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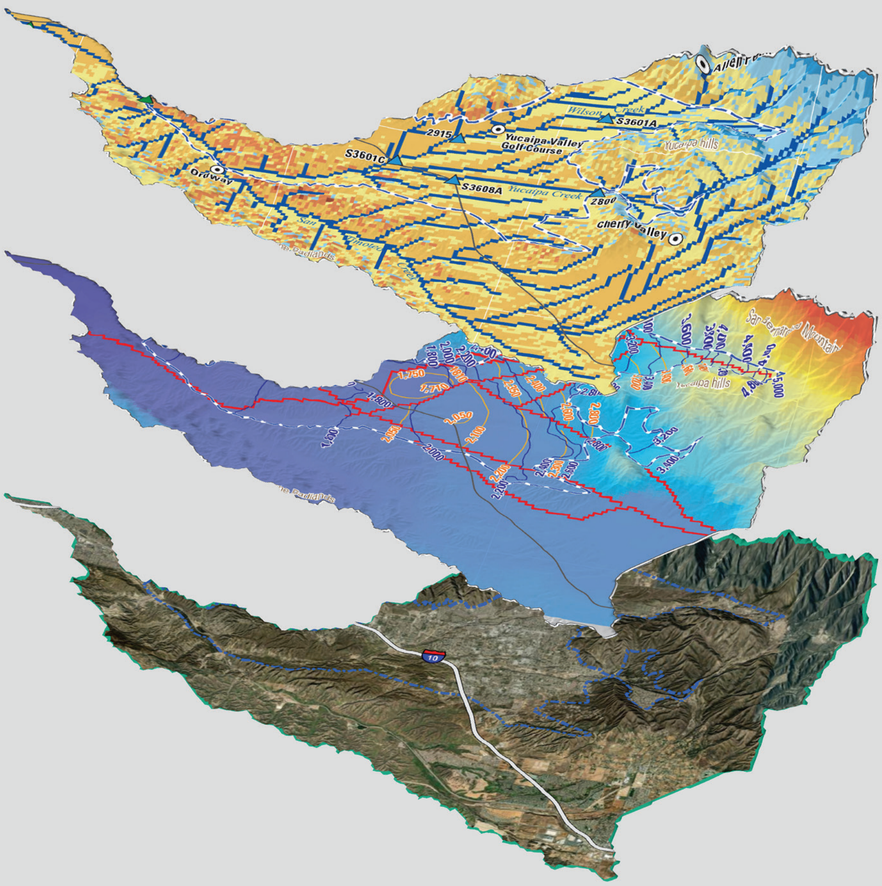
Hydrogeologic Characterization of the Yucaipa Groundwater Subbasin

Chapter A in

Hydrology of the Yucaipa Groundwater Subbasin: Characterization and Integrated Numerical Model, San Bernardino and Riverside Counties, California



Scientific Investigations Report 2021–5118–A

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

Cover: Visualization of the simulated domain and hydrologic components from the Yucaipa Integrated Hydrologic Model.

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By Geoffrey Cromwell, John A. Engott, Ayman H. Alzraiee, Christina L. Stamos, Gregory O. Mendez, Meghan C. Dick, and Sandra Bond

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U.S. Geological Survey, Reston, Virginia: 2022

Suggested citation:
Cromwell, G., Engott, J.A., Alzraiee, A.H., Stamos, C.L., Mendez, G.O., Dick, M.C., and Bond, S., 2022, Hydrogeologic characterization of the Yucaipa groundwater subbasin, chap. A *in* Cromwell, G., and Alzraiee, A.H., eds., Hydrology of the Yucaipa groundwater subbasin—Characterization and integrated numerical model, San Bernardino and Riverside Counties, California: U.S. Geological Survey Scientific Investigations Report 2021–5118–A, 81 p., https://doi.org/10.3133/sir20215118A.

Associated data for this publication:
Cromwell, G., Matti, J.C., and Roberts, S.A., 2022, Data release of hydrogeologic data of the Yucaipa groundwater subbasin, San Bernardino and Riverside Counties, California; U.S. Geological Survey Sciencebase data release, https://doi.org/10.5066/P9F7OYQR.

ISSN 2328-0328 (online)

Contents

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
Acre	4,047	square meter (m^2)
Acre	0.4047	hectare (ha)
Acre	0.4047	square hectometer (hm^2)
Acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)

Multiply	By	To obtain
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square foot ([gal/d]/ft^2)	0.040746	cubic meter per day per square meter ([m^3/d)]/km^2)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Specific capacity	
gallon per minute per foot ([gal/min]/ft)	0.2070	liter per second per meter ([L/s]/m)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Volume	
liter (L)	33.81402	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).

Abbreviations

^{14}C	carbon-14
bls	below land surface
DWR	California Department of Water Resources
ET	evapotranspiration
GIRAS	Geographic Information Retrieval and Analysis System
HFM	hydrogeologic framework model
ka	thousand years ago
LANDFIRE	Landscape Fire and Resource Management Planning Tools
Ma	Mega-annum
MAR	Managed Aquifer Recharge
NLCD	National Land Cover Database
PET	potential evapotranspiration
pmc	percent modern carbon
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
SBCFCD	San Bernardino County Flood Control District
SBVMWD	San Bernardino Valley Municipal Water District
SMWC	South Mesa Water Company
TDS	Total dissolved solids
USGS	U.S. Geological Survey
WHWC	Western Heights Water Company
YIHM	Yucaipa Integrated Hydrologic Model
YVW	Yucaipa Valley watershed
YVWD	Yucaipa Valley Water District
$\delta^{18}O$	Delta oxygen-18
$\delta^{2}H$	Delta hydrogen-2

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Introduction

Water management in the Santa Ana River watershed in San Bernardino and Riverside Counties in southern California (fig. A1) is complex with various water purveyors navigating geographic, geologic, hydrologic, and political challenges to provide a reliable water supply to stakeholders. As the population has increased throughout southern California, so has the demand for water. The Yucaipa groundwater subbasin (hereafter referred to as "Yucaipa subbasin"), one of nine groundwater subbasins in what the California Department of Water Resources (DWR) refers to as the Upper Santa Ana Valley groundwater basin (California Department of Water Resources, 2016; fig. A1; the DWR naming convention is used within this report), is no exception; steady population growth since the 1940s and changes in water use have forced local water purveyors to regularly adapt their water infrastructure. Water demands within the Yucaipa subbasin have historically been supplied by groundwater, but water imported via the California State Water Project has augmented the total water supply through direct use and through anthropogenic recharge at the Wilson Creek and Oak Glen Creek spreading basins since 2002. Overall demand for groundwater continues to rise, and local water managers are concerned that despite the influx of imported water, groundwater levels may decline to a point where producing water will be uneconomical, severely limiting the ability of local agencies to meet water-supply demand.

To better understand the hydrogeology and water resources in the Yucaipa subbasin, the U.S. Geological Survey (USGS) initiated a study in cooperation with the San Bernardino Valley Municipal Water District (SBVMWD) to characterize and model the hydrologic system of the Yucaipa subbasin and the surrounding Yucaipa Valley watershed (YVW; fig. A2). To gain this comprehensive understanding, a three-dimensional (3D) hydrogeologic framework model (HFM; Cromwell and Matti, 2022) was constructed to quantify the structure and extent of hydrogeologic units in the YVW; the hydrologic system was conceptualized and quantified (described in chapter A); and the Yucaipa Integrated Hydrological Model (YIHM; described in chapter B) was developed to simulate the integrated surface-water and aquifer systems, including natural and anthropogenic recharge and discharge throughout the study area during 1947–2014.

Previous Investigations

The earliest hydrologic investigation of the Yucaipa subbasin and surrounding area was by Hall (1888) and included maps showing regional irrigation and surface-water courses. More comprehensive hydrogeologic studies by Lippincott (1902a, b) and Mendenhall (1905, 1908) focused primarily on groundwater in the San Bernardino area (fig. A1). Groundwater storage capacity and groundwater flow and hydrogeology for 35 groundwater basins in southern California, including the Yucaipa subbasin, were estimated by Eckis (1934). The geology and hydrology of the Yucaipa subbasin were further refined by Burnham and Dutcher (1960), who established much of the foundational scientific understanding used in subsequent studies. Other hydrogeologic investigations focused on groundwater inflow and outflow of the Yucaipa subbasin (Gleason, 1947; Dutcher and Burnham, 1959; Dutcher and Fenzel, 1972), groundwater storage and artificial recharge (Moreland, 1970; Bloyd, 1971; Geoscience Support Services, Inc., 2015), groundwater levels and sustainable yield (Fletcher, 1976; Mann, 1986; Fox, 1987; Todd, 1988; Geoscience Support Services, Inc., 2014a), and water quality (Mendez and others, 2001).

Numerical simulations of the Yucaipa subbasin and adjacent aquifer systems include a simplified regional well-response model by Durbin (1974), hydrologic models of parts of the Yucaipa subbasin (Powers and Hardt, 1974; Geoscience Support Services, Inc., 2015), the San Timoteo groundwater subbasin (Rewis and others, 2006), and the San Bernardino groundwater subbasin (Durbin and Morgan, 1978; Hardt and Hutchinson, 1980; Hardt and Freckleton, 1987; Hughes, 1992; Danskin and others, 2006). Regional water-management studies are conducted regularly by the DWR (California Department of Water Resources, 1970, 1979, 1986), and SBVMWD (Water Systems Consulting, Inc., 2016).

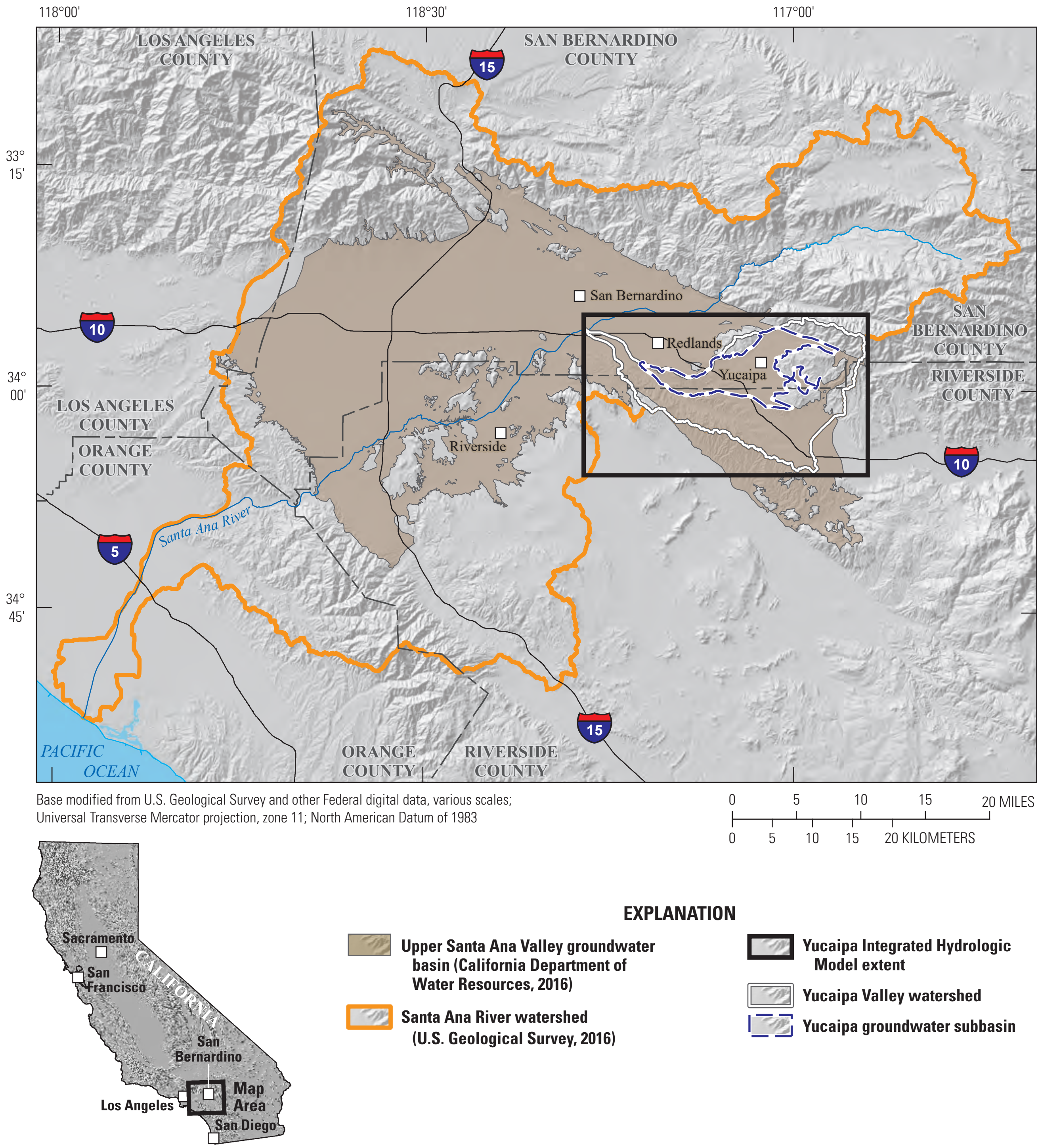


Figure A1. Location of the Yucaipa groundwater subbasin, Yucaipa Valley watershed, and Upper Santa Ana Valley groundwater basin, San Bernardino and Riverside Counties, California.

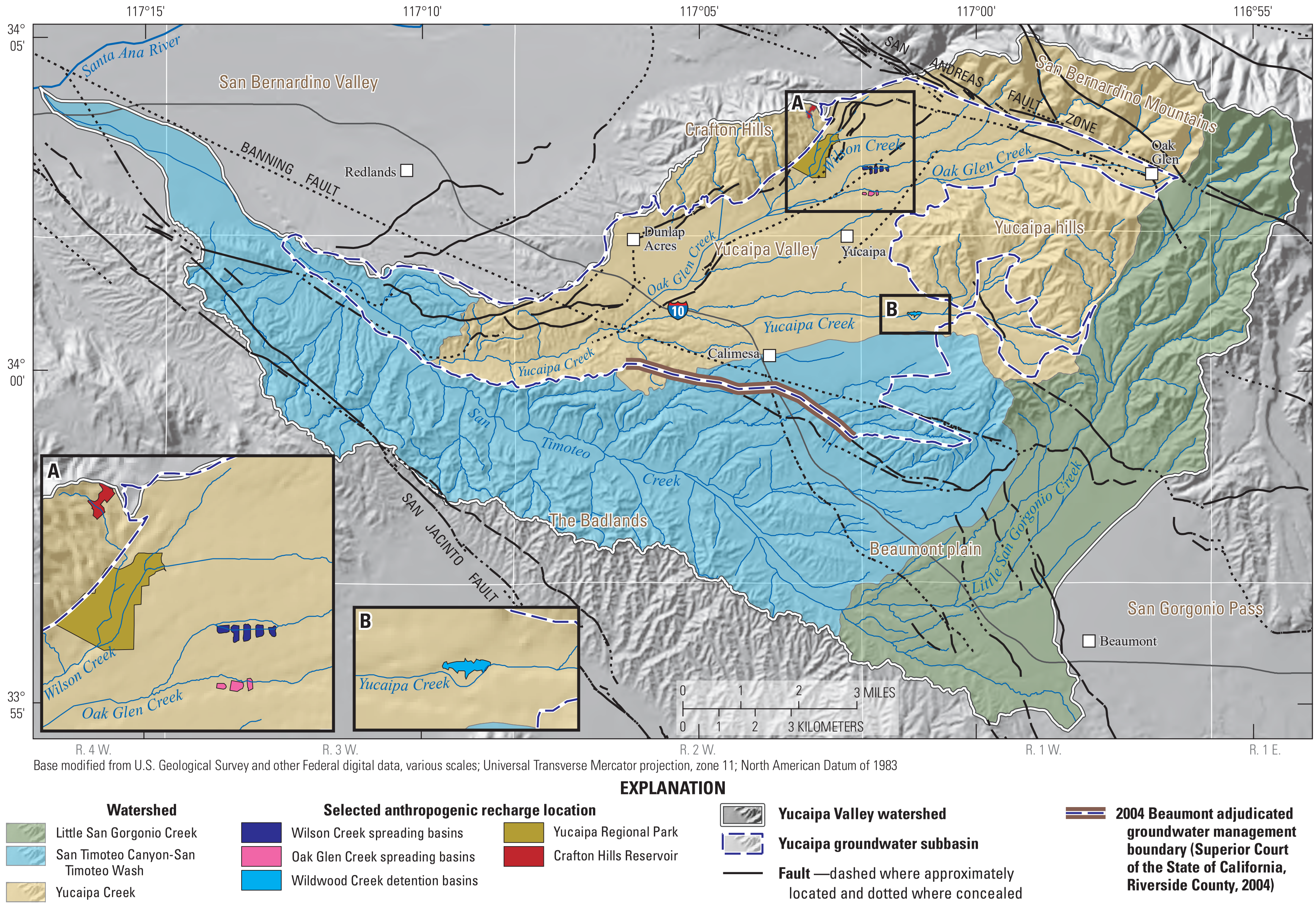


Figure A2. Watersheds of the Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Regional geologic and hydrogeologic mapping of the area was published originally by Eckis (1934) and then by Burnham and Dutcher (1960). A geologic mapping effort in the 1960s (with digital versions made available in the 2000s) provided baseline information for several later geologic maps throughout the greater Yucaipa subbasin area at various scales (Dibblee, 1964; Dibblee and Minch, 2003a, b, c, 2004). Revised geologic maps of the greater Yucaipa subbasin area have been published at various scales in the 2000s and 2010s (Morton and Matti, 2001; Matti and others, 2003a, b; Morton and Miller, 2006; Matti and others, 2015). A detailed map of surficial sediments and fault systems in the greater San Bernardino subbasin area was published by Matti and others (1985), which was then used to calculate the susceptibility of these sediments to earthquake-induced liquefaction (Matti and Carson, 1991). Geophysical investigations using gravity, aeromagnetic, and seismicity data established structural models of the Yucaipa subbasin (Mendez and others, 2016), the San Bernardino subbasin (Anderson and other, 2004), and the San Gorgonio Pass area south and east of the Yucaipa subbasin (Langenheim and others, 2005; fig. A1). Most recently, a hydrogeologic framework model (HFM) of the Yucaipa subbasin and the encompassing YVW was developed by Cromwell and Matti (2022); the HFM translates the physical subsurface hydrogeology into a numerical representation based on borehole data and other geologic and geophysical information.

Purpose and Scope

The purpose of chapter A is to document historical hydrogeologic conditions and develop a conceptual understanding of the hydrologic system. The purpose of chapter B is to describe the development of the YIHM, including model calibration and simulation results. Historical climatic, geologic, and hydrologic data were compiled for 1947–2014 to evaluate hydrogeologic conditions in the Yucaipa subbasin and to guide development of the YIHM. Groundwater levels measured in wells were used to determine groundwater-level elevations. Groundwater-quality data were used to evaluate variations in areal and temporal groundwater quality, and sources of groundwater. The YIHM is simulated using the coupled Groundwater and Surface-water FLOW model (GSFLOW; Markstrom and others, 2008) and assesses water availability in the YVW in response to climatic stresses, land-use changes, and water-use changes from 1947 to 2014.

Description of Study Area

The YVW is a semiarid inland valley that straddles southwestern San Bernardino County and northwestern Riverside County, about 12 miles (mi) southeast of the City of San Bernardino and about 75 mi east of Los Angeles, California (fig. A1). Located in the upper part of the Santa Ana River watershed, the YVW is bounded on the north by the San Bernardino Mountains, on the southeast by the San Gorgonio Pass, on the south by the The Badlands (located just south of San Timoteo Canyon), on the northwest by the San Bernardino Valley, and on the west by the Crafton Hills (fig. A2). The Yucaipa subbasin is located within the YVW and encompasses 39 square miles, including the City of Yucaipa (fig. A2). The subbasin boundaries are geologic, structural, administrative, and topographic (California Department of Water Resources, 2016). Geologic boundaries identified by the California Department of Water Resources (2016) include both faults and geologic contacts. For example, the western and northern boundaries of the subbasin largely are fault controlled (fig. A2), as are groundwater subareas within the subbasin (fig. A3). By contrast, the eastern subbasin boundaries coincide with geologic contacts that develop between sedimentary basin-fill and adjacent uplands underlain by crystalline basement rocks. For example, the subbasin boundaries between the Yucaipa Valley and the low hills just east of the City of Yucaipa (hereafter referred to as “Yucaipa hills”; fig. A2). The southeastern and southern boundaries of the Yucaipa subbasin are based on multiple criteria (California Department of Water Resources, 2016, citing boundary locations adjudicated by the Superior Court of the State of California, Riverside County, 2004; fig. A2). To the southeast, the subbasin boundary coincides with an outcrop trace of the Banning fault; to the south the boundary coincides partly with a concealed trace of the Banning fault (as inferred by Burnham and Dutcher, 1960, p. 100; and Bloyd, 1971) and partly with physiographic features of the San Timoteo drainage (fig. A2).

The Yucaipa subbasin is the area of hydrogeologic interest for this study; therefore, most of the discussion and evaluation of the hydrogeologic system in this report focuses on the Yucaipa subbasin. The YVW, which encompasses the Yucaipa subbasin and its three source watersheds (fig. A2), is used as the active domain for the YIHM, which enables the YIHM to calculate surface and subsurface recharge across the entire subbasin. Therefore, some climatic, geologic, and hydrologic aspects of the YVW are discussed and evaluated in this report. The three watersheds that comprise the YVW are (1) Yucaipa Creek, (2) San Timoteo Canyon–San Timoteo Wash, and (3) Little San Gorgonio Creek (Watershed Boundary Dataset 12-digit hydrologic unit codes [HUC 12]; U.S. Geological Survey, 2016). The Little San Gorgonio Creek watershed does not coincide directly with the Yucaipa subbasin but rather drains from north to south and feeds into the San Timoteo Canyon–San Timoteo Wash watershed (U.S. Geological Survey, 2016). The San Timoteo Canyon–San Timoteo Wash watershed (named by the U.S Geological Survey, 2016) refers to San Timoteo Creek (fig. A2), in this report “San Timoteo Wash” is used in reference to the watershed with the same name, and “San Timoteo Creek” is used in reference to the stream.

Groundwater Subareas of the Yucaipa Groundwater Subbasin

The Yucaipa subbasin historically has been divided into smaller groundwater subareas (hereafter referred to as “subareas”) based on the location of faults and other barriers to groundwater flow. The Yucaipa subbasin was split into smaller subareas on the basis of groundwater levels that were offset across then-mapped faults and other unnamed faults, which collectively were referred to as “barriers to groundwater flow” by Burnham and Dutcher (1960). The extents and positions of the subareas were further refined by Moreland (1970; fig. A3).

Studies since Moreland (1970) have, in some cases, revised the locations, geologic history, and names of faults and barriers, although the structural and hydrogeologic interpretations remain generally consistent. Faults and subareas of the Yucaipa subbasin are shown in figure A3. The mapped faults are from the Quaternary fault and fold database of the United States (U.S. Geological Survey and California Geological Survey, 2016), with the exception of the dotted where concealed Banning fault which is from the geologic maps of Matti and others (2003a, b, 2015). Subarea boundaries are from Moreland (1970; fig. A3*A*), Geoscience Support Services, Inc. (2014a; fig. A3*B*), and this study (fig. A3*C*). The structure with the most substantial revision since Moreland (1970) is the Banning fault, the southernmost groundwater-flow barrier defined by Moreland (1970; fig. A3). The Banning fault trace was initially mapped and interpreted as an active fault that formed the southern groundwater boundary of the Yucaipa subbasin by Burnham and Dutcher (1960) and was used by Moreland (1970) to define the southern extent of the Western Heights and Calimesa subareas. Later studies substantially revised the geologic history and location of the Banning fault (Matti and others, 1985; 1992a, b; 2003a, b, 2015; Morton and Miller, 2006); it was determined that the dotted where concealed part segment of the Banning fault that crosses the Yucaipa subbasin was of Miocene age, having ceased activity about 5 million years ago (Matti and others, 1992a; Cromwell and Matti, 2022). The revised mapped location of the dotted where concealed trace (fig. A3) is, in places, about 0.5 mi to the north of the location mapped by Burnham and Dutcher (1960). See Cromwell and Matti (2022) for a comprehensive discussion of the Banning fault in the Yucaipa subbasin.

All other faults and barriers used by Moreland (1970) to define subareas are, for the most part, structurally consistent with currently mapped fault locations, with the exception of the Gateway and South Mesa barriers. Neither barrier is associated with any currently mapped fault; however, the inferred existence and location of these barriers were determined by Moreland (1970) from groundwater-level offsets from wells on either side of their inferred locations.

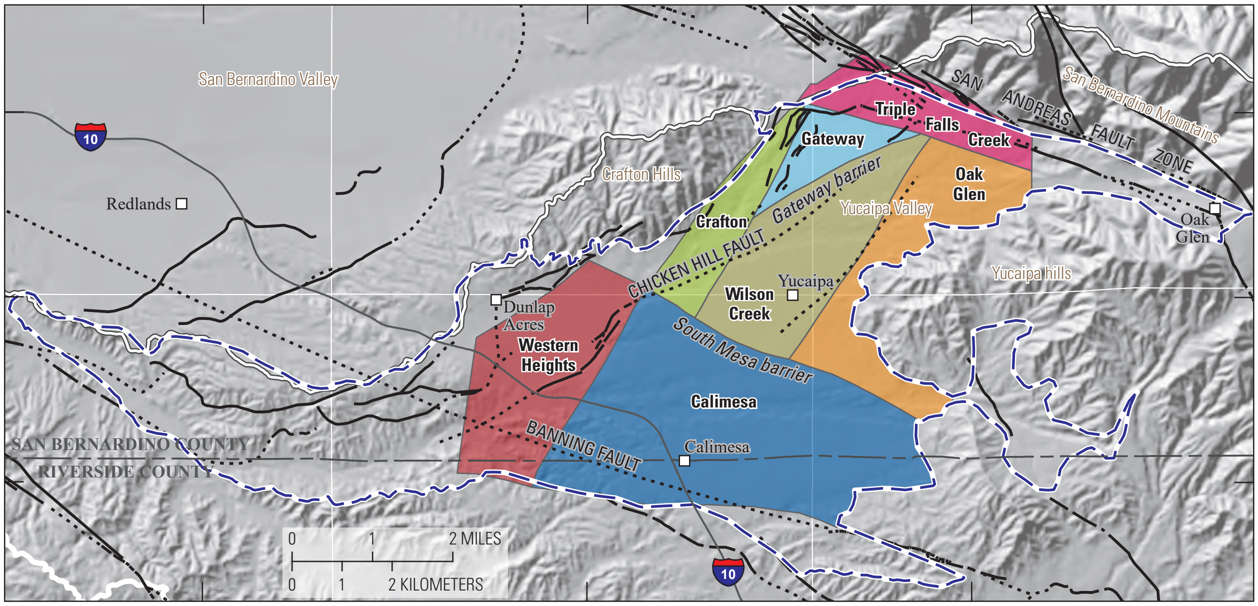
Recently, revised subarea boundaries were aligned with currently mapped faults (such as the Banning fault, see above) and a modified Gateway barrier location (which was adjusted south of that of Moreland, 1970; fig. A3*B*), by Geoscience Support Services, Inc. (2014a). For this current study, the subarea boundaries mapped by Moreland (1970) were retained, except where adjusted to align with currently mapped faults and to match the extent of the Yucaipa subbasin as defined by California Department of Water Resources (2016). As part of this effort, the number of subareas was expanded from 7 to 12. The five new subareas are, from east to west, Wildwood, Cherry Valley, Live Oak, Sand Canyon, and Smiley Heights. These new subareas were defined based on the boundaries of previously established subareas, the Yucaipa subbasin boundary, and current fault locations (fig. A3*C*).

