Surface-Water and Ground-Water Quality in the Yucaipa Area, San Bernardino and Riverside Counties, California, 1996–98

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Conversion Factors

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	.3048	meter
foot per year (ft/yr)	.3048	meter per year
gallon per day per square foot [(gal/d)/ft^2]	.3516	liter per day per square meter
gallon per minute (gal/min)	.003785	cubic meter per minute
inch (in)	25.4	millimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 9/5(°C) + 32.$$

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.

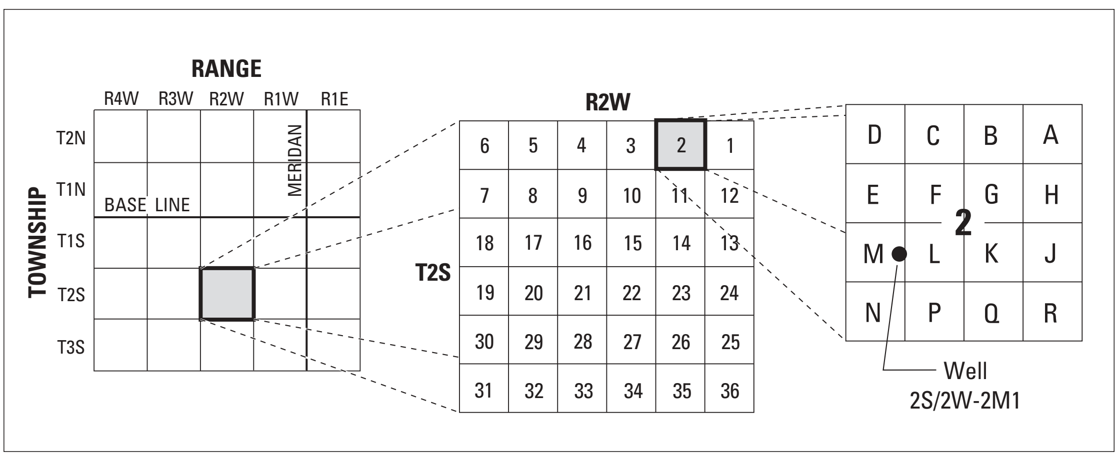
Acronyms and Abbreviations

mg/L	milligrams per liter
µg/L	micrograms per liter
µS/cm	microseimens per centimeter
δD	delta deuterium
$\delta^{18}O$	delta oxygen-18
per mil	parts per thousand, as used with delta (δ) notation
pCi/L	picocuries per liter
^{14}C	carbon-14
CCYN	Carbon Canyon Dam
CONV	Converse Fire Station
DEVO	Devore Fire Station
GIS	geographic information system
^{3}H	tritium

LKMA	Lake Mathews
LSD	Land-Surface datum relative to NGVD of 1929
MCL	maximum contaminant level
MTS	mountains
NO_2	nitrite
NO_3	nitrate
OAKG	Oak Glen
PRDO	Prado
SAR5	Santa Ana River 5th Street
SARM	Santa Ana River near Mentone
SMCL	secondary maximum contaminant level
SNTO	San Antonio Dam
VSMOW	Vienna Standard Mean Ocean Water

Well-Numbering System

Wells are identified and numbered according to their location in the rectangular system for the subdivision of public lands. The identification consists of the township number, north or south; the range number, east or west; and the section number. Each section is further 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 002S002W02M001S. In this report well numbers are abbreviated and written 2S/2W-2M1. Wells in the same township and range are referred to only by their section designation, 2M1. The following diagram shows how the number for well 2S/2W-2M1 is derived.



Well-numbering diagram

Surface-Water and Ground-Water Quality in the Yucaipa Area, San Bernardino and Riverside Counties, California, 1996–98

By Gregory O. Mendez, Wesley R. Danskin, *and* Carmen A. Burton

ABSTRACT

The quality of surface water and ground water in the Yucaipa area was evaluated to determine general chemical characteristics and to identify areas of recent ground-water recharge. Water samples, collected from 8 sites on 3 creeks and from 25 wells, were analyzed for general chemistry, nutrients, tritium, and stable isotopes of hydrogen and oxygen. At one production well (1S/2W-25R4), water samples were collected at discrete depths during pumping and a continuous profile of the vertical flow rate inside the well casing was recorded. In addition to general-chemistry samples, tritium and carbon-14 samples were collected at this well to interpret the age of water at different depths.

Results indicate that most water in the Yucaipa area is a calcium-bicarbonate type. The general chemical composition of surface water resembles that of ground water, although the concentration of most constituents is higher in ground water. The chemical composition of most ground-water samples is similar. Elevated concentrations of nitrate in some ground-water samples may indicate recharge from agricultural areas.

In surface water that recharges ground water tritium activity ranged from 7 to 18 picocuries per liter. The range of tritium activity found in ground water indicates different times since recharge and possible mixing along ground-water flow paths. The oldest ground-water sample had a tritium activity less than 0.3 picocuries per liter, indicating more than 50 years since recharge. Water samples that had tritium activity greater than 0.3 picocuries per liter indicate that some of the water was recharged since 1952. The youngest ground water (greater than 7 picocuries per liter) was found near the hills and mountains surrounding the Yucaipa area; the oldest ground water (less than 0.3 picocuries per liter) was found in the Western Heights subbasin.

Testing of the vertical contribution of ground water to well 1S/2W-25R4 showed that more than one-half of the water flowed into the well between depths of about 450 and 600 feet below land surface; the rest of the water flowed into the well between 600 and about 850 feet below land surface. At a discharge rate of 750 gallons per minute, virtually no water was contributed to the well below a depth of about 850 feet. The water samples collected at this well ranged in age from less than 50 to less than 400 years before present.

INTRODUCTION

The Yucaipa area is about 12 mi southeast of the city of San Bernardino and about 75 mi east of the city of Los Angeles in the upper part of the Santa Ana River drainage basin (fig. 1). Since about 1970 and especially during the 1990’s, the widespread urbanization of southern California has extended inland from the coast into the Yucaipa area. Undeveloped land, agricultural land, and sparsely populated residential land have been converted into housing tracts. The net effect of this change in land use has been an increase in the demand for water, especially potable water for domestic use. Because the local supply of both surface water and ground water is limited in this semiarid region, water purveyors need an accurate assessment of water resources. This report assesses the quality of water in the Yucaipa area, primarily in the Yucaipa plain (fig. 2). The report will aid local water purveyors in understanding and evaluating local resources and using them most effectively in combination with water imported from northern California and from the adjacent San Bernardino area.

Purpose and Scope

The purpose of this study, the results of which are presented in this report, was to survey the quality of surface water and ground water in the Yucaipa area. Water samples collected as part of the study were analyzed for general chemistry, nutrients, tritium, and stable isotopes of hydrogen and oxygen. Preliminary analysis of these data was used to identify areas of recent ground-water recharge and evapotranspiration, and to determine generalized ground-water flow paths.

The scope of this study was to collect and analyze water samples from streams and wells in the Yucaipa area. All samples were collected during 1996–98 as composite (bulk) samples, which then were split into appropriate subsamples for analysis. Previously collected data, which did not include analysis for tritium or stable isotopes, were not included in this study. Several water samples were collected from the surrounding hills and mountains, but the focus of the sampling and subsequent analysis was on water quality of the Yucaipa plain. A sample collected from Mill Creek (fig. 3), which originates in the San Bernardino

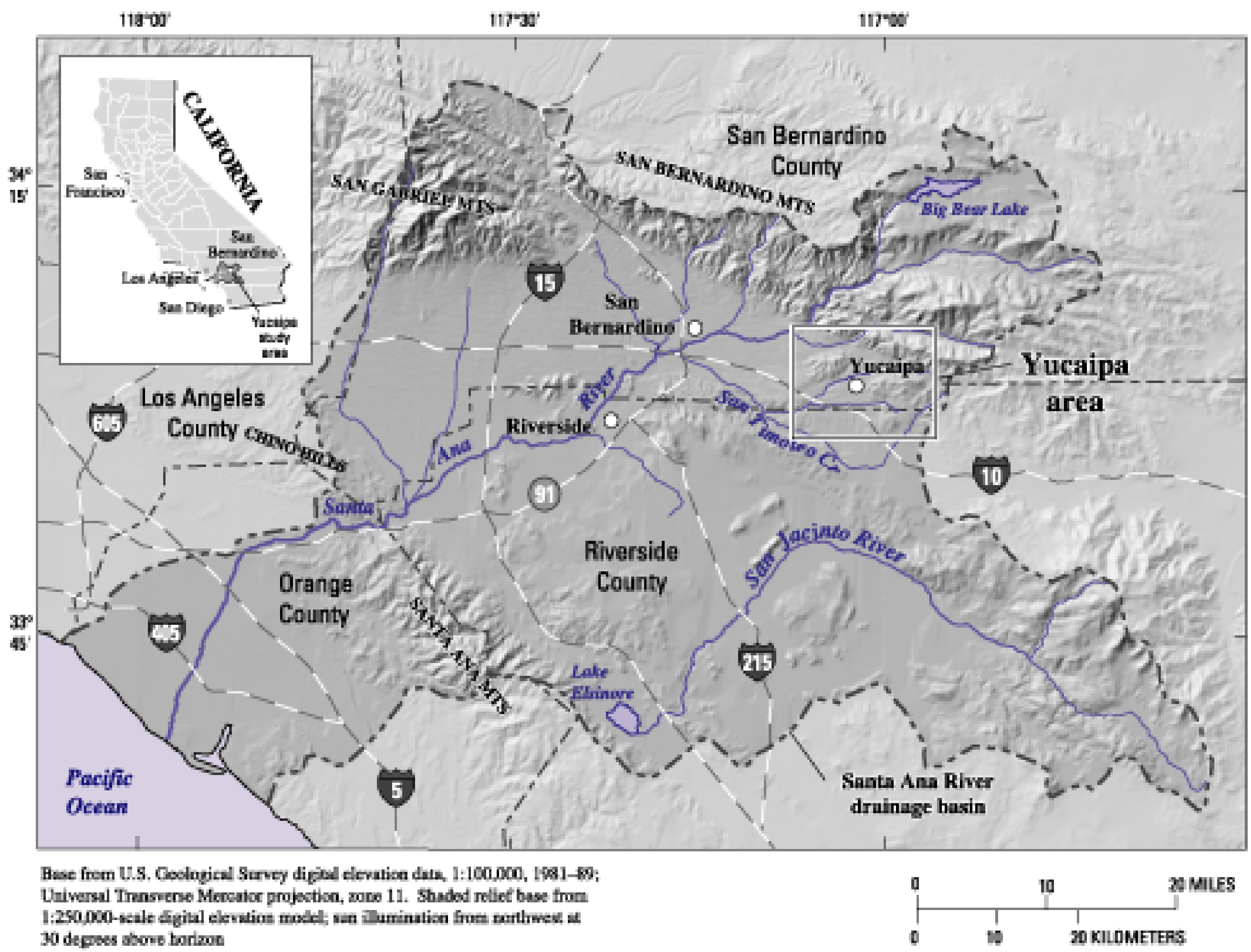
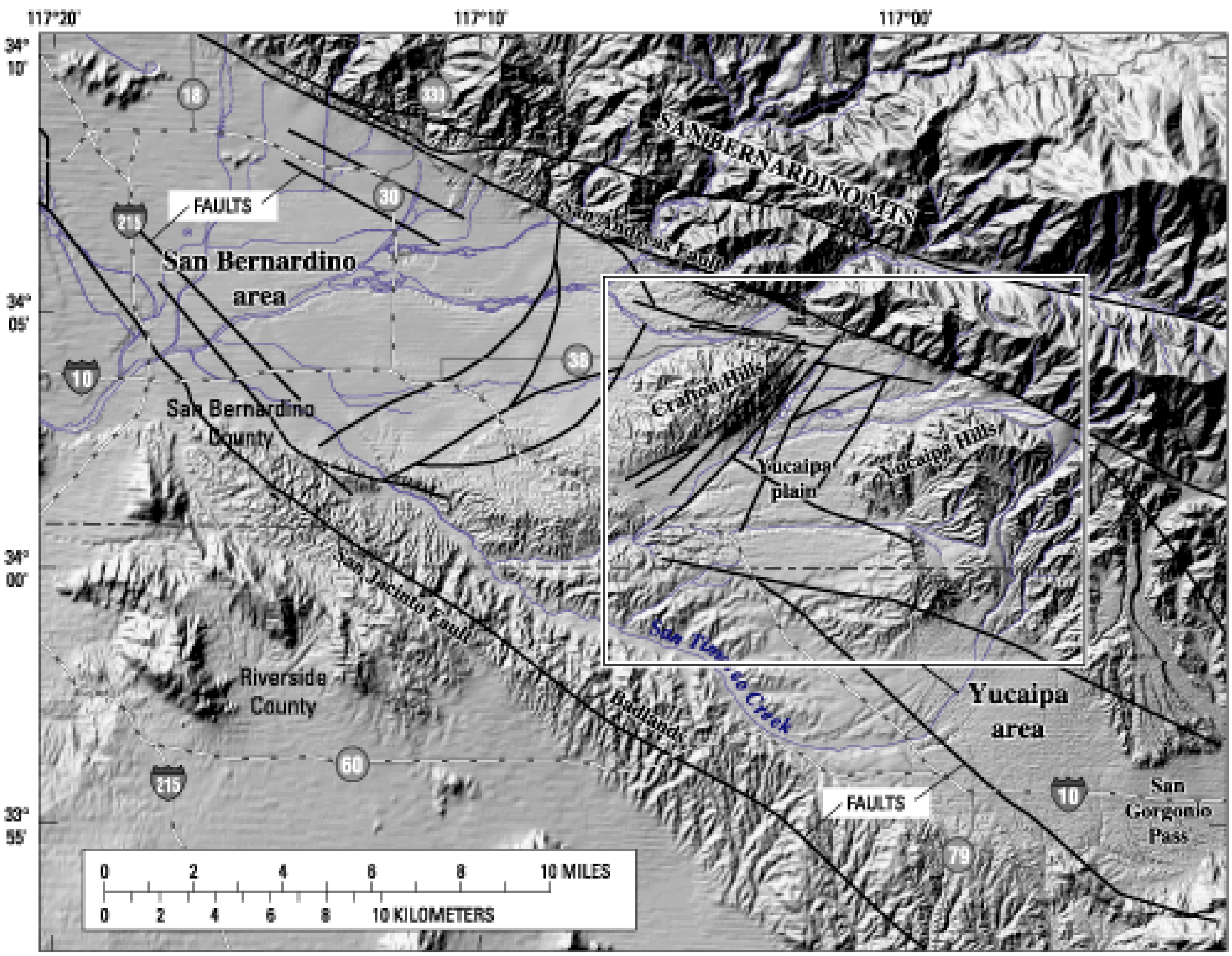


Figure 1. Location of the Yucaipa area in the Santa Ana River drainage basin, southern California.

Mountains east of Yucaipa, represents ground water emanating as springflow from nearby bedrock. This water is imported into the Yucaipa Regional Park and used to fill recreational lakes, and then recharges the ground water. Six depth-dependent water samples were collected from a single production well (1S/2W-25R4) and were compared to vertical flow rates within the well. A geographic information system (GIS) was developed to locate wells, to aid in interpretation of water-quality data, and to prepare figures for this report.

Methods of Investigation

Collection of several areally distributed surface-water samples was required to characterize surface-water quality and to identify the likely interaction between surface water and ground water. Because streamflow on the Yucaipa plain is infrequent and of short duration, simply finding surface water to sample can be difficult in this semiarid region. Fortuitously, the winter of 1997–98 was an El Niño year with greater than average runoff. Three storms in February 1998



Base from U.S. Geological Survey digital elevation data, 1:100,000, 1981–89; Universal Transverse Mercator projection, zone 11. Shaded relief base from 1:250,000-scale digital elevation model; sun illumination from northwest at 30 degrees above horizon

Figure 2. Physiography of the Yucaipa area, southern California.

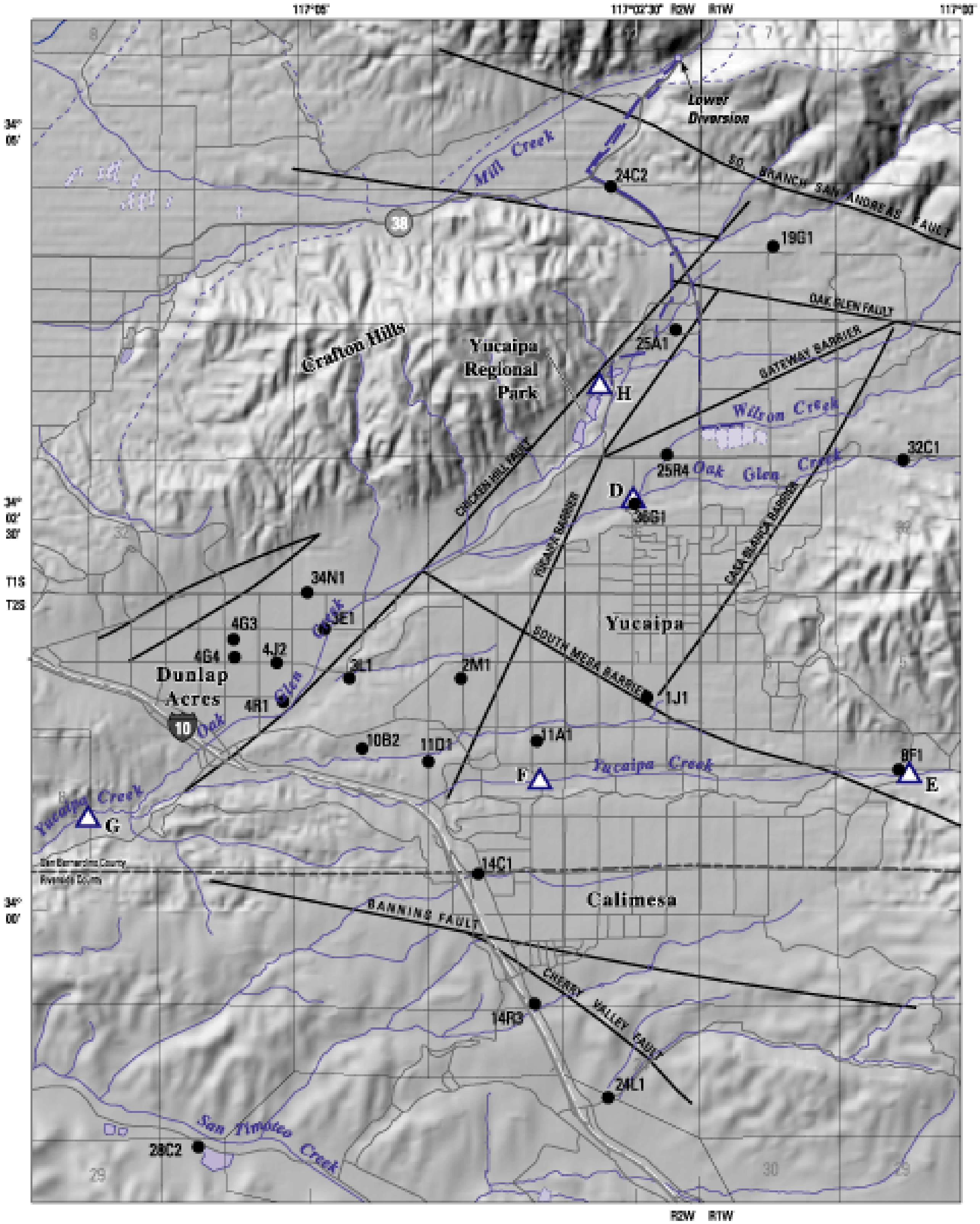


Figure 3. Selected wells and surface-water-quality sites in the Yucaipa area, southern California.

