1	09-06-96	210	—	228	450	45	.6
3N/21W-15G2	06-14-94	230	234	242	470	42	.7
3N/21W-15G2	04-03-95	—	—	237	450	42	.6
3N/21W-15G2	09-06-96	220	—	239	470	42	.7
3N/21W-15G3	06-15-94	220	223	232	420	43	.7
3N/21W-15G3	04-04-95	—	—	228	400	44	.7
3N/21W-15G3	09-06-96	220	—	231	430	44	.7
3N/21W-15G4	06-15-94	260	264	272	530	53	.7
3N/21W-15G4	04-30-94	—	—	255	460	51	.7
3N/21W-15G4	09-06-96	250	—	263	530	53	.7
3N/21W-15G5	06-14-94	280	286	296	490	50	.8
3N/21W-15G5	04-04-95	—	—	271	480	52	.8
3N/21W-15G5	09-06-96	250	—	268	480	52	.8
3N/21W-16H5	06-16-94	260	252	265	420	46	.6
3N/21W-16H5	04-05-95	—	—	264	380	42	.6
3N/21W-16H5	09-05-96	250	—	266	400	44	.6
3N/21W-16H6	06-16-94	260	262	270	570	56	.5
3N/21W-16H6	04-05-95	—	—	269	520	54	.5
3N/21W-16H6	09-05-96	250	—	269	530	55	.5
3N/21W-16H7	06-16-94	260	260	264	670	65	.7
3N/21W-16H7	04-05-95	—	—	268	600	62	.7
3N/21W-16H7	09-05-96	260	—	274	560	53	.7
3N/21W-16H8	06-15-94	260	260	315	680	76	<.10
3N/21W-16H8	04-05-95	—	—	319	820	110	.5
3N/21W-16H8	09-05-96	300	—	318	890	120	.5
4N/18W-31D3	06-25-94	160	158	174	430	30	.8
4N/18W-31D3	04-06-95	—	—	171	440	32	.9
4N/18W-31D3	09-17-96	170	—	174	500	34	.9
4N/18W-31D4	06-25-94	200	200	218	430	60	.9
4N/18W-31D4	04-06-95	—	—	223	440	68	.9
4N/18W-31D4	09-17-96	220	—	218	410	81	.9
4N/18W-31D5	06-25-94	130	138	158	270	65	.9
4N/18W-31D5	04-06-95	—	—	156	290	61	.9
4N/18W-31D5	09-17-96	170	—	174	370	54	.9
4N/18W-31D6	06-25-94	150	144	160	340	50	.8
4N/18W-31D6	04-06-95	—	—	167	330	52	.8
4N/18W-31D6	09-17-96	170	—	172	340	45	.8
4N/18W-31D7	06-25-94	170	168	187	320	55	.6
4N/18W-31D7	04-06-95	—	—	152	330	44	.6
4N/18W-31D7	09-17-96	170	—	173	370	38	.6

State well No.	Date	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)
3N/21W-15G-CORE	04-30-94	—	—	—	—	—	—
3N/21W-15G1	06-14-94	.24	.039	35	898	955	.02
3N/21W-15G1	04-03-95	.25	.037	34	988	918	.02
3N/21W-15G1	09-06-96	.25	.037	34	996	948	.03
3N/21W-15G2	06-14-94	.21	.02	33	1,010	996	.02
3N/21W-15G2	04-03-95	.22	.017	32	967	968	.02
3N/21W-15G2	09-06-96	.22	.018	32	1,030	983	.02
3N/21W-15G3	06-15-94	.21	.024	32	934	922	.01
3N/21W-15G3	04-04-95	.21	.02	32	954	888	.03
3N/21W-15G3	09-06-96	.22	.02	31	956	926	.02
3N/21W-15G4	06-15-94	.34	.029	32	1,150	1,130	.02
3N/21W-15G4	04-30-94	.29	.026	31	1,070	1,010	.03
3N/21W-15G4	09-06-96	.33	.027	31	1,150	1,110	.02
3N/21W-15G5	06-14-94	.22	.027	26	1,110	1,060	<.010
3N/21W-15G5	04-04-95	.25	.022	25	1,110	1,040	.03
3N/21W-15G5	09-06-96	.24	.015	25	1,060	1,040	.02
3N/21W-16H5	06-16-94	.32	.028	33	986	957	.04
3N/21W-16H5	04-05-95	.32	.028	34	968	914	.03
3N/21W-16H5	09-05-96	.3	.03	32	964	925	.03
3N/21W-16H6	06-16-94	.34	.03	31	1,230	1,220	.01
3N/21W-16H6	04-05-95	.34	.03	32	1,190	1,120	.01
3N/21W-16H6	09-05-96	.34	.026	30	1,160	1,130	<.010
3N/21W-16H7	06-16-94	.35	.024	30	1,400	1,310	<.010
3N/21W-16H7	04-05-95	.34	.025	31	1,320	1,240	<.010
3N/21W-16H7	09-05-96	.3	.028	29	1,200	1,160	.02
3N/21W-16H8	06-15-94	.58	.15	27	1,460	1,380	<.010
3N/21W-16H8	04-05-95	1.10	.25	28	1,800	1,670	<.010
3N/21W-16H8	09-05-96	1.10	.25	26	1,840	1,770	<.010
4N/18W-31D3	06-25-94	.19	.003	25	854	838	<.010
4N/18W-31D3	04-06-95	.2	.002	25	920	872	<.010
4N/18W-31D3	09-17-96	.23	.003	24	994	942	.03
4N/18W-31D4	06-25-94	.3	.005	27	968	934	<.010
4N/18W-31D4	04-06-95	.37	.003	26	1,040	981	<.010
4N/18W-31D4	09-17-96	.39	.003	24	992	942	.03
4N/18W-31D5	06-25-94	.24	.004	25	642	662	<.010
4N/18W-31D5	04-06-95	.24	.002	25	716	687	<.010
4N/18W-31D5	09-17-96	.23	.004	24	836	791	.03
4N/18W-31D6	06-25-94	.2	.006	23	712	735	<.010
4N/18W-31D6	04-06-95	.2	.003	23	762	743	<.010
4N/18W-31D6	09-17-96	.2	.004	22	776	735	.02
4N/18W-31D7	06-25-94	.19	.008	24	740	752	.02
4N/18W-31D7	04-06-95	.17	.005	23	764	719	<.010
4N/18W-31D7	09-17-96	.18	.03	22	820	759	.03