Climate

Elevation of the YVW ranges from less than 1,000 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88) near the City of Redlands, to more than 8,000 ft above NAVD 88 in the San Bernardino Mountains (fig. A2). The Yucaipa Valley and the Beaumont plain are both at an elevation of about 2,500 ft above NAVD 88. Climate in the area is characterized by long, warm, dry summers and short, cool, wet winters. Temperatures in the Yucaipa Valley range from about 60 to 100 degrees Fahrenheit (°F) in the summer, and from about 40 to 70 °F in the winter (California Irrigation Management Information System, 2018). Precipitation mostly is in the form of rain, except in colder months when snow sometimes falls at higher elevations. The snowpack in the San Bernardino Mountains, if present, commonly lasts until April or May.

Climate data compiled for the YVW consists of daily values of precipitation and minimum and maximum temperature for the period of 1947–2014. Most daily precipitation and temperature data were retrieved from the National Centers for Environmental Information (NCEI; formerly the National Climatic Data Center; National Centers for Environmental Information, 2017) climate station 47306 Redlands and were supplemented with data from NCEI climate station 40609 Beaumont #2 and from Remote Automatic Weather station 50002 Beaumont of the Western Regional Climate Center (2017; fig. A4). Station 47306 Redlands had a nearly complete record from 1947 to 2014 (National Centers for Environmental Information, 2017); for the 24,837 days during 1947–2014, precipitation data were missing for only 388 days, and temperature data were missing for only 499 days.

A



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Universal Transverse Mercator projection, zone 11; North American Datum of 1983

Faults from Matti and others, 1992a, 2003a, 2003b, 2015; U.S. Geological Survey and California Geological Survey, 2016

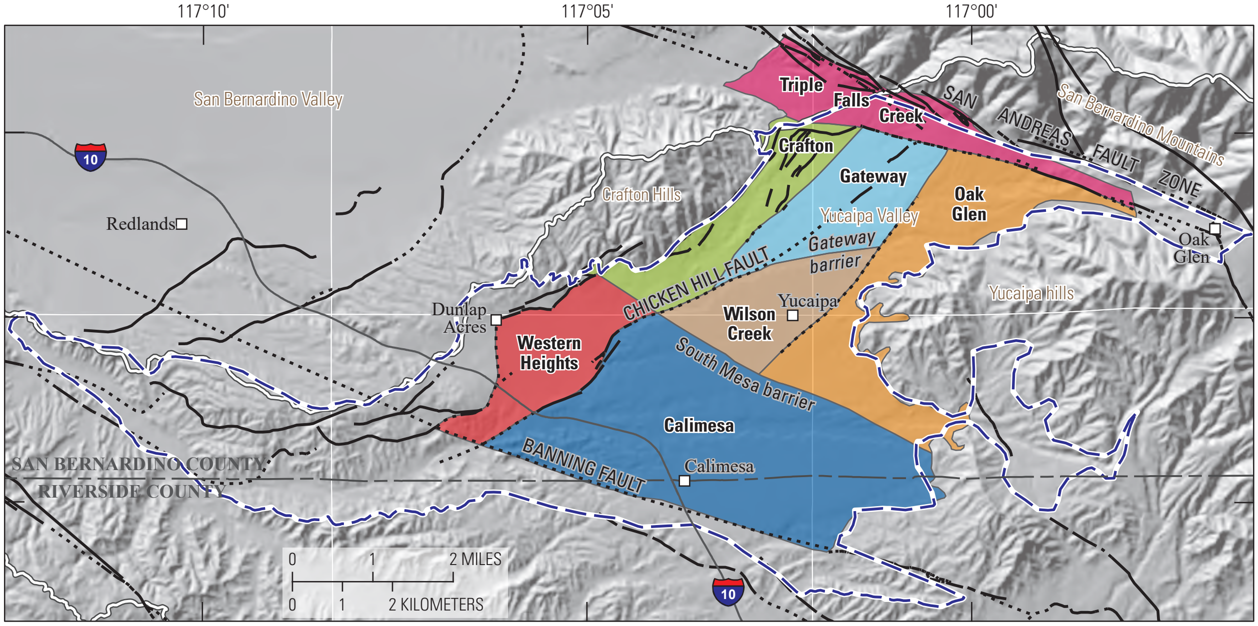
EXPLANATION

Yucaipa Valley watershed

Yucaipa groundwater subbasin

Fault—dashed where approximately located and dotted where concealed

B



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Universal Transverse Mercator projection, zone 11; North American Datum of 1983

Faults from Matti and others, 1992a, 2003a, 2003b, 2015; U.S. Geological Survey and California Geological Survey, 2016

EXPLANATION

Yucaipa Valley watershed

Yucaipa groundwater subbasin

Fault—dashed where approximately located and dotted where concealed

Figure A3. Groundwater subareas within the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. *A*, Moreland (1970); *B*, Geoscience Support Services, Inc., (2014a); *C*, this study.

C

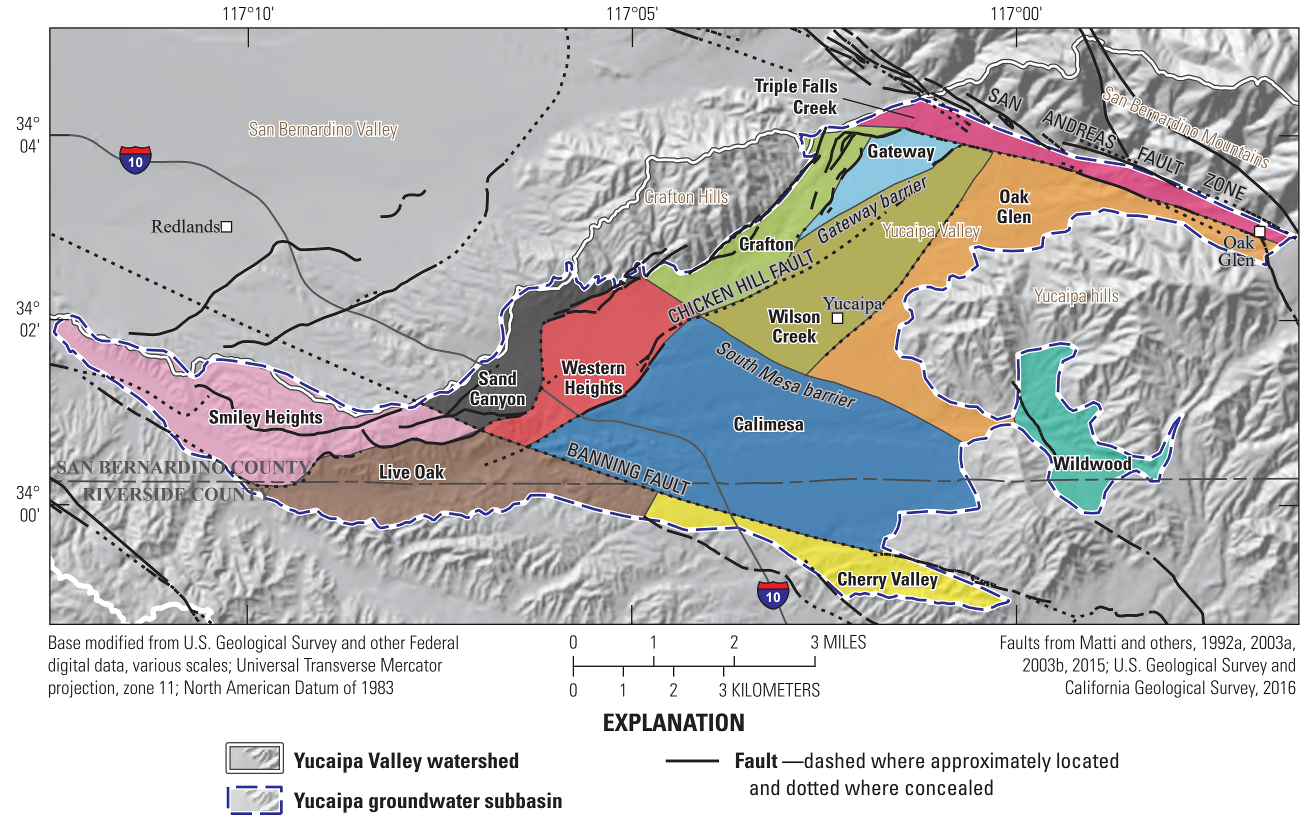


Figure A3.—Continued

Values for missing days were estimated using data from station 40609 Beaumont #2 and from station 50002 Beaumont when data were not available for 40609 Beaumont #2. Daily precipitation was estimated by calculating the ratio of mean monthly precipitation at station 47306 Redlands to stations 40609 Beaumont #2 and 50002 Beaumont and applying this ratio to precipitation for days when precipitation values at 47306 Redlands were missing. Similarly, gaps in temperature were estimated by calculating the difference in mean monthly minimum and maximum temperature between station 47306 Redlands, station 40609 Beaumont #2, or station 50002 Beaumont, if necessary, and applying this difference to temperatures for days in which temperature values at 47306 Redlands were missing.

Climate variability from 1947 to 2014 in the YVW was examined using the observed precipitation at 47306 Redlands with missing data estimated using the approach previously described (fig. A5). Average annual precipitation for the YVW during 1947–2014 was about 12.5 inches per year (in/yr; fig. A5). Cumulative departure from the mean and the 5-year moving average of precipitation were used to help define climate periods. Dry periods were 1947–51, 1959–64, 1971–77, 1984–90, 1999–2002, and 2011–16. Wet periods were 1978–83 and 1991–98. Periods of both wet and dry years were 1952–58, 1965–70, and 2003–10.

Estimated precipitation ranged from about 10 in/yr in the San Bernardino Valley to about 18 in/yr in the Yucaipa Valley and Beaumont plain to more than 30 in/yr in the San Bernardino Mountains above the Oak Glen subarea (fig. A4). Precipitation estimates were from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) precipitation and air temperature database (PRISM Climate Group, 2013) which provides monthly maps at an 800-meter spatial resolution. PRISM uses measured precipitation data and spatially distributes precipitation by using regressions to account for orographic effects.

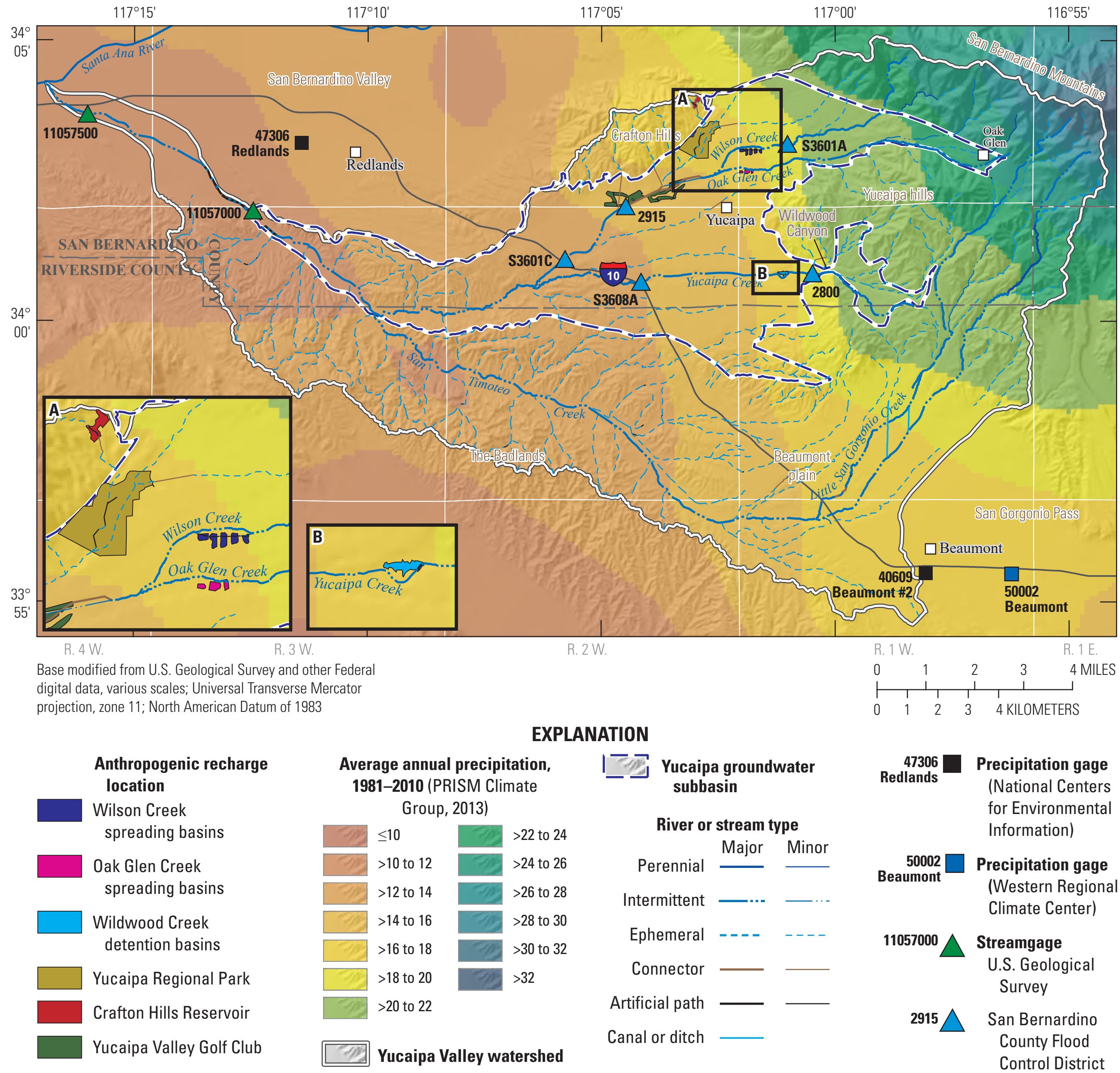


Figure A4. Average annual precipitation (PRISM Climate Group, 2013), major and minor streams, and water course type, for the Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

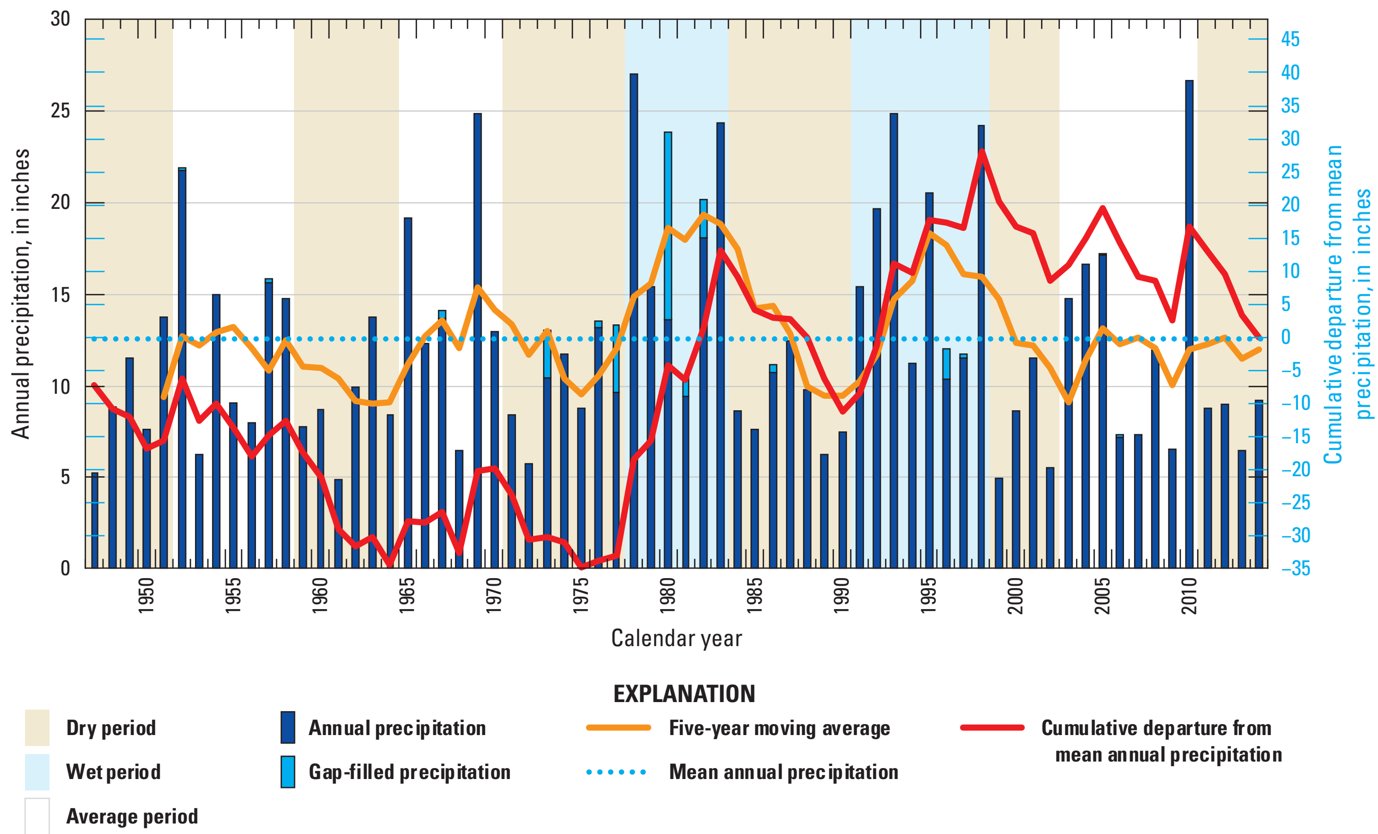


Figure A5. Annual precipitation during 1947–2014 at climate station 47306 Redlands (National Centers for Environmental Information, 2017), Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Surface-Water Hydrology

Surface-water flow in the Yucaipa subbasin occurs primarily during the wet season in intermittent, or ephemeral, streams. Surface water generally flows from the San Bernardino Mountains and Yucaipa hills in the north and east southwest toward San Timoteo Creek and the Santa Ana River before eventually discharging in the Pacific Ocean about 60 mi southwest of the Yucaipa subbasin (figs. A1, A4). Surface-water monitoring on streams in the Yucaipa subbasin provides estimates of streamflow and surface-water discharge.

Streams and Water Bodies

Most of the streams in the Yucaipa subbasin are intermittent, or ephemeral (generally flowing only during the wet season), except in the upper reaches of Wilson Creek and Oak Glen Creek, where perennial flow occurs in the San Bernardino Mountains (fig. A4; U.S. Geological Survey, 2016). The three major streams that traverse the Yucaipa subbasin are Wilson Creek, Oak Glen Creek, and Yucaipa Creek. When water is present, these streams originate from headwaters in the north and northeast and flow west-southwest across the subbasin and eventually drain out of the subbasin along San Timoteo Creek to the Santa Ana River about 5 mi west of the City of Redlands (fig. A4).

Wilson Creek and Oak Glen Creek (fig. A4) both originate in the San Bernardino Mountains, merge in the Wilson Creek subarea (fig. A3) and continue as Oak Glen Creek. Yucaipa Creek originates in the Yucaipa hills and flows west-southwest across the Calimesa subarea where it merges with Oak Glen Creek. Yucaipa Creek then continues its course westward, where it joins San Timoteo Creek and exits the YVW. These major streams generally only flow during precipitation events that generate runoff and are ephemeral; they are fed mostly by smaller, minor, ephemeral streams (fig. A4). In some places, the streams are routed along lined connectors, artificial paths, canals, and ditches (fig. A4). Two minor streams with perennial flow feed into Oak Glen Creek and Wilson Creek from the San Bernardino Mountains. Small springs were present historically along the Chicken Hill fault in the Western Heights subarea (fig. A3; Moreland, 1970); these springs are no longer flowing because of lowering of the groundwater table. Anthropogenic water bodies in and adjacent to the Yucaipa subbasin include the Crafton Hills Reservoir and holding ponds in the Yucaipa Regional Park (fig. A2). Other anthropogenic surface-water structures include the Wilson Creek and Oak Glen Creek spreading basins and the Wildwood Creek detention basins, which were developed as flood-control structures (fig. A2): the Wilson Creek and Oak Glen Creek spreading basins are also used for managed aquifer recharge (MAR).

Surface-Water Monitoring

Streamflow along Wilson Creek, Oak Glen Creek, Yucaipa Creek, and San Timoteo Creek have been historically, or are presently, monitored by the San Bernardino County Flood Control District (SBCFCD) or the USGS at seven streamgages (figs. A4, A6). The variable streamflow measured at different points along the streams (fig. A6) indicate (1) variable channel types along the reaches, which in various locations cause streamflow infiltration to the unsaturated zone and little to no infiltration where connectors are lined, (2) the influence of increased runoff from anthropogenic sources, and (3) measurement uncertainty. The five streamgages operated by SBCFCD (S3601A, 2915, S3601C, 2800, and S3608A; San Bernardino Flood Control District, 2018) were designed to measure high volumes of streamflow during flood conditions; therefore, the measured rates of discharge during low streamflow conditions may be less reliable (San Bernardino County Flood Control District, written commun., 2019). The two streamgages operated by the USGS (11057000 and 11057500) were designed to measure volumes of streamflow from low-flow to high-flow conditions (U.S. Geological Survey, 2018); therefore, the quality of the reported data is more reliable.

Streamflow in Wilson Creek was recorded at the SBCFCD streamgage S3601A from 1968 to 2013 (figs. A4, A6*A*); this streamgage is about 0.5 mi upstream from the Wilson Creek spreading basins and about 2.5 mi upstream from the confluence of Wilson Creek and Oak Glen Creek. Measured annual mean streamflows at streamgage S3601A ranged from about 0.1 to 85 cubic feet per second (ft^3/s). Measured streamflow generally was intermittent, often flowing for only a few days at a time during storm events, which is consistent with ephemeral streams in the Yucaipa Valley area where observed flow frequently occurs as short-lived, flash-flood flow events (Moreland, 1970). Patterns of annual mean streamflow generally reflect the temporal and spatial patterns of measured annual precipitation throughout the period of record, except for 1972–74, 1976, and 2011–13.

Streamflow in Oak Glen Creek has been recorded at the SBCFCD streamgages 2915 and S3601C (figs. A4, A6*B*, A6*C*). Streamgage 2915 is located about 2 mi south of the confluence with Wilson Creek, and has been operating since 2004. The upper reaches of Oak Glen Creek usually flow only in response to storm events and during winter months, but flow occasionally continues into the summer months during particularly wet years (Moreland, 1970). Streamgage S3601C is located about 1.5 mi downstream from streamgage 2915 and about 0.8 mi upstream from the confluence with Yucaipa Creek; streamgage S3601C was in operation from 1975 to 1982 and from 1996 to 2014. Annual mean streamflow generally was lower at station S601C than at station 2915 for similar periods: Oak Glen Creek was channelized but unlined (as observed from Google Earth, imagery date December 2, 2018, Google, Landsat/Copernicus, 2021) between the two stations, so the difference in mean streamflow could be the result of streamflow losses from streambed infiltration. Measured streamflow records at stations 2915 and S3601C show near-perennial annual streamflows with annual mean discharge ranging from about 0.5 to 400 ft^3/s and 0.02 to 15 ft^3/s, respectively. Station 2915 was located immediately downstream from a lined, underground reach of Oak Glen Creek, near the Yucaipa Valley Golf Club, the Yucaipa Regional Park, and a residential neighborhood located between the golf club and the park (fig. A4); irrigation runoff and urban runoff may contribute to streamflow at this station.

Streamflow in Yucaipa Creek has been recorded at the SBCFCD streamgages 2800 and S3608A (figs. A4, A6*D*, A6*E*). Station 2800 is located at the mouth of Wildwood Canyon, about 3.5 mi upstream from station S3608A, and was operated from 1999 through 2014. Station S3608A is located about 2.25 mi upstream from the confluence with Oak Glen Creek and was operated from 1975 to 1977, and from 1996 to 2014. Annual mean streamflow at streamgages 2800 and S3608A ranged from about 0.004 to 221 and 0.1 to 115 ft^3/s, respectively. Patterns of annual mean streamflow at both stations generally were inconsistent with patterns of annual precipitation for the period of record.

Streamflow in San Timoteo Creek has been recorded at USGS streamgages 11057000 and 11057500 (figs. A4, A6*F*, A6*G*). Streamgage 11057000 was about 3.3 miles downstream from the confluence with Yucaipa Creek and was operated from 1947 to 1979, after which time the streamgage was discontinued and removed. Streamgage 11057500 is about 4 mi downstream from streamgage 11057000 and about 1 mi upstream from the confluence of San Timoteo Creek and the Santa Ana River. Streamgage 11057500 was in operation from 1954 to 1965, 1968 to 1975, and 1979 to 2014. Annual mean streamflow records at streamgages 11057000 and 11057500 ranged from about 0.04 to 2 and 0.8 to 20 ft^3/s, respectively. Most streamflow at these streamgages occur between the months of November and May in response to winter and spring storms. Annual mean streamflow at station 11057500 is inconsistent with patterns of precipitation because urban runoff from the City of Redlands flows into the lined, channelized section of San Timoteo Creek upstream from the streamgage (Alzraiee and others, 2022).