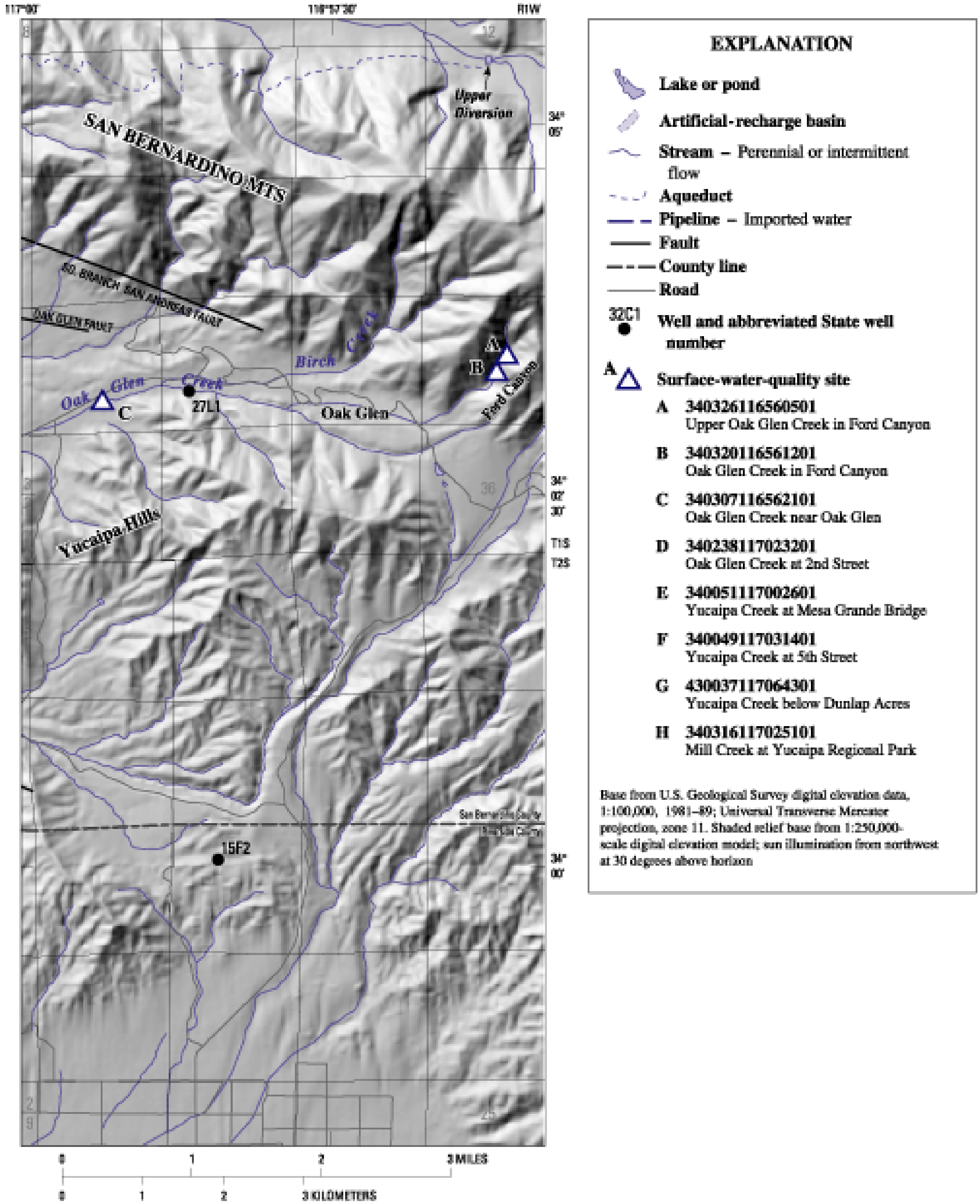


Figure 3—Continued.

were selected to collect water samples. Streamflow was sampled on Oak Glen and Yucaipa Creeks, which are the two primary streams in the area (fig. 3). Base-flow samples were collected on upper Oak Glen Creek in the foothills, where flow is present and originates as springflow from bedrock or as snowmelt. Yucaipa Creek originates in the southern part of the Yucaipa Hills and has no base flow. One water sample was collected from Mill Creek because part of its flow is pumped into the Yucaipa area in a pipeline and then is discharged at the Yucaipa Regional Park. The imported water is used for recreational purposes before it infiltrates into the ground. Water in the pipeline is a mixture of streamflow diverted in the upper Mill Creek drainage basin and streamflow diverted under Highway 38 (fig. 3). Water from Mill Creek was collected as a single grab sample; other surface-water samples were collected, depending on the stream conditions, as either an equal-width integrated sample or a grab sample.

The strategy for sampling ground water was to collect samples throughout the Yucaipa area to identify the general quality, the likely source of recharge, and the dominant paths of ground-water flow. Nearly all ground-water samples were obtained as bulk samples from discharge pipes of production wells. At a new production well (1S/2W-25R4), it was possible to obtain depth-dependent samples under pumped conditions using a sampling technique described by Izbicki and others (1999). Coincident with sampling, the flow rate inside the casing of the production well was measured using a spinner tool. Flow-rate measurements were used to determine the relative contributions of ground water from different strata to the pumped well.

In this study, naturally occurring stable isotopes of oxygen (oxygen-18) and hydrogen (deuterium) were used to help determine the source of ground water and to trace its movement. Atoms of oxygen-18 and deuterium have more neutrons and a greater atomic mass (weight) than do the more common isotopes,

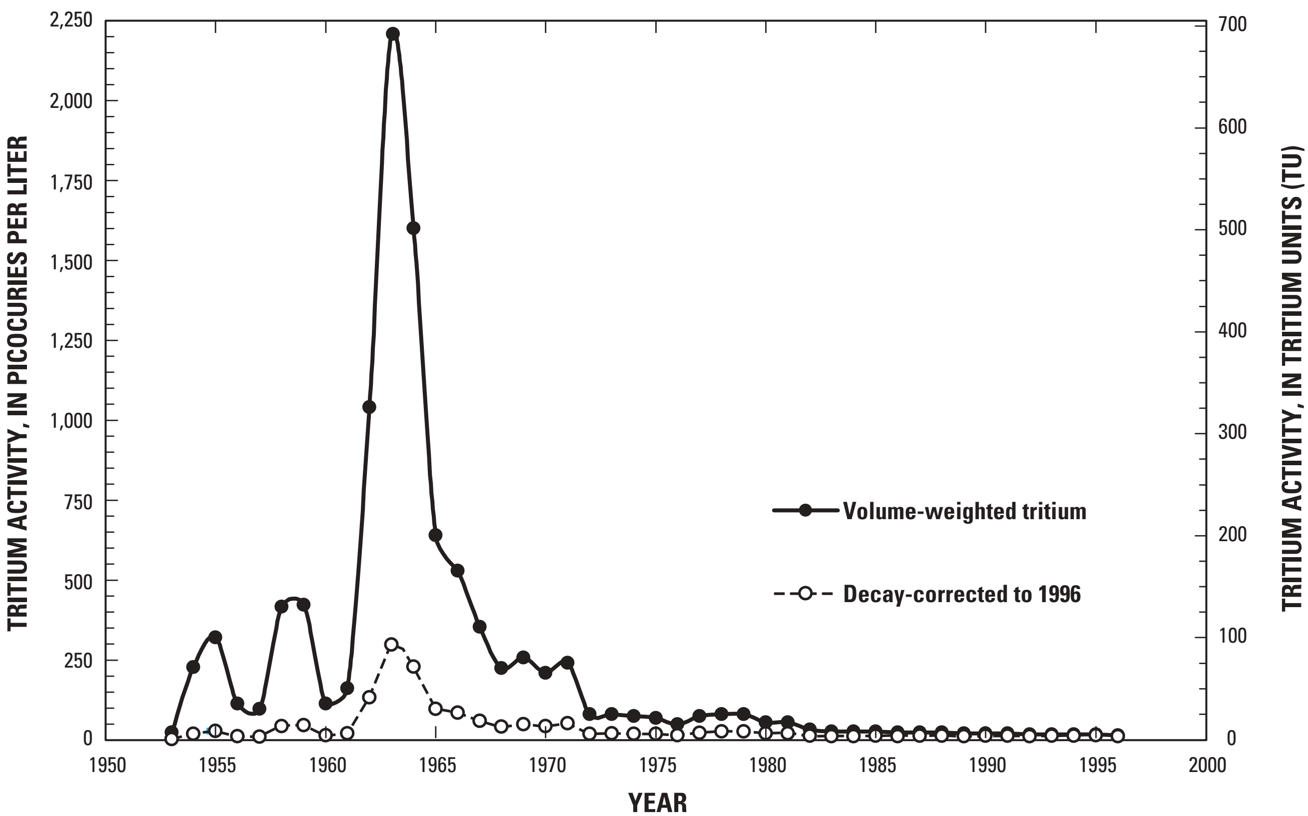


Figure 4. Tritium activity in precipitation at Los Angeles, California, 1953–96. Tritium was corrected using techniques from Michel (1989).

oxygen-16 and hydrogen. This difference in weight results in differences in the physical and chemical behavior of the heavier, less abundant isotopes (International Atomic Energy Agency, 1981).

Most of the world's precipitation originates from the evaporation of seawater. As a result, the oxygen-18 and deuterium composition of precipitation throughout the world is linearly correlated and often referred to on graphs as the meteoric water line (Craig, 1961). Oxygen-18 and deuterium abundances typically are expressed as ratios in delta notation (δ), as per mil (parts per thousand) differences, relative to the standard known as Vienna Standard Mean Ocean Water (VSMOW) (Gonfiantini, 1978). By convention, the value of VSMOW is 0 per mil. Oxygen-18 and deuterium ratios relative to VSMOW can be measured more precisely than absolute abundances. Analytical precision is generally within 0.05 per mil for $\delta^{18}O$ (delta oxygen-18) and within 1.5 per mil for δD (delta deuterium) (Izbicki, 1996).

Water that condenses at cooler temperatures (typically associated with higher altitudes, cooler climatic regimes, or higher latitudes) is lighter (more negative) than water that condenses at warmer temperatures (typically associated with lower altitudes, warmer climatic regimes, or lower latitudes). In addition, water that has been partly evaporated is enriched by fractionation of the heavier isotopes relative to its original composition. On graphs of $\delta^{18}O$ and δD, partly evaporated water samples plot to the right of the meteoric water line along a line known as the evaporative trend line. As a result, the $\delta^{18}O$ and δD composition of a water sample can provide a record of the source and evaporative history of the water.

Tritium and carbon-14 samples were collected to help identify the age of water. Tritium (^{3}H) is a naturally occurring radioactive isotope of hydrogen that has a half-life of about 12.4 years. In this study, the activity of tritium was measured in picocuries per liter (pCi/L); 1 pCi/L is equivalent to about 2.2 disintegrations of tritium per minute or about one tritium atom in 3.1×10^{17} atoms of hydrogen. Prior to 1952, tritium activity in precipitation in coastal southern California was about 6 pCi/L. As a result of atmospheric testing of nuclear weapons from 1952 to 1962, tritium activity increased to greater than 2,000 pCi/L (Michel, 1976). Tritium concentrations and decay-corrected values in precipitation at Los Angeles, California, were calculated using techniques described by Michel (1989), (fig. 4). Because tritium can be part of the water molecule, tritium is not affected by reactions other than radioactive decay; therefore, tritium is an excellent tracer of the movement of water on time scales ranging from 10 to about 50 years before present. Ground water having tritium activities less than the detection limit of 0.3 pCi/L is considered to have been recharged before 1952. Ground water having measurable tritium activity is considered to be recharged after 1952.

Carbon-14 (^{14}C) is a naturally occurring radioactive isotope of carbon that has a half-life of about 5,730 years. Carbon-14 data are expressed as percent modern carbon by comparing ^{14}C activities to the specific activity of National Bureau of Standards oxalic acid (12.88 disintegrations per minute per gram of carbon in 1950 equals 100 percent modern carbon).
Carbon-14 is not part of the water molecule and ^{14}C activities can be affected by chemical reactions between dissolved constituents and aquifer material. Carbon-14 is a tracer of the movement and relative age of water on time scales ranging from several hundred to more than 20,000 years before present.

Field parameters such as specific electrical conductance, pH, and dissolved oxygen were measured for both surface-water and ground-water samples in the field using probes calibrated with appropriate standards. Alkalinity was determined in the field by titration with a dilute sulfuric acid. All field measurements were made in accordance with the National Field Manual for the Collection of Water-Quality Data (Wilde and Radtke, 1998). The techniques used for the collection and processing of inorganic constituents were made in accordance with Horowitz and others (1994). Analyses for inorganic constituents were done by the U.S. Geological Survey National Water Quality Laboratory using techniques described by Fishman and Friedman (1989), Fishman (1993), Patton and Truitt (1992), and Struzeski and others (1996).

Previous Investigations

Many investigations have been made since the early 1900's in the upper Santa Ana River drainage basin and, in particular, in the adjacent San Bernardino area (fig. 2). Several previous investigators have included parts of the Yucaipa area on the periphery of their study, but most have described only generalized data and concepts for the Yucaipa area. Such generalized information includes description of the regional hydrology (Mendenhall, 1905), estimation of ground-water-storage capacity (Eckis, 1934), calculation of ground-water outflow from the Yucaipa area (Dutcher and Burnham, 1959; Burnham and Dutcher, 1960), depiction of ground-water levels and susceptibility of liquefaction during a major earthquake (Matti and Carson, 1991), and evaluation of regional water-management options (California Department of Water Resources, 1970, 1979, 1986).

The more detailed investigations in the Yucaipa area have focused on surficial geology and ground-water quantity. Surficial geology of the area has been mapped at a scale of 1:48,000 by Morton (1974) and more recently at a scale of 1:24,000 by Matti and others (1992). A detailed calculation of ground-water outflow from the area south of the Crafton Hills was made by Dutcher and Fenzel (1972). Sustainable yield of the ground-water basin was calculated by Mann (1986) and later by Todd (1988), and an explanation of the differences between the two yield calculations was made by Mann and Todd (1990). The potential for artificial recharge was evaluated by Moreland (1970). Changes in ground-water levels were summarized by Fletcher (1976) and Fox (1987), and a plan to monitor ground-water levels for much of the Yucaipa area was proposed by Fox (1990). A ground-water-flow model was developed for the upper part of the Oak Glen Creek drainage by Powers and Hardt (1974). Water-management plans were prepared for the Western Heights Water District (Egan and Associates, Inc., 1989) and for the Yucaipa Valley Water District (Camp, Dresser, and McKee, 1994).

Measurements of surface-water discharge in the Yucaipa area are scant. A much greater number of ground-water-level measurements are available for many wells in the area, including historical data that span several decades. Measurements of water quality for both surface water and ground water are made routinely to ensure that drinking-water standards are met. Other measurements of water chemistry, such as isotopic concentrations of hydrogen and oxygen, had not been made prior to this study.

Acknowledgments

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DESCRIPTION OF STUDY AREA

Physiography

The study area is bordered on the west by the Crafton Hills, on the east by the Yucaipa Hills, on the north by the San Bernardino Mountains, and on the south by the badlands (fig. 2). Between the hills and mountains is a gently sloping area of unconsolidated deposits, commonly referred to as the Yucaipa plain or the Yucaipa ground-water basin. On the northwest side, the plain merges into the San Bernardino valley, and on the southeast side, the plain opens to the San Gorgonio Pass. The Yucaipa plain ranges in altitude from about 1,800 to 3,600 ft above sea level. The hills and mountains surrounding the plain range in altitude from about 3,000 ft in the Crafton Hills, to 5,000 ft along the ridge of the Yucapia Hills, to more than 8,000 ft in the San Bernardino Mountains.

Population and Climate

The study area includes parts of San Bernardino and Riverside Counties and the major cities of Yucaipa and Calimesa (fig. 3). In 1998, the population in the Yucaipa study area was about 38,200. Most residents in the area live on the plain, but many live in the surrounding foothills. Recent residential development is concentrated on the east side of Crafton Hills, on the Yucaipa Hills, and along the lower altitudes of the San Bernardino Mountains.

Climate in the study area is moderate with long, dry summers and short, wet winters. On the plain, summer temperatures range from about 60 to 100 ^{o}F and winter temperatures range from about 40 to 70 ^{o}F. Annual precipitation in this semiarid region averages about 18 in/yr on the plain, and as much as 40 in/yr in the San Bernardino Mountains (Todd, 1988). Precipitation falls almost exclusively as rain on the plain; snow is the predominant precipitation above an altitude of about 6,000 ft. Snowpack in the San Bernardino Mountains commonly lasts into April and, occasionally, May.

Geology

Bedrock, which forms the hills and mountains that surround the Yucaipa plain on the north, east, and west sides, is composed mostly of crystalline igneous and metamorphic rocks of Cenozoic to Mesozoic age (fig. 5). These basement rocks consist predominantly of granodiorite, although granite, quartz monzonite, tonalite, dioritic gneiss, and schist also are present (Matti and others, 1992). Basement rocks in the Yucaipa Hills are cataclastically deformed and contain abundant fractures and intruded quartz veins. Some sedimentary rocks, mostly sandstone, mantle part of the crystalline bedrock in the vicinity of Mill Creek. The badlands to the south consist of poorly to moderately consolidated continental deposits of Pleistocene and Pliocene age that have been uplifted and dissected. In the badlands, the deposits consist of alternating beds or lenses of gray, yellow, or brown gravel, sand, silt, and clay. The gravel is predominantly from granitic rocks but contains numerous fragments of metamorphic and volcanic rocks. These badland deposits are cut by numerous faults and in places are gently to intensely folded.

Between the San Bernardino Mountains and the badlands is a down-dropped block of crystalline rocks bounded on either side by the San Andreas Fault and the San Jacinto Fault (fig. 2). Erosion of the hills and mountains that surround the Yucaipa area has filled this tectonically created trough, called a graben, with alluvial deposits that are as much as 1,500 ft thick. The alluvial deposits are composed of several units ranging in age from late Pleistocene (very old alluvium) to Holocene age (recent alluvium) (fig. 5). The very old or older alluvium unconformably overlies most of the basement rocks. These alluvial deposits are both of late Pleistocene age and consist of boulders, gravel, sand, silt, and clay. Subsequent erosion of these moderately to well-consolidated deposits has resulted in deeply incised streambeds such as the channels of Oak Glen and Yucaipa Creeks. Isolated deposits of slightly consolidated younger alluvium border parts of the stream channels and badlands. Unconsolidated recent alluvium is present in stream channels throughout the Yucaipa plain and has its greatest width in the Western Heights subbasin.

The geologic structure and landforms in the Yucaipa area are mostly a result of regional tectonism. To the north, the San Andreas Fault separates two tectonic plates—the North American Plate on the east and the Pacific Plate on the west (Harden, 1998, fig. 1–4). In addition to creating the sediment-filled graben that forms the Yucaipa ground-water basin, the structural forces associated with plate tectonics have caused several additional faults, some of which are visible at the land surface. One set of visible faults is subparallel to the northwest-trending San Andreas and San Jacinto Faults and includes the Banning and Oak Glen Faults; another set is nearly perpendicular to the first and includes the Chicken Hill Fault (fig. 5). Numerous additional barriers, which are hypothesized to be faults, have been inferred by geophysical and ground-water-level data.

Hydrology

The Yucaipa area is within the upper part of the Santa Ana River drainage basin and encompasses much of the San Timoteo Creek drainage (figs. 1 and 2). Although surface-water drainage is well defined to the north in the San Bernardino Mountains, the drainage becomes progressively less defined to the south in the more extensively eroded badlands. The Yucaipa area is drained by three primary streams: Wilson and Oak Glen Creeks, which flow from the San Bernardino Mountains, and Yucaipa Creek, which flows from the Yucaipa Hills (fig. 3). These streams coalesce and flow into San Timoteo Creek, which exits the area to the southwest (fig. 2).