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia + organic, dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphate, ortho, dissolved (mg/L as P)	Barium, dissolved (µg/L as Ba)
3N/21W-15G-CORE	04-30-94	<.100	—	—	—	—	—
3N/21W-15G1	06-14-94	.79	.05	<.20	.02	.02	20
3N/21W-15G1	04-03-95	.8	<.015	<.20	.02	.02	20
3N/21W-15G1	09-06-96	.8	<.015	<.20	.02	.03	17
3N/21W-15G2	06-14-94	2	.08	<.20	.34	.27	23
3N/21W-15G2	04-03-95	2	<.015	<.20	.06	.07	23
3N/21W-15G2	09-06-96	2	<.015	<.20	.02	.05	20
3N/21W-15G3	06-15-94	2	.04	<.20	.18	.14	25
3N/21W-15G3	04-04-95	2	<.015	<.20	.05	.05	25
3N/21W-15G3	09-06-96	3	<.015	<.20	.04	.04	23
3N/21W-15G4	06-15-94	2	.08	<.20	.44	.22	32
3N/21W-15G4	04-30-94	2	.02	<.20	.22	.23	28
3N/21W-15G4	09-06-96	2	<.015	<.20	.18	.22	28
3N/21W-15G5	06-14-94	.3	.03	<.20	.15	.11	23
3N/21W-15G5	04-04-95	.4	<.015	<.20	.07	.07	23
3N/21W-15G5	09-06-96	.51	<.015	<.20	.04	.05	24
3N/21W-16H5	06-16-94	4	.03	<.20	.06	.05	23
3N/21W-16H5	04-05-95	4	<.015	—	—	.06	26
3N/21W-16H5	09-05-96	4	<.015	<.20	.05	.03	23
3N/21W-16H6	06-16-94	2	.02	<.20	.73	.31	27
3N/21W-16H6	04-05-95	2	<.015	<.20	.24	.23	29
3N/21W-16H6	09-05-96	3	<.015	<.20	.08	.11	27
3N/21W-16H7	06-16-94	.92	.02	<.20	.67	.25	27
3N/21W-16H7	04-05-95	1	<.015	<.20	.13	.11	29
3N/21W-16H7	09-05-96	1	<.015	<.20	.04	.07	24
3N/21W-16H8	06-15-94	<.050	.03	<.20	.06	.06	26
3N/21W-16H8	04-05-95	<.050	.04	<.20	<.010	.02	<100
3N/21W-16H8	09-05-96	.08	.06	<.20	.03	.03	24
4N/18W-31D3	06-25-94	1	.02	<.20	.23	.17	12
4N/18W-31D3	04-06-95	2	<.015	<.20	.1	.09	14
4N/18W-31D3	09-17-96	2	<.020	<.20	.03	.04	16
4N/18W-31D4	06-25-94	3	.02	.2	1.20	.57	15
4N/18W-31D4	04-06-95	4	<.015	<.20	.24	.22	20
4N/18W-31D4	09-17-96	3	.02	<.20	.11	.12	20
4N/18W-31D5	06-25-94	.93	.02	<.20	.47	.36	12
4N/18W-31D5	04-06-95	1	<.015	<.20	.13	.14	16
4N/18W-31D5	09-17-96	2	.02	<.20	.05	.08	21
4N/18W-31D6	06-25-94	2	.02	<.20	.56	.35	15
4N/18W-31D6	04-06-95	.84	<.015	<.20	.08	.09	23
4N/18W-31D6	09-17-96	2	<.015	<.20	.04	.07	23
4N/18W-31D7	06-25-94	2	.02	<.20	1.80	.81	16
4N/18W-31D7	04-06-95	.84	<.015	<.20	.27	.26	28
4N/18W-31D7	09-17-96	.46	.03	<.20	.08	.12	35