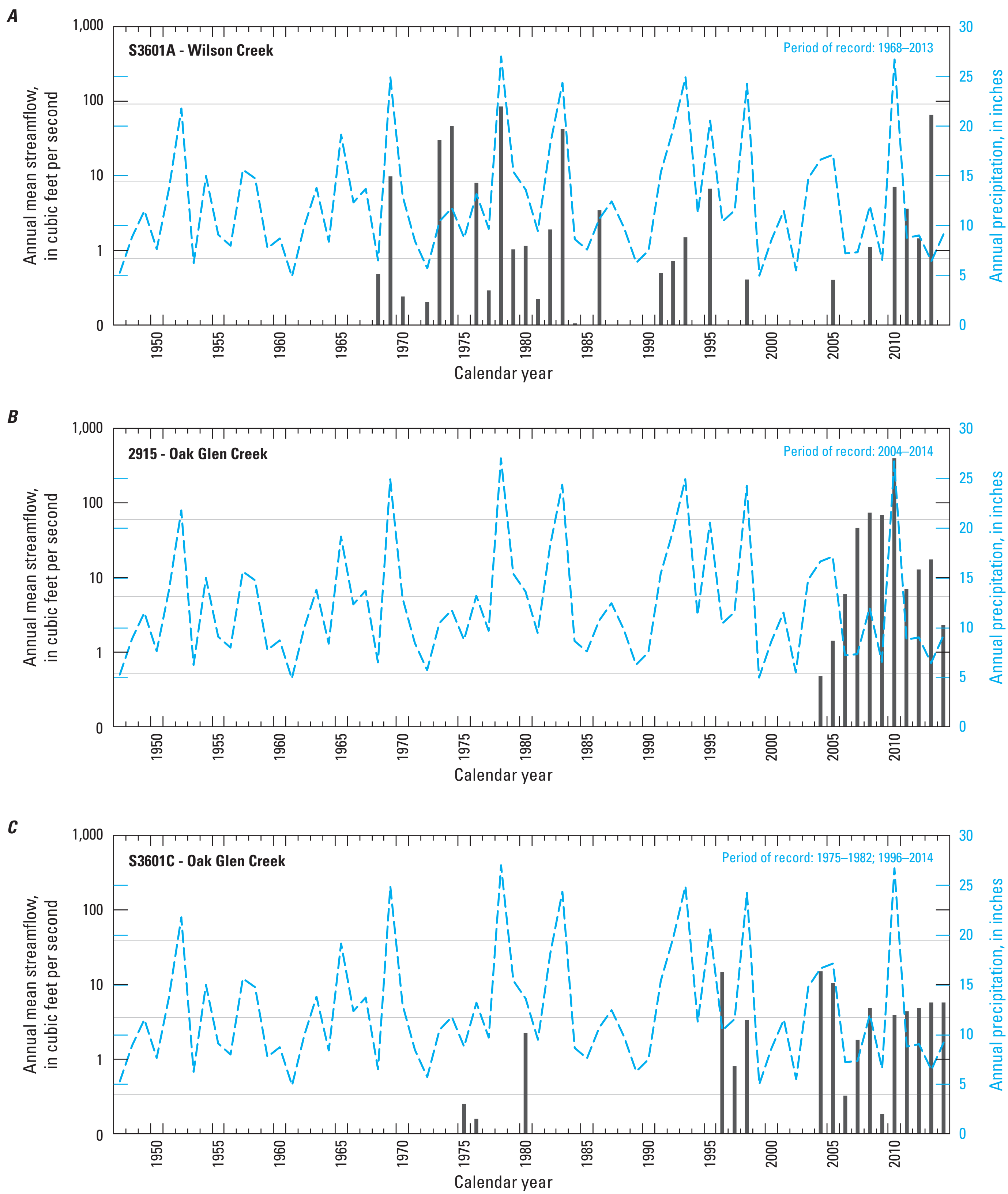
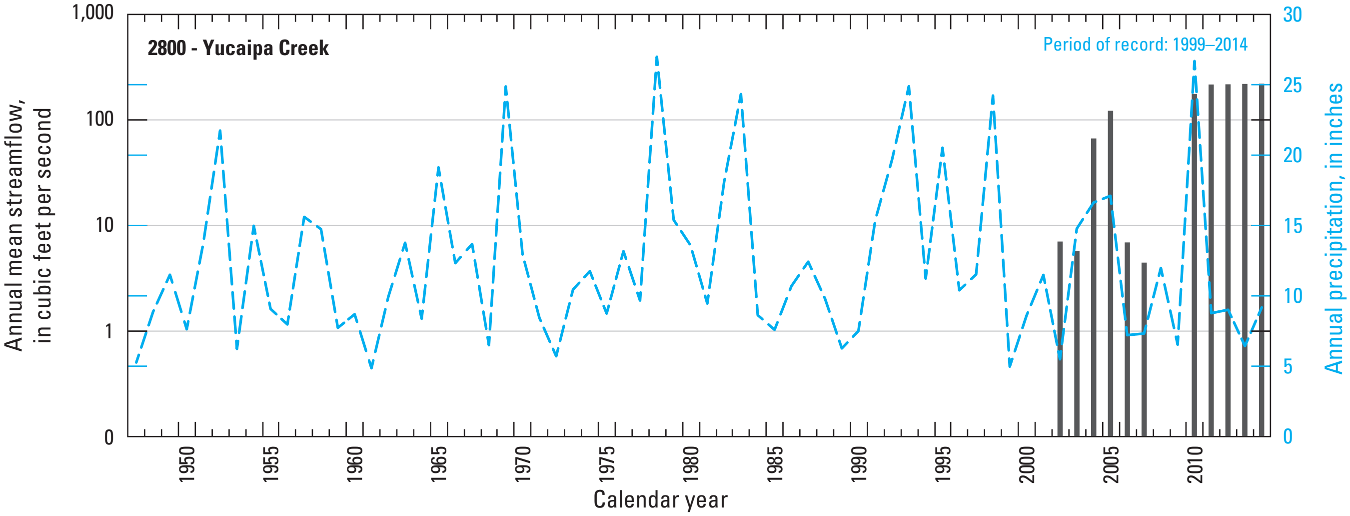
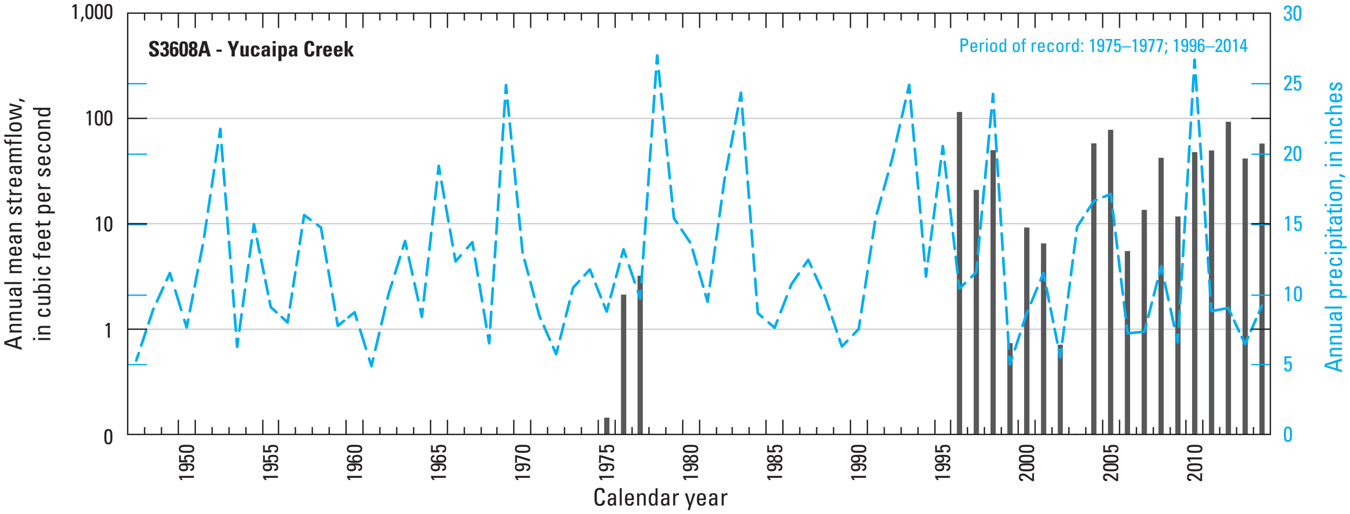


Figure A6. Measured annual mean streamflow and annual precipitation at San Bernardino County Flood Control District (SBCFCD) streamgages *A*, S3601A; *B*, 2915; *C*, S3601C; *D*, 2800; *E*, S3608A; and U.S. Geological Survey (2018) streamgages *F*, 11057000; and *G*, 11057500, in the Yucaipa groundwater subbasin and Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Years lacking streamflow data indicate that the streamgage was inoperative or data for that year were incomplete.

D



E



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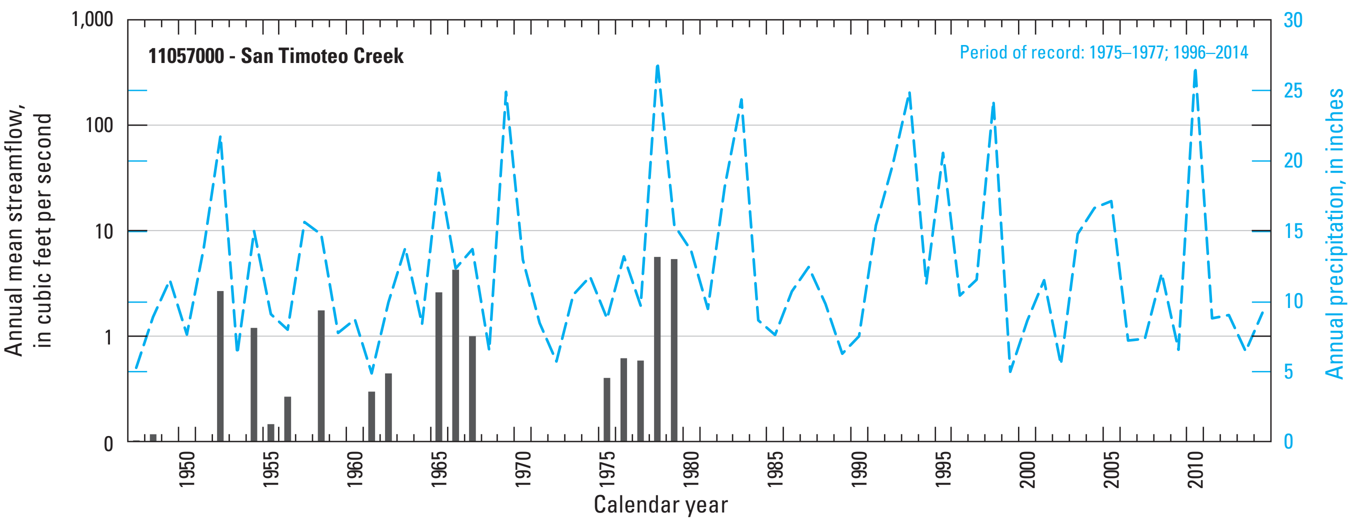


Figure A6.—Continued

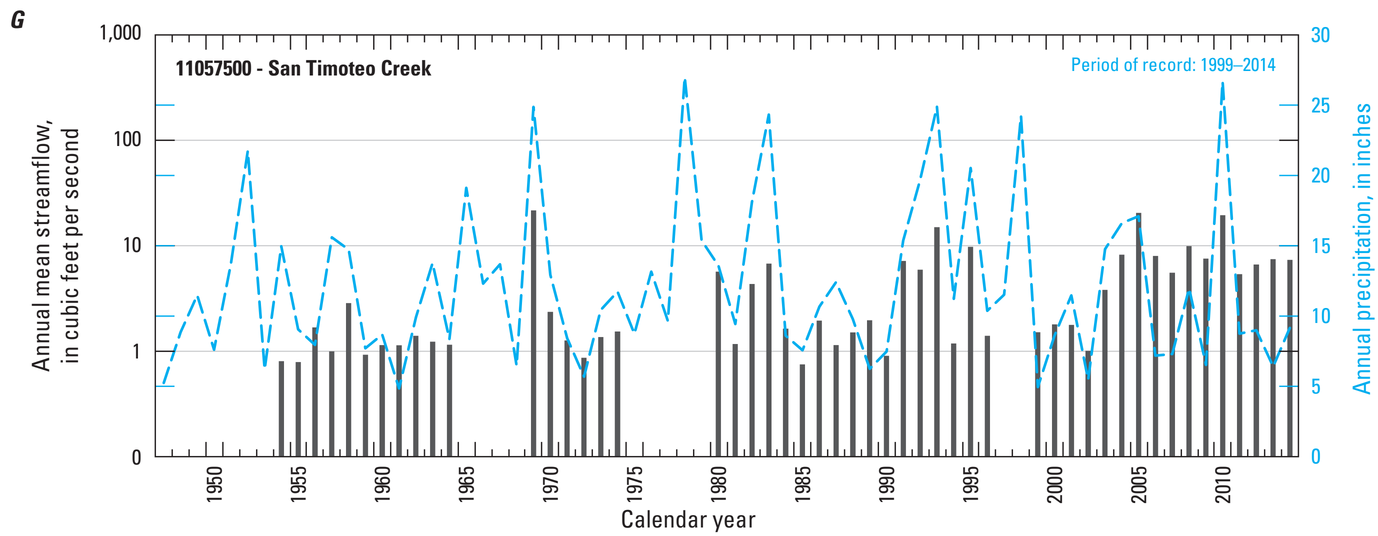


Figure A6.—Continued

Land Use

The Yucaipa Valley was inhabited originally by Native Americans; the word "Yucaipa" is a variant of several names associated with the Native American Tribes of this area and refers to "wet lands" (Yucaipa Valley Water District, 2010). Small springs that discharged along the Chicken Hill fault and artesian conditions that created peaty areas in the Western Heights subarea may have contributed to the perception of the Yucaipa Valley having wetlands (Moreland, 1970). European settlement began in this area by the late 1700s, and the region around San Bernardino was controlled by Spanish mission churches that were transitioned to Spanish and later Mexican ranchos until the mid-1800s (Yucaipa Valley Water District, 2010). Grazing and agricultural development grew from the late 1700s through the 1800s, with irrigation infrastructure that brought water from perennial streams to drier parts of the Yucaipa Valley (Yucaipa Valley Water District, 2010). By the early 1900s, farming interests were mainly fruit orchards, and the area became synonymous with red apples (Mendez and others, 2001). Beginning in the 1940s, the area became a popular retirement destination and bedroom community for the greater Los Angeles metropolitan area. As the population increased (table A1) and more of the area was urbanized, agricultural lands shifted away from the Yucaipa Valley and into the surrounding mountains and foothills. Since about 1990, most of the agricultural lands have been replaced with planned residential developments and natural lands, although apple growing is still popular on the lower slopes of the San Bernardino Mountains, particularly along Oak Glen Creek (Mendez and others, 2001).

Land-use maps of the Yucaipa subbasin and the encompassing YVW were compiled for 1972, 1992, 2001, and 2014; the maps show changes in the use of developed, agricultural, and natural lands (figs. A7*A*–*D*). The sources of data for each land-use map are (1) for 1972, the USGS Geographic Information Retrieval and Analysis System (GIRAS; Mitchell and others, 1977), (2) for 1992, the National Land Cover Database (NLCD; Vogelmann and others, 2001), (3) for 2001, Landscape Fire and Resource Management Planning Tools (LANDFIRE) version 105 (LANDFIRE 105; LANDFIRE, 2001), and (4) for 2014, LANDFIRE version 140 (LANDFIRE 140; LANDFIRE, 2014). A consistent set of land-use categories was established by reclassifying the GIRAS, NLCD, and LANDFIRE 105 datasets to match the LANDFIRE 140 vegetation coding scheme and grouping these vegetation codes into general categories (table A2). The resolution of each dataset was maintained during reclassification, except for developed land categories in the 1972 GIRAS dataset. Developed lands can have a substantial impact on water-budget estimates; therefore, areas classified as developed lands in the relatively low-resolution GIRAS dataset were replaced with the coinciding land cover from the higher-resolution LANDFIRE 105 dataset. The resulting land-use maps for each year are shown in figures A7*A*–*D*, and summary statistics are listed in table A3.

Table A1. Estimated population of the Yucaipa groundwater subbasin for selected census years, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Census year	Estimated population
1950	539
1970	21,460
1990	36,869
2000	45,958
2010	56,473

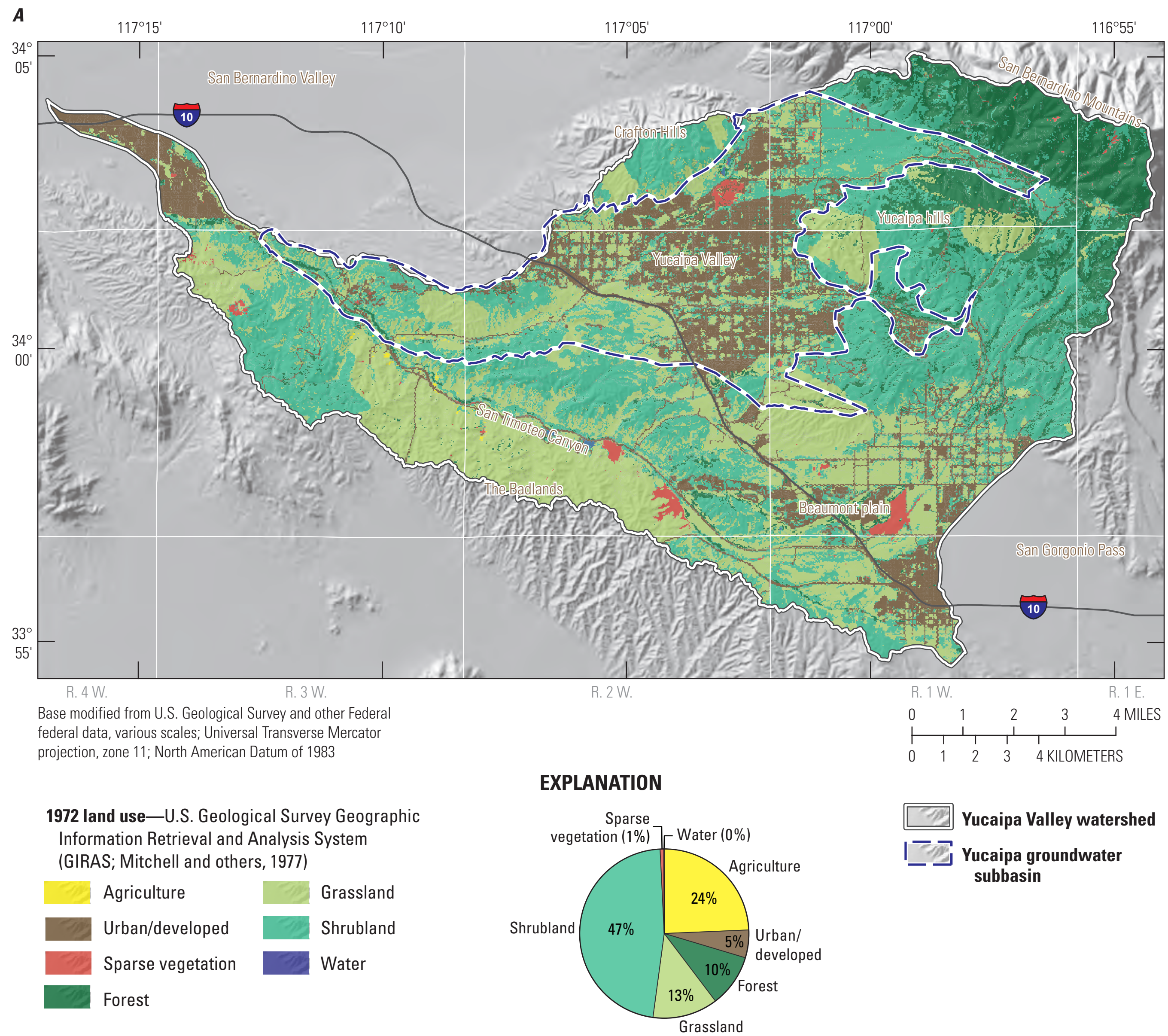
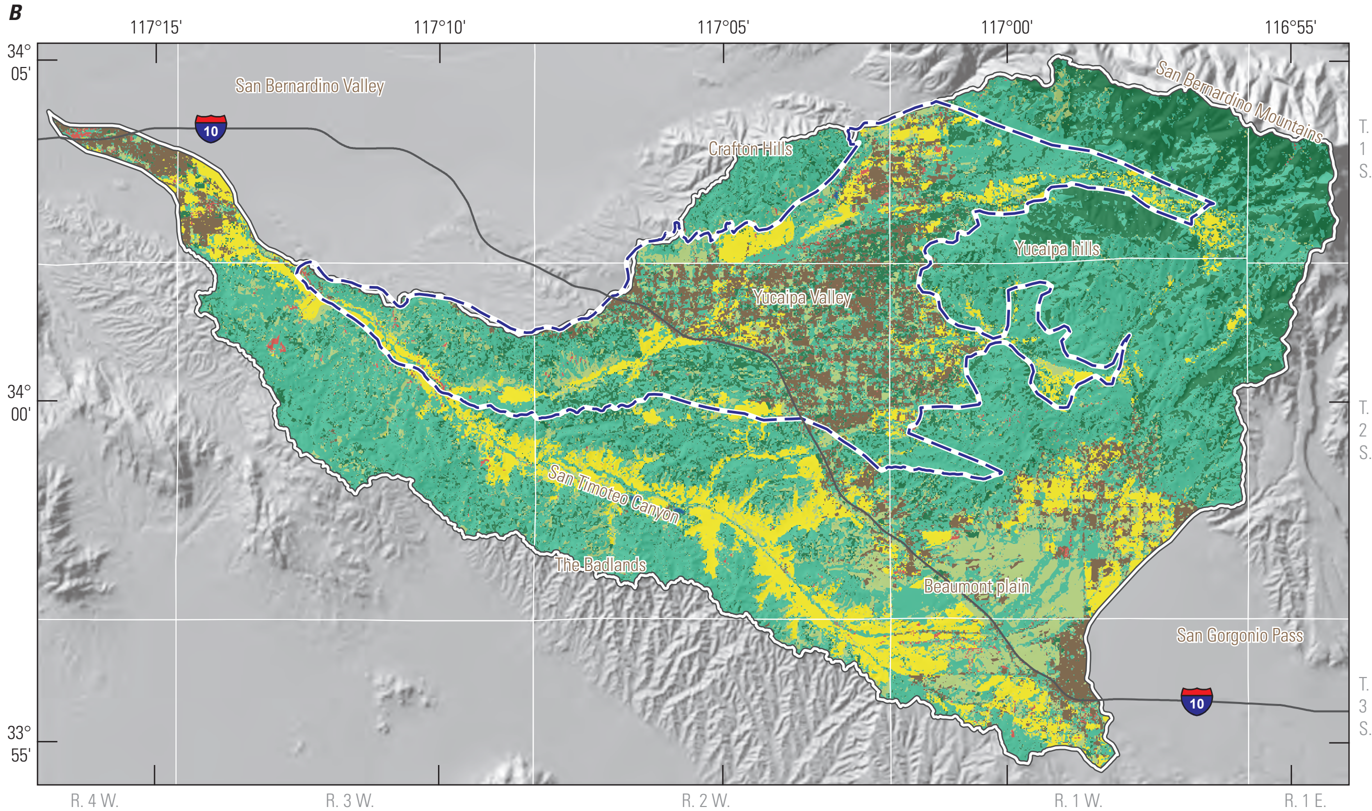


Figure A7. Land-use maps, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California: *A*, 1972 (Mitchell and others, 1977); *B*, 1992 (Vogelmann and others, 2001); *C*, 2001 (LANDFIRE, 2001); and *D*, 2014 (LANDFIRE, 2014).

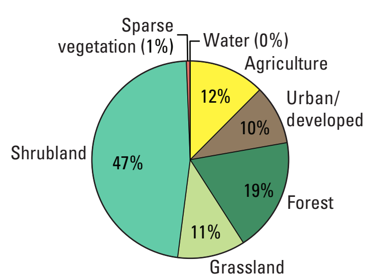


Base modified from U.S. Geological Survey and other Federal digital data, various scales; Universal Transverse Mercator projection, zone 11; North American Datum of 1983

EXPLANATION

1992 land use—National Land Cover Database (Vogelmann and others, 2001)

- Agriculture
- Grassland
- Urban/developed
- Shrubland
- Sparse vegetation
- Water
- Forest



- **Yucaipa Valley watershed**
- **Yucaipa groundwater subbasin**

Figure A7.—Continued

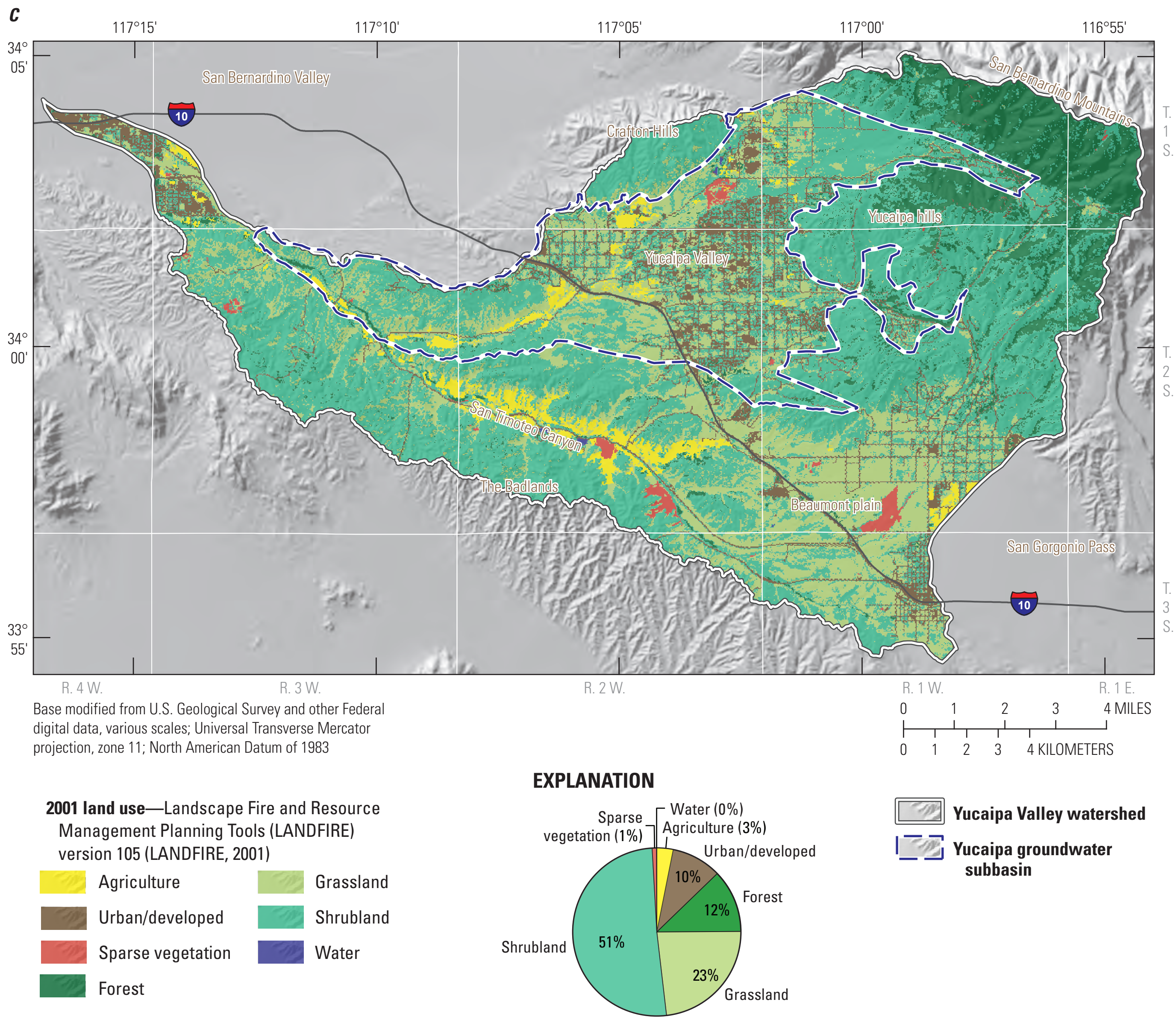


Figure A7.—Continued

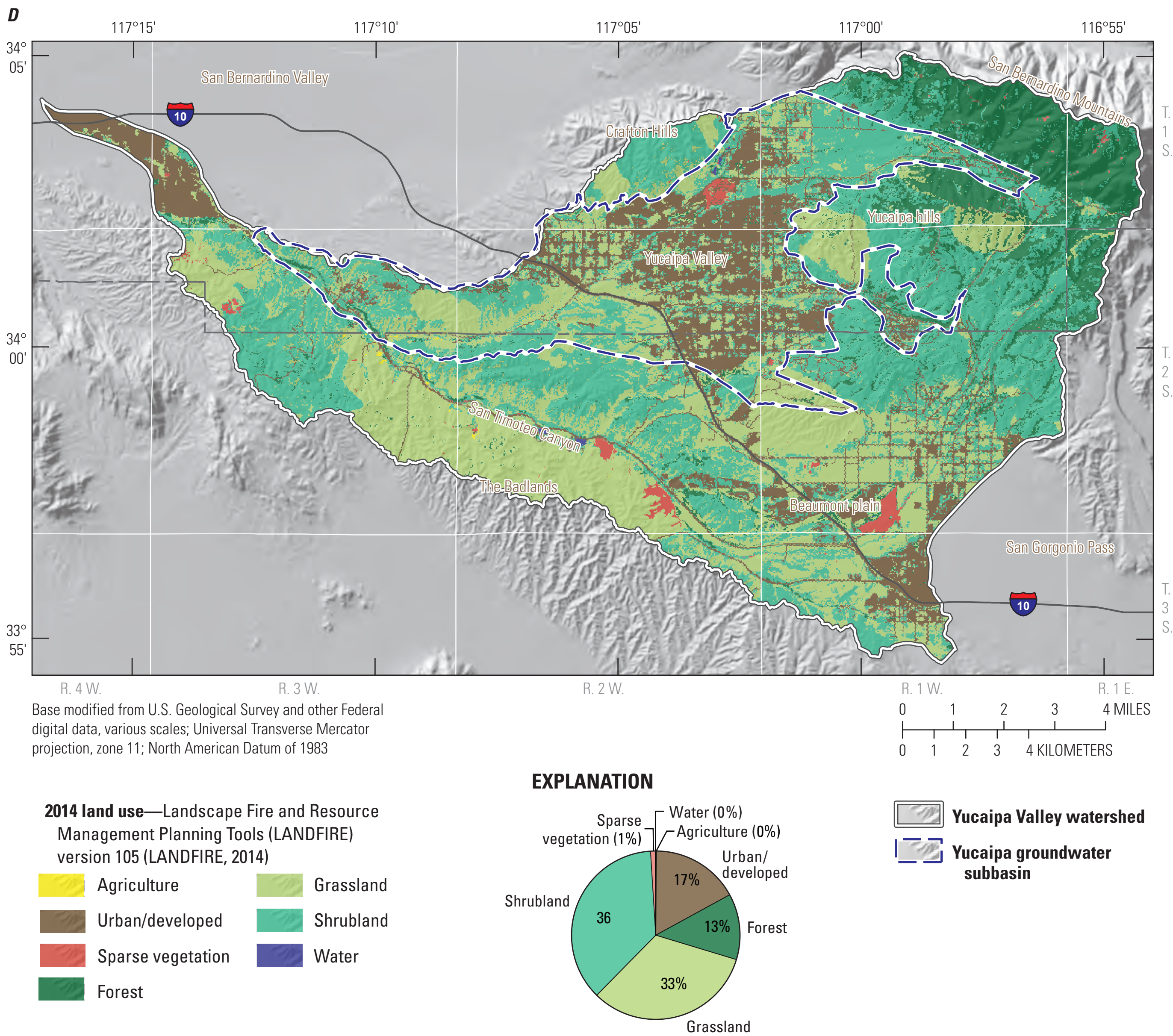


Figure A7.—Continued

Table A2. General land-use categories with corresponding LANDFIRE 140 (LANDFIRE, 2014), GIRAS (Mitchell and others, 1977), NLCD (Vogelmann and others, 2001), and LANDFIRE 105 (LANDFIRE, 2001) vegetation codes and classes, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