The semiarid conditions in the Yucaipa area limit the quantity and frequency of streamflow. Generally, streamflow is present in the middle and lower reaches of Wilson, Oak Glen, and Yucaipa Creeks only for brief periods after rain. Flow in the upper reaches of Oak Glen Creek is perennial as a result of ground-water discharge from Ford Canyon in the San Bernardino Mountains (fig. 3). Some of this flow is diverted for public supply. Just upstream from the Casa Blanca Barrier

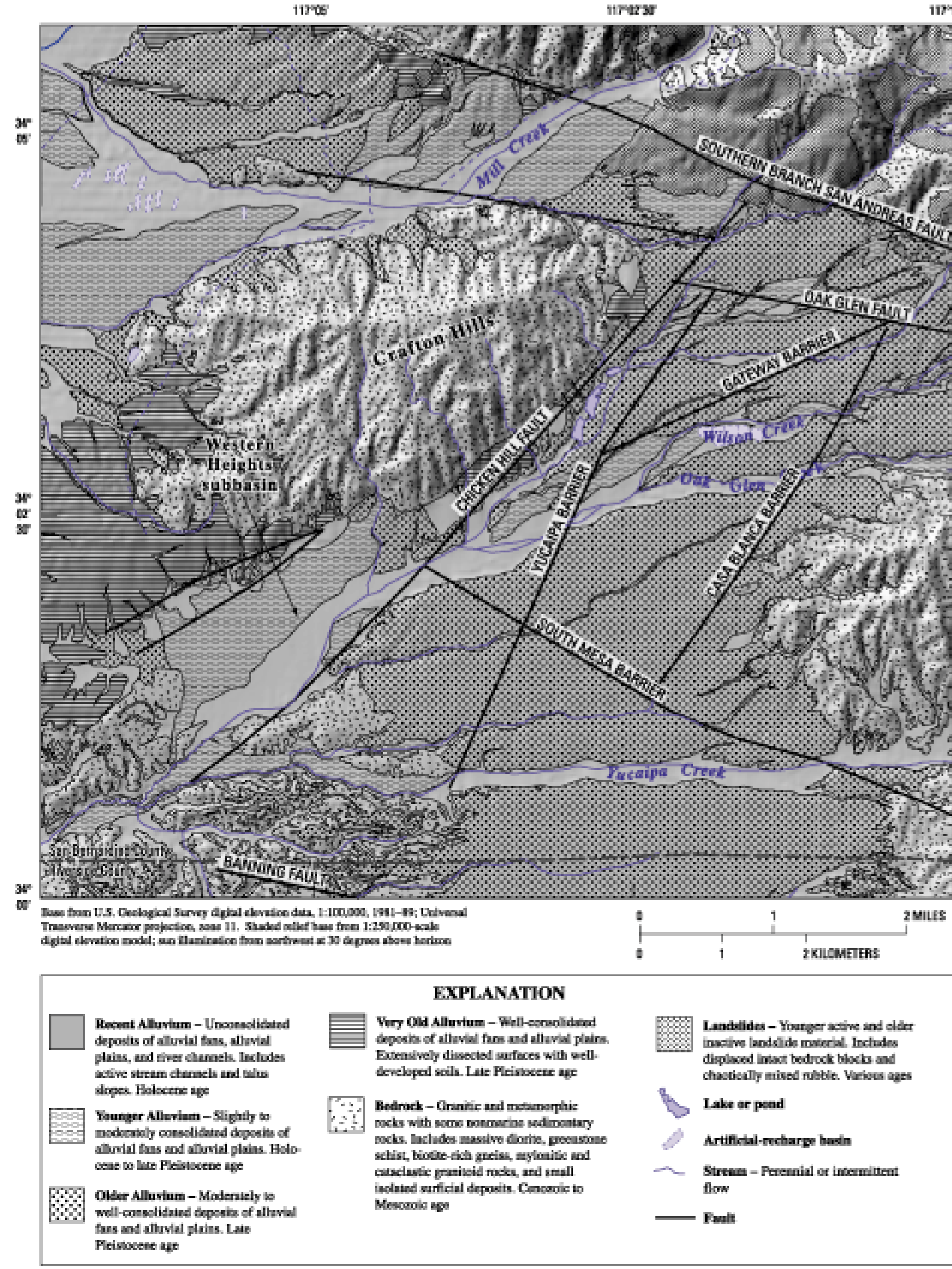


Figure 5. Surficial geology of the Yucaipa area, southern California.

(fig. 5), streamflow infiltrates into the unconsolidated deposits of the Yucaipa plain. In some places, flow in San Timoteo Creek is now perennial as a result of agricultural and urban runoff.

The unconsolidated deposits of the Yucaipa plain—the recent, younger, older, and very old alluvium (fig. 5)—constitute the primary source of ground water in the area and together compose the valley-fill aquifer. Permeability of these deposits ranges from 50 to 300 (gal/d)/ft^2 (Burnham and Dutcher, 1960, p. 80). Recent river-channel deposits, especially near the hills and mountains, appear to be unweathered and very permeable, but most are above the water table. Most ground water occurs in the older, moderately consolidated alluvium at minimum depths of about 200 ft below land surface. Although the base of the valley-fill aquifer is unknown, it probably is more than 1,500 ft below land surface in most parts of the Yucaipa plain. In the western part of the plain, ground water historically was under artesian conditions, which may indicate the presence of fine-grained material of lower permeability within the valley-fill aquifer.

For the most part, the crystalline rocks of the surrounding hills and mountains and underlying the valley-fill aquifer are poorly permeable. However, the multi-directional tectonic forces in the Yucaipa area have created highly fractured, cataclastic rock, which in some places is moderately permeable. Some wells, including large municipal wells, have been completed in the crystalline rocks in order to increase well yield.

Faults are important not only because of their influence on the general topography, but also because of their influence on the flow of ground water. Fault zones in consolidated rocks commonly consist of fissures that may serve as conduits for ground-water flow. Conversely, faults that transect permeable unconsolidated materials may produce barriers to ground-water flow. For example, the San Andreas Fault along the base of the San Bernardino Mountains is known to be a barrier to ground-water flow because its trace in the alluvium at the mouth of nearly every canyon is marked by springs and dense vegetation. Although the barrier effects displayed by faults are not completely understood, the presence of offset beds, gouge material, sharp folds, and chemical cementation are suspected to contribute to reduced permeability.

On a basinwide scale, the general movement of both surface water and ground water is southward and westward from the surrounding hills and mountains. On a local scale, however, the movement of ground water is more complex. Faults in the area divide the ground-water basin into several subbasins (Moreland, 1970), which previous investigators have characterized as being relatively isolated from one another (fig. 6). Flow in and between subbasins is complex and is not well understood except as can be inferred from contour maps of ground-water levels (Moreland, 1970, figs. 6–8; Todd, 1988, fig. 11). This lack of understanding of ground-water movement was a major impetus for this water-quality study, in particular for the collection of isotopic data.

Detailed ground-water-level maps for different time periods, possibly corroborated by results from a ground-water flow model, are needed to better understand the flow between subbasins and to help interpret water-quality data. As a starting point, however, ground-water-level data from spring 1997 were obtained from local water agencies (fig. 6 and table 1). On the basis of these data and ground-water-level maps from Moreland (1970), ground water in the Triple Falls Creek subbasin (fig. 6) appears to flow from the east to the west toward the north end of Crafton Hills. In the Wilson Creek and Crafton subbasins, ground water flows generally from north to south. In the Calimesa subbasin, ground water flows from east to west, toward the San Bernardino area. Insufficient data were available in the Western Heights subbasin to determine the direction of ground-water flow, but in the past (1930–70), a pumping depression was present near Dunlap Acres (Moreland, 1970).

Land Use

Originally, the Yucaipa area was inhabited by Native Americans, and the name “Yucaipa” is derived from the Serrano Indian word “Ucipe,” which means wet and sandy. Until the early 1800’s, the area was under Spanish rule as part of the San Bernardino Rancho. By 1860, the land was privately owned by a few families. In the early 1900’s, part of the area was subdivided into apple orchards, and the area became synonymous with red apples.

After 1940, the Yucaipa area became extremely popular as a retirement destination. Many mobile-home parks were built, mostly along the upper part of the Yucaipa plain near the San Bernardino Mountains. Rural-type residential development continued to be popular and covered much of the central part of the Yucaipa plain. As more of the area was urbanized, cultivation of citrus was moved to the edges of the plain,

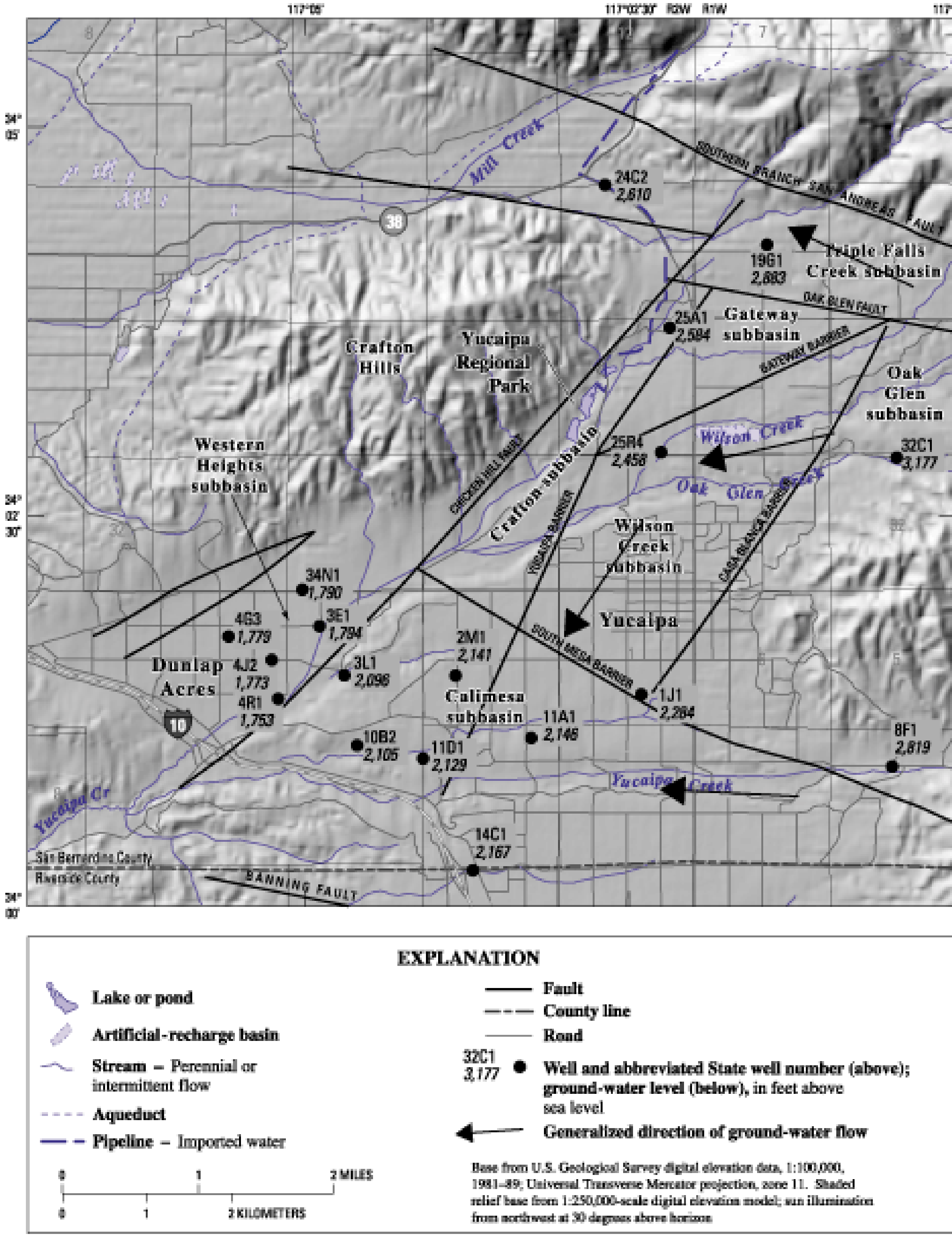


Figure 6. Ground-water levels at selected wells in the Yucaipa area, southern California, spring 1997.

Table Location and characteristics of selected surface-water sites and wells in the Yucaipa area, southern California.

[YVWD, Yucaipa Valley Water District; WHWD, Western Heights Water District; SMWD, South Mesa Water District; LSD, land-surface datum; ft, foot; na, not applicable; —, no data]

Site name or State well number	Well owner	Other well identifiers	Latitude	Longitude	Altitude of LSD (ft)	Altitude of water table (ft above sea level)[1]	Depth of well (ft)	Open intervals below LSD (ft)
Upper Oak Glen Creek in Ford Canyon	na	na	340326	1165605	5,920	na	na	na
Oak Glen Creek in Ford Canyon	na	na	340320	1165612	5,560	na	na	na
Oak Glen Creek near Oak Glen	na	na	340307	1165621	3,550	na	na	na
Oak Glen Creek at 2nd street	na	na	340238	1170232	2,620	na	na	na
Yucaipa Creek at Mesa Grande Bridge	na	na	340051	1170026	2,880	na	na	na
Yucaipa Creek at 5th street	na	na	340049	1170314	2,390	na	na	na
Yucaipa Creek below Dunlap Acres	na	na	340037	1170643	1,880	na	na	na
Mill Creek at Yucaipa Regional Park	na	na	340316	1170251	2,630	na	na	na
1S/1W-19G1	YVWD	YVWD # 31	340415	1170127	3,086	2,883	384	—
1S/1W-27L1	YVWD	YVWD # 25	340312	1165839	3,875	—	30	15–30
1S/1W-32C1	YVWD	YVWD # 13	340253	1170027	3,194	3,177	307	26–415
1S/2W-24C2	YVWD	YVWD # 51	340438	1170242	2,695	2,610	610	230–590
1S/2W-25A1	YVWD	YVWD # 37	340343	1170212	2,780	2,584	305	—
1S/2W-25R4	YVWD	YVWD # 53	340255	1170216	2,730	2,458	970	450–950
1S/2W-34N1	City of Redlands	—	340202	1170502	2,157	1,790	—	—
1S/2W-36G1	YVWD	YVWD # 46	340236	1170231	2,623	—	1,150	340–1,140
2S/1W-08F1	YVWD	YVWD # 27	340054	1170029	2,878	2,819	314	164–314
2S/1W-15F2	YVWD	YVWD # 61	340003	1165825	3,515	—	462	189–462
2S/2W-01J1	YVWD	YVWD # 50	340124	1170213	2,600	2,284	352	330–350
2S/2W-02M1	YVWD	YVWD # 11	340129	1170351	2,401	2,141	525	260–450; 465–525
2S/2W-03E1	WHWD	WHWD # 6	340148	1170454	2,170	1,794	599	135–578
2S/2W-03L1	City of Redlands	Chicken Hill	340129	1170442	2,200	2,096	505	198–485
2S/2W-04G3	WHWD	WHWD # 2A	340144	1170536	2,100	1,779	630	400–620
2S/2W-04G4	WHWD	WHWD # 11	340137	1170535	2,080	—	1,690	705–1,205; 1,210–1,690
2S/2W-04J2	WHWD	WHWD # 5A	340135	1170516	2,095	1,773	1,100	390–1,090
2S/2W-04R1	WHWD	WHWD # 9	340120	1170513	2,091	1,753	600	150–576
2S/2W-10B2	City of Redlands	Hog Canyon #2	340106	1170450	2,180	2,105	700	260–440; 460–680
2S/2W-11A1	YVWD	YVWD # 24	340105	1170316	2,446	2,146	585	320–585
2S/2W-11D1	YVWD	YVWD # 10	340057	1170406	2,327	2,129	515	170–500
2S/2W-14C1	SMWD	SMWD # 2	340014	1170343	2,393	2,167	363	205–363
2S/2W-14R3	SMWD	SMWD # 4	335924	1170317	2,340	—	1,000	352–976
2S/2W-24L1	YVWD	YVWD # 48	335848	1170243	2,327	—	1,180	380–870; 930–1,160
2S/2W-28C2	Fisherman's Retreat	—	335829	1170552	1,943	—	—	—

[1]Altitude of water levels provided by water districts for spring 1997.

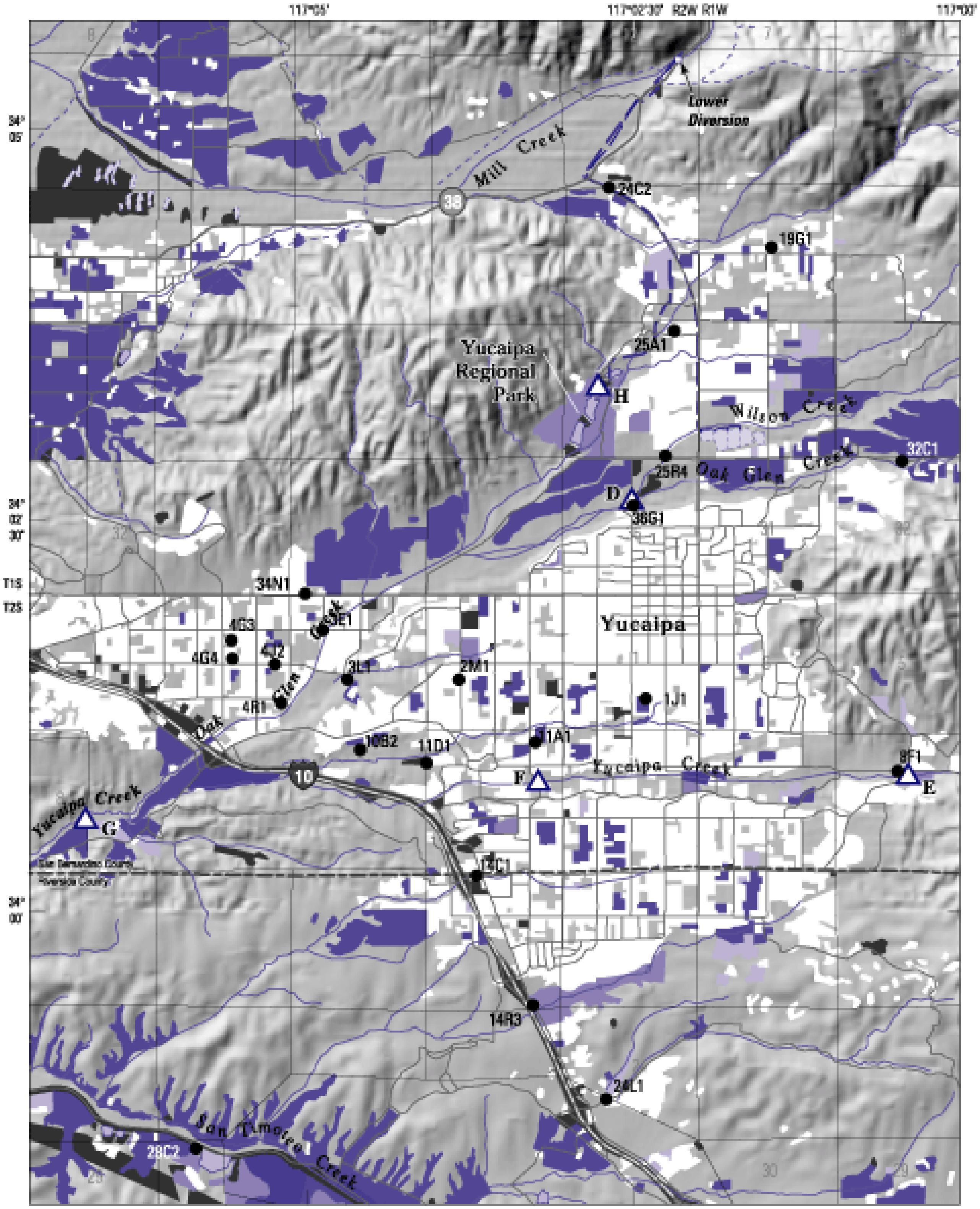


Figure 7. Land use in the Yucaipa area, southern California, 1990.