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Boron, dissolved, (µg/L as B)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	H^2/H^1 (per mil)	O^{18}/O^{16} (per mil)
3N/21W-15G-CORE	04-30-94	—	—	—	—	-50.80	–7.29
3N/21W-15G1	06-14-94	520	<3.0	470	1,000	-54.10	–7.84
3N/21W-15G1	04-03-95	550	<3.0	450	1,000	—	—
3N/21W-15G1	09-06-96	486	<3.0	430	960	—	—
3N/21W-15G2	06-14-94	580	<3.0	510	1,100	-53.80	–7.86
3N/21W-15G2	04-03-95	610	<3.0	560	1,100	—	—
3N/21W-15G2	09-06-96	535	<3.0	540	1,000	—	—
3N/21W-15G3	06-15-94	540	<3.0	250	970	-52.90	–7.67
3N/21W-15G3	04-04-95	530	<3.0	260	960	—	—
3N/21W-15G3	09-06-96	488	<3.0	260	900	—	—
3N/21W-15G4	06-15-94	590	530	550	1,100	-51.00	–7.53
3N/21W-15G4	04-30-94	580	<3.0	510	1,100	—	—
3N/21W-15G4	09-06-96	568	<3.0	570	1,100	—	—
3N/21W-15G5	06-14-94	820	<3.0	9	1,400	-51.20	–7.38
3N/21W-15G5	04-04-95	770	<3.0	10	1,400	—	—
3N/21W-15G5	09-06-96	767	<3.0	8	1,400	—	—
3N/21W-16H5	06-16-94	550	<3.0	100	1,100	-48.70	–7.39
3N/21W-16H5	04-05-95	570	3	100	1,100	—	—
3N/21W-16H5	09-05-96	494	<3.0	97	1,000	—	—
3N/21W-16H6	06-16-94	630	4	15	1,500	-50.80	–7.32
3N/21W-16H6	04-05-95	650	5	7	1,500	—	—
3N/21W-16H6	09-05-96	591	<3.0	9	1,400	—	—
3N/21W-16H7	06-16-94	760	<3.0	50	1,500	-51.90	–7.43
3N/21W-16H7	04-05-95	790	<3.0	47	1,500	—	—
3N/21W-16H7	09-05-96	705	<3.0	42	1,200	—	—
3N/21W-16H8	06-15-94	880	89	130	1,300	-49.60	–7.21
3N/21W-16H8	04-05-95	1,200	250	280	1,600	—	—
3N/21W-16H8	09-05-96	1,110	320	270	1,500	—	—
4N/18W-31D3	06-25-94	770	<3.0	4	920	-62.00	–8.84
4N/18W-31D3	04-06-95	700	<3.0	<1.0	1,000	-60.70	–8.74
4N/18W-31D3	09-17-96	672	<3.0	<1.0	1,100	—	—
4N/18W-31D4	06-25-94	620	9	11	1,100	-49.80	–6.91
4N/18W-31D4	04-06-95	600	<3.0	1	1,200	-50.50	–6.96
4N/18W-31D4	09-17-96	569	<3.0	<1.0	1,200	—	—
4N/18W-31D5	06-25-94	600	<3.0	2	800	-57.30	–7.86
4N/18W-31D5	04-06-95	590	<3.0	<1.0	860	-57.30	–7.79
4N/18W-31D5	09-17-96	459	<3.0	<1.0	1,000	—	—
4N/18W-31D6	06-25-94	450	5	2	950	-54.80	–7.80
4N/18W-31D6	04-06-95	470	<3.0	<1.0	1,000	-54.50	–7.55
4N/18W-31D6	09-17-96	500	<3.0	<1.0	1,000	—	—
4N/18W-31D7	06-25-94	500	13	10	920	-56.10	–7.90
4N/18W-31D7	04-06-95	510	<3.0	<1.0	990	-55.10	–7.82
4N/18W-31D7	09-17-96	496	<3.0	16	1,000	—	—

Appendix 4. Water-quality measurements at ground-water monitoring sites, Ventura County, California—Continued