[LANDFIRE 140, Landscape Fire and Resource Management Planning Tools version 140; GIRAS, Geographic Information Retrieval and Analysis System; NLCD, National Land Cover Database; LANDFIRE 105, Landscape Fire and Resource Management Planning Tools version 105; —, not applicable]

LANDFIRE 140 code	GIRAS class	NLCD class	LANDFIRE 105 code
		Agriculture	
3980	Orchards, Groves, Vineyards, Nurseries	Orchards/Vineyards/Other	—
3984	—	Row Crops	82
3985	—	—	65
3986	—	Fallow	—
3987	Cropland and Pasture	Pasture/Hay	81
3988	—	Small Grains	—
		Developed	
3296	Mixed Urban or Built-up Land	Low Intensity Residential	—
—	Other Urban or Built-up Land	—	—
3297	Residential	High Intensity Residential	23
3298	Commerical and Services	Commercial/Industrial/Transportation	24
—	Industrial	—	—
—	Transportation, Communications and Utilities	—	—
3299	—	—	25
		Forest	
3014	Evergreen Forest Land	Evergreen Forest	2014
3019	—	—	2019
3027	—	—	2027
3028	—	—	2028
3029	—	—	2029
3031	—	—	2031
3034	—	—	2034
3113	—	—	2113
3118	Mixed Forest Land	Deciduous Forest	2118
—	—	Mixed Forest	—
3152	—	—	2152
3155	—	—	2155
3536	—	Woody Wetlands	—
3910	—	—	13
3911	—	—	14
3912	—	—	15
		Grassland	
3129	—	—	75
—	—	—	76
—	—	—	2129
3181	—	—	2181
3184	Herbaceous Rangeland	Grassland/Herbaceous	2184
—	Mixed Rangeland	—	—

Table A2. General land-use categories with corresponding LANDFIRE 140 (LANDFIRE, 2014), GIRAS (Mitchell and others, 1977), NLCD (Vogelmann and others, 2001), and LANDFIRE 105 (LANDFIRE, 2001) vegetation codes and classes, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.—Continued

[LANDFIRE 140, Landscape Fire and Resource Management Planning Tools version 140; GIRAS, Geographic Information Retrieval and Analysis System; NLCD, National Land Cover Database; LANDFIRE 105, Landscape Fire and Resource Management Planning Tools version 105; —, not applicable]

LANDFIRE 140 code	GIRAS class	NLCD class	LANDFIRE 105 code
	Grassland—Continued		
3538	—	Emergent Herbaceous Wetlands	—
3913	—	Urban/Recreational Grasses	16
3949	Confined Feeding Operations	—	—
	Shrubland		
3082	—	—	2082
3087	—	—	2087
3088	—	—	2088
3092	—	—	2092
3097	Shrub and Brush Rangeland	Shrubland	2097
3098	—	—	2098
3099	—	—	2099
3105	—	—	2105
3108	—	—	2108
3110	—	—	2110
3914	—	—	17
	Sparse vegetation		
3002	—	—	2002
3004	—	—	2004
3294	Sandy Areas Other than Beaches	Bare Rock/Sand/Clay	31
—	Transitional Areas	—	—
	Sater		
3292	Reservoirs	Open Water	11

1972 Land Use

In 1972, 5 percent of the YVW was developed and concentrated in the Yucaipa Valley, in the Beaumont plain, and in the San Bernardino Valley west of the City of Redlands (fig. A7*A*). Agricultural lands made up 24 percent of the YVW and were distributed throughout the YVW in the northern part of Yucaipa Valley, in the Beaumont plain, and along major and minor streams. Natural lands (forest, grassland, shrubland, and sparse vegetation) together comprised the remaining 70 percent of the YVW and were primarily located in the mountains and highland areas.

1992 Land Use

By 1992, the percentage of developed lands had increased to 10 percent of the YVW; developed lands had expanded out from the city centers in the Yucaipa Valley and the Beaumont plain and had expanded at the western end of the YVW toward the City of Redlands (fig. A7*B*). The percentage of agricultural lands had decreased to 12 percent of the YVW; agricultural lands maintained a similar distribution as was observed in 1972 but shrank by half in total acreage and were replaced by both developed and natural lands, primarily forest. The percentage of natural lands had increased to 78 percent of the YVW; natural lands increased in northern Yucaipa Valley and the Beaumont plain, primarily replacing agricultural lands.

Table A3. General land use for 1972, 1992, 2001, and 2014, Yucaipa Valley watershed, San Bernardino County, California.

[See table A2 for general land-use categories. **Abbreviation**: mi^2, square mile]

General land-use category	Land-use surveys											
	1972			1992			2001			2014		
	Acres	mi^2	Percent	Acres	mi^2	Percent	Acres	mi^2	Percent	Acres	mi^2	Percent
Agriculture	12,131,793	18,956	24	6,223,794	9,725	12	1,563,658	2,443	3	41,561	65	0
Developed	2,640,718	4,126	5	4,859,584	7,593	10	4,802,974	7,505	10	8,452,378	13,207	17
Forest	5,012,269	7,832	10	9,315,270	14,555	19	6,050,678	9,454	12	6,305,606	9,853	13
Grassland	6,207,921	9,700	12	5,552,041	8,675	11	11,592,640	18,114	23	16,297,018	25,464	33
Shrubland	23,477,760	36,684	47	23,597,408	36,871	47	25,405,926	39,697	51	18,266,598	28,542	37
Sparse vegetation	353,940	553	1	297,354	465	1	422,900	661	1	471,611	737	1
Water	35,725	56	0	14,676	23	0	21,350	33	0	25,352	40	0
TOTAL	49,860,126	77,906	—	49,860,128	77,906	—	49,860,127	77,906	—	49,860,124	77,906	—

2001 Land Use

By 2001, the percentage of developed lands stayed constant at 10 percent of the YVW; the acreage of developed lands declined in parts of Yucaipa Valley and the Beaumont plain but increased at the western end of the YVW west of the City of Redlands (fig. A7*C*). The percentage of agricultural lands decreased to 3 percent of the YVW; the acreage of agricultural lands was substantially reduced in Yucaipa Valley, the Beaumont plain, and at the western end of the YVW, and the agricultural land that remained was concentrated along San Timoteo Creek and Yucaipa Creek near the The Badlands. Agricultural lands were replaced primarily by natural lands, particularly shrubland and grassland. The percentage of natural lands increased to 87 percent of the YVW; natural lands increased near the developed centers in Yucaipa Valley and the Beaumont plain, and along San Timoteo Creek, primarily replacing agricultural lands.

2014 Land Use

By 2014, the percentage of developed lands had increased to 17 percent of the YVW; the increase in acreage of developed lands was primarily the result of increased density in the Yucaipa Valley, in the Beaumont plain, and at the western end of the YVW near the City of Redlands (fig. A7*D*). The percentage of agricultural lands decreased to less than 0.1 percent of the YVW; agricultural lands remained only in a few areas along San Timoteo Creek and in the highlands near Oak Glen Creek. Agricultural lands were replaced primarily by developed lands in Yucaipa Valley, in the Beaumont plain, and near the City of Redlands and were replaced primarily by natural lands along San Timoteo Creek and Yucaipa Creek. Overall, the percentage of natural lands decreased to 83 percent of the YVW; the largest loss of natural lands was caused by the expansion of population centers in Yucaipa Valley and the Beaumont plain. Natural lands gained in acreage along San Timoteo Creek and Yucaipa Creek, primarily replacing agricultural lands in those areas.

Geology

The Yucaipa subbasin is geologically, structurally, and hydrologically complex, with several faults and one major fold structure affecting a variety of surface-water and groundwater processes. This section presents the geologic setting and structure of the Yucaipa subbasin.

Geologic Setting and Faults

The Yucaipa subbasin is a sediment-filled depression (up to more than 8,000 ft deep) situated between the northwest-trending San Andreas fault zone and San Jacinto fault (fig. A8). The geology of the Yucaipa subbasin and the encompassing YVW consists of Mesozoic and older crystalline basement rocks overlain by Tertiary and early Quaternary sedimentary materials—including the San Timoteo Formation and sedimentary deposits of Live Oak Canyon—and later Quaternary alluvial deposits (fig. A8; Cromwell and Matti, 2022). The San Timoteo Formation, sedimentary deposits of Live Oak Canyon, and later Quaternary alluvial deposits (consisting of middle and upper Pleistocene and latest Quaternary alluvial deposits; fig A8) comprise the majority of the sedimentary basin-fill materials that overlie the crystalline rocks. These basin-fill materials are sourced from the crystalline basement rocks northwest of the Yucaipa subbasin.

The San Andreas fault zone is an active right-lateral fault zone that forms the northern boundary of the Yucaipa subbasin and is the most widely recognized structural element in the area. In the Yucaipa subbasin, the fault zone is characterized by individual en echelon fault segments with a northwesterly trend (fig. A8). The Banning fault transects the subbasin (fig. A8) and is a late Miocene right-lateral structure whose movement history ended at about 5 Mega-annum (Ma; Matti and others, 1985, 1992a). The age of the fault along the southeastern extent of the Yucaipa subbasin is less certain: The Quaternary Fold and Fault Database of the United States (U.S. Geological Survey and California Geological Survey, 2016) indicates that this segment may have been active as recently as the late Quaternary, while Matti and others (2015) attributed slip to local late Quaternary reactivation of the fault.

A region-wide “right step” transfers right-lateral slip between the San Andreas fault zone and the San Jacinto fault and produces a domain of extension (Morton and Matti, 1993; Anderson and others, 2004) and a series of northeast-southwest trending dip-slip faults in the Yucaipa subbasin. Activity along the San Jacinto fault also has caused folding along the San Timoteo anticline. The dip-slip faults generally have normal displacement (with the exception of the Live Oak Canyon fault zone; Matti and others, 2003a; Cromwell and Matti, 2022) and bound the northwestern margin of the Yucaipa subbasin (such as the Crafton Hills fault zone) and traverse other parts of the subbasin (such as the Chicken Hill fault and possibly the Casa Blanca fault). Some of the dip-slip faults have been active in the Holocene and are expressed at land surface; other faults such as the Casa Blanca fault have been inactive long enough to lack identifiable surface expression.

Displacement on dip-slip faults caused tectonic subsidence in the Yucaipa subbasin, down-dropping crystalline basement rocks and facilitating the accumulation of the sedimentary basin-fill material in the resulting sedimentary basin (Matti and others, 2015). East of the Yucaipa subbasin in the YVW, tectonic convergence in the San Gorgonio Pass fault zone (Matti and others, 2015) generated north-dipping thrust and reverse faults such as the Cherry Valley thrust fault, the Wildwood Canyon fault, and other faults associated with the San Gorgonio Pass fault zone. These faults offset the Plio-Pleistocene sedimentary materials of the San Timoteo Formation in the hanging wall over younger sedimentary materials in the footwall of the Cherry Valley thrust fault.

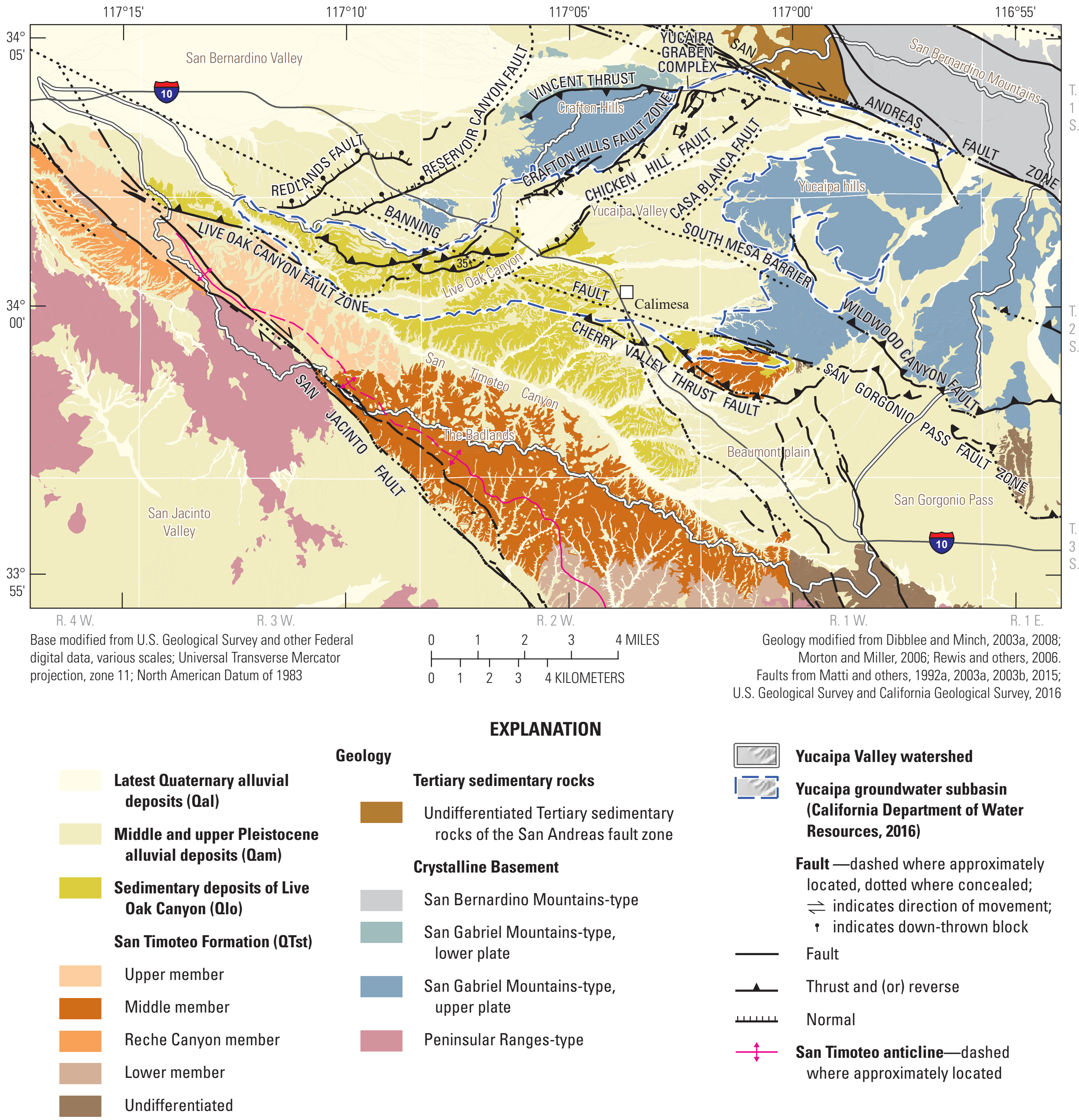


Figure A8. Geologic map of the Yucaipa Valley watershed, San Bernardino and Riverside Counties, California, from Cromwell and Matti (2022).

The San Timoteo anticline is a northwest-trending and gently northwest-plunging anticlinal fold present throughout much of The Badlands (fig. A8). Folding of the San Timoteo anticline likely initiated about 1.2 million years ago (Matti and others, 2015), deforming existing Pliocene and Pleistocene sedimentary materials of the San Timoteo Formation. Folding likely terminated some time prior to 100 thousand years ago (ka; Kendrick and others, 2002). Deposition of sedimentary deposits of Live Oak Canyon post-dates much of the folding associated with the San Timoteo anticline, probably resulting in an angular unconformity with the underlying San Timoteo Formation (Matti and others, 2015).

Depth to Crystalline Basement

Basin structure of the Yucaipa subbasin and the encompassing YVW was defined in Cromwell and Matti (2022) using geologic data from boreholes and geologic maps and a compilation of gravity-derived depth-to-basement estimates from Anderson and others (2004), Langenheim and others (2005), and Mendez and others (2016). The previously published depth-to-basement studies estimated depth-to-basement for different but overlapping geographic extents using gravity, aeromagnetic, and seismic geophysical methods (Cromwell and Matti, 2022). The result of this compilation was a continuous interpolation of the depth-to-crystalline basement (fig. A9) that was derived from the original datasets mentioned above. Depth-to-crystalline basement ranged from about 300 to more than 3,000 ft in the Yucaipa Valley, from about 1,000 to 8,000 ft in the Beaumont plain, and to almost 9,000-ft south of the Banning fault. Depth-to-crystalline basement is relatively shallow (generally less than about 100 ft) in modern stream channels in the San Bernardino Mountains and in areas adjacent to the Crafton Hills, the Yucaipa hills, the San Bernardino Mountains, and the southern part of The Badlands. Variations in depth-to-crystalline basement in this area are the result of down-dropping along dip-slip faults as a result of extension in the right-step between the San Andreas fault zone and the San Jacinto fault (Cromwell and Matti, 2022).

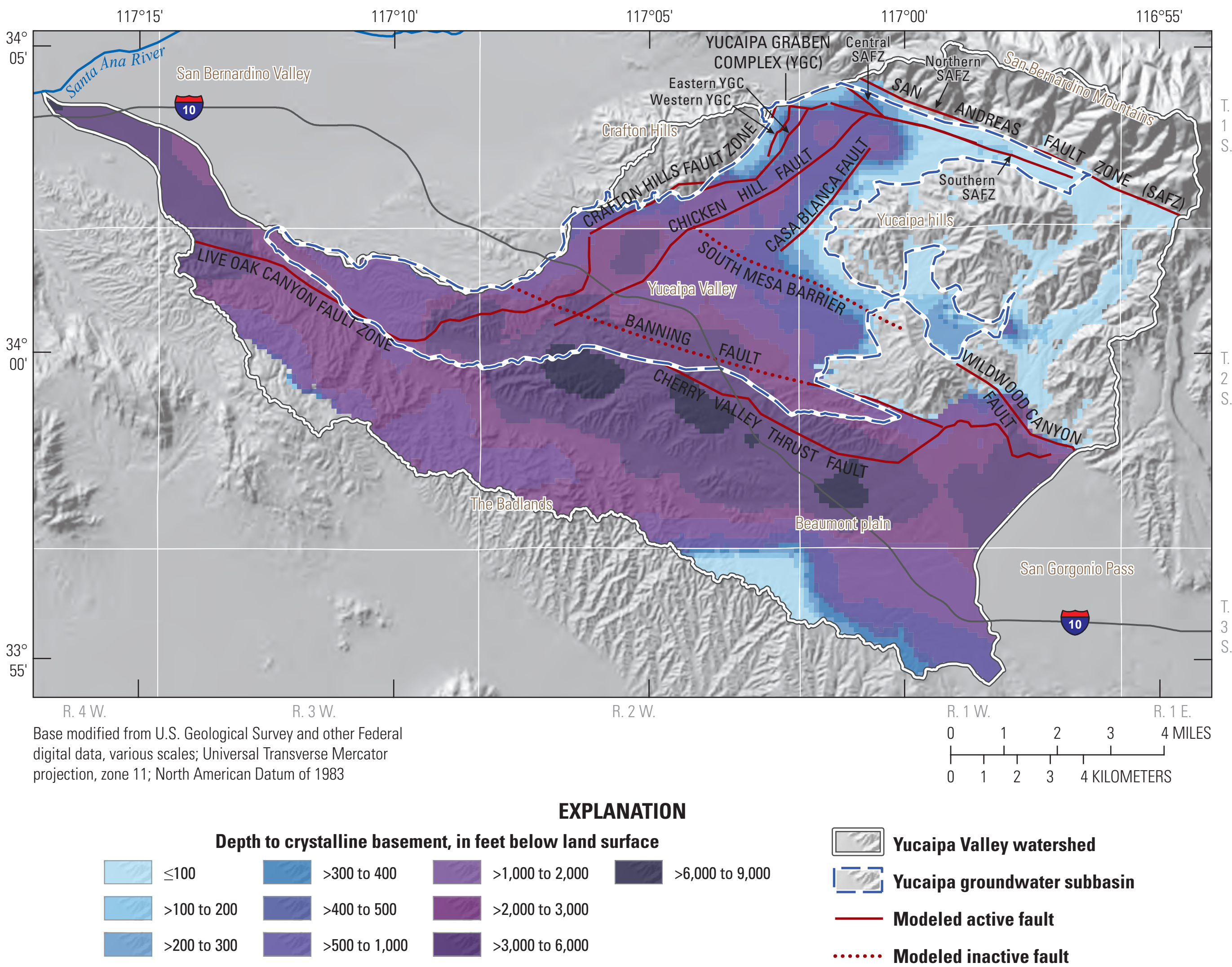


Figure A9. Depth-to-crystalline basement and model faults from the three-dimensional hydrogeologic framework model (Cromwell and Matti, 2022), Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Modified from Cromwell and Matti (2022).

Geologic Formations and Deposits

Mesozoic and older crystalline basement rocks underlie the sedimentary basin-fill materials and are exposed in the Crafton Hills, Yucaipa hills, and the San Bernardino Mountains (fig. A8). These rocks consist of igneous and metamorphic rocks that comprise three different lithologic provenances (Cromwell and Matti, 2022). These rocks form the structural basin in which sedimentary basin-fill materials were deposited. A zone of weathered saprolitic basement material is found in outcrops and at depth in certain areas (such as USGS multiple-depth, monitoring well sites YV6E and YVEP; Mendez and others, 2016, 2018; U.S. Geological Survey, 2018); this weathered material overlies more competent crystalline rock and may be extensive across the Yucaipa subbasin (Cromwell and Matti, 2022). Electric logs from USGS multiple-depth monitoring-well sites YV6E and YVEP showed an increase in resistivity where the lithologic logs identified crystalline basement rocks; cores collected from the bottom of these well sites confirmed they penetrated crystalline basement rocks (Mendez and others, 2018; Cromwell and Matti, 2022).

Undifferentiated Tertiary sedimentary rocks located between strands of the San Andreas fault zone at the northeastern margin of the Yucaipa subbasin (fig. A8) include the Mill Creek (Gibson, 1971) and Warm Springs Canyon Formations (Matti and others, 2003a; Morton and Miller, 2006). The age of these continental sedimentary rocks is not well constrained, but they are probably late Miocene and constitute thick sedimentary fill sequences deposited in and adjacent to the San Andreas fault zone (Matti and others, 2003a). Deep, old sedimentary rocks are likely present in the subsurface in the deep structural lows of the Western Heights subarea and south of the Banning fault (fig. A9; Cromwell and Matti, 2022). Not enough is known about these rocks to interpret their formational assignment, and these units were not identified in lithologic boreholes during development of the HFM (Cromwell and Matti, 2022). If present, these rocks are likely below the depth of investigation of this report.

The San Timoteo Formation crops out mainly in The Badlands (fig. A8; Morton and Matti, 2001; Matti and others, 2003b, 2015) and on the hanging wall of the Cherry Valley thrust fault. From The Badlands, the San Timoteo Formation dips to the north-northeast beneath the younger sedimentary basin-fill materials, likely pinching out at depth northeast of the Banning fault (Cromwell and Matti, 2022). Regionally, the San Timoteo Formation is separated into multiple members and subunits (fig. A8; Morton and Miller, 2006; Matti and others, 2015). The upper member and Reche Canyon member crop out in the northwestern part of The Badlands (Morton and Matti, 2001; Matti and others 2003b; Morton and Miller, 2006) and probably have no counterparts within the Yucaipa subbasin, although the upper member crops out adjacent to the Yucaipa subbasin boundary. The middle and lower members of the San Timoteo Formation crop out mainly south of the Yucaipa subbasin (Matti and others, 2015), as do undifferentiated sediments of the formation (Dibblee and Minch, 2003a; Rewis and others, 2006). The San Timoteo Formation consists primarily of compacted, consolidated, and cemented clays and silts (Frick, 1921; Matti and others, 2015). The middle and upper members of the San Timoteo Formation range from about 5.0 Ma (Albright 1997, 1999) to about 1.2–1.5 Ma (Morton and others, 1986; Repenning, 1987; Morton and Matti, 1993; Reynolds and others, 2013), with cessation of deposition roughly coinciding with inception of folding along the San Timoteo anticline (Matti and others, 2015) around 1.2 Ma.

The sedimentary deposits of Live Oak Canyon generally crop out north and east of San Timoteo Canyon, between The Badlands and Interstate 10. The sedimentary deposits of Live Oak Canyon likely comprise much of the sedimentary basin fill in the Yucaipa subbasin north of San Timoteo Canyon (Matti and others, 2015; Cromwell and Matti, 2022). Sedimentary deposits of Live Oak Canyon consist of light-gray to very pale-brown, sand- and gravel-bearing deposits; with lesser amounts of yellow, brown, and light-gray mud-bearing deposits (Matti and others, 2015). A magnetostratigraphic profile across the sedimentary deposits of Live Oak Canyon (Albright, 1997, 1999) captured the Brunhes-Matuyama geomagnetic field reversal at about 780 ka. Parts of the Live Oak sequence overlying the Brunhes-Matuyama reversal are younger than 780 ka and may be as young as 500–600 ka (Matti and others, 2015, p. 20). Albright (1997, 1999) and Matti and others (2015) discussed evidence that the lower part of the sedimentary deposits of Live Oak Canyon is as old as 1.2–1.5 Ma, with Matti and others (2015) preferring an age of 1.2 Ma for the base of the formation.