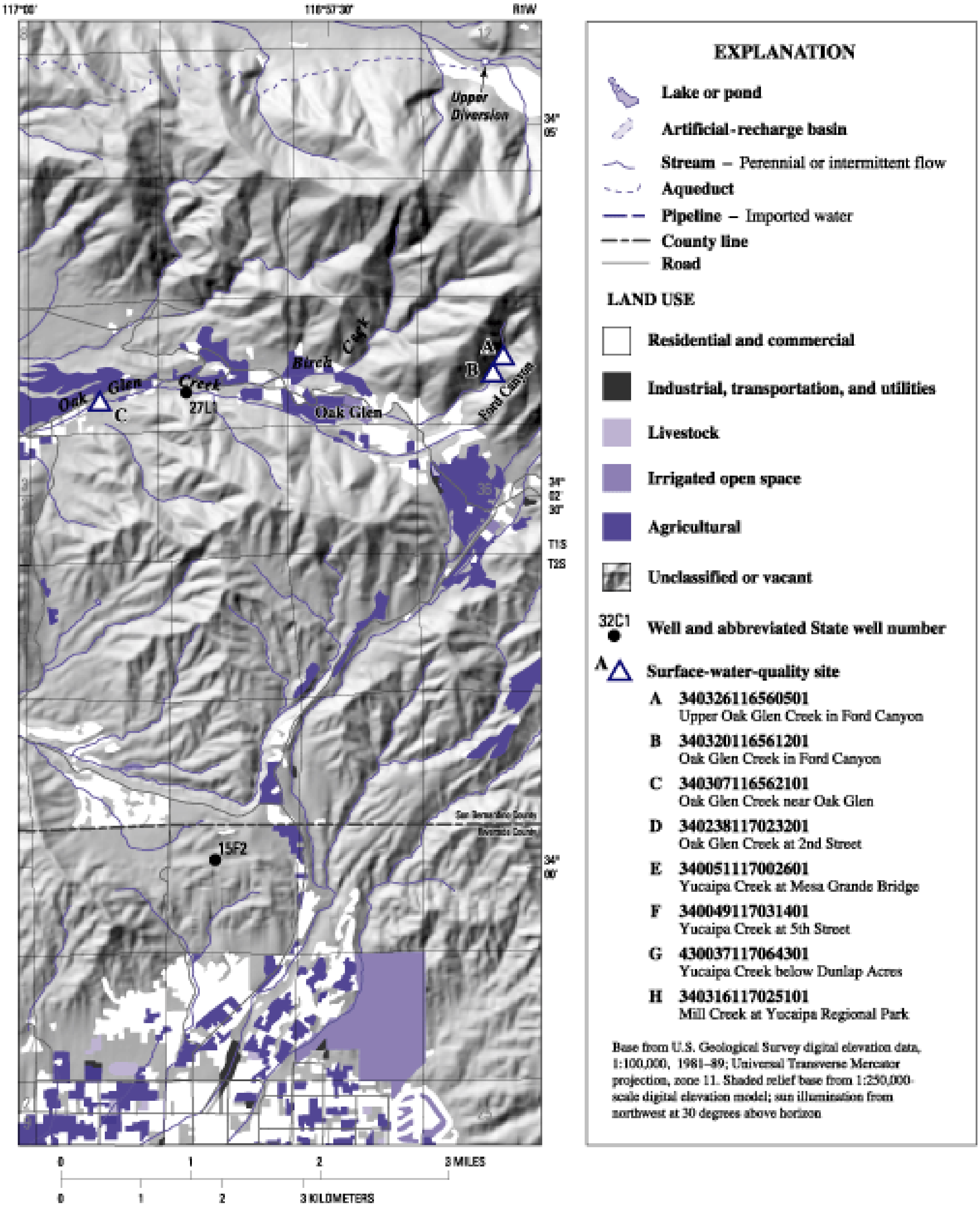


Figure 7—Continued.

and since about 1990, most of the citrus groves have been replaced with planned residential developments.

As of 1990, land use in the Yucaipa area was a combination of residential land covering much of the Yucaipa plain, and isolated pieces of agricultural land (fig. 7). The central part of the plain continues to be filled with small, older homes occupying as much as an acre of land. Mobile-home parks continue in their same location along the northern part of the plain. Recently constructed tract housing, at densities of 1 to 6 homes per acre, extends to the edges of the plain and onto the surrounding hills. Within the boundaries of the Yucaipa Valley Water District, which covers most of the plain, rural residential housing (less than or equal to 1 dwelling unit per acre) accounts for 35 percent of the land use, low-density residential housing (1 to 4 dwelling units per acre) accounts for 21 percent, and planned residential development (mixed residential, public land, and some commercial use) accounts for 29 percent (Camp, Dresser, and McKee, 1994).

The small amount of commercial development in the Yucaipa area is located along a few main streets, and there is almost no industrial development. Apple growing is still popular on the lower slopes of the San Bernardino Mountains, particularly along Oak Glen Creek, and each fall many visitors attend the apple harvest festival. The Yucaipa Regional Park, with its small lakes and grassy areas, is located on the northwest side of the Yucaipa plain adjacent to Crafton Hills. The small lakes are sustained by water imported from Mill Creek. On Wilson Creek, a large artificial-recharge basin has been constructed and can be used to recharge both local runoff and water imported from Mill Creek.

Water Use

Prior to the late 1800’s, the water supply of the Yucaipa area was limited to surface flow in the mountain streams and small quantities of springflow along the Chicken Hill Fault. In the 1890's and early 1900's, a number of flowing wells were completed in the Western Heights subbasin. At that time, several water companies were formed to distribute water for irrigation. Agricultural development during the period 1900–30 required the installation of more wells throughout the area. By the 1930’s, this increased pumping had lowered the hydraulic head in the valley-fill aquifer to below land surface. This gradual decline in ground-water levels continued until the post-World War II development boom began in 1945. A combination of increased pumpage and reduced recharge caused by below-normal precipitation resulted in an increased rate of decline in ground-water levels of 10 to 20 ft/yr. This rate continued into the early 1960's and then decreased to 5 to 10 ft/yr (Moreland, 1970). Because population predictions indicate that local water needs will increase sharply over the next decade, it is likely that ground-water levels will continue to decline in some parts of the Yucaipa area.

WATER QUALITY

Water samples were collected from selected surface-water sites and wells in the Yucaipa area during 1996–98. These sites and wells are shown in figure 3 and listed in table 1. Results of chemical analyses of 15 surface-water samples from 8 sites on 3 creeks and of 32 ground-water samples from 25 wells are given in tables 2 and 3, respectively, in the back of this report. On the basis of these data, the major-ion composition of water was evaluated using Stiff (polygon) and Piper (trilinear) diagrams (figs. 8 and 9). A Stiff diagram shows the relative abundance of cations and anions expressed in milliequivalents per liter and plotted on one of four parallel horizontal axes (Stiff, 1951). The resulting polygon shows similarities or differences in general water chemistry, and the width of the polygon is an approximation of the total ionic content. A Piper diagram (Piper, 1944) shows the relative contribution of major cations and anions, on a charge-equivalent basis, to the total ionic content of the water. Percentage scales along the sides of the diagram indicate the relative concentrations, in milliequivalents per liter, of each major ion. Cations are shown in the left triangle, anions are shown in the right triangle, and the central diamond integrates the data.

Surface Water

Oak Glen, Yucaipa, and Mill Creeks were selected for the collection of water-quality samples. Four sites were located on Oak Glen Creek, in downstream order: two sites in Ford Canyon, one site near the town of Oak Glen, and one site at the Second Street crossing, just downstream from the confluence with Wilson Creek. Three sites were chosen on Yucaipa Creek, in downstream order: at the Mesa Grande bridge, at the Fifth Street bridge, and southwest of Dunlap Acres downstream from the confluence with

Oak Glen Creek (fig. 3). One sample was collected at Yucaipa Regional Park where water from Mill Creek is imported to the park in a pipeline. The water in the pipeline originates as diversions from two locations on Mill Creek. The upper diversion is located in the incised drainage channel and is used as inflow to a powerhouse; the lower diversion is under the Highway 38 bridge (fig. 3).

The winter of 1997–98 was much wetter than average because of El Niño conditions. This weather pattern is caused by warming of the tropical Pacific Ocean and can result in extreme weather throughout the world and greater than average precipitation in southern California. As a result of El Niño conditions, February 1998 was the wettest February on record in southern California. Late-season storms typically come from the Pacific northwest, but also may result from warm, moist air drawn into southern California from the southwest. This latter effect produces many of the larger magnitude and longer duration storms.

Storms differ in magnitude, duration, intensity, and direction—each of which may produce changes in water chemistry. In February 1998, three storms were sampled. From the many precipitation stations in the Santa Ana River drainage basin, nine were chosen to show storm patterns (fig. 10). The first storm entered the basin from the west and started producing rain at Carbon Canyon Dam (CCYN). The rain started falling at about 0700 (local time) on February 3, was basin-wide in about 6 hours, and lasted about 16 hours. The greatest precipitation, 2.3 in., was recorded at Prado Dam (PRDO). The least precipitation, about 0.5 in., fell at higher altitudes in the mountains to the northeast of the study area at Converse Fire Station (CONV). Lower altitudes to the north and east of Yucaipa received approximately 2.0 in. of rain, as recorded at the Oak Glen station (OAKG).

The second storm was the smallest and entered the basin from the west and then moved eastward. Rain began falling in the western end of the Santa Ana River drainage basin during the morning of February 19 and moved into the rest of the basin starting at about 2000. The greatest precipitation, 0.8 in., was recorded at OAKG; the least was 0.1 in. at CONV.

The third storm was the largest and started in the mountains to the north. This storm is typical of an El Niño-influenced storm whereby tropical moisture from the southwest is entrained in a slow-moving, low-pressure system moving in from the northwest. The precipitation generally fell in two distinct periods, except at the Devore Fire Station (DEVO) and San Antonio Dam (SNTO) stations, both of which recorded nearly constant rainfall (fig. 10). The first rain fell in the afternoon of February 22, and the rest fell in the early evening of February 23. The precipitation was greatest in the mountains to the north: 6.3 in. at DEVO; 5.2 in. at SNTO; and 4.5 in. at OAKG. The precipitation was least, about 1.9 in., in the southern part of the basin at the Santa Ana River at Fifth Street (SAR5) and at Lake Mathews (LKMA).

Storm runoff flows quickly out of the surrounding hills and mountains onto the plain with little time for the water to dissolve minerals and salts. As a result, water-quality samples from Yucaipa Creek had very low concentrations of dissolved solids, cations, and anions. At the two upstream sites, the concentration of dissolved solids (residue on evaporation) ranged from 40 to 57 mg/L (milligrams per liter) (table 2, at back of report). Calcium and bicarbonate, although low in concentration, were the dominant ions on the basis of milliequivalents (fig. 8).

The chemistry of Oak Glen Creek and Yucaipa Creek was similar in that water samples were dominated by calcium and bicarbonate ions. However, concentrations of sodium, magnesium, and sulfate were higher in samples from Oak Glen Creek. (fig. 8, table 2). Dissolved-solids concentrations also were higher in Oak Glen Creek, ranging from 74 to 249 mg/L (table 2). The higher concentrations of these constituents may result simply from the source of the water. Oak Glen Creek has its source in the San Bernardino Mountains and is perennial in the foothills, whereas the source for Yucaipa Creek is in the Yucaipa Hills. Samples collected during base flow in Oak Glen Creek near Oak Glen contained higher concentrations of ions than samples collected during stormflows (fig. 8). Calcium concentrations ranged from 24 to 45 mg/L in base-flow samples, and from 13 to 30 mg/L in stormflow samples. Dissolved-solids concentrations ranged from 120 to 249 mg/L during base flows, and from 74 to 227 mg/L during stormflows. Concentrations of other major ions also decreased during stormflows (fig. 8, table 2). This decrease in concentrations probably results from dilution of base flow with stormflow having a lower ionic strength.

The highest concentration of major ions in Yucaipa Creek was found at the downstream site, located below the confluence with Oak Glen Creek where the surface water exits the study area southwest of Dunlap Acres (figs. 8 and 9*A*). The dissolved-solids

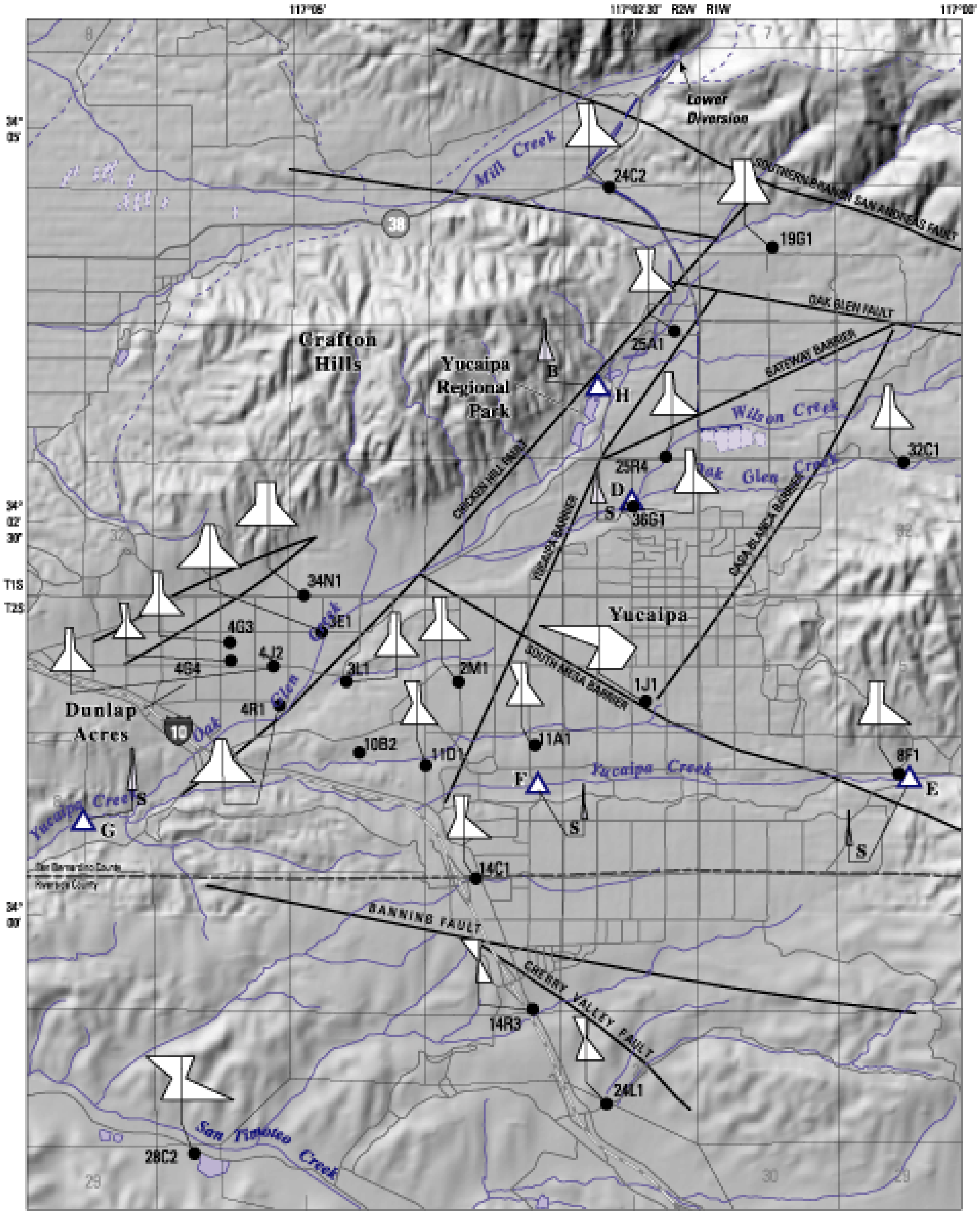
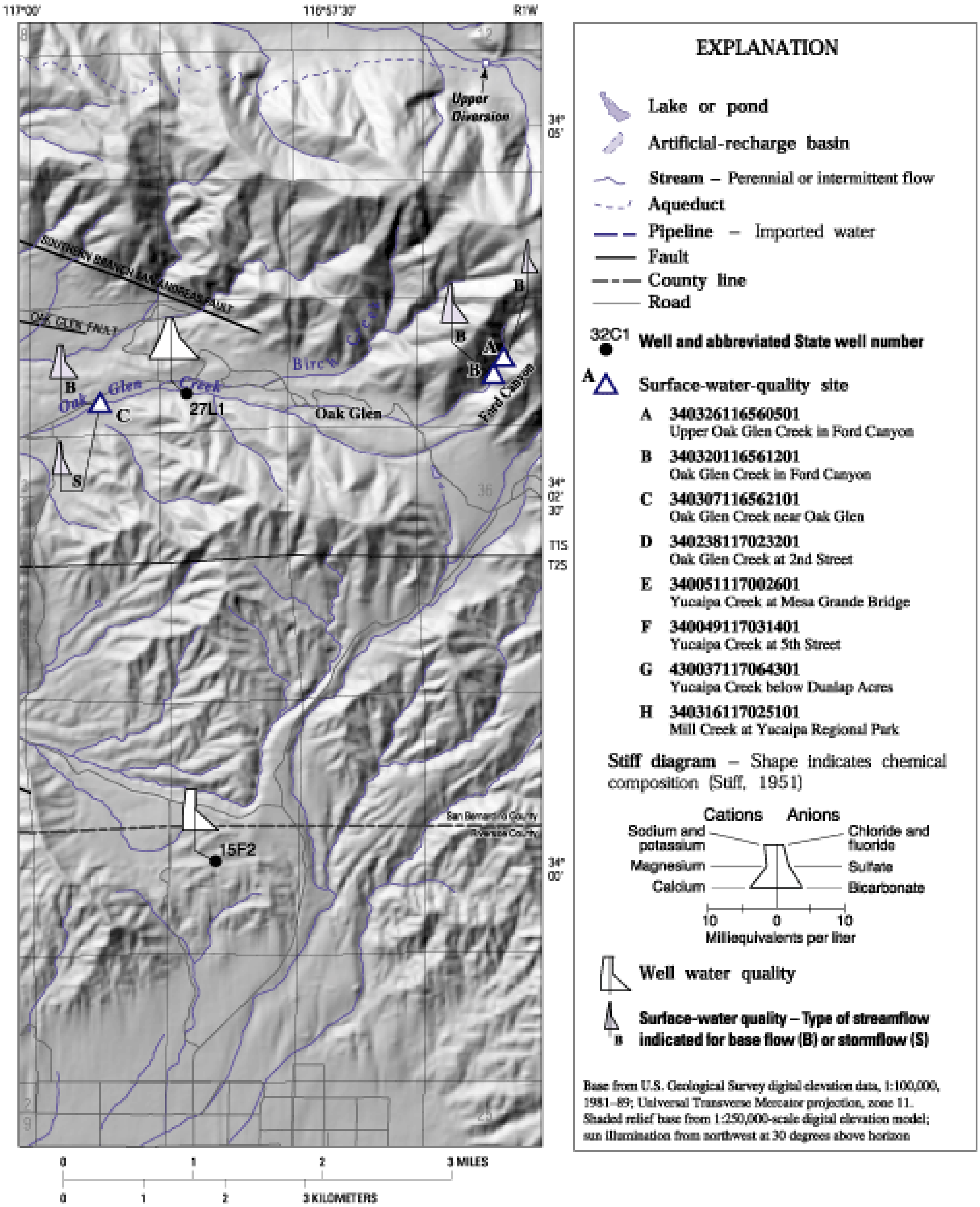


Figure 8. Water chemistry in samples from selected wells and surface-water sites in the Yucaipa area, southern California.