State well No.	Date	Tritium, in water molecules (TU)	Tritium counts error (TU)	Carbon 13/12 (per mil)	Carbon-14 (percent modern)	Strontium 87/86 (ratio)
3N/21W-15G-CORE	04-30-94	—	—	—	—	0.70956
3N/21W-15G1	06-14-94	.1	.2	-13.4	54.3	—
3N/21W-15G1	04-03-95	—	—	—	—	—
3N/21W-15G1	09-06-96	—	—	—	—	—
3N/21W-15G2	06-14-94	.6	.2	—	—	—
3N/21W-15G2	04-03-95	—	—	—	—	—
3N/21W-15G2	09-06-96	—	—	—	—	—
3N/21W-15G3	06-15-94	.3	.2	—	—	—
3N/21W-15G3	04-04-95	—	—	—	—	—
3N/21W-15G3	09-06-96	—	—	—	—	—
3N/21W-15G4	06-15-94	2.2	.2	—	—	—
3N/21W-15G4	04-30-94	—	—	—	—	—
3N/21W-15G4	09-06-96	—	—	—	—	—
3N/21W-15G5	06-14-94	4.7	.3	—	—	—
3N/21W-15G5	04-04-95	—	—	—	—	—
3N/21W-15G5	09-06-96	—	—	—	—	—
3N/21W-16H5	06-16-94	1.8	.2	-13.1	53.4	—
3N/21W-16H5	04-05-95	—	—	—	—	—
3N/21W-16H5	09-05-96	—	—	—	—	—
3N/21W-16H6	06-16-94	4.7	.3	—	—	—
3N/21W-16H6	04-05-95	—	—	—	—	—
3N/21W-16H6	09-05-96	—	—	—	—	—
3N/21W-16H7	06-16-94	5.6	.4	—	—	—
3N/21W-16H7	04-05-95	—	—	—	—	—
3N/21W-16H7	09-05-96	—	—	—	—	—
3N/21W-16H8	06-15-94	5.3	.3	—	—	—
3N/21W-16H8	04-05-95	—	—	—	—	—
3N/21W-16H8	09-05-96	—	—	—	—	—
4N/18W-31D3	06-25-94	.2	.2	—	—	—
4N/18W-31D3	04-06-95			-.8	76.9	—
4N/18W-31D3	09-17-96	—	—	—	—	—
4N/18W-31D4	06-25-94	6.3	.4	—	—	—
4N/18W-31D4	04-06-95	—	—	—	—	—
4N/18W-31D4	09-17-96	—	—	—	—	—
4N/18W-31D5	06-25-94	5.0	.3	—	—	—
4N/18W-31D5	04-06-95	—	—	—	—	—
4N/18W-31D5	09-17-96	—	—	—	—	—
4N/18W-31D6	06-25-94	4.7	.3	—	—	—
4N/18W-31D6	04-06-95	—	—	—	—	—
4N/18W-31D6	09-17-96	—	—	—	—	—
4N/18W-31D7	06-25-94	4.4	.3	—	—	—
4N/18W-31D7	04-06-95	—	—	—	—	—
4N/18W-31D7	09-17-96	—	—	—	—	—

Appendix 5. Depths and perforated intervals for non-USGS monitoring wells, Ventura County, California
[ft below lsd, feet below land-surface datum; —, no data]

State well No.	Well depth (ft below lsd)	Perforated interval (ft below lsd)
3N/19W-6D3	400	184–400
3N/20W2A1	92	—
3N/20W-3N1	184	120–172
3N/20W-6P2	252	—
3N/21W-11D2	570	232–543
3N/21W-12F3	300	120–284
3N/21W-12H1	158	74–150
3N/21W-15C4	284	—
3N/21W-15C6	670	452–673
3N/21W-16A2	600	430–580
3N/21W-16K1	216	105–210
3N/21W-16K3	795	672–760
3N/21W-19G4	794	450–720
3N/21W-30H4	500	100–400
3N/21W-34A1	150	—
3N/22W-36K4	871	699–867
3N/22W-36R1	250	100–250
4N/18W-20M1	397	—
4N/18W-20N1	441	—
4N/18W-20P1	100	—
4N/18W-28C2	750	390–750
4N/18W-29F1	285	—
4N/18W-29K1	745	465–745
4N18W-29M2	142	—
4N18W-31D2	500	220–500
4N19W-25J4	500	—
4N19W-26Q3	—	—
4N19W-27R3	402	240–402
4N19W-29R4	180	80–180
4N19W-30Q2	510	310–510
4N19W-30R1	305	173–300
4N19W-34R1	—	—
4N19W-35L5	302	—
4N19W-06D3	400	184–400
4N20W-24R2	2,018	730–1,820
4N20W-25B1	300	50–280
4N20W-26L1	397	100–397
4N20W-32R1	334	—
4N20W-33C3	724	470–700

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