Middle and upper Pleistocene alluvial deposits occur throughout the Yucaipa subbasin (fig. A8). They underlie the broad mesa-like landform of Yucaipa Valley (fig. A8) and can be observed best in the steep walls of that landform and the flanks of nearby geomorphic terraces. The lithologic character and depositional setting of middle and upper Pleistocene alluvial deposits vary throughout the study area. Near crystalline-basement rock source areas, the deposits are gravel rich and more poorly sorted; in distal settings, the deposits are sandier and locally have fine-grained intervals of silt and clay. Oldest sedimentary materials comprising the middle and upper Pleistocene alluvial deposits are capped by pedogenic-soil profiles having thick, very red argillic B horizons that probably are on the order of 500,000 years old (Matti and others, 2003a).

Latest Quaternary alluvial deposits are the youngest geologic materials in the Yucaipa subbasin, and are comprised of latest Pleistocene and Holocene alluvial deposits that occur along streams and in channels incised into older geologic formations (fig. A8). The young alluvial deposits are comprised of very young and young axial-channel, alluvial-valley, and wash deposits; with local landslide deposits and are likely younger than about 15,000 years old (Matti and others, 2003a). Very young wash deposits are located in the lowlands of the Yucaipa Valley and include active and progressively less active to abandoned materials (Matti and others, 2003a). Young deposits (the oldest materials of the late Quaternary alluvial deposits) are sandy and gravelly deposits with minimal soil-profile development, indicating that these are Holocene to latest Pleistocene soils that are between 15,000 and 1,000 years old (Matti and others, 2003a).

Hydrogeology

This section presents the hydrogeologic setting of the Yucaipa subbasin and evaluates aquifer characteristics and controls on the aquifer system. To define and visualize the hydrogeologic and structural architecture of the Yucaipa subbasin, a 3D HFM of the Yucaipa subbasin and the encompassing YVW was constructed by Cromwell and Matti (2022) and archived in a USGS data release (Cromwell and others, 2022). The HFM was used to help understand the groundwater hydrology and define the model boundaries and hydraulic characteristics of the YIHM (described in chapter B). The HFM was developed from geologic, geophysical, and hydrogeologic data and is a digital representation of thickness and extent of four hydrogeologic units (described in the "Hydrogeologic Units" section) and the structural geometry of hydrogeologically important faults and folds. The HFM was constructed using EarthVision, a 3D geologic-modeling software package (Dynamic Graphics, Inc., 2015) and Esri ArcGIS geographic information system software. A complete discussion of the HFM development and results can be found in Cromwell and Matti (2022).

Hydrogeologic Units

The geologic units of the Yucaipa subbasin (fig. A8) were classified into four hydrogeologic units that represent the aquifer system (fig. A10). Three units comprise the sedimentary basin-fill aquifer system, and the fourth unit comprises the basal hard rock that underlies the basin-filling units. The four units from youngest (shallowest) to oldest (deepest) are (1) surficial materials, which comprises parts of the middle and upper Pleistocene alluvial deposits and latest Quaternary alluvial deposits, (2) unconsolidated sediment, which comprises the sedimentary deposits of Live Oak Canyon and parts of the middle and upper Pleistocene alluvial deposits, (3) consolidated sedimentary materials, which comprises deep subsurface sedimentary rocks and the San Timoteo Formation, and (4) crystalline basement, which comprises Mesozoic crystalline rocks and undifferentiated Tertiary sedimentary rocks of the San Andreas fault zone. The hydrogeologic units discussed in this chapter are identical to those discussed in chapter B and used in the HFM of Cromwell and Matti (2022). Sections through the HFM show (1) the hydrostratigraphic relation of the hydrogeologic units and faults simulated in the model and (2) the depth and perforated intervals of the USGS multiple-depth, monitoring-well sites (fig. A11; table A1.1).

The surficial materials unit ranges in thickness from about 30 to 300 ft, blankets the broad floor of the Yucaipa Valley, and is present in stream channels incised into underlying hydrogeologic units (figs. A10, A11). The surficial materials unit is generally above the water table, which is about 200 to 300 ft below land surface (bls) throughout much of the subbasin (fig. A11); therefore, the unit is unsaturated in most places. The surficial materials unit is characterized by a heterogeneous mixture of fine-, medium-, and coarse-grained sediment (fig. A12; Cromwell and Matti, 2022). The unconsolidated sediment unit comprises the principal basin-fill aquifer and are found across the Yucaipa subbasin. These materials range in thickness from about 600 to 1,500 ft in the Yucaipa Valley (Cromwell and Matti, 2022). Most wells in the subbasin are perforated in this hydrogeologic unit. The unconsolidated sediment unit is characterized by a heterogeneous mixture of fine-, medium-, and coarse-grained sediment (fig. A12; Cromwell and Matti, 2022). Median specific capacity is 21.2 gallons per minute per foot (gal/min/ft), with a range of 0.1–1,333 gal/min/ft based on data from 20 wells, as reported by Rewis and others (2006). Median specific capacity is 18.0 gal/min/ft, with a range of values from 4 to 36 gal/min/ft, as reported by Geoscience Support Services, Inc. (2014b). The unconsolidated sediment have an estimated permeability of 220 gallons per day per square foot (gal/d/ft^2; Dutcher and Fenzel, 1972).

In the Western Heights subarea, a layer of fine-grained material overlies the main aquifer system, forming a perched zone within the unconsolidated sediment unit (Moreland, 1970). Measured groundwater levels in USGS multiple-depth, monitoring-well site YVDA indicate a 200-ft downward vertical gradient in groundwater-level elevation between the shallowest well (YVDA5; perforated from 230 to 250 ft bls) and the next shallowest well (YVDA4; perforated from 440 to 460 ft bls). This substantial gradient indicates that YVDA5 is perforated within the perched zone (see "Long Term Trends in Groundwater Levels" or Mendez and others, 2018). Geophysical logs and drillers' lithologic descriptions for YVDA indicate that the depth of the fine-grained layer is about 270 ft bls at that location (Mendez and others, 2018). The depth of the fine-grained layer in the Western Heights subareas was previously estimated to be about 300 ft bls (Moreland, 1970).

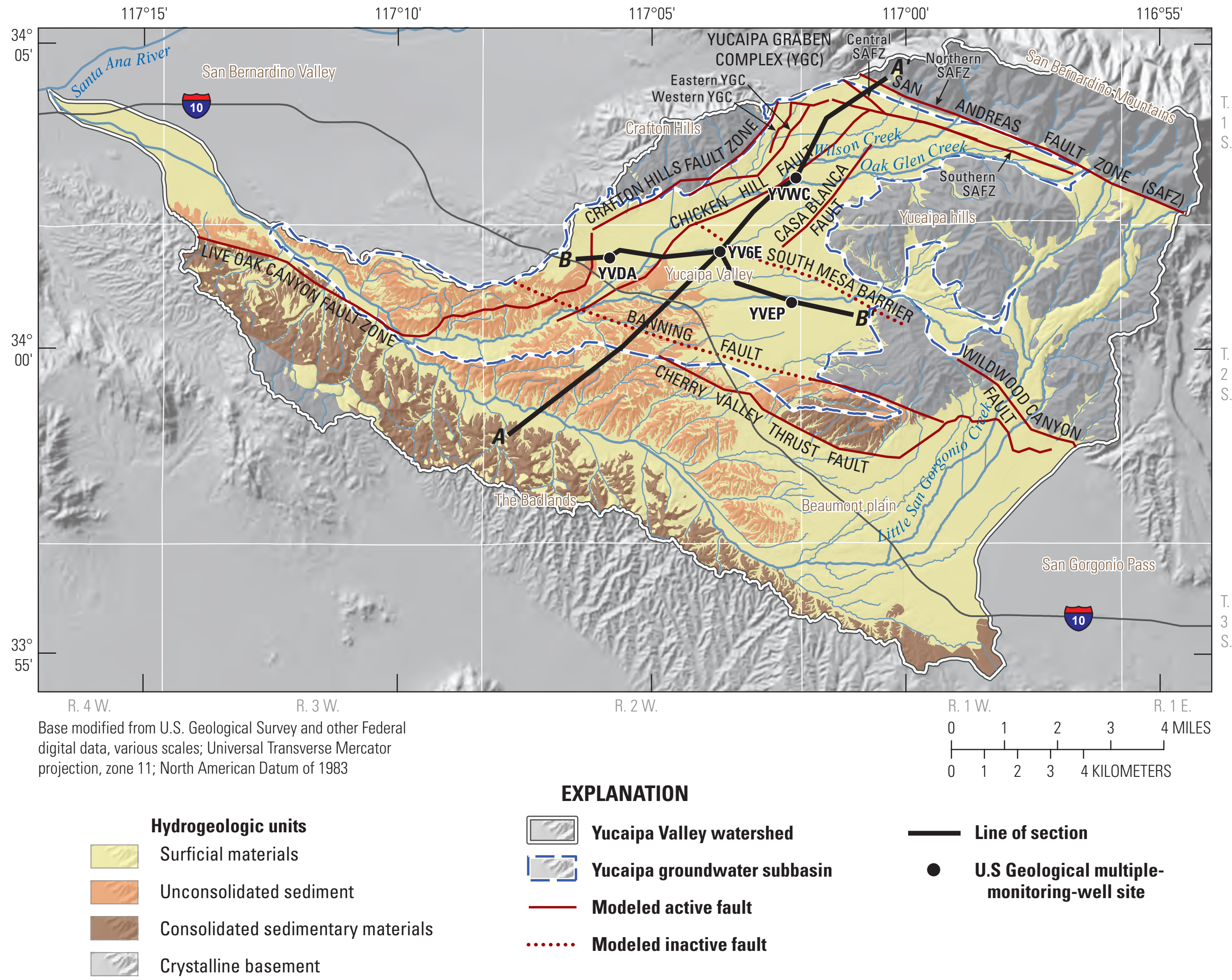


Figure A10. Hydrogeologic units and model faults used in the three-dimensional hydrogeologic framework model of the Yucaipa Valley watershed, San Bernardino and Riverside Counties, California (modified from Cromwell and Matti, 2022).

The consolidated sedimentary materials unit is exposed at land surface in The Badlands, where it dips to the north-northeast beneath the unconsolidated sediment and surficial materials; the unit also crops out in the hanging wall of the Cherry Valley thrust fault (fig. A10). The consolidated sedimentary materials are characterized by a relatively large percentage of fine-and medium-grained sediment (fig. A12; Cromwell and Matti, 2022) and have a relatively low estimated permeability of 5 gal/d/ft^2 (Dutcher and Fenzel, 1972), indicating that this unit has less readily available groundwater in storage. The estimated permeability value is from the “lower member of the San Timoteo Formation” (Dutcher and Fenzel, 1972); the approximate measurement location of this measurement is consistent with the San Timoteo Formation which corresponds to the consolidated sedimentary materials hydrogeologic unit used in this study. The substantial geographic exposure of this unit in The Badlands may provide moderate amounts of recharge.

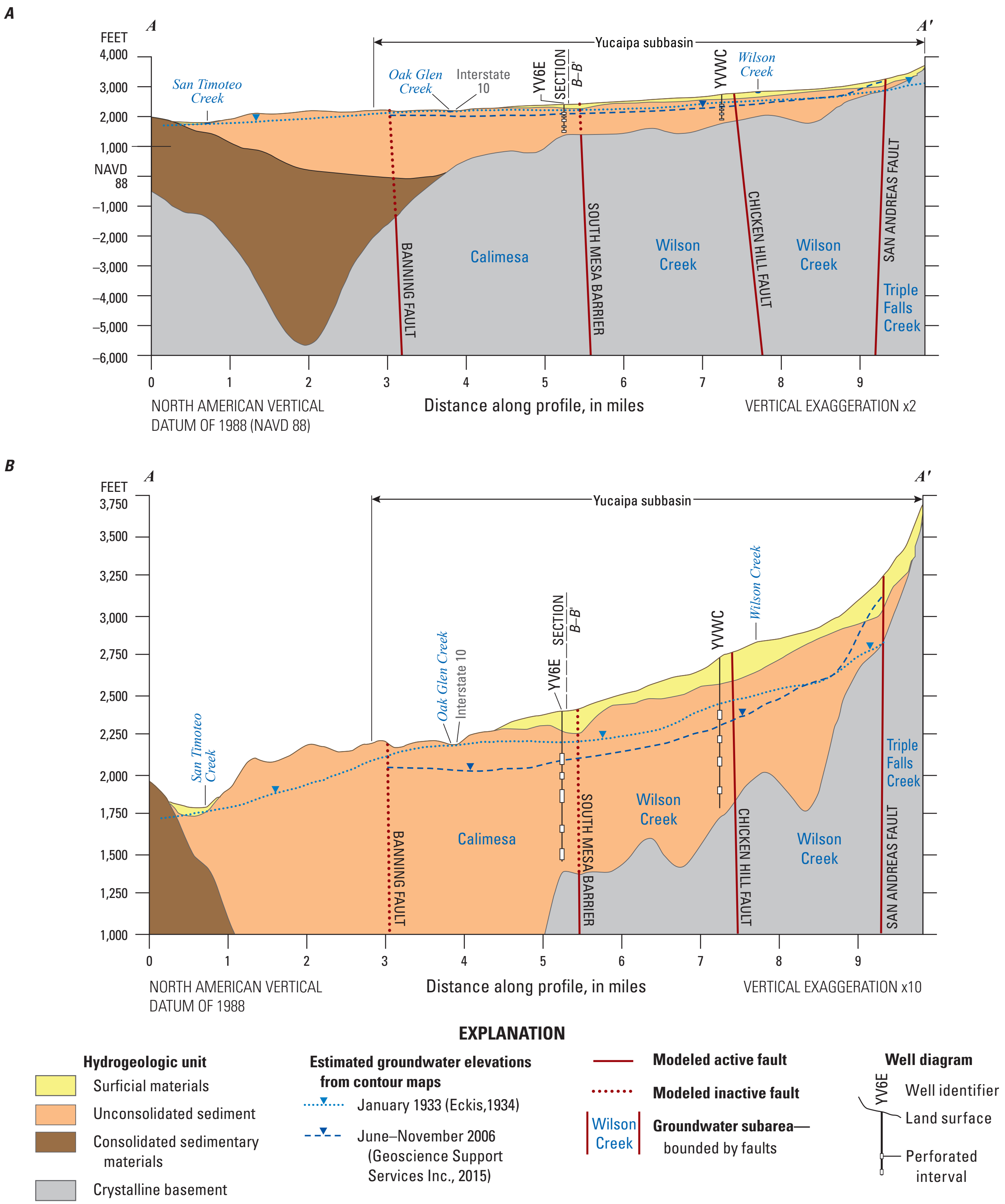


Figure A11. Sections through the three-dimensional hydrogeologic framework model of Cromwell and Matti (2022), Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Section lines are shown in figure A10. Sections show faults, subareas, and estimated groundwater levels from groundwater level contour maps for January 1933 (Eckis, 1934) and June to November 2006 (Geoscience Support Services, Inc., 2015). *A*, and *B*, southwest-northeast section; *C*, and *D*, west-east section. U.S. Geological Survey multiple-depth, monitoring-well sites with perforation intervals are shown.

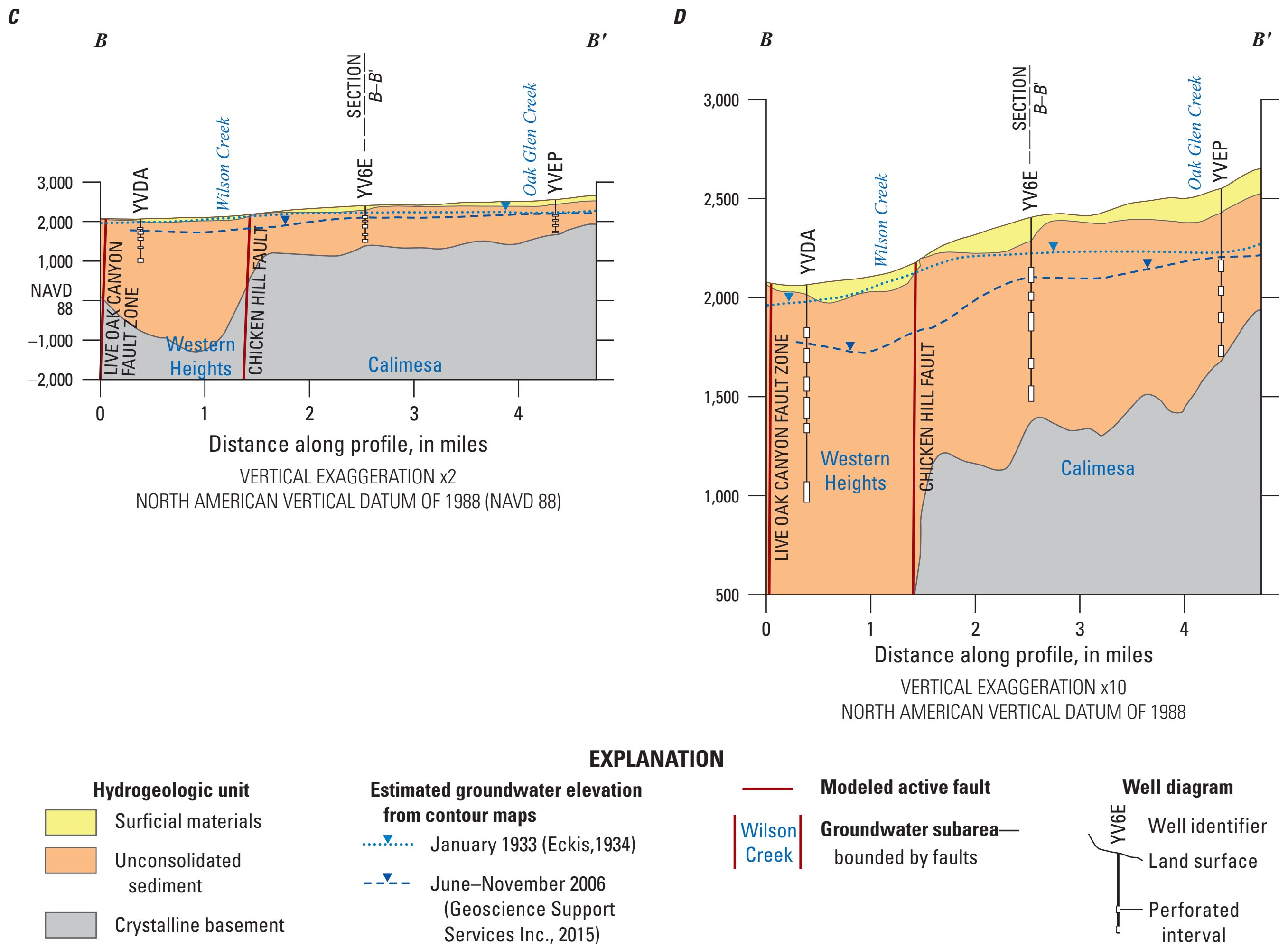


Figure A11.—Continued

Crystalline basement is exposed at land surface in the Crafton Hills, the Yucaipa hills, and the San Bernardino Mountains; and underlies the three younger hydrogeologic units (figs. A10, A11). Crystalline basement generally is faulted, fractured and weathered, in both surface outcrops and in the subsurface (Cromwell and Matti, 2022). This unit likely does not contain large volumes of groundwater; however, small-scale fractures, joints, and faults may provide conduits for transmitting recharge into the crystalline subsurface and then laterally into the sedimentary basin-fill deposits (Cromwell and Matti, 2022). The crystalline basement surface of the HFM in figure A11 is projected below the total depth of USGS multiple-depth, monitoring well sites YV6E and YVEP, despite the fact that, as noted earlier, electric logs, lithologic logs, and cores collected from the sites showed that they penetrated crystalline basement (Mendez and others, 2016). There are two reasons for this discrepancy: (1) the original gravity-derived depth-to-basement estimates for these well sites were lower than the observed depths of crystalline basement in the logs, likely due to the large amounts of fractured crystalline rock in the area (Mendez and others, 2016); and (2) the crystalline basement surface of the HFM was interpolated over a grid spacing that was three times coarser than the original gravity-derived, depth-to-basement estimates. Therefore, the crystalline basement surface is an approximation of the original estimates (Cromwell and Matti, 2022).

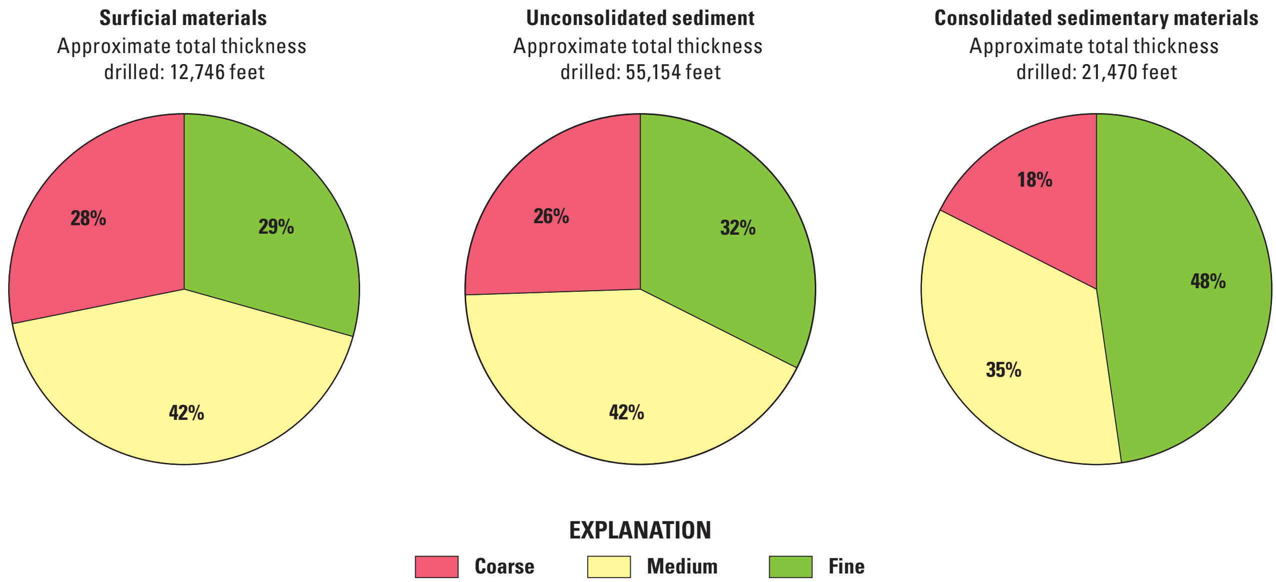


Figure A12. Frequency of the percentage of coarse-, medium-, and fine-grained materials in hydrogeologic units used in the three-dimensional hydrogeologic framework model of the Yucaipa Valley watershed, San Bernardino and Riverside Counties, California (Cromwell and Matti, 2022). Frequency values are normalized by the total thickness of boreholes that penetrate each hydrogeologic unit.

Faults and Flow Barriers

The HFM includes 13 faults that affect the structure of the Yucaipa subbasin and may be barriers to groundwater flow (fig. A10; Cromwell and Matti, 2022). The surface traces of these model faults are derived from the Quaternary faults and fold database of the United States (fig. A7; Moreland, 1970; Matti and others, 2003a, b, 2015; Nicholson and others, 2013, 2014; U.S. Geological Survey and California Geological Survey, 2016) and most faults were projected into the subsurface at near-vertical or vertical orientations (Cromwell and Matti, 2022). However, the Cherry Valley thrust fault and southern San Andreas fault were projected at dip-angles derived from their data sources. All faults, with the exception of the western segment of the Banning fault and the South Mesa barrier, were considered active faults and were modeled so that they cut across all hydrogeologic units. The western segment of the Banning fault and the South Mesa barrier were considered inactive and were modeled to only cross-cut crystalline basement (fig. A11). Activity along the western segment of the Banning fault predates deposition of the San Timoteo Formation and the sedimentary deposits of the Live Oak Canyon (Matti and others, 1985, 1992a, b, 2003a; Morton and Miller, 2006; Cromwell and Matti, 2022), and the hydrogeologic units that represent them; therefore, this segment of the Banning fault only cross-cuts crystalline basement. The South Mesa barrier is not recognized as an active fault in the Quaternary Fault and Fold Database of the United States (fig. A8; U.S. Geological Survey and California Geological Survey, 2016), and surface expression has not been identified at land surface (Moreland, 1970). Therefore, the South Mesa barrier was assumed to only offset the crystalline basement and not the overlying unconsolidated sediment or surficial materials (Cromwell and Matti, 2022).

Previous investigations have shown that faults in the Yucaipa subbasin affect groundwater flow in the basin-fill hydrogeologic units (Burnham and Dutcher, 1960; Moreland, 1970; Dutcher and Fenzel, 1972) based on vertical changes in groundwater levels across the faults. Faults can act as barriers to groundwater flow because of the presence of fine-grained sediment in the fault gouge, chemical cementation of proximal sediment, or the juxtaposition of layers across faults caused by either sharp folds or the vertical and (or) horizontal displacement of beds. The inactive faults—the inactive strand of the Banning fault and South Mesa barrier—are not interpreted to directly offset or juxtapose layers within the basin-fill hydrogeologic units. However, the inactive faults indirectly may cause thinning or pinching out of hydrostratigraphic layers that “drape” across structural crests in crystalline basement (fig. A11; Cromwell and Matti, 2022), potentially restricting the movement of groundwater (Reichard and others, 2003).

Aquifer Storage

Specific yield is one type of storage measurement that is used to characterize the capacity of an aquifer to release groundwater from storage. Specific yield is unitless and is defined as the ratio of the volume of water that a saturated unconfined aquifer will yield by gravity, compared to the total volume of the aquifer (Johnson, 1967). Specific yield throughout the Yucaipa subbasin was estimated to be about 0.06–0.10 (fig. A13; Eckis, 1934) from borehole lithology data 100 ft above and below the groundwater elevation in January 1933. Lesser specific yield values generally were observed in the southwestern part of the Yucaipa subbasin where the unconsolidated sediment crops out or are near land surface; lesser specific yield values generally also were observed in the northern part of the Yucaipa subbasin adjacent to the Crafton Hills and San Bernardino Mountains. Greater specific yield values generally were observed in the central part the Yucaipa subbasin, where surficial materials are observed at land surface and are as much as 200 ft thick (figs. A10, A11).

Changes in groundwater levels may affect estimates of specific yield because of changes in sediment grain size at different depths within the aquifer. Specific yield values based on historical groundwater levels may no longer be appropriate if groundwater levels have declined or risen substantially, as is the case in some parts of the Yucaipa subbasin. A comparison of the difference in the percentage of fine-, medium-, and coarse-grained sediment above and below groundwater elevations in January 1933 (Eckis, 1934) and fall 2006 (Geoscience Support Services, Inc., 2015) demonstrates how changes in specific yield can occur with groundwater-level variations. By the fall of 2006, groundwater levels in the Yucaipa subbasin had declined more than 100 ft since January 1933 in certain areas (fig. A13; see the "Groundwater Levels, Flow, and Movement" section chapter A of this report). In January 1933, boreholes in the Western Heights and Calimesa subareas showed that sediment within 100 ft of the groundwater table was generally fine and medium grained, and sediment in the Wilson Creek subarea was generally medium and coarse grained (fig. A13*A*).