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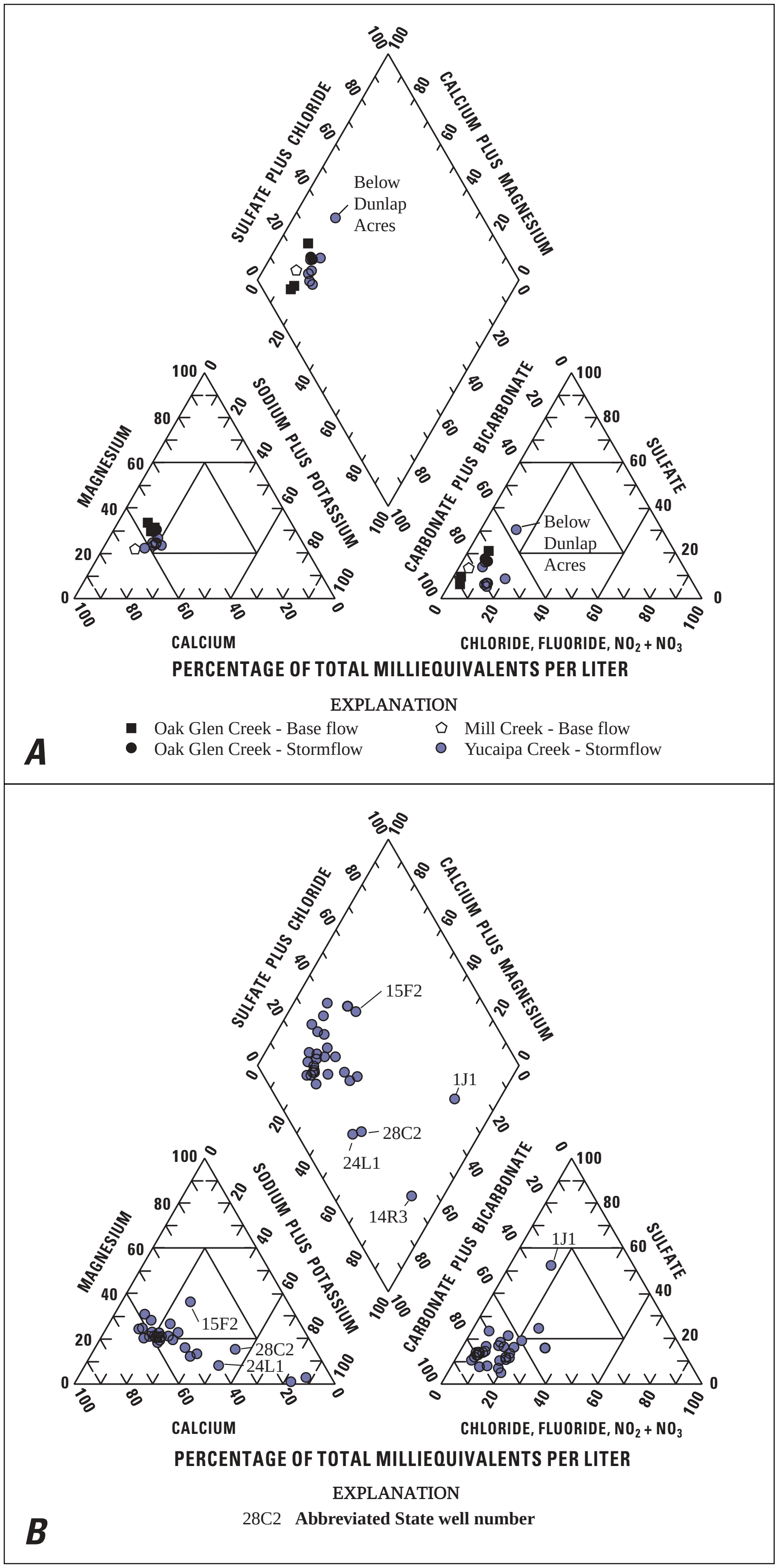


Figure 9. Major-ion composition of ***(A)*** surface water and ***(B)*** ground water in the Yucaipa area, southern California.

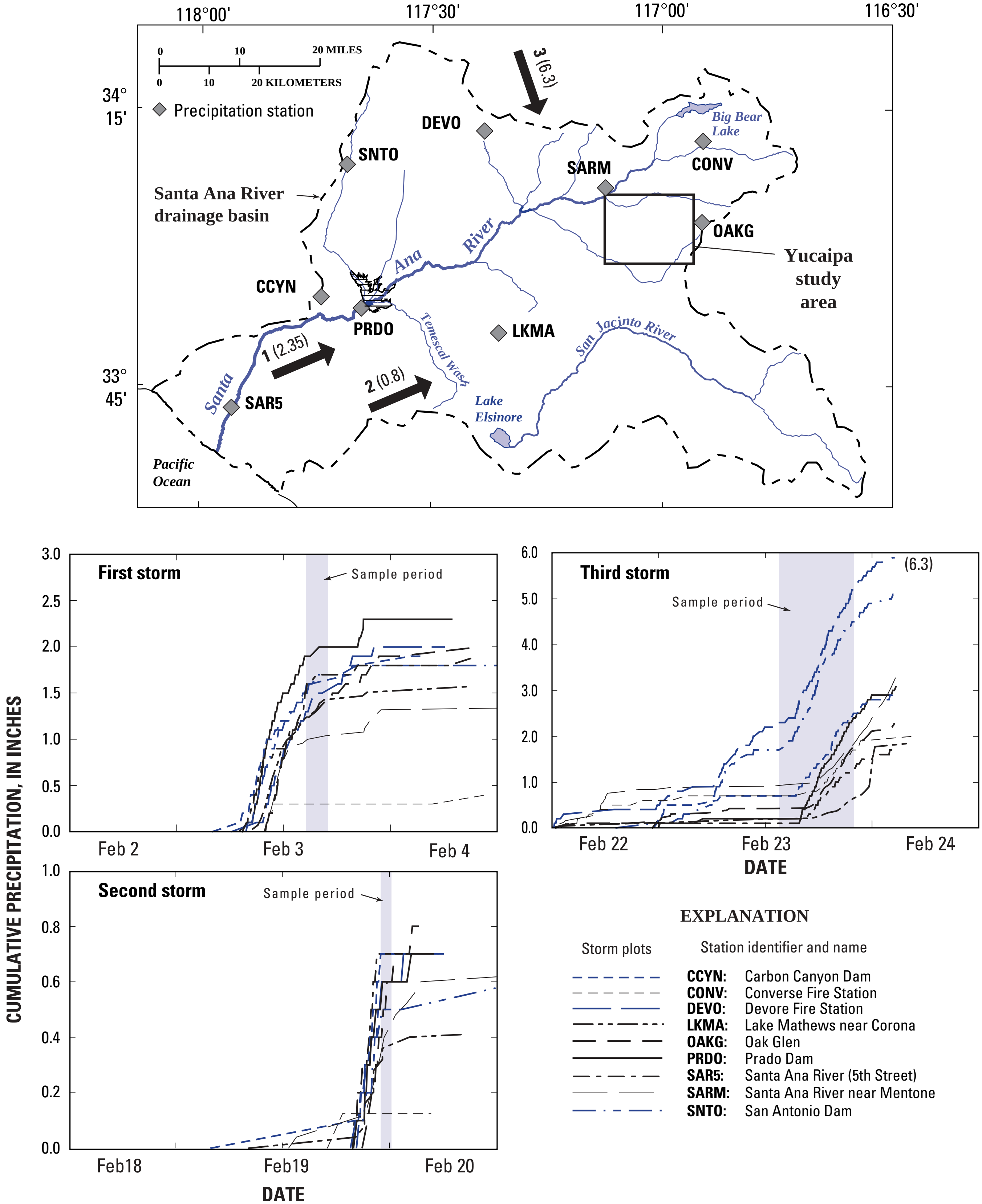


Figure 10. Precipitation stations and cumulative precipitation for three February 1998 storms in the Santa Ana River drainage basin, southern California (note change in vertical scale on graphs). Arrows on map show direction storm started in basin; numbers indicate storm sequence sampled and largest amount of total precipitation, in inches. Precipitation data from U.S. Army Corps of Engineers (Gregory Peacock, written commun., 1998).

concentration was slightly greater than 100 mg/L (table 2). The Piper (trilinear) diagram for this surface-water sample shows that the dominant ions were mostly calcium and bicarbonate (fig. 9*A*). In comparison with the two upstream sites, this site had a much higher concentration of sulfate (22 mg/L compared to <3.2 mg/L) and a slightly higher concentration of chloride. The large differences in the concentrations of many constituents between the two upstream sites on Yucaipa Creek and the downstream site may be a result of runoff from Oak Glen Creek and the town of Yucaipa, or the differences may result from the larger discharge at the time of sampling of the downstream site (190 ft^3/s in comparison to 2.3 ft^3/s). The sample taken at the downstream site was collected during the rising limb of the runoff which typically carries more sediment.

As found in samples collected from Oak Glen Creek and Yucaipa Creek, the dominant ions in the sample collected from Mill Creek at the inlet to the Yucaipa Regional Park (site H) were calcium and bicarbonate (fig. 8). Most constituent concentrations, such as sodium, chloride, silica, phosphate, boron, and iron, were similar to concentrations in base-flow samples collected from Oak Glen Creek at site A and B in Ford Canyon (fig. 8 and table 2). These similarities would be expected because the source of the water in both creeks is the San Bernardino Mountains. Other constituents, such as calcium, magnesium, dissolved solids, and sulfate, had concentrations similar to those in stormflow (figs. 8 and 9; table 2). Lithium concentration [(5 μg/L) micrograms per liter] was higher in the Mill Creek sample.

In addition to Stiff and Piper diagrams, the major-ion composition of water samples was evaluated using boxplots. The variability of selected constituents as well as differences between surface and ground water can be observed from these boxplots (fig. 11). Boxplots show the range of values for a selected water-quality constituent. The vertical size of the box is determined by the range of the data, as in a histogram. The width of the box is meaningless and is for display purposes only. The median and selected percentiles of the data are indicated along with any outliers.

Phosphate showed the highest variability (ranging from the upper 75 to the lower 25 percentile fig. 11) of any constituent sampled, perhaps as a result of the higher phosphate concentrations found in storm runoff in Yucaipa Creek (table 2). Nitrate (NO_3) concentrations were low, ranging from 0.18 to 2.3 mg/L as nitrogen. These low values indicate the lack of a significant source of nitrate from runoff under these conditions. The higher values of nitrate were found in samples collected downstream from the agricultural land adjacent to Oak Glen Creek and Yucaipa Creek (figs. 7 and 12). Organic ammonia values ranged from less than the detection limit of 0.1 mg/L to 0.7 mg/L. More studies are needed to evaluate the rates at which species are converted to and from nitrate.

Calcium concentrations ranged from 5.8 to 45 mg/L. Chloride and fluoride concentrations ranged from 1.2 to 7.7 mg/L, and from 0.1 to 0.8 mg/L, respectively. Sulfate concentrations ranged from 1.4 to 37 mg/L. Sodium concentrations ranged from 2.2 to 15 mg/L. Iron and manganese concentrations ranged from less than the detection limit of 3 μg/L to 110 μg/L, and from less than the detection limit of 1 μg/L to 15 μg/L, respectively. Boron concentrations ranged from 7 to 24 μg/L. Barium concentrations ranged from 4.3 to 20 μg/L. All constituents were well below their respective maximum contaminant levels (MCL) (U.S. Environmental Protection Agency, 1994).

Concentrations of dissolved oxygen in samples collected during the summer from Mill and Oak Glen Creeks were 8.2 and 8.5 mg/L, respectively. Dissolved-oxygen concentrations in winter samples from Oak Glen and Yucaipa Creeks ranged from 9.4 to 10.8 mg/L. Lower dissolved-oxygen concentrations in the summer samples may result from less turbulence in the river than during winter stormflow, and may result from the lower solubility of oxygen in warmer water. Also in summer, dissolved oxygen can be depleted by biochemical processes, such as respiration by algae that consume dissolved, suspended, or precipitated organic matter.

Ground Water

Ground-water samples were collected from 25 wells mostly on the Yucaipa plain (fig. 3) and from 1 well in San Timoteo Canyon. On the basis of these samples, most ground water in the Yucaipa area shows little areal variability and is of good quality by U.S. Environmental Protection Agency (EPA) drinking water standards (U.S. Environmental Protection Agency, 1994). Dissolved-solids concentrations ranged

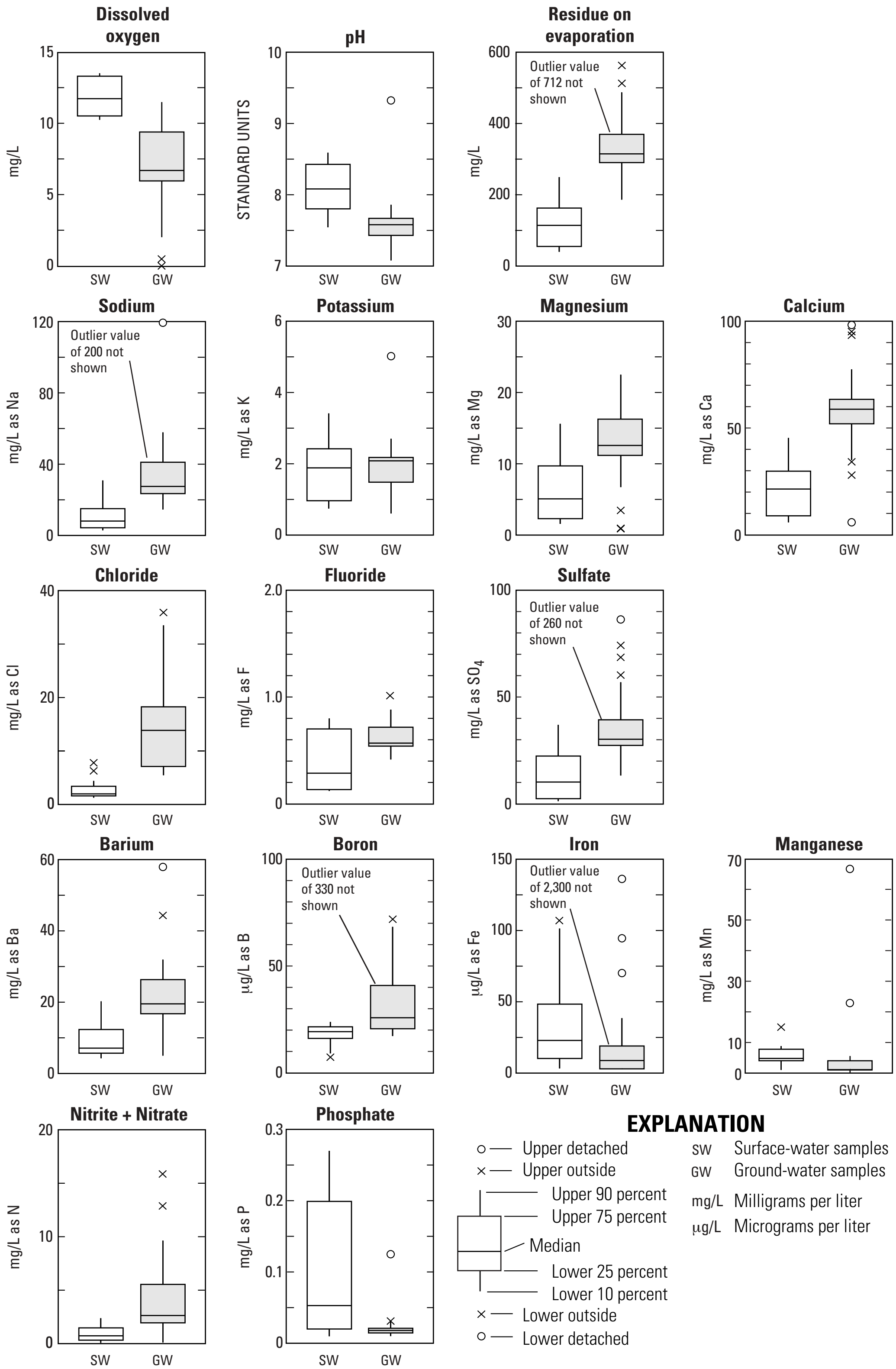


Figure 11. Concentration of selected constituents for selected wells and surface-water sites in the Yucaipa area, southern California.

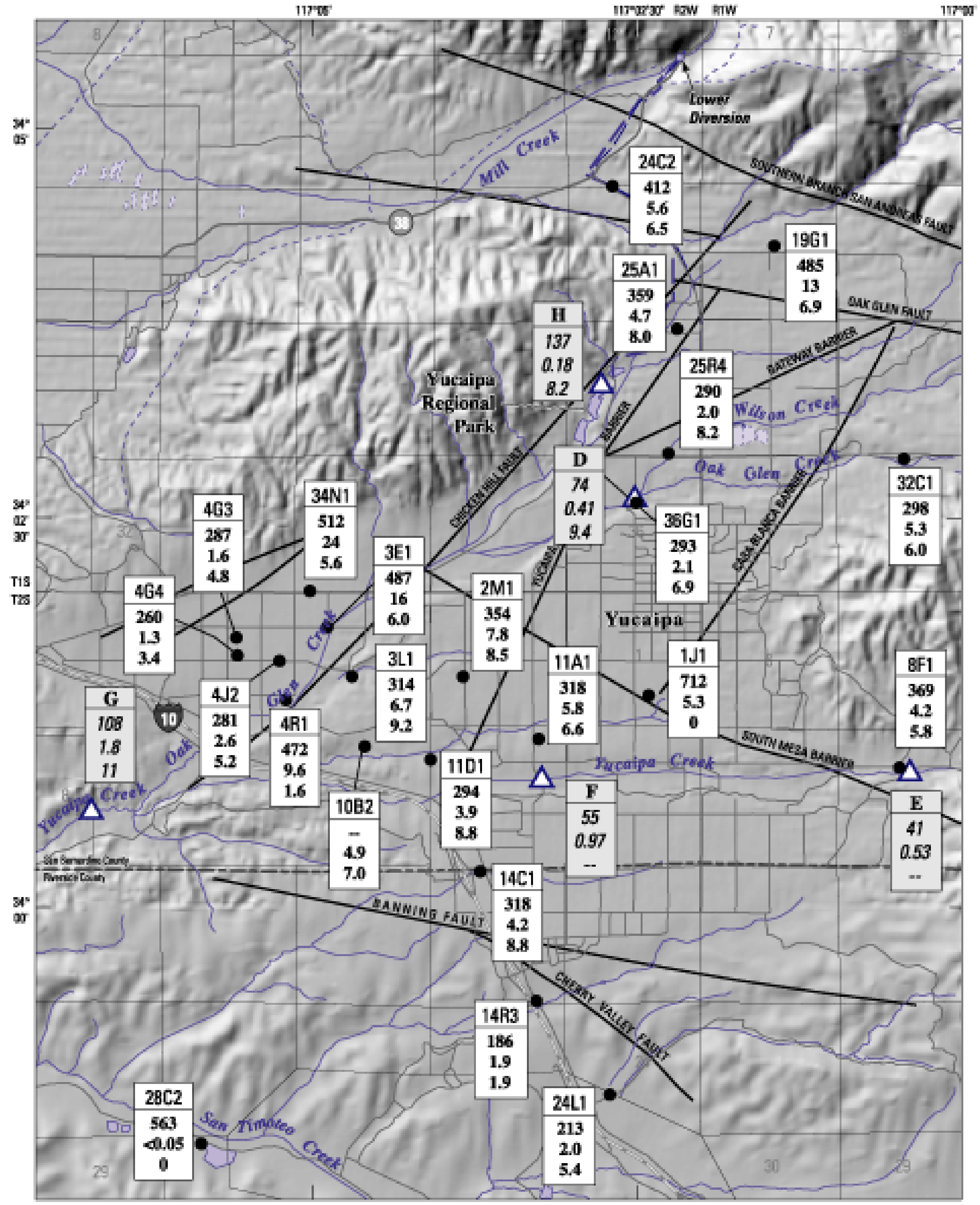


Figure 12. Concentration of dissolved solids, nitrites plus nitrates, and dissolved oxygen for selected wells and surface-water sites in the Yucaipa area, southern California.