In the fall of 2006, boreholes in the Western Heights and Calimesa subareas showed that sediment within 100 ft of the groundwater table was generally fine and coarse grained (fig. A13*B*). The increase in coarse-grained sediment in these subareas could result in greater specific yield estimates for fall 2006 relative to specific yield estimates for January 1933. Boreholes in the Wilson Creek groundwater subarea showed that sediment within 100 ft of the groundwater table was generally medium grained with a greater percentage of fine-grained sediment in some places. The relative increase in fine-grained sediment in this subarea could result in lesser specific yield estimates for fall 2006 relative to specific yield estimates for January 1933.

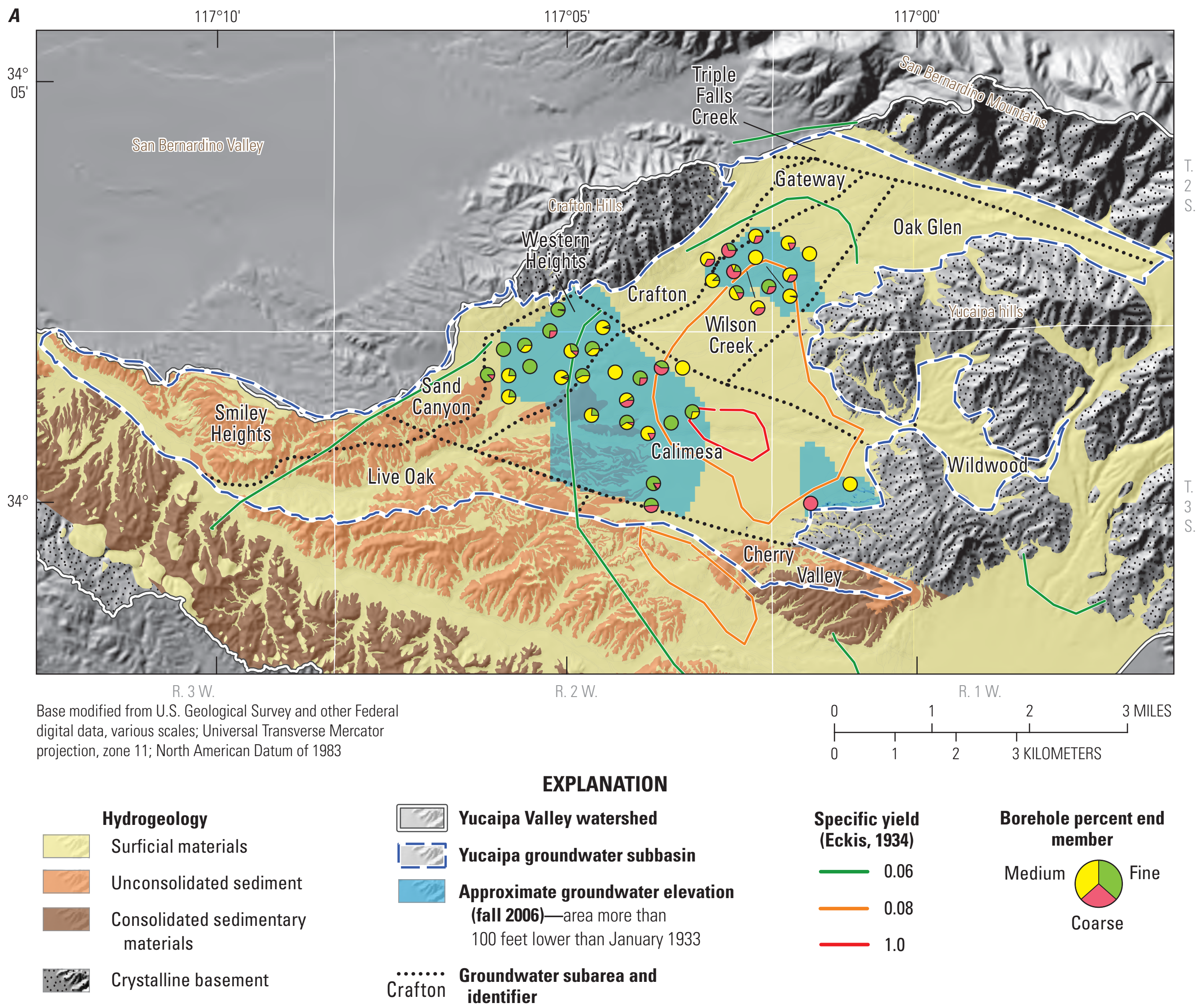


Figure A13. Specific yield of the Yucaipa groundwater subbasin from Eckis (1934) and the percentage of coarse-, medium-, and fine-grained materials in boreholes from within 100 feet above and below the groundwater elevation for *A*, January 1933 and *B*, fall 2006, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

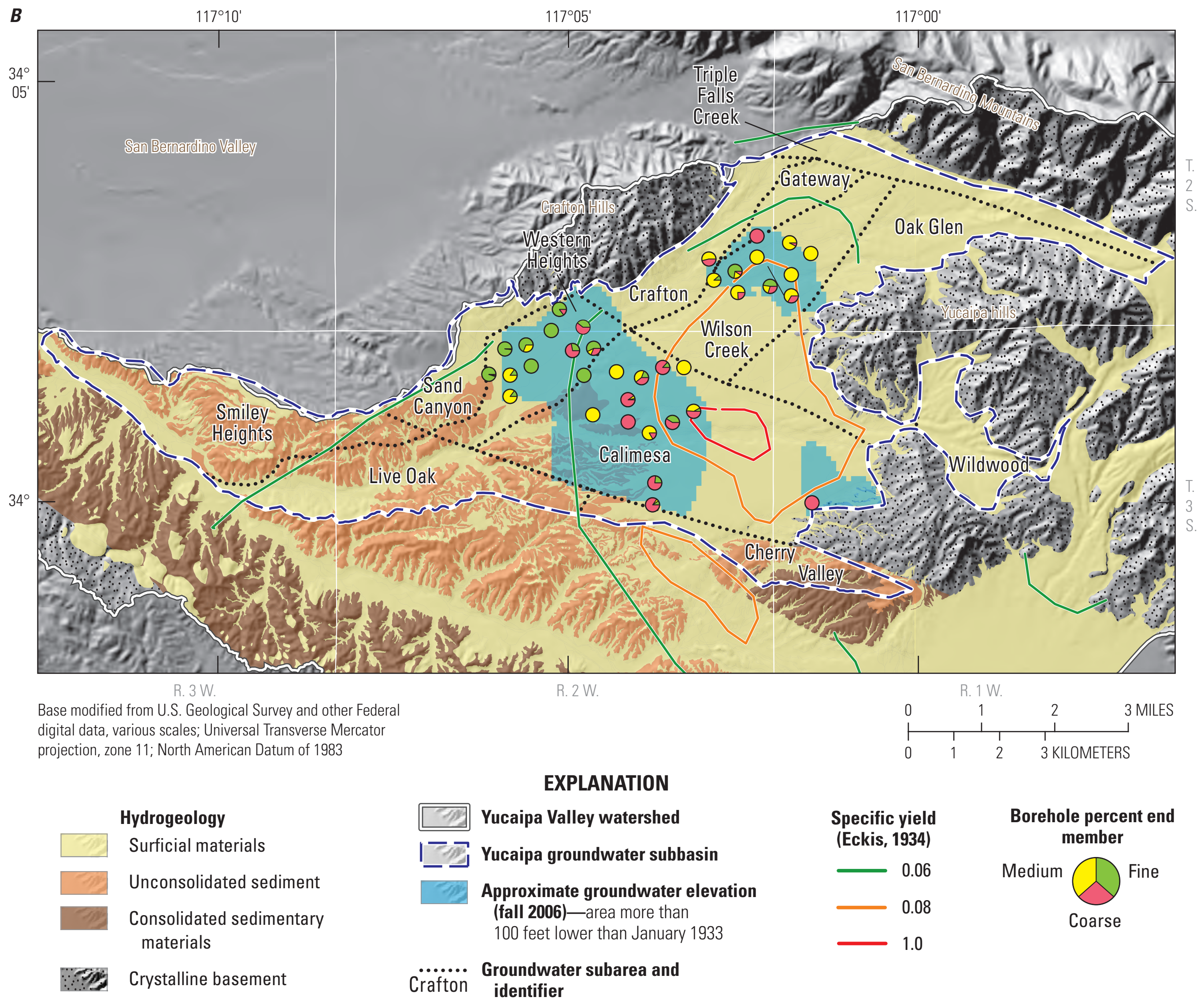


Figure A13.—Continued

Water Budget

The aquifer system of the Yucaipa subbasin is recharged from both natural and anthropogenic sources and is affected by the withdrawal of water primarily from groundwater pumpage. The contributions to and withdrawals from the aquifer system vary across the Yucaipa subbasin and vary through time. This section presents (1) sources and estimates of groundwater recharge and discharge in the Yucaipa subbasin; (2) historical levels, flow, and movement of groundwater across the Yucaipa subbasin; (3) long-term trends in groundwater levels for individual subareas; and (4) water chemistry information describing the chemical character, source, and age of groundwater in the Yucaipa subbasin.

Sources and Estimates of Recharge

Groundwater recharge to the aquifer system occurs from natural and anthropogenic sources and occurs in different quantities across the subbasin. Recharge to the basin-fill aquifer is the primary interest of this study because most groundwater is stored in and extracted from the sediments that comprise the basin-fill aquifer, not the underlying crystalline basement. Sources of natural recharge to the basin-fill aquifer include (1) mountain-front runoff and infiltration of streamflow that percolates below the root zone (known as deep percolation) as delivered by inflow from ephemeral streams, (2) deep percolation of precipitation, (3) subsurface inflow of groundwater from adjacent groundwater basins, and (4) underflow from the crystalline basement. Known and potential sources of anthropogenic recharge to the basin-fill aquifer include (1) application of water for managed aquifer recharge (MAR); (2) potential leakage of reservoirs and holding ponds; (3) infiltration of wastewater effluent from septic tanks; (4) irrigation return from agriculture, golf courses, parks, and residential landscaping; and (5) potential leakage from municipal water systems.

Natural Recharge

Sources of natural recharge to the basin-fill aquifer include (1) deep percolation of mountain-front runoff and infiltration of streamflow, (2) deep percolation of precipitation, (3) subsurface inflow from adjacent groundwater basins, and (4) underflow from the crystalline basement. Estimates of natural groundwater recharge in the Yucaipa subbasin have been reported by some previous investigators as values of available water supply or safe yield and range from about 7,000 to 13,300 acre-feet per year (acre-ft/yr; fig. A14*A*; Moreland, 1970; Mann, 1986; Todd, 1988; Mann and Todd, 1990; Geoscience Support Services, Inc., 2014a). The variability in these estimates likely resulted from different methods of calculation, different periods of investigation, and different areas of study; however, the wide variation in estimates provides a range in the potential amount of recharge that may occur under various conditions.

Mountain-Front Runoff and Infiltration of Streamflow

Water from deep percolation of mountain-front runoff as delivered by streamflow infiltration and surface streamflow infiltration are the main sources of natural recharge to the aquifer system. For 1979–2012, recharge from deep percolation of mountain-front runoff and surface streamflow infiltration was estimated to account for 53 percent of natural recharge, or about 4,500 acre-ft/yr (Geoscience Support Services, Inc., 2014a). Recharge from mountain-front runoff generally was from the Triple Falls Creek and Oak Glen subareas (adjacent to the San Bernardino Mountains), the Calimesa subarea (adjacent to the Yucaipa hills), and the Crafton subarea (adjacent to the Crafton Hills; Moreland, 1970). Mountain-front runoff usually was from flash-flood streamflow events; therefore, potential recharge may have been limited in some subareas (Moreland, 1970). Recharge from surface streamflow infiltration was primarily in the Wilson Creek subarea where Oak Glen Creek has a large drainage area (figs. A2, A15) and often has streamflow late into the summer months, particularly during years of above-average precipitation (Moreland, 1970). A relatively high percentage of medium- and coarse-grained sediment in the Wilson Creek subarea (fig. A13) likely allowed streamflow in Oak Glen Creek to infiltrate readily into the thick unsaturated zone and percolate to the aquifer system. Surface streamflow infiltration also resulted in recharge in the Calimesa subarea from Yucaipa Creek and other streams that feed into Yucaipa Creek (fig. A15), and from smaller streams flowing from the Yucaipa hills (Burnham and Dutcher, 1960). In the Western Heights subarea, the layer of fine-grained material at 270–300 ft bls may have limited the deep percolation of mountain-front runoff and surface streamflow infiltration to the aquifer system (Moreland, 1970).

Precipitation

Groundwater recharge from deep percolation of precipitation occurs across the Yucaipa subbasin. For 1979–2012, recharge from deep percolation of precipitation was estimated to account for 12 percent of natural recharge, or about 1,000 acre-ft/yr (Geoscience Support Services, Inc., 2014a). Depth-to-groundwater was generally greater than 100 ft, and was more than 300 ft deep in some subareas (fig. A11), which could infer that deep percolation from precipitation may be minimal in most subareas. Substantial recharge from precipitation probably is limited to the Triple Falls Creek and Oak Glen subareas, where average annual precipitation is greatest. In the Western Heights subarea, the layer of fine-grained material at 270–300 ft bls may limit infiltration of precipitation to the aquifer system (Moreland, 1970).

Subsurface Inflow

Subsurface inflow of groundwater from adjacent areas is a likely source of recharge to the Yucaipa subbasin. Groundwater generally flows from northeast to southwest through the Yucaipa subbasin (see “Long-term Trends in Groundwater Levels” section); therefore, subsurface inflow is likely across the San Andreas fault zone, at the base of the San Bernardino Mountains, and at the base of the Yucaipa hills (Eckis, 1934; Burnham and Dutcher, 1960; Moreland, 1970). Subsurface inflows are primarily in the Triple Falls Creek and Oak Glen subareas, where groundwater flows through saturated fractures and fissures in the crystalline basement hydrogeologic unit (Burnham and Dutcher, 1960; Moreland, 1970). For 1979–2012, recharge from subsurface inflow was estimated to account for 35 percent of natural recharge, or about 2,900 acre-ft/yr (Geoscience Support Services, Inc., 2014a).

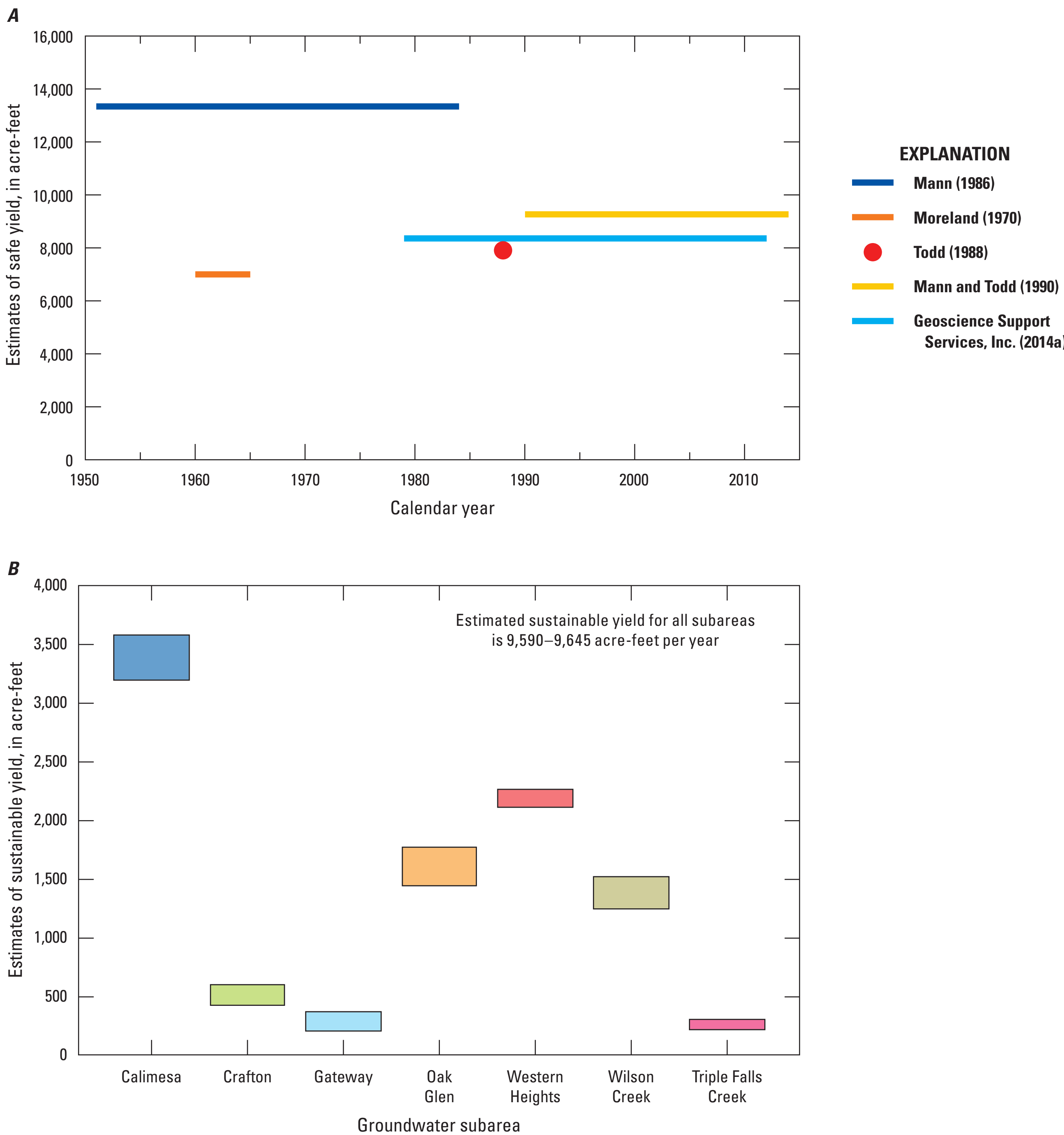


Figure A14. Estimates of *A*, safe yield to the Yucaipa groundwater subbasin and *B*, sustainable yield for groundwater subareas (Geoscience Support Services, Inc., 2014a), Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

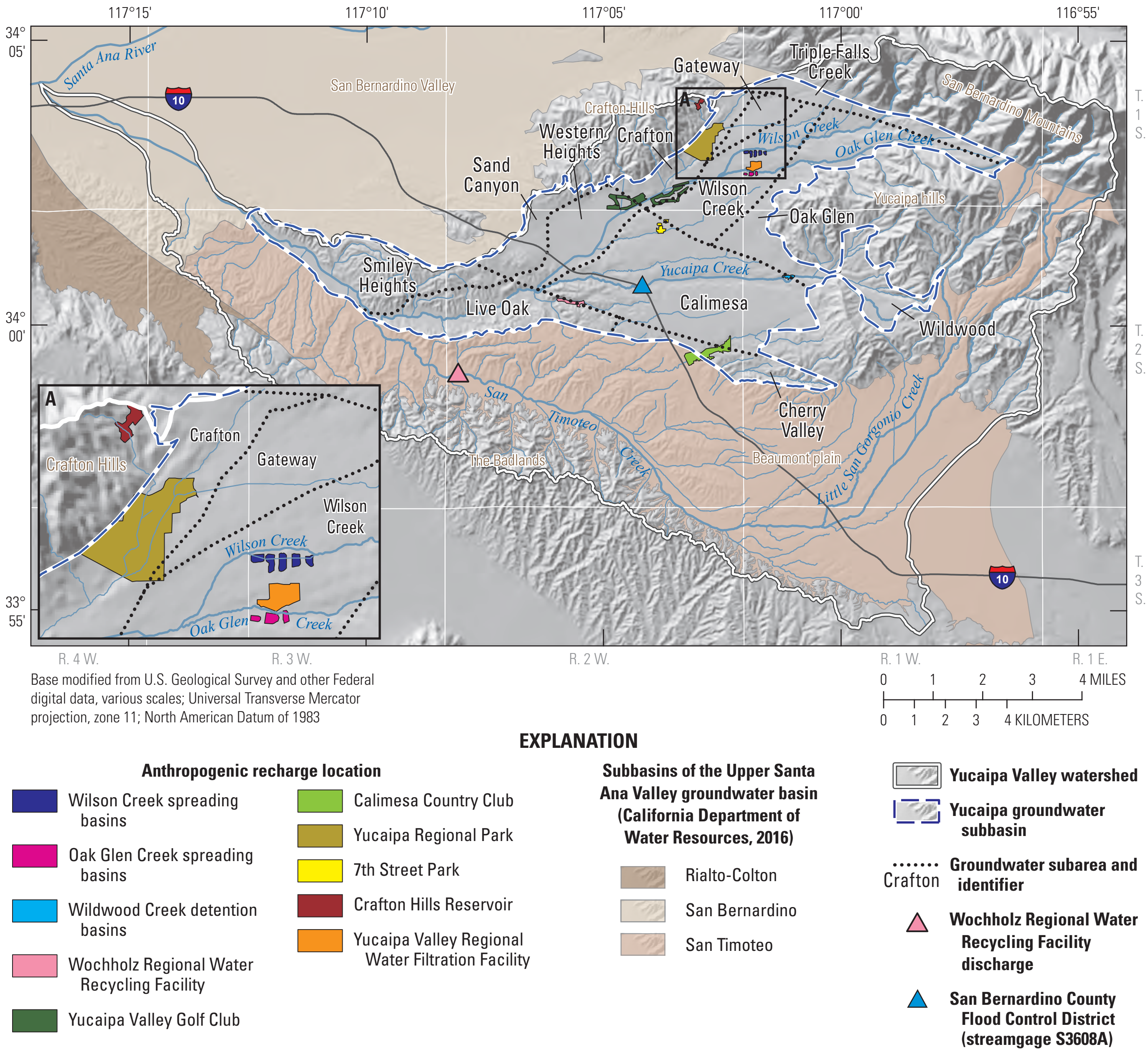


Figure A15. Locations of anthropogenic recharge in the Yucaipa groundwater subbasin, and in the adjacent San Timoteo, San Bernardino, and Rialto-Colton groundwater subbasins, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Anthropogenic Recharge

Sources of anthropogenic recharge to the basin-fill aquifer include (1) the application of water for MAR; (2) potential leakage of reservoirs and holding ponds; (3) infiltration of wastewater effluent from septic tanks; (4) irrigation return from agriculture, golf courses, parks, and residential landscaping; and (5) potential leakage from municipal water systems. The estimated quantity of potential recharge from these sources is generally an estimate of the amount of water applied at or lost near land surface. For example, Mills (2009) estimated a 50 percent loss of wastewater from septic-return flow because of evaporation and transpiration. The actual amount of infiltration to the basin-fill aquifer from these sources could be less because of losses from evaporation at or near land surface. The rate at which anthropogenic sources recharge the aquifer system is subject to travel time necessary for the water to migrate through the thick unsaturated zone to the groundwater table, which is affected by the hydrogeology of the subbasin. In the Western Heights subarea, the fine-grained perched layer may cause substantially longer travel times than in other parts of the Yucaipa subbasin.

Imported Water and Managed Aquifer Recharge

Water from northern California has been imported to the Yucaipa subbasin via the California State Water Project aqueduct since 2002 and has been distributed for many purposes. From 2002 to 2014, about 69,000 acre-ft of water was imported to the Yucaipa subbasin (A. Jones, San Bernardino Valley Municipal Water District, written commun., 2016; fig. A16). Imported water was stored in the Crafton Hills Reservoir and was (1) applied directly to the Wilson Creek and Oak Glen Creek spreading basins (fig. A15) for MAR via infiltration, (2) released as seepage to holding ponds in the Yucaipa Regional Park, and (3) used to augment the municipal-water and recycled-water supply for irrigation to golf courses, parks, and residential landscaping.

During 2002–14, a combined amount of about 18,000 acre-ft of imported water from northern California was applied to the Wilson Creek and Oak Glen Creek spreading basins, which were constructed originally as flood-control structures along Wilson and Oak Glen Creeks (fig. A15). Up to about 4,600 and 300 acre-ft/yr were applied at the Wilson Creek and Oak Glen Creek spreading basins, respectively (fig. A16; A. Jones, San Bernardino Valley Municipal Water District, written commun., 2016; B. Brown, Yucaipa Valley Water District, written commun., 2016). Additional recharge beyond direct application of imported water likely occurred at both MAR locations during large streamflow and precipitation events where surface water was captured in the spreading basins. For example, the Wilson Creek spreading basins have a diversion structure to capture water from Wilson Creek during such events. The amount of non-imported water captured at the spreading basins is generally not metered or reported, however, an estimated 1,220 acre-ft of water was captured at the Wilson Creek spreading basins in the 1958 water year (Moreland, 1970), during which time precipitation was slightly above average.

The Wildwood Creek detention basins along Yucaipa Creek (fig. A15) that were constructed in 2010 are sources of potential MAR. Water for MAR has not been applied regularly at these locations, but recharge may occur from inadvertent capture of surface water during large streamflow and precipitation events. The annual mean streamflow at SBCFCD streamgage S3608A, about 2.5 mi downstream from the Wildwood Creek detention basins along Yucaipa Creek (fig. A15), is about 30,000–67,000 acre-ft/yr (42–93 ft^3/s) for 2010–14 (fig. A6*E*). This range of streamflow could be considered the maximum potential quantity of water available to be captured at the Wildwood Creek detention basins.

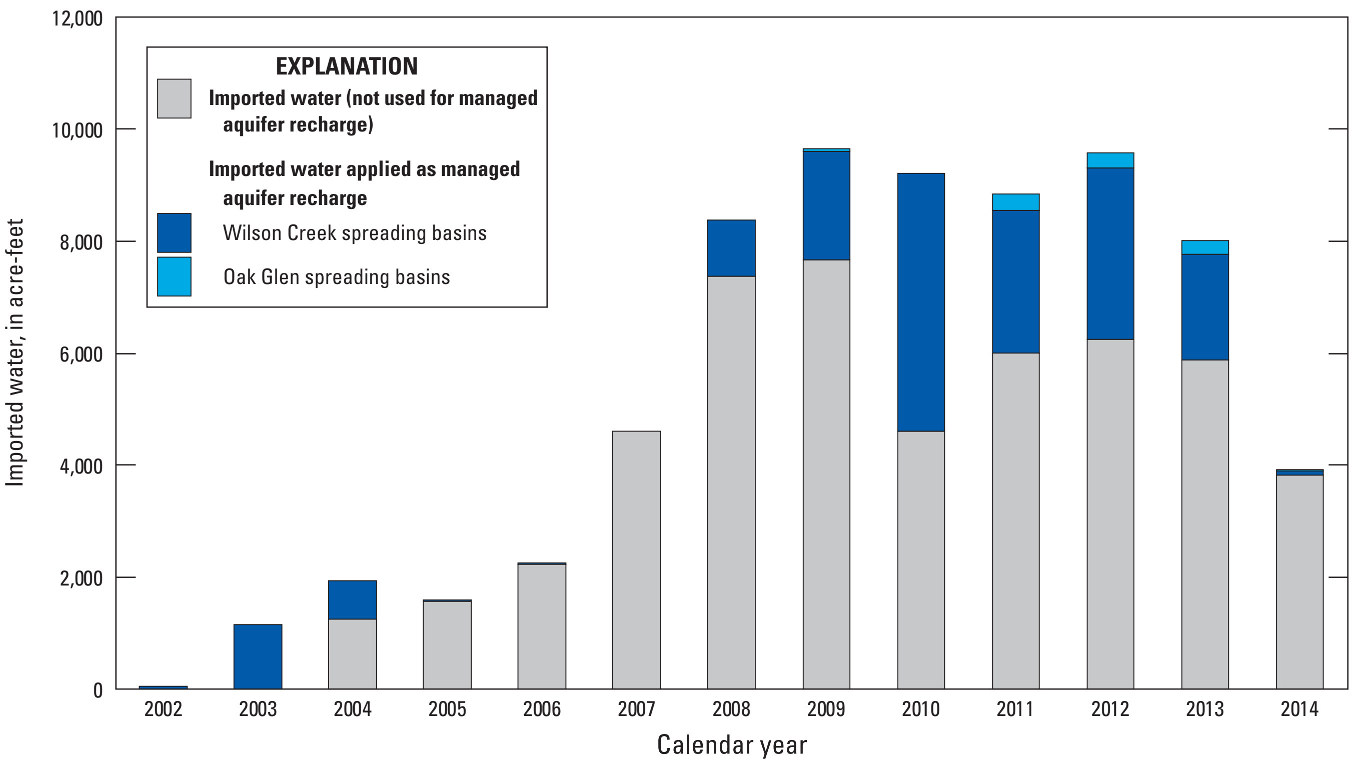


Figure A16. Reported quantity of imported water to the Yucaipa groundwater subbasin from northern California, 2002–14, Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Imported water released as seepage from the Crafton Hills Reservoir (fig. A15) helps maintain water levels in three holding ponds in Yucaipa Regional Park (not pictured in fig. A15) and is estimated to be about 80 acre-ft/yr (T. Wehling, California Department of Water Resources, written commun., 2020). These three holding ponds in the park were constructed in the 1990s and are used for recreation. In the holding ponds, clay and asphaltic liners prevent leakage, and drain blankets control seepage at the base of the dams (W. Huang, San Bernardino Valley Municipal Water District, written commun., 2020). Although these ponds were constructed to eliminate or minimize leakage, some recharge to the aquifer system may result from infiltration of water through cracks in the pond liners or from seepage through the drain blankets. The Crafton Hills Reservoir is unlined, and leakage directly from the reservoir may be an additional source of recharge.

Wastewater Effluent

Infiltration of wastewater effluent results from domestic septic systems and treatment facilities. Prior to 1986, septic systems were the primary method for disposal of residential wastewater effluent in the Yucaipa subbasin (Yucaipa Valley Water District, 2010). Since the construction of a sewer network in 1986, most wastewater from the Yucaipa Valley Water District (YVWD) sewer service area has been piped to the Wochholz Regional Water Recycling Facility. Treated wastewater is either discharged as effluent to San Timoteo Creek (fig. A15) or used to augment the recycled-water supply.

Since 1986, treated wastewater effluent from the Wochholz Regional Water Recycling Facility has been discharged to San Timoteo Creek, which is south of the Yucaipa subbasin (fig. A15); from 1986 to 2014, the amount of treated effluent discharged to San Timoteo Creek has ranged from about 100 to 4,200 acre-ft/yr, with an average of about 3,100 acre-ft/yr (K. King, Yucaipa Valley Water District, written commun., 2016). However, not all residences in the Yucaipa subbasin have been connected to the sewer system. In 2016, several areas, including much of the Western Heights subarea, used septic systems for disposal of wastewater effluent (J. Zoba, Yucaipa Valley Water District, written commun., 2017).

Estimates of infiltration of wastewater effluent from septic systems were calculated for 1950, 1970, 1990, 2000, and 2010. The spatial and temporal distribution of septic systems was estimated from land-use data for 1972 and 2014 (figs. A7, A17; Mitchell and others, 1977; LANDFIRE, 2014) and from the YVWD sewer network service area (fig. A17*B*; J. Zoba, Yucaipa Valley Water District, written commun., 2017). The quantity of discharge from septic systems was based on population estimates of the Yucaipa subbasin (table A1; U.S. Census Bureau, 1952; Manson and others, 2019) and an average septic-tank discharge of 70 gallons per day per person (gal/d/p; Umari and others, 1993).

The spatial distribution of septic systems for 1950 and 1970 (fig. A17*A*) was assumed to include all areas designated as “Developed” in the 1972 land-use map (fig. A7*A*). For years prior to 1986, we assumed that the entire population of the Yucaipa subbasin (table A1) used septic systems. The estimated quantity of discharge from septic systems for 1950 and 1970 was about 40 and 1,700 acre-ft, respectively.

The spatial distributions of septic systems for 1990, 2000, and 2010 (fig. A17*B*) were assumed to include (1) “Developed” areas in the 2014 (fig. A7*D*; LANDFIRE, 2014) land-use map that intersected areas designated as “Unavailable” in the 2016 YVWD sewer network service area and (2) “Developed” areas from the 2014 land-use map located outside of the 2016 YVWD sewer network service area (fig. A17*B*). After 1986, we assumed the use of septic systems was limited to those areas without access to the sewer network. For 2010, we estimated 4.5 percent of the estimated population of the Yucaipa subbasin (table A1) was using septic. This estimate was based on the overlap of the distribution of septic systems for 2014 (fig. A17*B*) with spatial population data for 2010 from Manson and others (2019). For the purposes of this calculation, we assumed that the same percentage of the population was using septic in 1990 and 2000. The estimated quantity of discharge from septic systems for 1990, 2000, and 2010 was about 130, 160, and 200 acre-ft, respectively.

Irrigation Return from Agriculture, Golf Courses, Parks, and Residential Landscaping

Irrigation return is the fraction of water that has been used to irrigate agriculture, grassy areas in golf courses, parks, and residential landscaping; is not consumed by evapotranspiration; and subsequently infiltrates to the aquifer system. The amount of water that is lost through evapotranspiration and does not infiltrate to the water table is considered consumptive use. The consumptive use associated with each type of irrigation was estimated based on the percentage of irrigated land, reference evapotranspiration, and crop coefficients. The methods used to estimate consumptive use and the magnitudes of these estimates are described in more detail in chapter B of this report.

Irrigation return from agriculture is water that has been applied to irrigate crops, is not consumed by the crops, and subsequently infiltrates to the aquifer system. Water for this type of irrigation is supplied from locally pumped groundwater. Recharge based on crop type and irrigation requirements in the Yucaipa subbasin was estimated using the calibrated YIHM; recharge estimates and the YIHM are discussed in more detail in chapter B.

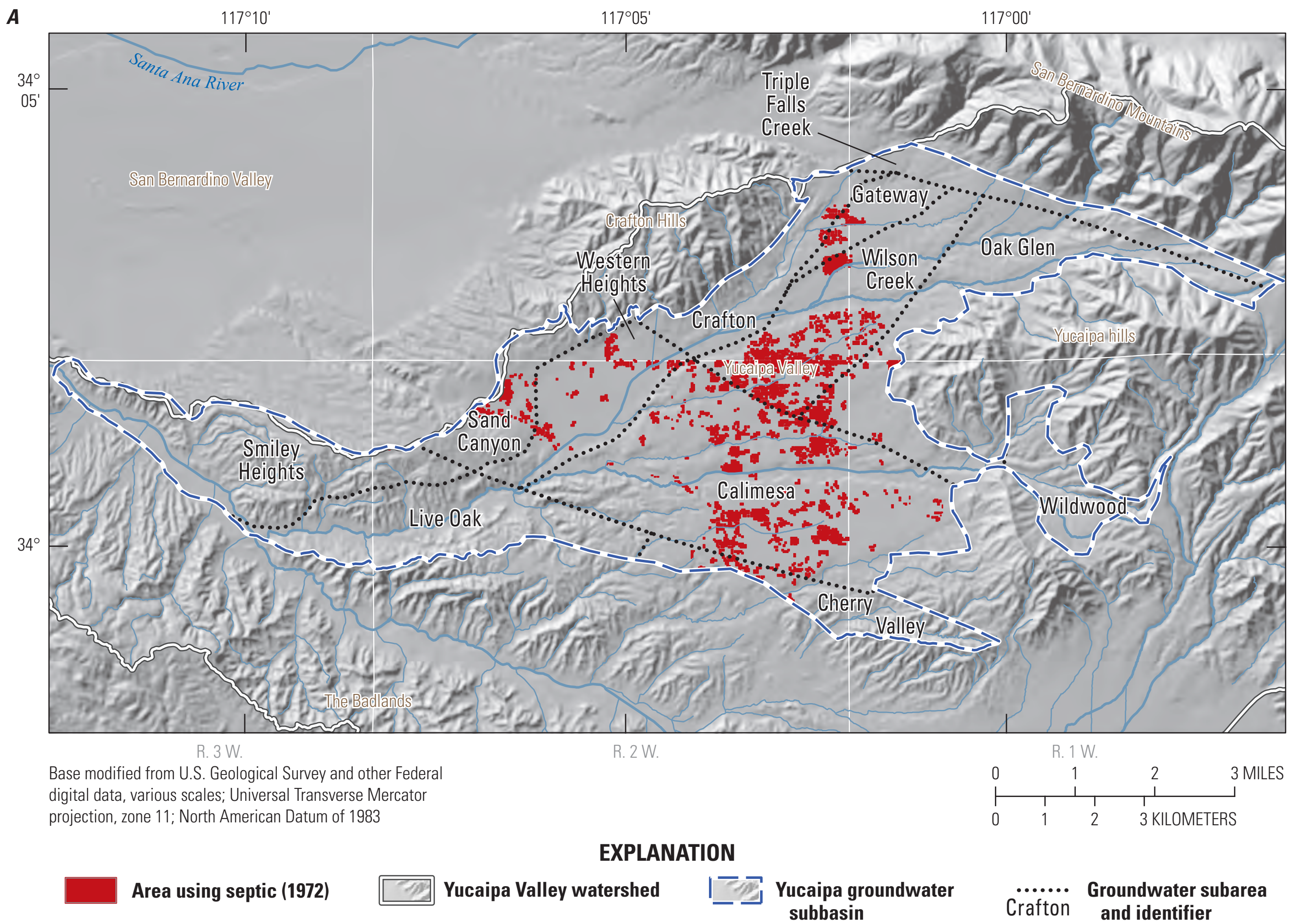


Figure A17. Estimated distribution of septic systems for *A*, 1972 and *B*, 2014, in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Irrigation return from golf courses, parks, and residential landscaping is water that has been applied to irrigate turf grass; is not consumed by the turf grass; and subsequently infiltrates to the aquifer system. Water for this type of irrigation is supplied from locally pumped groundwater and recycled water. Recycled water consists of untreated imported water from northern California, treated water from the Wochholz Regional Water Recycling Facility, or water from backwashing filters in water-treatment plants. The desired water demand of turf grass has been estimated to be about 4 acre-ft/yr per irrigated acre for golf courses (U.S. Golf Association, 2012) and about 1.6 acre-ft/yr of per irrigated acre for recreational-use at parks and residential landscaping (Hanak and Neumark, 2006). The amount of return flow from golf courses, parks, and residential landscaping was estimated to range from about 15 to 30 percent of total applied water at each location (Hardt and Hutchinson, 1980; Danskin and others, 2006; Water Systems Consulting, Inc., 2016).

The Yucaipa subbasin had two golf courses in operation during the study period (1947–2014)—Yucaipa Valley Golf Club and Calimesa Country Club (fig. A15). Yucaipa Valley Golf Club has been in operation since 1999, and Calimesa Country Club operated during 1958–2017. About 215 acre-ft of recycled water was applied at the Yucaipa Valley Golf Club for 2019 (J. Ares, Yucaipa Valley Water District, written commun., 2020), and an average of about 260 acre-ft/yr was applied at Calimesa Country Club during 2010–14.

Yucaipa Regional Park, which was been in operation since the late 1990s (Hanak and Neumark, 2006), and other smaller parks, such as the 7th Street Park in the Calimesa subarea, require irrigation to maintain turf grass for recreational use (fig. A15). During 2010–14, about 35 acre-ft/yr of recycled water was applied at 7th Street Park (J. Ares, Yucaipa Valley Water District, written commun., 2020). Residential landscaping also requires irrigation, but the locations and amounts of applied irrigation often are unavailable. In 2019, about 730 acre-ft of recycled water was applied as irrigation in Chapman Heights, a residential neighborhood at the base of the Crafton Hills that is adjacent to the Yucaipa Valley Golf Club. (J. Ares, Yucaipa Valley Water District, written commun., 2020).

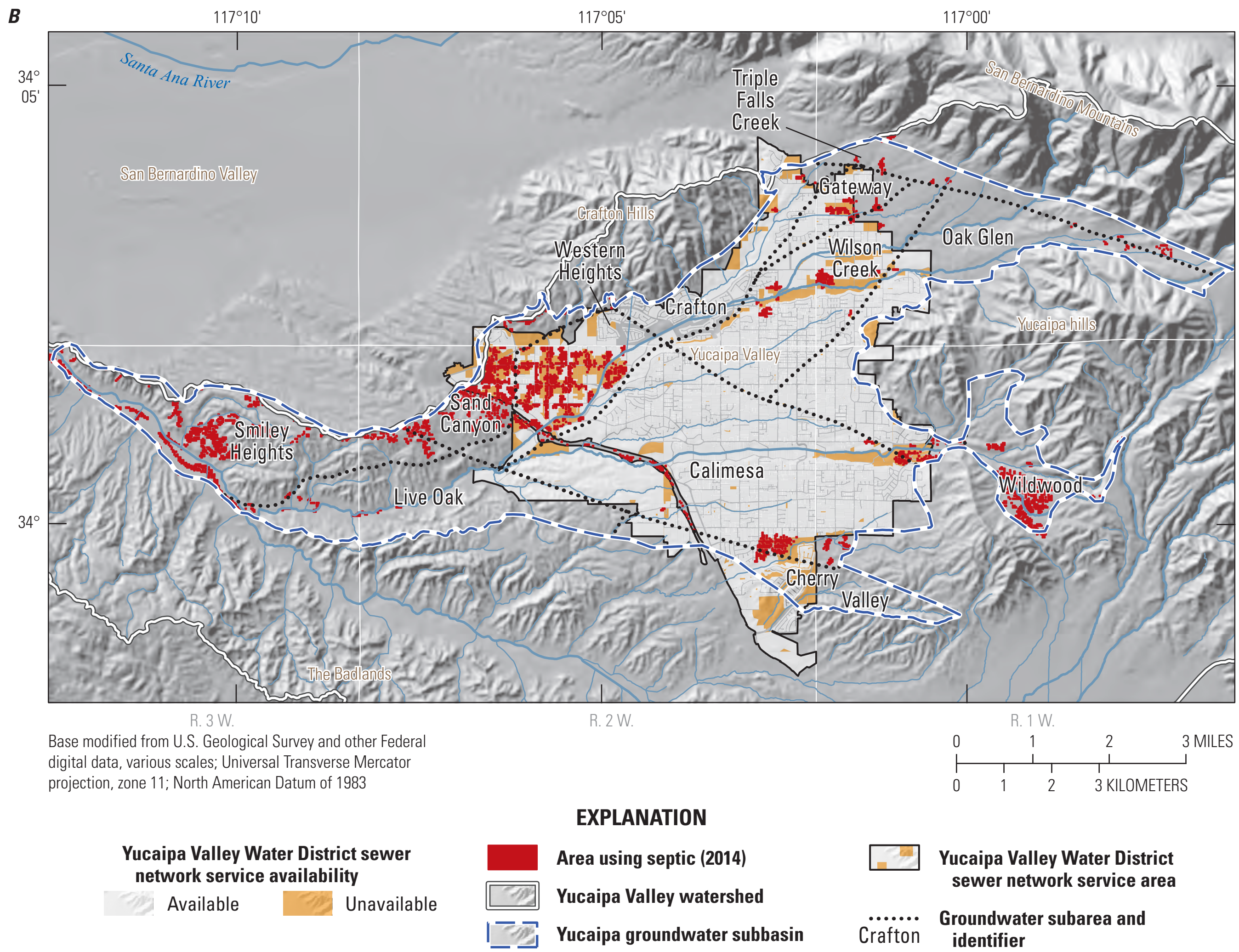


Figure A17.—Continued

Municipal Water Systems

Leakage from a municipal water system is water that was routed for domestic and municipal use that infiltrates to the aquifer system via leaks and cracks in the municipal piping infrastructure. The amount of return flow from leakage in the municipal-water system for the YVWD service area is estimated to range from about 5 to 10 percent of the total municipal water demand (Yucaipa Valley Water District, 2010; American Water Works Association, 2018).

Estimates and Sources of Discharge

Groundwater is discharged from the Yucaipa subbasin by three general mechanisms: (1) groundwater pumping for agricultural, municipal, and recreational uses; (2) groundwater evapotranspiration; and (3) subsurface outflow to adjacent areas. Pumpage, or anthropogenic discharge, is the main mechanism by which groundwater is removed from the Yucaipa subbasin.

Pumpage

Groundwater pumpage in the Yucaipa subbasin is used to meet water demands from four water-use sectors: residential, landscape, industrial and commercial, and agricultural. In the early 1900s, water was used mainly for fruit orchards and other crops (see the “Land Use” section). By the late 1940s to mid-1950s, the population increased, and water use shifted to satisfy mostly the residential water demand. By 2010, residential water use in the Yucaipa subbasin was about 77 percent of the total water demand, followed by landscape water use that accounted for about 15 percent of the total water use. Agricultural, industrial, and other water uses accounted for about 8 percent of total water use (Yucaipa Valley Water District, 2010).

Groundwater pumpage data were compiled from five sources. The primary source of pumpage information was from SBVMWD (A. Jones, San Bernardino Valley Municipal Water District, written commun., 2016), which provided annual pumpage data for private and municipal wells during 1947–2014. These data were supplemented by monthly and annual pumpage data from YVWD (B. Brown, Yucaipa Valley Water District, written commun., 2016), South Mesa Water Company (SMWC; D. Armstrong, South Mesa Water Company, written commun., 2016), Western Heights Water Company (WHWC; B. Brown, Western Heights Water Company, written commun., 2016), and Geoscience Support Services, Inc. (J. Yeh, Geoscience Support Services, Inc., written commun., 2018). Pumpage data compiled from YVWD, SMWC, and WHWC were considered more accurate overall than the pumpage data from SBVMWD because these sources (1) reported data monthly instead of annually, (2) sometimes had pumpage data for wells and time periods not in the SBVMWD dataset, and (3) often contained updated well names and California state well numbers. Pumpage data from Geoscience Support Services, Inc. were used to fill in missing data by well and month if data were absent in the other datasets. The locations of wells for which pumpage data were compiled are shown in figure A18. The quantities of total annual pumpage were compiled from these wells by groundwater subarea for the period 1947–2014 (fig A19; table A1.2).

During 1947–2014, groundwater pumpage ranged from about 4,000 to 18,500 acre-ft/yr, and the cumulative quantity of groundwater extracted by pumpage was almost 870,000 acre-ft/yr (fig. A19). From 1950 to 1985, groundwater pumpage ranged from about 10,000 to 14,000 acre-ft/yr. From 1986 to the mid-2000s, groundwater pumpage increased steadily from about 10,000 acre-ft/yr and culminated in a period of 8 years (2000–07) with annual pumpage exceeding 16,000 acre-ft/yr (fig. A19). From 2008 to 2013, annual groundwater pumpage was reduced, corresponding to deliveries of imported water of more than about 8,000 acre-ft/yr (figs. A16, A19).

Most of the groundwater pumpage occurred in the Calimesa subarea, accounting for about 35 percent of the total quantity of groundwater pumpage extracted in the Yucaipa subbasin, or about 4,500 acre-ft/yr. The Western Heights and Wilson Creek subareas accounted for about 20 and 16 percent of total pumpage, or about 2,500 and 2,000 acre-ft/yr, respectively. All other subareas accounted for less than about 6 percent of total pumpage each, or less than about 700 acre-ft/yr.

Evapotranspiration

Evapotranspiration (ET) is the combined water loss to the atmosphere from evaporation of surficial water and soil water and transpiration by plants. Evapotranspiration is a function of potential evapotranspiration (PET), water availability, soil texture, vegetation type, vegetation density, and root depth. Potential evapotranspiration is the rate of ET that is possible given an unlimited supply of soil water (California Irrigation Management Information System, 2005) under specific climatic conditions. If the water supply is limited, actual ET will be less than PET. Estimates of natural discharge from evapotranspiration for 1966–2016 and 1996–2015 were about 800 and 1,000 acre-ft/yr, respectively (Geoscience Support Services, Inc., 2017, 2018). The average PET rate and the total actual ET from the soil, unsaturated, and saturated zones were estimated as part of calibration of the YIHM using vegetation types and other land-use categories in land-use maps as shown in figure A7.

Subsurface Outflow

Subsurface outflow to adjacent groundwater basins is a source of natural discharge from the Yucaipa subbasin. Groundwater generally flows from north and east to south and west through the Yucaipa subbasin. Therefore, subsurface outflow is likely (1) across the northwestern margin of the Yucaipa subbasin west of the Triple Falls Creek groundwater subarea, between the Crafton Hills and San Bernardino Mountains; and (2) across the western margin of the Yucaipa subbasin, southwest of the Crafton Hills toward the Santa Ana River and into the San Bernardino groundwater subbasin (fig. A15). For 1955, subsurface outflow across the northwestern margin of the subbasin was estimated to be about 2,000 acre-ft/yr (Dutcher and Burnham, 1959). For 1905–2014, subsurface outflow across the western margin was estimated to range from about 2,400 to 20,000 acre-ft/yr (fig. A20; Gleason, 1947; Burnham and Dutcher, 1960; Dutcher and Fenzel, 1972; Danskin and others, 2006; Geoscience Support Services, Inc., 2009, 2017). Results of early and recent studies were combined in figure A20 to demonstrate a general decrease in estimated subsurface flow that likely can be attributed to a steady decline in groundwater levels in the Yucaipa subbasin caused by pumpage (Dutcher and Fenzel, 1972; Danskin and others, 2006; see also the "Long-term trends in Groundwater Levels" section). However, some variability in these estimates likely results from different methods of calculation, different periods of investigation, and different areas of study along the western margin.

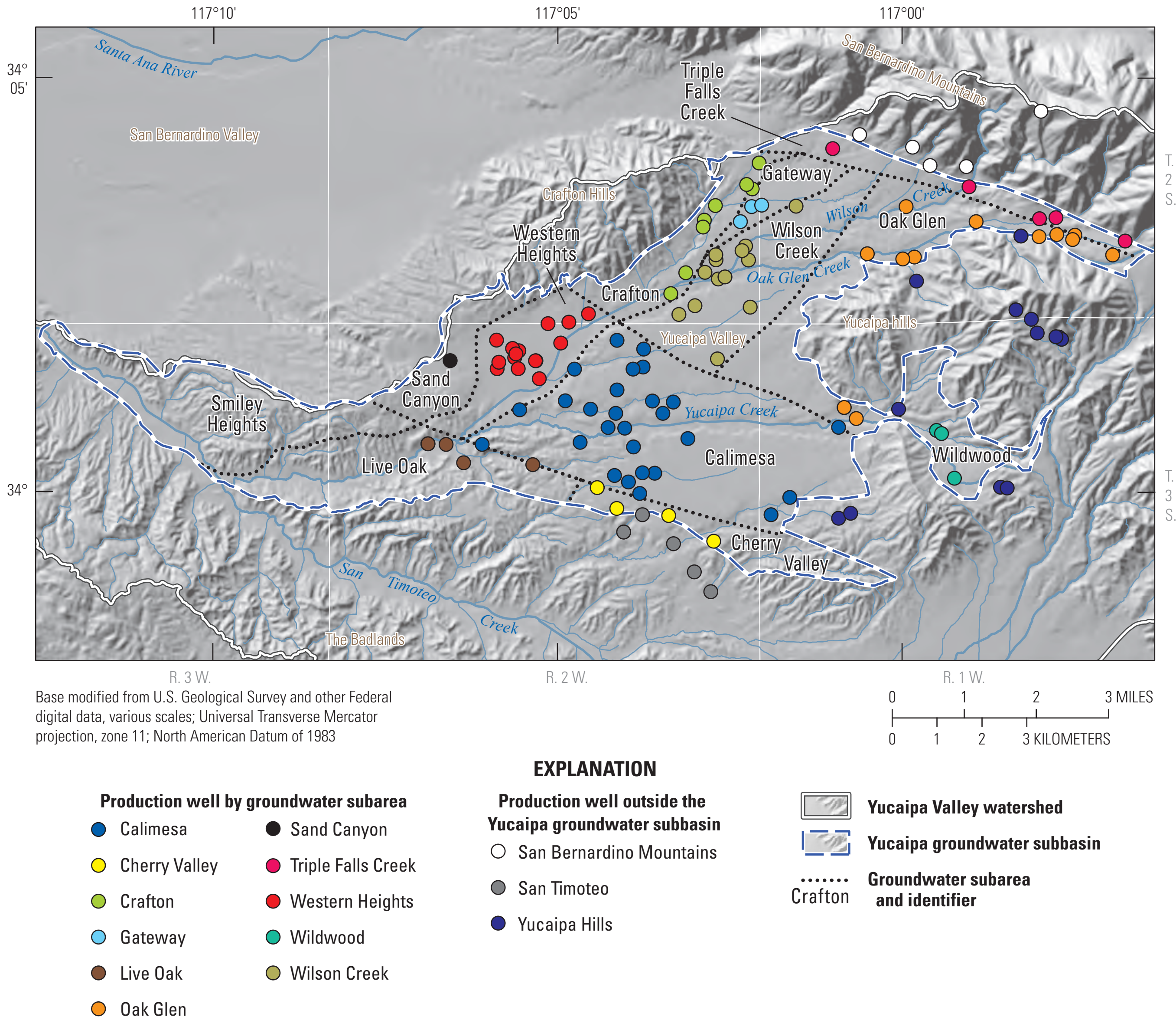


Figure A18. Wells with reported groundwater pumping information in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

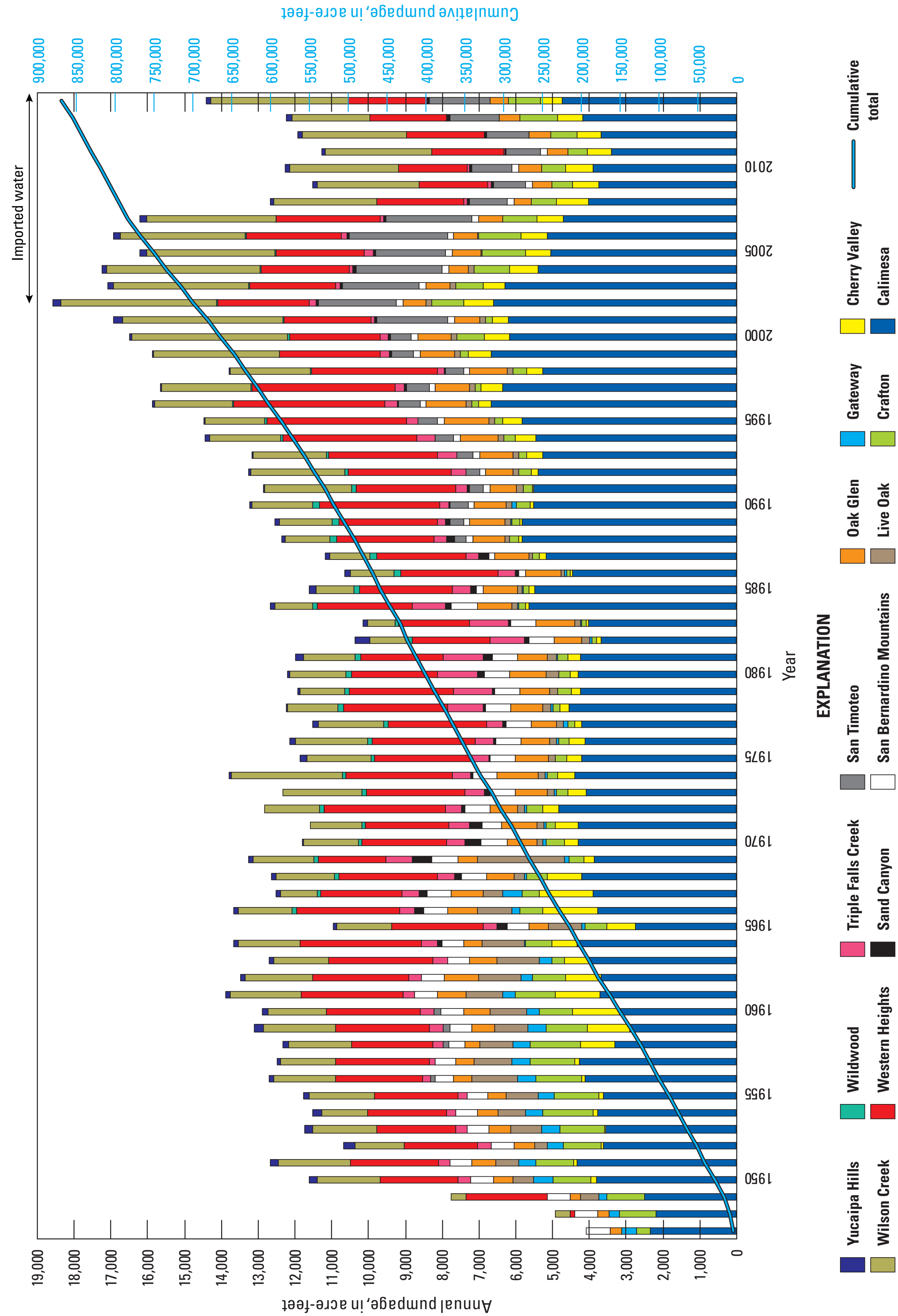


Figure A19. Reported annual groundwater pumpage by groundwater subarea and total cumulative pumpage for the period 1947–2014 in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