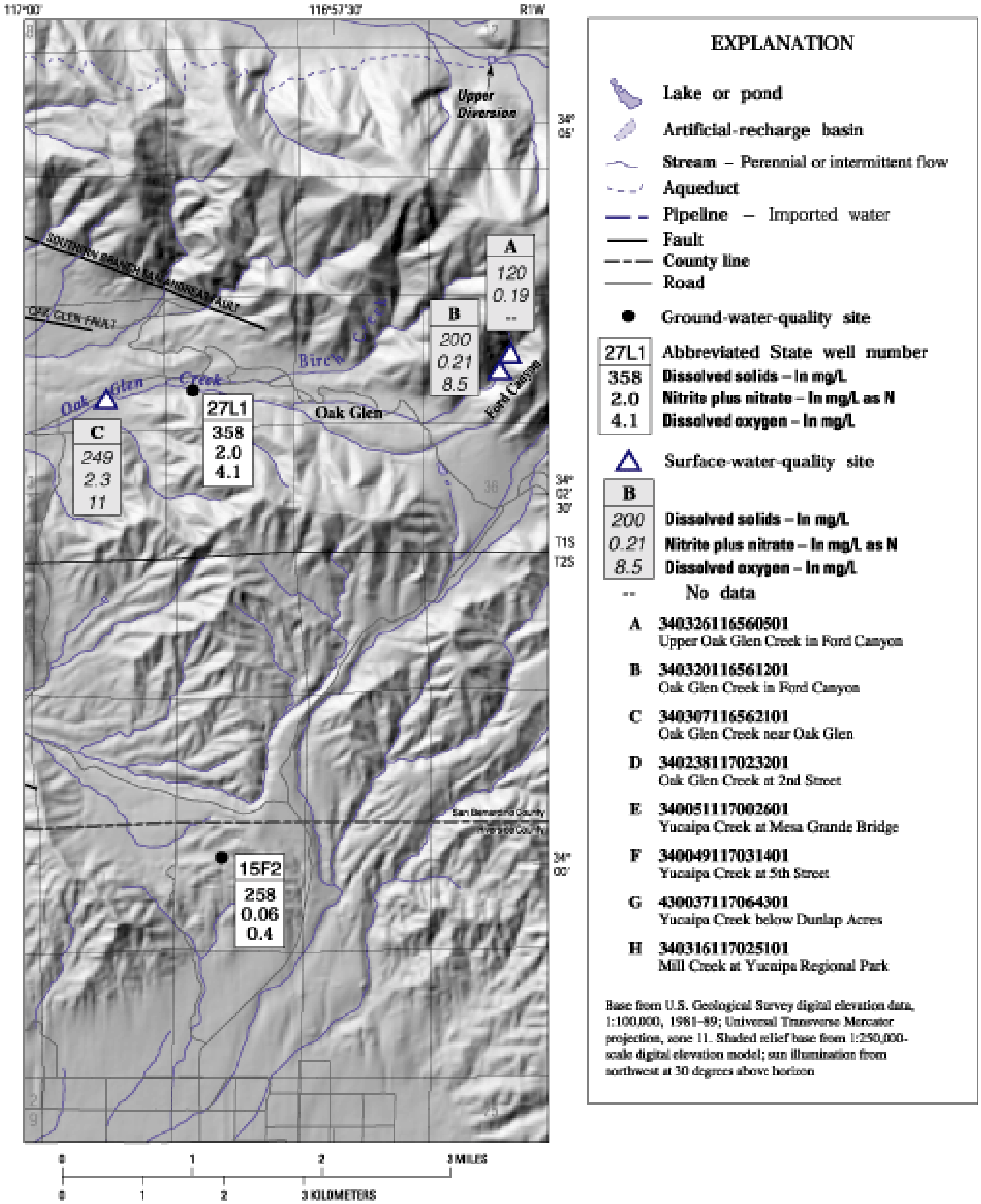


Figure 12—Continued.

from 186 to 563 mg/L (table 3, at back of report; fig. 12), with an outlier of 712 mg/L at well 2S/2W-1J1. Sodium concentrations ranged from 14 to 58 mg/L, with outliers of 120 mg/L and 200 mg/L at wells 2S/2W-28C2 and 2S/2W-1J1, respectively. Chloride concentrations ranged from 6.3 to 36 mg/L, with an outlier of 65 mg/L at well 2S/2W-28C2. Sulfate concentrations ranged from 13 to 86 mg/L, with an outlier of 260 mg/L at well 2S/2W-1J1. Iron concentrations ranged from less than the detection limit of 3 mg/L to 140 mg/L, with an outlier of 2,300 mg/L, also at well 2S/2W-1J1. This unusually high concentration of iron may result from corrosion of the steel well casing. The sample from well 2S/2W-1J1 also showed signs of a reducing environment and had no dissolved oxygen, a condition that causes iron to become soluble. Boron concentrations ranged from 20 to 70 μg/L, with an outlier of 330 μg/L at well 2S/2W-1J1.

As in surface water, calcium and bicarbonate were the major ions found in ground water on the basis of milliequivalence (figs. 8 and 9*B*). Four wells were not dominated by calcium and bicarbonate. Water from well 2S/2W-1J1 was high in sodium, sulfate, and dissolved-solids concentration and contained almost no magnesium. Water from this well also had elevated concentrations of fluoride and boron, which may indicate a contribution of mineralized ground water emanating from a nearby fault zone. This explanation seems plausible because well 2S/2W-1J1 is located near the intersection of the South Mesa and Casablanca Barriers (figs. 3 and 8). Wells 2S/2W-14R3 and 2S/2W-24L1 yielded water having more than 80 percent sodium and potassium and less than 20 percent calcium and magnesium (fig. 9*B*). These two wells are located south of the Banning and Cherry Valley Faults (figs. 3 and 8). Ground water moving to these wells probably has a geochemical signature more representative of the unconsolidated nonmarine sediment of the badlands than of the crystalline rocks found in the other hills and mountains in the Yucaipa area. Well 2S/2W-28C2 is located in San Timoteo Canyon, which is eroded into the badlands, and has the same water type as well 2S/2W-24L1 (fig. 9*B*). Well 2S/2W-28C2 is located near and probably downgradient from fishing ponds. The elevated concentrations of sodium, calcium, chloride, and bicarbonate in water from this well may result from evaporative processes that occur in the ponds before water infiltrates into the ground.

Three wells (1S/2W-34N1, 2S/2W-3E1, and 2S/2W-4R1) located in the western part of the Yucaipa area and one well (1S/1W-19G1) in the northern part of the Yucaipa area yielded water with a high concentration of nitrate (fig. 12). Water from three of these wells (19G1, 34N1, and 3E1) had nitrate concentrations that exceed the MCL of 10 mg/L as N; water from well 2S/2W-4R1 had a nitrate concentration of 9.6 mg/L, just below the MCL. Water from these four wells also was higher in dissolved solids, sodium, calcium, chloride, sulfate, and bicarbonate. These wells are located downgradient from an area that has been used for agriculture (fig. 7). The high concentrations of these constituents at well 1S/2W-34N1 may result from agricultural practices and evaporative processes. The lower concentrations of nitrate in wells 2S/2W-3E1 and 2S/2W-4R1 may result either from a different source of nitrate or from dilution with less contaminated water as ground water moves through the area. The later seems more plausible, suggesting a separate but converging ground-water-flow path, possibly coincident with Oak Glen Creek.

Most constituents analyzed in ground-water samples were below their respective MCL’s. All sulfate concentrations, except for well 2S/2W-1J1, were below the Secondary Maximum Contaminant Level (SMCL) of 250 mg/L, as defined by the U.S. Environmental Protection Agency (1994). Water from one well (2S/2W-1J1) exceeded the SMCL for iron, which is 300 μg/L. Water from two wells (1S/1W-19G1 and 2S/2W-28C2) exceeded the SMCL for manganese, which is 50 μg/L. Barium concentration in all water samples was far below the MCL of 2,000 μg/L.

In general, sodium, calcium, magnesium, chloride, nitrate, sulfate, and dissolved-solids concentrations were higher in ground water than in surface water (fig. 11) probably as a result of dissolution of minerals in the aquifer matrix. However, concentrations of iron, manganese, and phosphate were higher in surface water than in ground water.

Flowmeter Data

Flowmeter data were collected from well 1S/2W-25R4 using a commercial, vertical-axis current meter, commonly called a spinner tool. This tool measures the velocity of water flowing inside the well casing by recording the number of revolutions per second made by a spinning impeller. Flowmeter data are helpful in determining the water-yielding characteristics of aquifer material opposite the screened interval and in evaluating mixtures of water collected at different depths within the well. A continuous profile of velocity was recorded for the entire depth of the well, and static data (stop counts) were collected every 10 ft.

Flowmeter data for well 1S/2W-25R4 demonstrate that water does not enter the well in a uniform manner (fig. 13). Rather, the data suggest that there are three distinct zones. About one-half of the total discharge from the well entered the casing through the top 150 ft of perforations—that is, between depths of 450 and 600 ft below land surface. The rest of the discharge entered the well at a nearly uniform rate between depths of 600 and 820 ft. Virtually no water entered the well between depths of 820 and 950 ft. Because the water table was at a depth of about 300 ft below land surface, it is likely that some additional contribution of water to the well would have occurred if the well were perforated above a depth of 450 ft.

Variations in water yield can be caused by many factors such as the hydraulic characteristics of adjacent aquifer material or any encrustation of the well screen. The inferred change in aquifer characteristics at about 600 ft is not evident from the driller's or electric logs, but the change at 820 ft is supported by a change in signature of the 16-inch normal resistivity log (fig. 13). The material below 820 ft appears to have thinner layering and a higher percentage of clay. These observed

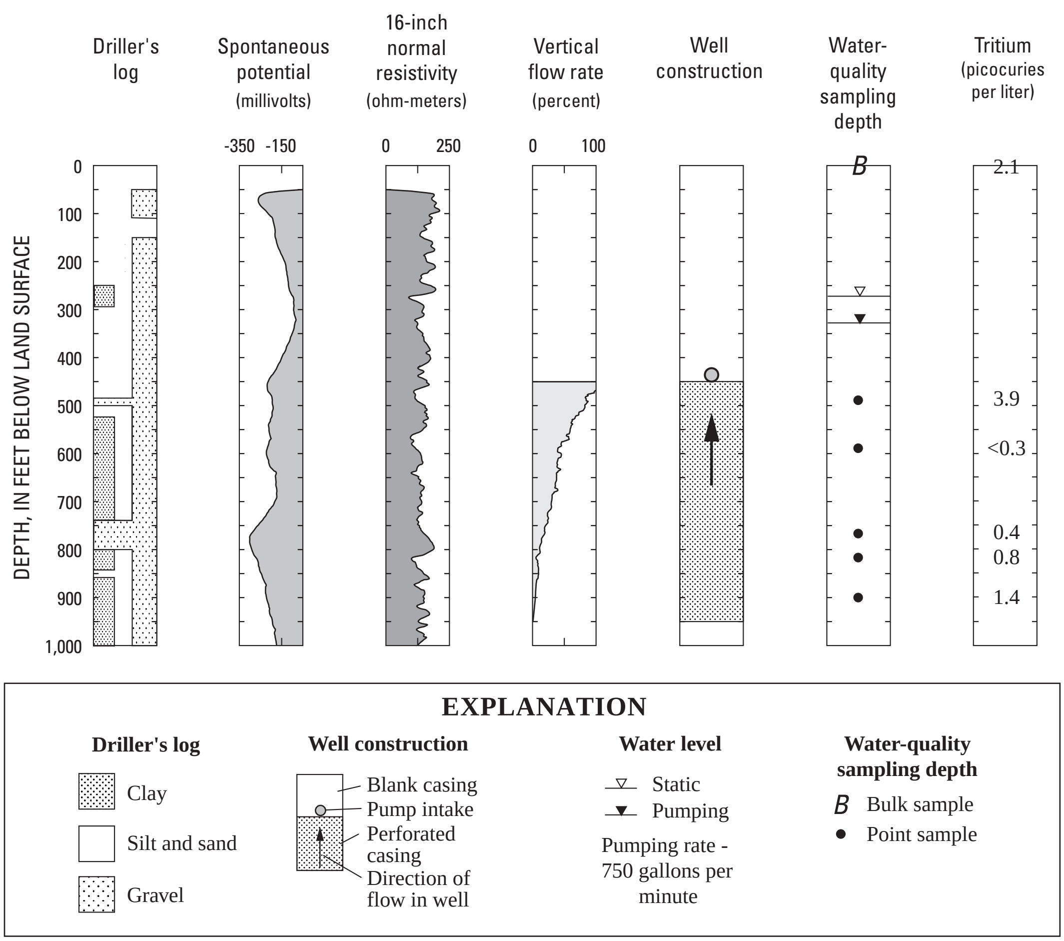


Figure 13. Driller's log, electric logs, vertical flow rate, well construction, and water-quality sampling for well 1S/2W-25R4 in the Yucaipa area, southern California.

changes in flow rate and possible changes in lithology were used to select specific depths at which to sample water quality.

Depth-Dependent Samples

Depth-dependent and bulk samples for chemical and isotopic analyses were collected from production wells (table 3). Production wells generally have long screened intervals and can be open to more than one geologic or hydrogeologic unit. Bulk samples from production wells typically are a mixture of ground water from different units; nevertheless, only bulk samples were obtained for production wells sampled in this study, except for well 1S/2W-25R4, because of the expense and difficult logistics of depth-dependent sampling.

At well 1S/2W-25R4, depth-dependent chemical and flowmeter data were collected using special sample-collection techniques while the well was pumped. All depth-dependent water samples and one bulk sample were collected while the production well was discharging at a rate of 750 gal/min. To facilitate this discrete-depth sampling, the well had been modified with a temporary, lower capacity pump. A second bulk sample was collected while the well was pumped at a rate of 1,450 gal/min using the standard-capacity production pump. Depth-dependent water samples were collected using a high-pressure hose equipped with a one-way valve that allows water to enter from a specific depth (Gossell and others, 1995; Izbicki and others, 1999). The hose is lowered to the desired depth, the valve is opened, and the sample is collected. Then the hose is retrieved from the well, and the sample water is collected from the hose at land surface. Prior to sample collection, the well was pumped for over 12 hours to ensure that ground water entering the well through the screened interval was representative of the aquifer.

All samples were collected below the pump intake. The sample collected from the deepest part of the screened interval is interpreted as representing water entering below that depth. Water sampled above the lowest sample depth and below the pump intake is a mixture of water in the well at the first sample depth and water that entered the well between the two sample depths. The proportions of water in that mixture can be determined from the flowmeter data.

Results of the depth-dependent sampling show that the general water chemistry for the samples from well 1S/2W-25R4 are almost identical. Stiff diagrams of each sample collected at the different depths are similar to the Stiff diagram of the bulk sample shown in figure 8. This small vertical variability in general water chemistry can be explained in at least two ways. First, the geologic materials adjacent to the perforated intervals may be chemically similar despite their hydraulic differences (fig. 13). Second, ground water flowing in this recharge area near the mountains may not have had sufficient time to convert into chemically different, vertically stratified compositions.

Some vertical differences, however, were noted. The dissolved-oxygen concentrations were highest near the water table and lowest at the bottom of the well. The concentration of nitrate and nitrite also decreased with depth. Dissolved-solids and chloride concentrations tended to peak in the middle depths of the well. These results suggest that the most active part of the ground-water flow system is near the top of the well.

Tritium, a naturally occurring radioactive isotope of hydrogen, was used to determine the age (time since recharge) of the ground water. Tritium activity above the detection level of 0.3 pCi/L (picocuries per liter) was used as an indication of ground water recharged since 1952. Some processes that could affect tritium values are dispersion, mixing with different waters, and degassing during sampling. All depth-dependent samples from well 1S/2W-25R4 were analyzed for tritium. The highest tritium value (3.9 pCi/L) came from the shallowest sample depth, indicating that at least some of this water was recharged since 1952 (fig. 13). The other samples ranged from less than the detection limit of 0.3 pCi/L at 590 ft to 1.4 pCi/L (fig. 13 and table 3) at the bottom of the well.

The presence of an elevated value of tritium at the bottom of the well is unlikely, because it implies that younger water is present at the top and bottom of the well. A more likely explanation is that the bottom of the well is inactive and was not purged of water during pumping. This explanation is consistent with the flowmeter data showing that virtually no water enters the well below a depth of about 820 ft. If this explanation is correct, then all water-chemistry data collected for depths at 820 and 900 ft represent largely unpurged water originating from shallower perforated intervals.

Tritium values for the bulk samples were 2.1 pCi/L for a pumping rate of 750 gal/min and 3.4 pCi/L for a pumping rate of 1,450 gal/min. The higher tritium value for the higher pumping rate indicates that more water is being withdrawn from the uppermost zone.

Depth-dependent samples at the lower pumping rate (750 gal/min) also were analyzed for ^{14}C (table 3). The collected water samples are relatively young given the time scale for waters dated using ^{14}C. Expressed as percent modern carbon, the ^{14}C value was 86.1 in the well where no tritium (< 0.3 pCi/L) was detected (fig. 13). Assuming radioactive decay, with an initial ^{14}C activity of 90 percent modern carbon (Izbicki and others, 1997, p. 16) and neglecting reactions with the aquifer material, this sample has an approximate time of recharge of less than 400 years before present.

A simple three-cell mixing model can be used to test the data and interpretations of the depth-dependent sampling. If Q_1, Q_2, and Q_3 are the discharge rates for the upper, middle, and lower zones, respectively; and C_1, C_2, and C_3 are concentrations of a selected constituent for the same zones, then

$$Q_T C_T = Q_1 C_1 + Q_2 C_2 + Q_3 C_3, \tag{1}$$

where Q_T and C_T are total discharge and concentration from the well. Using flowmeter and tritium data,

$$750\ (2.1) = 375\ (3.9) + 375\ (0) + 0\ (1.4), \text{ or} \tag{2A}$$

$$2.1 \sim \frac{375(3.9)}{750}, \tag{2B}$$

which suggests that the assumed contribution from each zone to total discharge is reasonable. Applying the same test to other constituents (alkalinity, sulfate, nitrate) yielded similar results. Additional depth-dependent samples from nearby wells might help verify these results and extend analysis to other parts of the Yucaipa area.

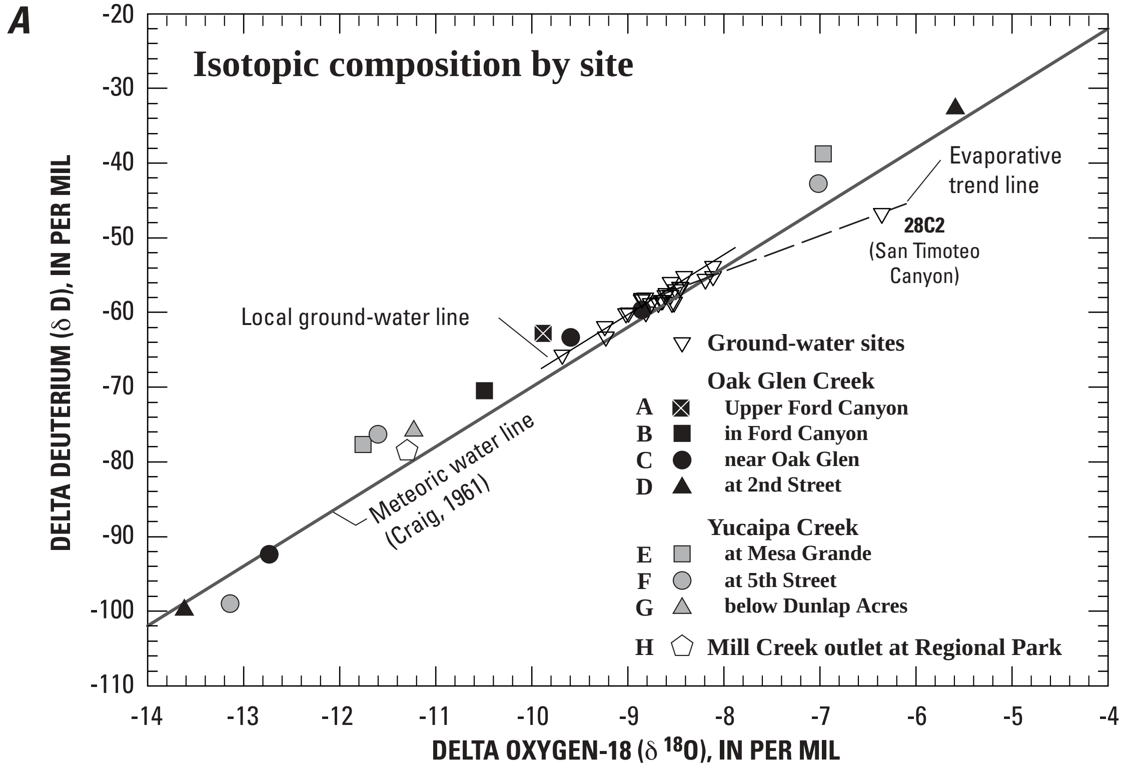
ISOTOPIC COMPOSITION OF WATER

Oxygen-18 and Deuterium

Surface-water isotopes at a particular site have a wide range of values (fig. 14*A*) which are highly influenced by the direction from which storms are generated and over time will approximate the values of ground water. Although all three storms originated in the northwest, the first and second storms entered the basin from the west and moved northeastward (fig. 10). The third storm entered the basin from the north and produced much more precipitation than did the first two storms. The third storm had warm moist air drawn into the system from the west. This effect typically occurs later in the rainy season and produces many of the larger magnitude, longer duration storms. Because the moist air from the storm is generated from a lower latitude and warmer climate than is air from the north, the precipitation is isotopically heavier (fig. 14).

Isotopic values for base flow (table 2) plot slightly above the meteoric water line (fig. 14*B*), and mean isotope ratios are –10.3 and –69.0 for $\delta^{18}O$ and δD, respectively. The mean isotopic ratios for the first storm are –12.7 and –91.8 for $\delta^{18}O$ and δD, respectively. These values are grouped below the meteoric water line near the bottom of the graph and indicate that this runoff is isotopically much lighter than is base flow. The mean isotope ratios for the second storm are –11.7 and –77.3 for $\delta^{18}O$ and δD, respectively, and are grouped above the meteoric water line and slightly below the middle of the graph. The mean isotopic ratios for the third storm are –6.51 and –38.2 for $\delta^{18}O$ and δD, respectively, and are grouped above the meteoric water line, near the top of the graph. Runoff from this storm is isotopically much heavier than is base flow.

Over time, the isotopic ratio of water vapor in different storms trends to an average value; therefore, the isotopic ratio of ground water is determined primarily by local differences in the temperature of condensation of water vapor, prior to its being recharged in different places and at different times. The deuterium content of precipitation varies seasonally as well as by storm and is highly dependent on storm- track trajectories (Friedman and others, 1992). The $\delta^{18}O$ and δD ratios of water from most wells ranged from –8.11



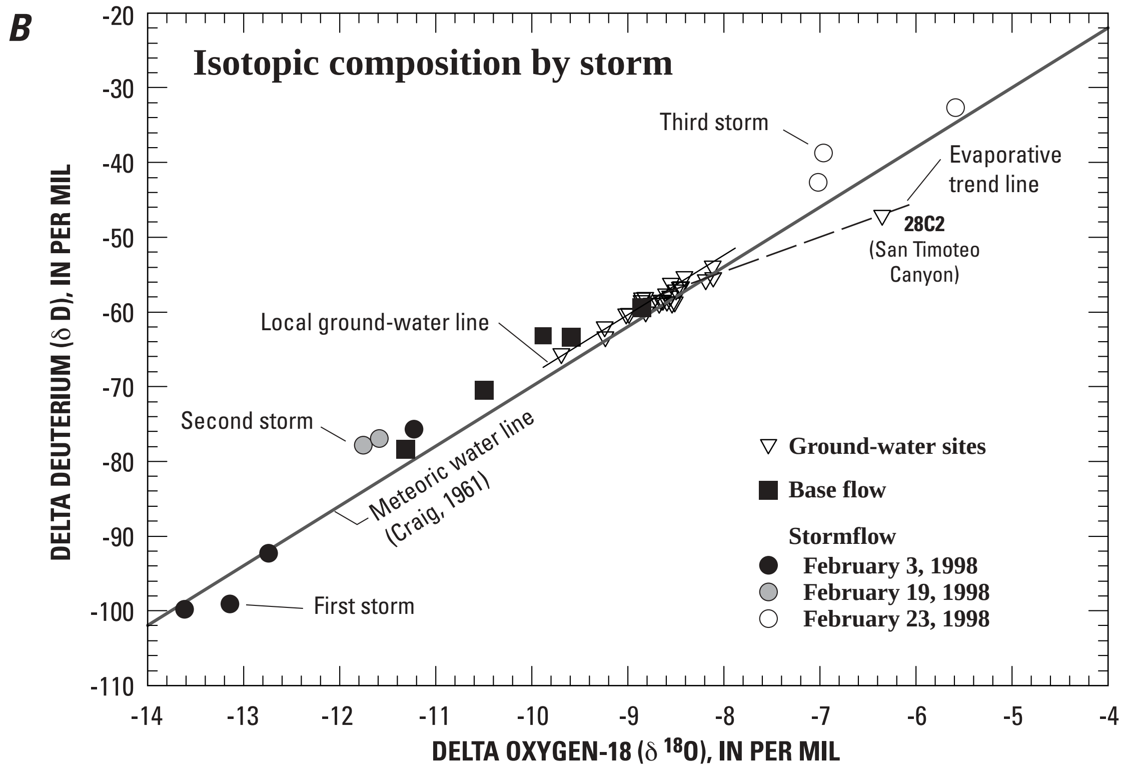


Figure 14. Isotopic concentrations of delta deuterium (∂D) compared to delta oxygen-18 ($\partial^{18}O$) by site ***(A)*** and by storm ***(B)*** for selected wells and surface-water sites in the Yucaipa area, southern California.

to −9.97 per mil and from −53.8 to −65.5 per mil, respectively, and the values are tightly grouped above the meteoric water line. The average $\delta^{18}O$ and δD ratios of surface water samples was −10.2 and −68.3 per mil which approximate ground-water values. The isotopic ratio of water from wells plots along a local ground-water line about 1 per mil above, and parallel to, the meteoric water line. Similar data from Woolfenden (1994) and Izbicki and others (1997) corroborate the local ground-water line for the western slope of the San Bernardino Mountains. Snow and, in turn, snowmelt have been shown to plot above the meteoric water line (Magaritz and others, 1989). The heaviest (least negative) water sampled, with respect to $\delta^{18}O$, is from well 2S/2W-28C2. Because the well is near fishing ponds, water moving to the well may have been partly evaporated prior to being recharged. An evaporative trend line can be drawn from well 2S/2W-28C2 to a point that intersects the local ground-water line near the mean value (fig. 14).

Tritium

Tritium activity in water from wells (table 3 and fig. 15) in the Yucaipa area ranged from less than the detection limit of 0.3 to 15 pCi/L, and tritium activity in water from surface-water sites (table 2) ranged from 7.3 to 18 pCi/L. Tritium activity in 27 of 31 well samples ranged from 0.7 to 15 pCi/L, indicating that all or part of the pumped water was recharged after 1952. Many of these wells are located on the Yucaipa plain and likely extract ground water from a water-bearing zone that is hydraulically connected to areas of recent recharge (fig. 15). Tritium activity in water from wells near the hills and mountains—in particular north of the Oak Glen Fault, or east of the Casa Blanca Fault and north of the South Mesa Barrier— ranged from 7.2 to 11 pCi/L. These values are similar to surface-water samples, and probably indicate that most pumped water was recharged recently.

Tritium activity in water from well 2S/2W-28C2 was 7.8 pCi/L. The proximity of the well to the fishing ponds, as well as the general chemistry data and the anomalous $\delta^{18}O$ and δD data, suggests that the ponds may be a source of recharge to the well. The tritium activity in water from well 2S/2W-3E1 was 15 pCi/L, the highest value found in ground-water samples. Well 2S/2W-3E1 is located along Oak Glen Creek, which may be a source of recharge to the well.

In water from wells 2S/2W-4G3, 2S/2W-4G4, and 2S/2W-4J2, tritium activity was less than the detection limit of 0.3 pCi/L. These wells are located at the west end of Yucaipa in the Western Heights subbasin and have the oldest water sampled. The depth of two of the three wells is greater than 1,000 ft (1,690 and 1,090 ft), and the wells may be extracting a greater proportion of deeper, older ground water than other, shallower wells. The Western Heights subbasin, in particular Dunlap Acres, also historically had a pumping depression, which is caused by ground-water extractions exceeding recharge. The pumping depression, the absence of tritium, and the greater distance of this area from the greater precipitation found in the San Bernardino Mountains suggests that Dunlap Acres receives less recharge than other parts of the Yucaipa area.

LIMITATIONS AND FUTURE NEEDS

The primary limitation of this study is the small number of vertically discrete ground-water samples that were obtained. No multiple-depth monitoring wells were available in the Yucaipa area at the time of this study. Since sampling was done for this study, some multiple-depth monitoring wells have been installed. If these wells were sampled for the same chemical constituents, the data likely would aid in understanding the vertical and horizontal characteristics of ground-water flow in the Yucaipa area. Depth-dependent sampling of production wells is logistically challenging, but can yield excellent flow and water-quality data to compare with water-level and water-quality data from multiple-depth monitoring wells.

The second major limitation of this study is the lack of detailed, ground-water-level maps—ideally for different time periods and for each significant hydrogeologic unit in the Yucaipa area. Because areal and vertical ground-water-level data are sparse, and the arrangement of subbasins is complex, this mapping may need to be done iteratively with development of a ground-water flow model.

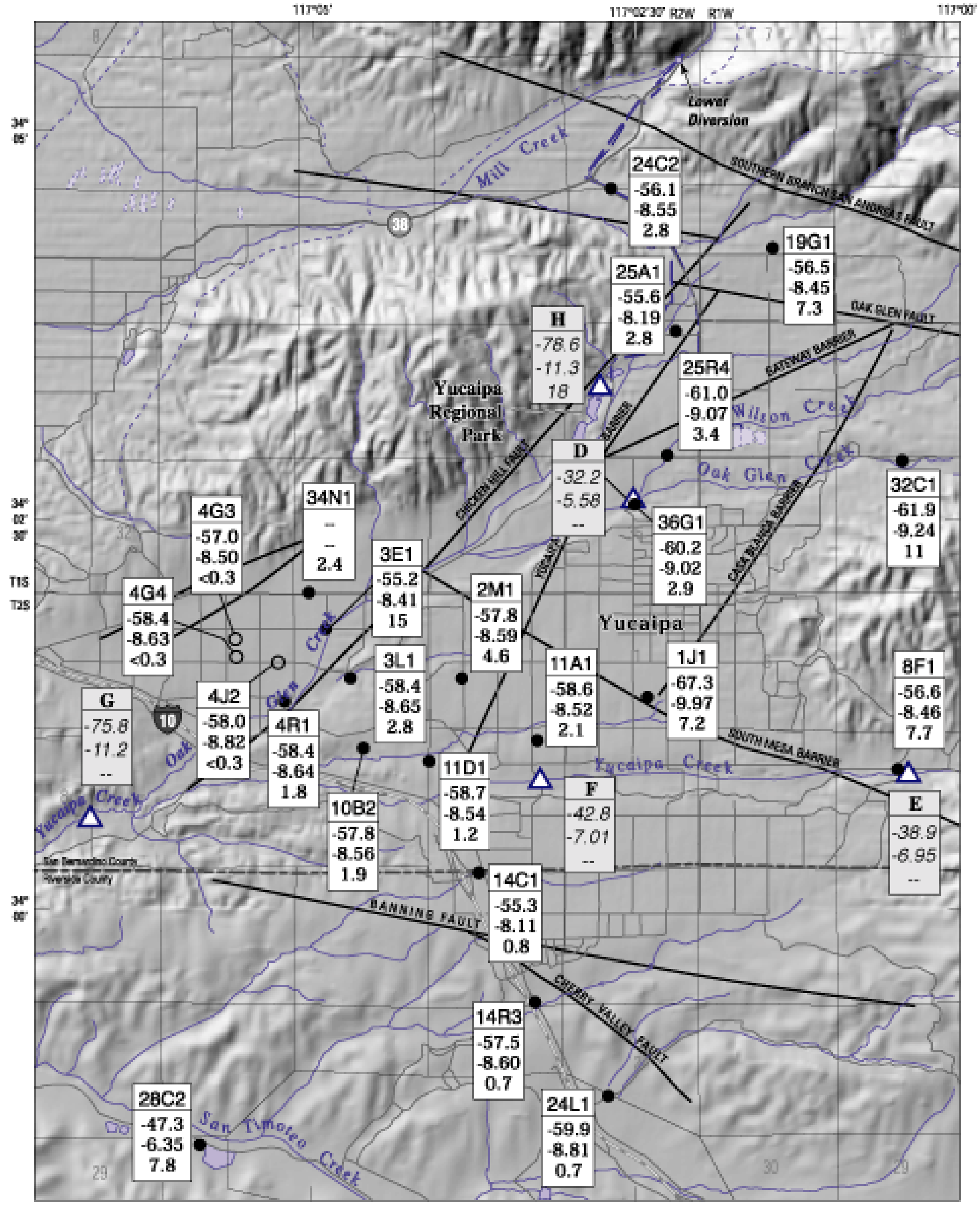


Figure 15. Delta deuterium (δD), delta oxygen-18 ($\delta^{18}O$), and tritium activity in selected wells and surface-water sites in the Yucaipa area, southern California.

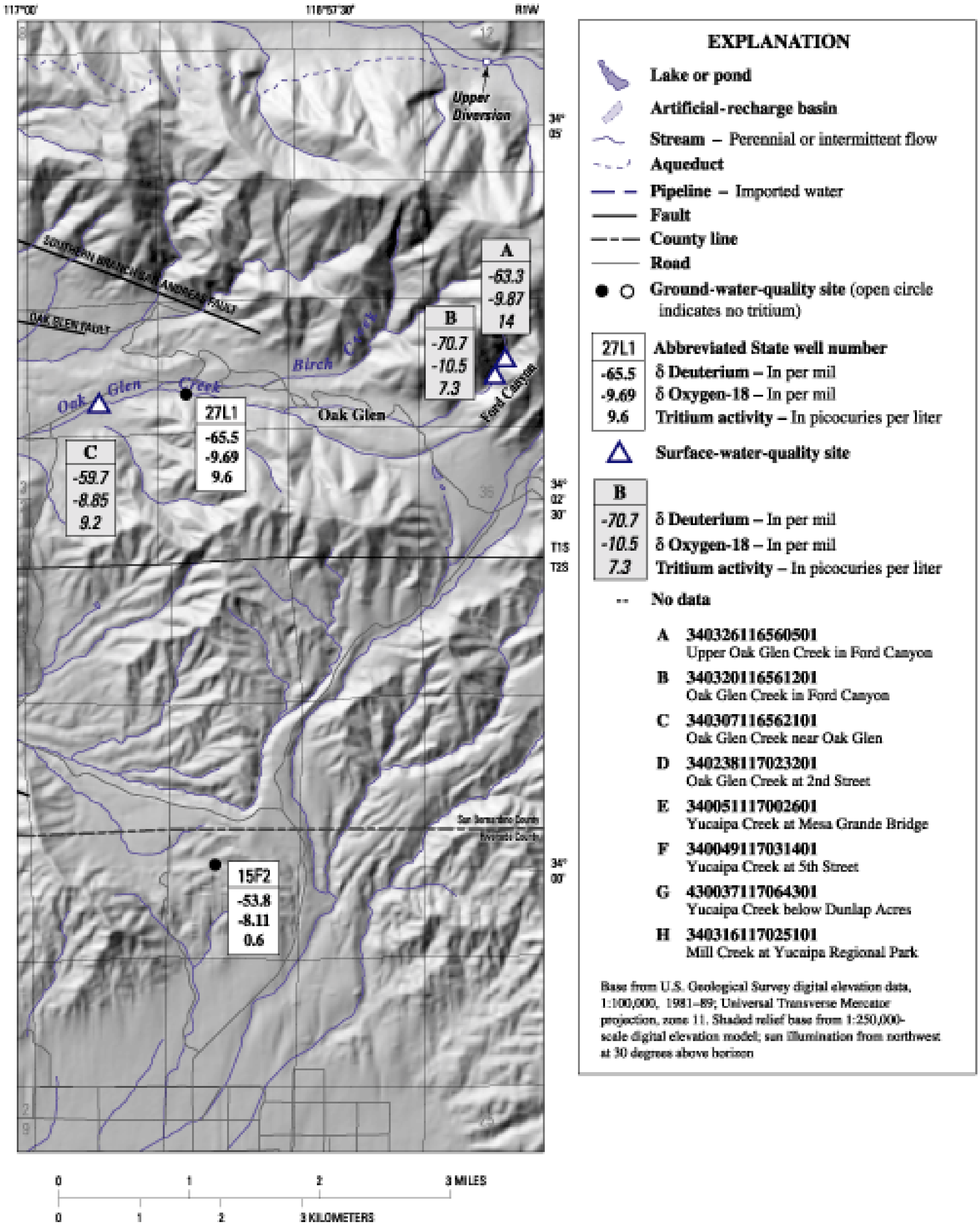


Figure 15—Continued.

SUMMARY AND CONCLUSIONS

Most water sampled in the Yucaipa area is a calcium-bicarbonate type. The general chemical composition of surface water resembles that of ground water, although the concentrations of most constituents are higher in ground water. The ionic strength of most ground-water samples was similar. Elevated concentrations of nitrate were found in some ground-water samples from wells and may indicate recharge of water from agricultural areas. Water samples from nearby wells suggest that the elevated nitrate concentrations are diluted by ground water that originates as recharge from Oak Glen Creek.

Ground water was found to have a range of tritium activity, indicating different times since recharge and possible mixing along ground-water flow paths. The oldest water had tritium values less than 0.3 pCi/L, indicating more than 50 years since recharge. Tritium values greater than 0.3 pCi/L indicate that at least part of the pumped water was recharged since 1952. Ground water near the hills and mountains—in particular, ground water that is north of the Oak Glen Fault, or east of the Casa Blanca Barrier and north of the South Mesa Barrier—had tritium values similar to those of surface-water samples and indicates that it is likely to be the most recently recharged ground water.

Flowmeter data from well 1S/2W-25R4 showed that more than one-half of the water flowed into the well between depths of 450 and 600 ft below land surface. At a flow rate of 750 gal/min, virtually no water was contributed to the well below a depth of about 820 ft. Water recharged since 1952 was found in the uppermost part of the well. Water flowing into the well from depths below 590 ft probably was recharged more than 50 years and less than about 400 years before present. Tritium and flowmeter data from well 1S/2W-25R4 suggest that the well could extract additional water if perforations were present between the water table at a depth of about 300 ft below land surface and the top of existing perforations at a depth of 450 ft.

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Table 2. Chemical and isotopic analyses of water from selected surface-water sites in the Yucaipa area, southern California

[USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; µS/cm, microsiemen per centimeter at 25 °C; mg/L, milligram per liter; °C, degree Celsius; B, base flow; µg/L, micrograms per liter; pCi/L, picocurie per liter; per mil, parts per thousand; <, less than; —, no data]

USGS station name	USGS station number	Date	Time	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH, field (standard units)
Upper Oak Glen Creek in Ford Canyon	340326116560501	4/30/98	1715	0.31B	216	7.8
Oak Glen Creek in Ford Canyon	340326116560601	7/31/97	0940	.60B	351	8.4
Oak Glen Creek near Oak Glen	340307116592101	2/3/98	1645	2.2	260	8.3
		1/13/98	0750	.79B	395	8.5
		1/3/97	1040	1.4	361	8.5
Oak Glen Creek at 2nd St.	340238117023201	2/23/98	1545	6.9	190	8.5
		2/23/98	1330	2.3	384	8.6
		2/3/98	1615	4.3	117	7.9
Yucaipa Creek at Mesa Grande Bridge	340051117002601	2/23/98	2115	100	74	7.5
		2/19/98	2245	15	63	7.6
Yucaipa Creek at 5th St.	340049117031401	2/23/98	2200	110	75	7.8
		2/20/98	0010	26	55	7.9
		2/3/98	1530	2.4	78	7.7
Yucaipa Creek below Dunlap Acres	340037117064301	2/3/98	1430	190	172	8.3
Mill Creek at Yucaipa Regional Park	340316117025101	7/10/96	1330	1.0B	240	8.1

	Oxygen, dissolved (mg/L)	Temp-erature, air (°C)	Temp-erature, water (°C)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)
Upper Oak Glen Creek in Ford Canyon	—	15.5	7.5	24	9.4	4.4
Oak Glen Creek in Ford Canyon	8.5	17.0	12.5	40	15	7.6
Oak Glen Creek near Oak Glen	—	5.5	6.5	30	9.6	8.1
	10.8	6.0	7.5	45	16	15
	—	13.0	12.0	43	14	12
Oak Glen Creek at 2nd St.	—	11.0	11.0	23	7.6	6.7
	9.4	13.0	12.5	—	—	—
	—	6.0	7.0	13	3.8	3.8
Yucaipa Creek at Mesa Grande Bridge	—	10.0	9.0	8.3	2.1	2.4
	—	9.0	7.0	6.9	1.8	2.2
Yucaipa Creek at 5th St.	—	11.0	7.0	8.9	2.3	3.1
	—	7.0	6.5	5.8	1.5	2.2
	—	10.0	8.5	9.1	2.2	2.8
Yucaipa Creek below Dunlap Acres	10.6	12.0	11.0	20	4.3	5.2
Mill Creek at Yucaipa Regional Park	8.2	32.5	15.5	28	5.7	4.7

Table 2. Chemical and isotopic analyses of water from selected surface-water sites in the Yucaipa area, southern California—Continued

USGS station name	Potassium dissolved (mg/L)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)
Upper Oak Glen Creek in Ford Canyon	2	98	6.7	1.6	0.7	<0.01
Oak Glen Creek in Ford Canyon	3	160	17	2.2	.8	<.01
Oak Glen Creek near Oak Glen	2	99	22	4.3	.8	<.01
	2	150	32	7.7	.5	.02
	2	130	37	6.2	.5	—
Oak Glen Creek at 2nd St.	2	—	17	3.3	.3	<.01
	—	—	—	—	—	—
	2	45	7.8	2.5	.2	<.01
Yucaipa Creek at Mesa Grande Bridge	.9	27	2.2	1.7	.1	<.01
	.9	24	1.9	1.6	.1	<.01
Yucaipa Creek at 5th St.	.9	34	2.5	1.7	.1	<.01
	.7	22	1.4	1.3	.1	<.01
	1	28	3.2	1.4	.2	<.01
Yucaipa Creek below Dunlap Acres	1	43	22	2.5	.3	<.01
Mill Creek at Yucaipa Regional Park	2	84	13	1.2	.8	<.01

USGS station name	Iodide, dissolved (mg/L)	Silica, dissolved (mg/L)	Residue at 180°C (mg/L)	Nitrite, dissolved (mg/L as N)	$NO_2 + NO_3$, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)
Upper Oak Glen Creek in Ford Canyon	<0.001	7.0	120	0.01	0.19	0.05
Oak Glen Creek in Ford Canyon	<.001	10	200	<.01	.21	<.01
Oak Glen Creek near Oak Glen	.001	11	162	<.01	.92	<.02
	.001	21	249	<.01	2.3	.03
	.001	17	227	.03	1.5	.08
Oak Glen Creek at 2nd St.	.002	8.5	124	<.01	1.5	.07
	—	—	—	—	—	
	.001	4.3	74	<.01	.41	.04
Yucaipa Creek at Mesa Grande Bridge	.001	4.4	51	<.01	.67	.06
	.001	3.3	41	<.01	.53	<.02
Yucaipa Creek at 5th St.	.001	5.2	55	<.01	.97	<.02
	.001	3.2	40	<.01	.57	.04
	.002	3.2	57	.01	1.6	.09
Yucaipa Creek below Dunlap Acres	.002	3.3	108	.03	1.8	.09
Mill Creek at Yucaipa Regional Park	<.001	12	137	<.01	.18	.02

Table 2. Chemical and isotopic analyses of water from selected surface-water sites in the Yucaipa area, southern California—Continued

USGS station name	Ammonia + organic, (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Boron, dissolved (µg/L)	Iron, dissolved (µg/L)
Upper Oak Glen Creek in Ford Canyon	<0.10	<0.01	0.02	<1	5.3	<16	<10
Oak Glen Creek in Ford Canyon	<.20	<.01	<.01	<1	20	7	<3
Oak Glen Creek near Oak Glen	.20	.03	.05	<1	12	22	21
	.13	.04	.03	<1	18	<16	<10
	<.20	.02	.02	<1	19	20	14
Oak Glen Creek at 2nd St.	.30	.04	.05	<1	7.0	22	<10
	—	—	—	—	—	—	—
	.37	.05	.05	<1	7.0	19	100
Yucaipa Creek at Mesa Grande Bridge	.46	.21	.19	<1	7.0	20	34
	.46	.20	.20	<1	6.0	<16	48
Yucaipa Creek at 5th St.	.43	.21	.20	<1	5.7	18	25
	.35	.22	.22	<1	4.3	19	110
	.61	.23	.27	<1	6.0	23	52
Yucaipa Creek below Dunlap Acres	.67	.19	.20	<1	8.0	24	29
Mill Creek at Yucaipa Regional Park	<.20	<.01	.01	<1	10	9	<3

USGS station name	Lithium, dissolved (µg/L)	Manganese, dissolved (µg/L)	Strontium, dissolved (µg/L)	H-2/H-1 isotope ratio (per mil)	O-18/O-16 isotope ratio (per mil)	Tritium, total (pCi/L)
Upper Oak Glen Creek in Ford Canyon	<4	9	80	–63.3	–9.87	14
Oak Glen Creek in Ford Canyon	<4	<1	190	–70.7	–10.48	7.3
Oak Glen Creek near Oak Glen	<4	15	120	–92.4	–12.73	—
	<4	9	180	–63.5	–9.59	—
	<4	3	190	–59.7	–8.85	9.2
Oak Glen Creek at 2nd St.	<4	8	110	–32.8	–5.58	—
	—	—	—	—	—	—
	<4	5	60	–99.9	–13.61	—
Yucaipa Creek at Mesa Grande Bridge	<4	4	50	–38.9	–6.95	—
	<4	6	50	–77.9	–11.74	—
Yucaipa Creek at 5th St.	<4	<4	50	–42.8	–7.01	—
	<4	8	40	–76.6	–11.60	—
	<4	6	60	–99.0	–13.14	—
Yucaipa Creek below Dunlap Acres	<4	4	100	–75.8	–11.23	—
Mill Creek at Yucaipa Regional Park	5	1	70	–78.6	–11.30	18

Table 3. Chemical and isotopic analyses of water from selected wells in the Yucaipa area, southern California

[State well number, see “Well-Numbering System” in text; USGS, U.S. Geological Survey; gal/min, gallons per minute; ft blw LSD, feet below land-surface datum; µS/cm, microsiemen per centimeter at 25 °C; mg/L, milligram per liter; µg/L, microgram per liter; pCi/L, picocurie per liter; per mil, parts per thousand; °C, degree Celsius; B, bulk sample; <, less than; —, no data]

State well number	USGS station number	Date	Time	Flow rate (gal/min)	Depth to sample (ft blw LSD)	Specific conductance (µS/cm)	pH, field (standard units)	Oxygen, dissolved (mg/L)	Temperature, air °C	Temperature, water °C
1S/1W-19G01	340415117012701	7/29/97	1330	180	—	745	7.3	6.9	25.0	18.5
1S/1W-27L01	340312116583901	7/29/97	0930	240	—	568	7.1	4.1	19.5	14.0
1S/1W-32C01	340253117002701	7/29/97	1145	90	—	476	7.2	6.0	23.0	16.5
1S/2W-24C02	340438117024201	7/31/97	1230	—	—	650	7.4	6.5	32.5	20.0
1S/2W-25A01	340343117021201	7/17/97	1330	260	—	584	7.6	8.0	—	21.5
1S/2W-25R04(B)	340255117021601	2/25/98	1600	750	—	477	7.6	—	11.0	19.0
-25R04	340255117021601	2/25/98	1730	750	480	458	7.4	8.2	10.5	11.0
-25R04	340255117021601	2/25/98	1930	750	590	491	7.4	7.5	6.0	13.5
-25R04	340255117021601	2/25/98	2100	750	770	510	7.5	7.4	3.5	12.0
-25R04	340255117021601	2/25/98	2330	750	820	513	7.5	6.0	2.5	12.0
-25R04	340255117021601	2/26/98	0030	750	900	486	7.4	6.0	2.5	12.5
-25R04(B)	340255117021601	5/1/98	1000	1450	—	463	7.6	8.2	13.5	19.5
1S/2W-34N01	340202117050201	7/10/96	1430	600	—	831	7.6	5.6	32.0	20.5
1S/2W-36G01	340236117023101	7/18/97	0950	1,700	—	466	7.6	6.9	—	20.0
2S/1W-08F01	340054117002901	7/16/97	1210	250	—	601	7.2	5.8	—	18.0
2S/1W-15F02	340003116582501	7/16/97	1430	140	—	445	7.8	.4	—	20.0
2S/2W-01J01[1]	340124117021301	6/2/98	1945	2.5	—	1,100	7.8	.0	24.5	22.5
2S/2W-02M01	340129117035101	7/15/97	1200	550	—	569	7.7	8.5	—	20.5
-02M01	340129117035101	7/10/98	1210	550	—	553	7.7	—	29.5	20.0
2S/2W-03E01	340148117045401	7/9/96	1330	1,200	—	734	7.5	6.0	30.0	20.0
2S/2W-03L01	340129117044201	7/11/96	1120	450	—	498	7.7	9.2	30.0	19.5
2S/2W-04G03	340144117053601	7/10/96	1020	1,000	—	477	7.6	4.8	29.0	19.0
2S/2W-04G04	340137117053501	4/30/98	1430	1,550	—	417	7.6	3.4	29.0	21.5
2S/2W-04J02	340135117051601	7/10/96	0900	2,000	—	455	7.7	5.2	30.0	19.0
2S/2W-04R01	340120117051301	7/9/96	1430	300	—	717	7.4	1.6	34.5	19.5
2S/2W-10B02	340106117045001	7/11/96	0930	750	—	510	7.8	7.0	28.5	21.0
2S/2W-11A01	340105117031601	7/15/97	1450	725	—	496	7.8	6.6	—	21.5
2S/2W-11D01	340057117040601	7/15/97	1000	700	—	462	7.8	8.8	—	21.0
2S/2W-14C01	340014117034301	7/17/97	1000	250	—	522	7.6	8.8	—	21.5
2S/2W-14R03	335924117031701	7/17/97	0915	775	—	297	9.3	1.9	—	24.5
2S/2W-24L01	335848117024301	7/16/97	0925	2,100	—	346	7.9	5.4	—	23.0
2S/2W-28C02[1]	335829117055201	7/28/97	1620	—	—	942	7.6	.0	29.5	24.0

See footnote at end of table.

Table 3. Chemical and isotopic analyses of water from selected wells in the Yucaipa area, southern California—Continued

State well number	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Iodide, dissolved (mg/L)
1S/1W-19G01	78	18	42	1	190	86	34	0.8	0.10	0.001
1S/1W-27L01	67	22	14	2	220	69	9.7	.7	.04	.001
1S/1W-32C01	53	16	16	2	170	39	11	.5	.05	.001
1S/2W-24C02	69	15	42	1	220	57	18	.8	.07	.001
1S/2W-25A01	57	11	45	1	200	31	30	.8	.17	.001
1S/2W-25R04(B)	59	12	25	2	190	28	6.9	.6	.04	<.001
-25R04	55	12	23	2	200	27	6.4	.6	.04	<.001
-25R04	61	13	25	2	180	29	7.3	.6	.04	<.001
-25R04	63	13	28	2	190	29	7.9	.6	.04	<.001
-25R04	63	13	23	2	140	29	8.0	.6	.04	<.001
-25R04	61	14	21	2	170	27	7.0	.6	.04	.001
-25R04(B)	61	12	24	2	—	24	6.3	.6	.04	.001
1S/2W-34N01	95	23	40	2	210	60	32	.5	.13	.002
1S/2W-36G01	53	12	24	2	190	32	7.3	.5	.05	.001
2S/1W-08F01	62	19	33	.6	230	29	28	.6	.13	.002
2S/1W-15F02	34	20	25	5	190	16	18	.4	.09	.015
2S/2W-01J01[1]	34	1.0	200	1	170	260	36	6.0	.12	.019
2S/2W-02M01	68	12	28	2	200	31	19	.7	.09	.001
-02M01	70	13	25	3	190	29	17	.5	.07	.001
2S/2W-03E01	98	22	21	2	220	68	17	.5	.14	.001
2S/2W-03L01	63	13	21	2	160	30	17	.5	.07	.001
2S/2W-04G03	58	12	22	2	180	31	12	.6	.06	.001
2S/2W-04G04	50	8.5	27	2	160	27	7.9	.6	.04	.002
2S/2W-04J02	61	12	17	2	170	29	7.8	.5	.04	.001
2S/2W-04R01	94	22	23	2	240	74	15	.5	.09	.001
2S/2W-10B02	55	8.7	41	3	160	—	—	—	—	—
2S/2W-11A01	46	8.0	44	2	160	39	18	.9	.08	.002
2S/2W-11D01	46	6.8	39	2	160	36	16	.6	.08	.001
2S/2W-14C01	51	14	33	1	200	13	26	.9	.13	.001
2S/2W-14R03	5.8	.9	58	.6	100	15	14	.5	.07	.003
2S/2W-24L01	28	3.5	39	2	140	14	11	.5	.07	.001
2S/2W-28C02[1]	59	17	120	1	380	32	65	1.0	.38	.063

See footnote at end of table.

Table 3. Chemical and isotopic analyses of water from selected wells in the Yucaipa area, southern California—Continued

State well number	Silica, dissolved (mg/L)	Residue at 180°C (mg/L)	Nitrite, dissolved (mg/L as N)	$NO_2 + NO_3$, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Ammonia + organic, (mg/L as N	Phosphorus, dissolved (mg/L as P)	Phosphorus ortho, dissolved (mg/L as P)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Boron, dissolved (µg/L)
1S/1W-19G01	23	485	0.09	13	0.14	0.2	<0.01	0.02	<1	45	70
1S/1W-27L01	20	358	<.01	2.0	.03	<.2	<.01	<.01	<1	12	20
1S/1W-32C01	21	298	.02	5.3	.02	<.2	<.01	.01	<1	16	20
1S/2W-24C02	25	412	<.01	5.6	<.02	<.2	<.01	.02	<1	27	70
1S/2W-25A01	25	359	<.01	4.7	<.02	<.2	.01	.02	<1	19	60
1S/2W-25R04(B)	28	295	<.01	2.0	.03	<.1	<.01	.02	3	17	30
-25R04	28	283	<.01	1.9	.03	<.1	<.01	.02	3	16	40
-25R04	28	305	<.01	2.2	.03	<.1	<.01	.02	3	17	40
-25R04	28	317	<.01	1.9	.02	<.1	<.01	.02	2	18	40
-25R04	28	315	<.01	1.4	.03	<.1	<.01	.02	3	18	50
-25R04	28	303	<.01	1.0	.03	<.1	<.01	.02	3	19	40
-25R04(B)	26	290	.01	2.0	.06	<.1	<.01	<.01	3	16	30
1S/2W-34N01	25	512	<.01	24	.02	<.2	.01	.03	<1	58	30
1S/2W-36G01	26	293	<.01	2.1	<.02	<.2	<.01	.01	<1	15	20
2S/1W-08F01	24	369	<.01	4.2	<.02	<.2	.03	.03	<1	28	20
2S/1W-15F02	17	258	<.01	.06	<.02	<.2	<.01	<.01	<1	24	20
2S/2W-01J01[1]	16	712	.05	5.3	.08	<.1	<.01	.02	<1	8	330
2S/2W-02M01	23	363	<.01	7.9	<.02	<.2	<.01	.01	<1	21	20
-02M01	25	354	<.01	7.8	.03	<.1	<.01	.02	<1	21	20
2S/2W-03E01	24	487	<.01	16	.03	<.2	<.01	.02	<1	27	20
2S/2W-03L01	26	314	<.01	6.7	.03	.2	<.01	.02	<1	15	20
2S/2W-04G03	24	287	<.01	1.6	.03	<.2	.03	.02	<1	23	20
2S/2W-04G04	23	260	.01	1.3	.05	<.1	<.01	.02	<1	17	30
2S/2W-04J02	25	281	<.01	2.6	.03	<.2	<.01	.02	<1	18	20
2S/2W-04R01	25	472	.01	9.6	.03	<.2	.02	.03	<1	29	20
2S/2W-10B02	—	—	<.01	4.9	.02	<.2	<.01	.01	<1	26	—
2S/2W-11A01	24	318	<.01	5.8	<.02	<.2	.02	.02	<1	24	30
2S/2W-11D01	22	294	<.01	3.9	<.02	<.2	.03	.02	<1	19	20
2S/2W-14C01	26	318	<.01	4.2	<.02	<.2	.03	.03	<1	32	20
2S/2W-14R03	15	186	<.01	1.9	<.02	<.2	<.01	.02	5	5	20
2S/2W-24L01	17	213	<.01	2.0	<.02	<.2	<.01	.01	<1	22	20
2S/2W-28C02[1]	22	563	.02	<.05	.44	.3	.01	.13	<1	130	50

See footnote at end of table.

Table 3. Chemical and isotopic analyses of water from selected wells in the Yucaipa area, southern California—Continued

State well number	Iron, dissolved (µg/L)	Lithium, dissolved (µg/L)	Manganese, dissolved (µg/L)	Strontium, dissolved (µg/L)	H-2/H-1 isotope ratio (per mil)	O-18/O-16 isotope ratio (per mil)	Tritium, total (pCi/L)	C-13/C-12 isotope ratio (per mil)	C-14 dissolved, (percent modern carbon)
1S/1W-19G01	140	5	67	490	–56.5	–8.45	7.3	—	—
1S/1W-27L01	<3	4	<1	270	–65.5	–9.69	9.6	—	—
1S/1W-32C01	31	<4	6	250	–61.9	–9.24	11	—	—
1S/2W-24C02	<3	4	<1	350	–56.1	–8.55	2.8	—	—
1S/2W-25A01	9	<4	<1	340	–55.6	–8.19	2.8	—	—
1S/2W-25R04(B)	<10	<4	<4	250	–60.1	–8.99	2.1	–12.9	86.9
-25R04	<10	<4	<4	230	–63.2	–9.23	3.9	—	—
-25R04	70	<4	<4	260	–58.1	–8.85	<.3	–13.4	86.1
-25R04	<10	<4	<4	270	–58.8	–8.76	.4	–13.8	85.4
-25R04	34	<4	<4	270	–58.8	–8.68	.8	–13.2	87.3
-25R04	<10	<4	<4	260	–58.4	–8.86	1.4	—	—
-25R04(B)	19	<4	<4	251	–61.0	–9.07	3.4	—	—
1S/2W-34N01	12	<4	2	470	—	—	2.4	—	—
1S/2W-36G01	<3	<4	<1	230	–60.2	–9.02	2.9	—	—
2S/1W-08F01	<3	<4	<1	270	–56.6	–8.46	7.7	—	—
2S/1W-15F02	39	<4	5	170	–53.8	–8.11	.6	—	—
2S/2W-01J01[1]	2,300	<4	23	362	–67.3	–9.97	7.2	—	—
2S/2W-02M01	4	<4	<1	290	—	—	4.6	—	—
-02M01	17	<4	<4	296	–57.8	–8.59	—	—	—
2S/2W-03E01	8	<4	<1	390	–55.2	–8.41	15	—	—
2S/2W-03L01	<3	<4	<1	270	–58.4	–8.65	2.8	—	—
2S/2W-04G03	4	<4	<1	260	–57.0	–8.50	<.3	—	—
2S/2W-04G04	<10	<4	<4	254	–58.4	–8.63	<.3	—	—
2S/2W-04J02	<3	<4	<1	250	–58.0	–8.82	<.3	—	—
2S/2W-04R01	22	<4	<1	350	–58.4	–8.64	1.8	—	—
2S/2W-10B02	<3	<4	<1	270	–57.8	–8.56	1.9	—	—
2S/2W-11A01	<3	<4	<1	260	–58.6	–8.52	2.1	—	—
2S/2W-11D01	6	<4	<1	260	–58.7	–8.54	1.2	—	—
2S/2W-14C01	<3	<4	<1	230	–55.3	–8.11	.8	—	—
2S/2W-14R03	<3	<4	<1	50	–57.5	–8.60	.7	—	—
2S/2W-24L01	3	<4	<1	330	–59.9	–8.81	.7	—	—
2S/2W-28C02[1]	95	4	410	520	–47.3	–6.35	7.8	—	—

[1]Not a production well.