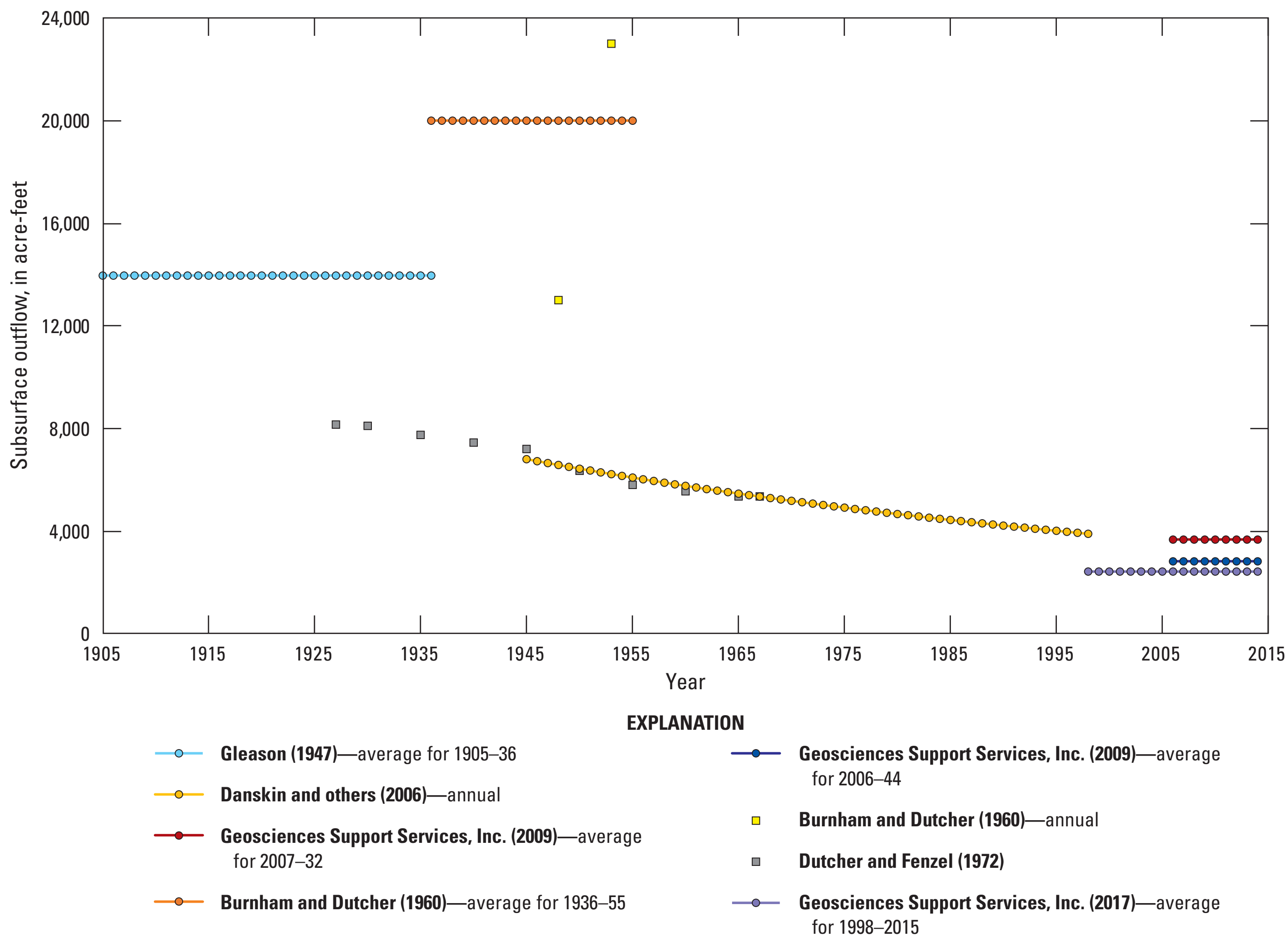


Figure A20. Estimates of subsurface outflow across the western margin of the Yucaipa groundwater subbasin to the San Bernardino groundwater subbasin, for 1905–2014, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Groundwater Levels, Flow, and Movement

The long-term reliance on groundwater in the Yucaipa subbasin for agricultural and municipal use caused a substantial decline in the depth of groundwater starting in the early 1900s followed by a modest recovery resulting from recent MAR and deliveries of imported water. In general, most groundwater in the Yucaipa subbasin originates as recharge from deep percolation of mountain-front runoff as delivered by streamflow infiltration from the San Bernardino Mountains and Yucaipa hills that flows west-southwest toward San Timoteo Creek (fig. A21). This general direction of groundwater flow was the same during natural conditions (pre-1900s), early development (about 1900–45), and post-World War II development (about 1945–2014). Although local changes in the direction of groundwater flow have occurred within the different subareas as a result of varying amounts and locations of natural recharge and anthropogenic recharge, pumpage has been the primary influence of groundwater-flow direction.

Historically, springs and small areas of peaty land were present in the Western Heights subarea at the mouth of Live Oak Canyon (Mendenhall, 1905) and near the Sand Canyon subarea at the top of Reservoir Canyon (fig. A21*A*) crossing into the San Bernardino Valley (Burnham and Dutcher, 1960). The presence of springs and peaty land in the Western Heights subarea is coincident with northeasterly dipping beds of the (now called) sedimentary deposits of Live Oak Canyon, which were interpreted to inhibit groundwater flow, causing groundwater to rise to the surface (Mendenhall, 1905). From 1895 to 1900, several wells drilled in the Western Heights and Sand Canyon subareas were artesian (Mendenhall, 1905). Other springs were present at the mouth of and in the Calimesa subarea along the Chicken Hill fault (Burnham and Dutcher, 1960; Moreland, 1970) and at the mouth of Wildwood Canyon (fig. A4) in the southeastern part of the Oak Glen subarea (Burnham and Dutcher, 1960).

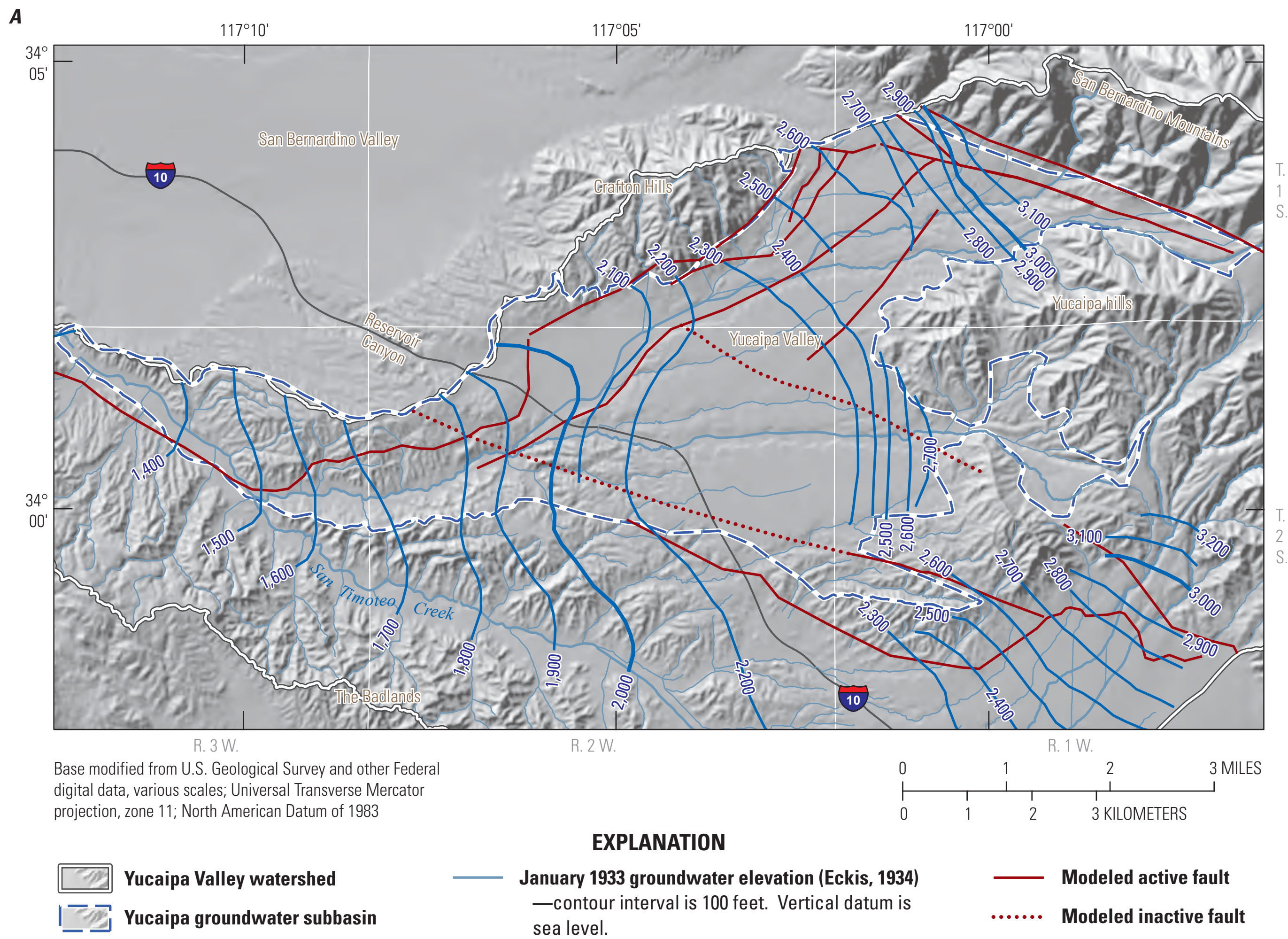


Figure A21. Groundwater elevations in the Yucaipa groundwater subbasin for *A*, January 1933 (Eckis, 1934); *B*, 1967–68 (Moreland, 1970; Bloyd, 1971; Dutcher and Fenzel, 1972); *C*, June–November 2006 (Geoscience Support Services, Inc., 2015); and *D*, June–November 2014 (Geoscience Support Services, Inc., 2015).

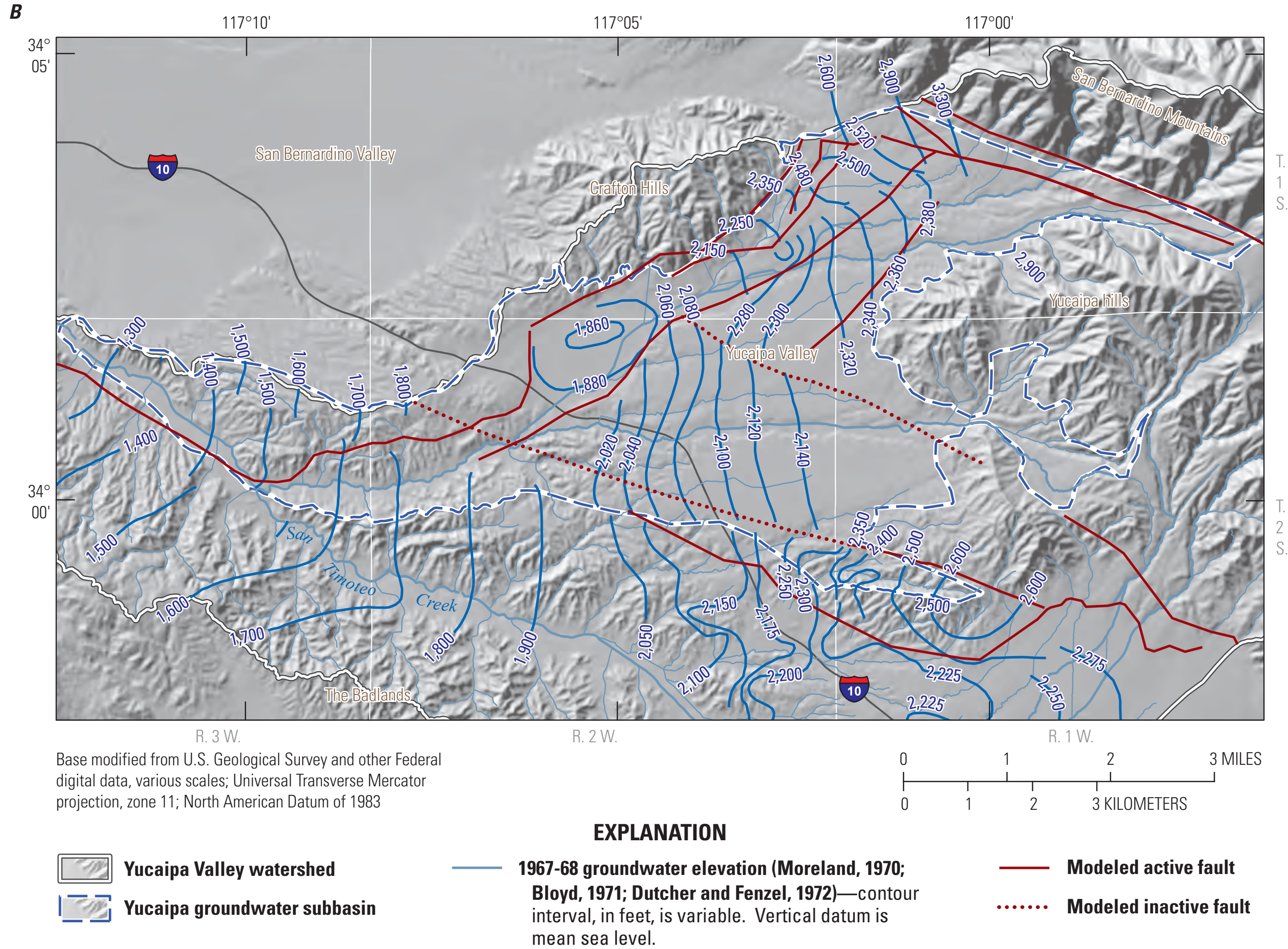


Figure A21.—Continued

The expansion of agriculture in the early 1900s and the subsequent increase in pumpage eventually lowered the groundwater table throughout the Yucaipa subbasin and caused the springs along the faults and artesian wells in the Western Heights and Sand Canyon subareas to go dry (Moreland, 1970). A regional groundwater map was produced for the greater Los Angeles area for January 1933 including the Yucaipa subbasin (fig. A21*A*; Eckis, 1934). Groundwater elevations for January 1933 ranged from higher than 3,100 ft in the northeastern part of the Yucaipa subbasin near the San Bernardino Mountains, to about 1,300 ft along San Timoteo Creek at the western end of the Yucaipa subbasin. Groundwater elevations adjacent to the San Bernardino Mountains and Yucaipa hills sloped steeply to the southwest and were above land surface in Oak Glen Creek (referred to as Live Oak Creek by Eckis [1934]) and other streams in the northeast part of the Yucaipa subbasin (Eckis, 1934). In the Western Heights subarea, groundwater was observed at land surface, indicating that the groundwater table had not yet been lowered below land surface by 1933 (Eckis, 1934).

The gradual decline of groundwater levels in the Yucaipa subbasin continued into the post-World War II development boom that started in about 1945. By the late 1960s, increases in pumpage in response to population growth exceeded most estimates of recharge (figs. A14, A19), which resulted in local changes in the direction of groundwater flow and a decline of groundwater levels in some subareas (fig. A21*B*). The direction of groundwater flow in the Yucaipa subbasin had the same general character from January 1933 (fig. A21*A*) through the 1960s (fig. A21*B*). Groundwater elevations during 1967–68 ranged from higher than 3,300 ft near the San Bernardino Mountains to less than 1,300 ft along San Timoteo Creek at the western end of the Yucaipa subbasin. Groundwater elevations were compiled for 1968 from Moreland (1970) for the central and northern part of the Yucaipa subbasin, for 1967 from Bloyd (1971) for the area south and east of the Yucaipa subbasin, and for spring 1967 from Dutcher and Fenzel (1972) for the area south and west of the Yucaipa subbasin. Overall maximum and minimum groundwater levels across the Yucaipa subbasin

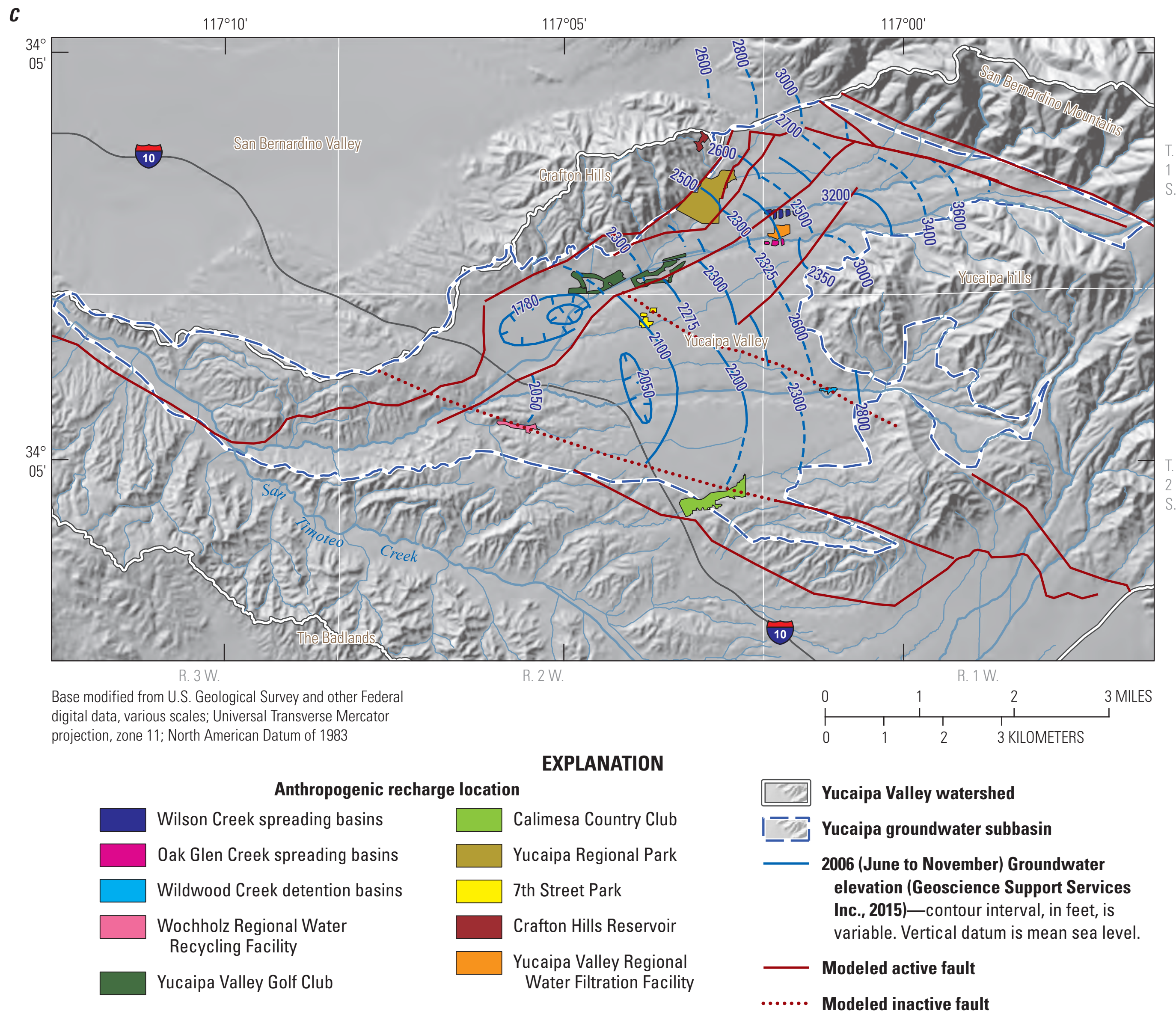


Figure A21.—Continued

were similar to those in January 1933, but groundwater levels declined from about 100 to 200 ft in the Gateway, Wilson Creek, Calimesa, and Western Heights subareas as a result of pumping. Notable pumping depressions occurred in the Wilson Creek and Western Heights subareas (fig. A21*B*).

Groundwater pumpage increased steadily from 1986 to the mid-2000s, culminating in a period of 8 years (2000–07) with the most annual pumpage during the period of record (fig. A19). Groundwater elevations in the Yucaipa subbasin during June–November 2006 (Geoscience Support Services, Inc., 2015) indicated additional decline in groundwater elevations since 1967–68 and more pronounced pumping depressions in the Western Heights and Calimesa subareas (fig. A21*C*). Since 1967–68, groundwater elevations declined about 50–200 ft, mostly in the Western Heights and Calimesa subareas.

During June–November 2014, groundwater elevations in the Yucaipa subbasin indicated that the direction of regional groundwater flow had the same general regional trends as previous years (fig. A21*D*; Geoscience Support Services, Inc., 2015). Groundwater elevations declined in some parts of the Yucaipa subbasin but remained near or were higher than levels in 2006 in subareas that received imported water. The introduction of imported water corresponded to a decrease in groundwater pumping, especially after 2007, when deliveries of imported water exceeded about 8,000 acre-ft/yr (figs. A16, A19); the combination of this additional source of water and

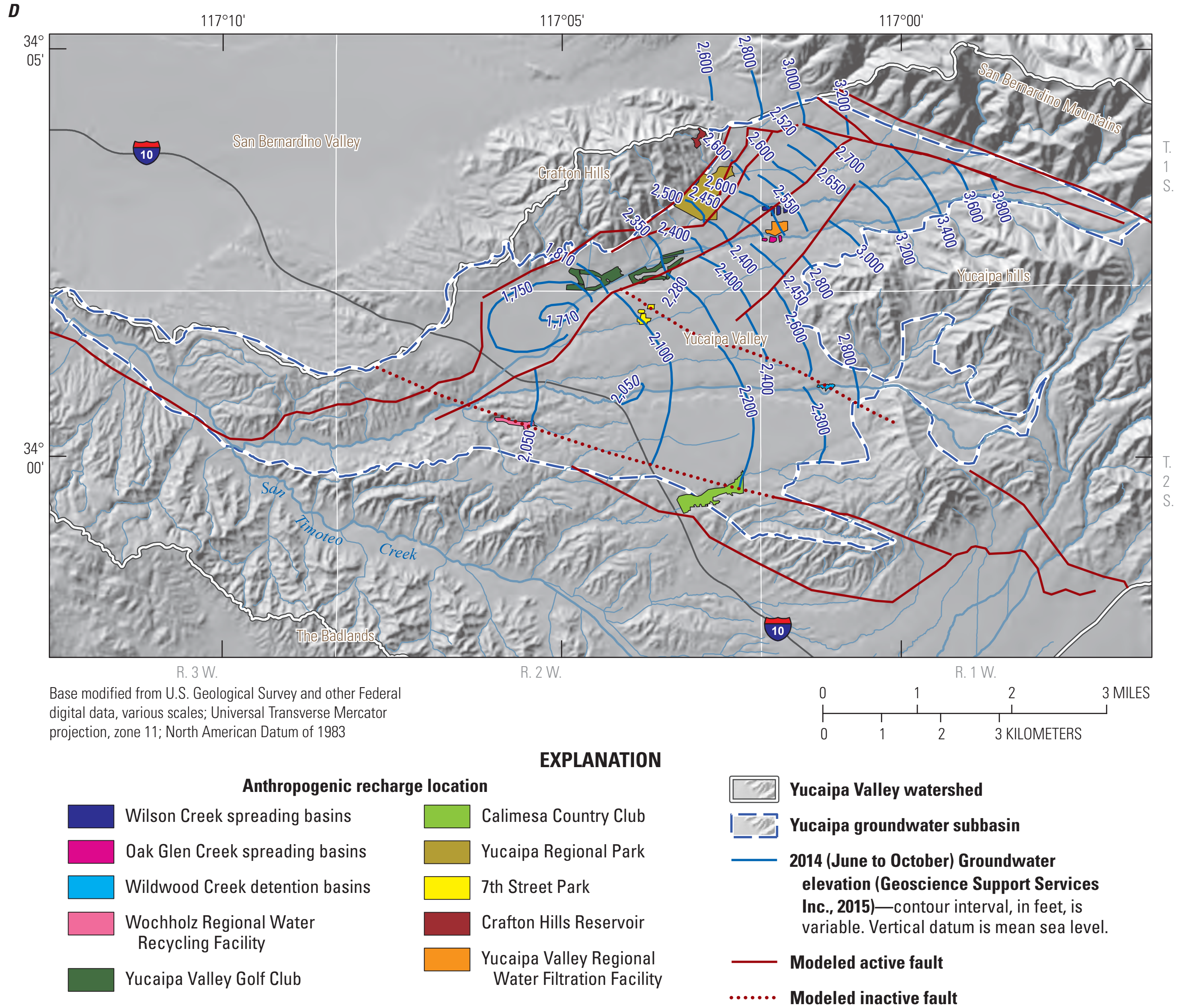


Figure A21.—Continued

a decrease in pumping caused the groundwater elevations to rise by as much as 200 ft since about 2006 in the Wilson Creek subarea (figs. A21*C*, A21*D*).

Long-term Trends in Groundwater Levels

Long-term groundwater-level data from individual wells with multiple measurements can provide insights about how stresses on the aquifer system affect groundwater levels through time. The historical data available in the Yucaipa subbasin document the long-term trends in groundwater levels throughout the Yucaipa subbasin, and the data were used to evaluate hydrologic differences among subareas, the effects of long-term pumping, the effects of MAR water, and potential hydrologic barriers to groundwater flow. Long-term hydrographs were constructed for wells throughout the Yucaipa subbasin with groundwater-level data spanning the periods 1947–2014 (figs. A22, A23; table A1.1; U.S. Geological Survey, 2018) and 1998–2014 (fig. A24; table A1.1; U.S. Geological Survey, 2018). To show trends throughout the longest possible period, groundwater-level data from nearby wells of similar construction were combined on the same hydrographs.

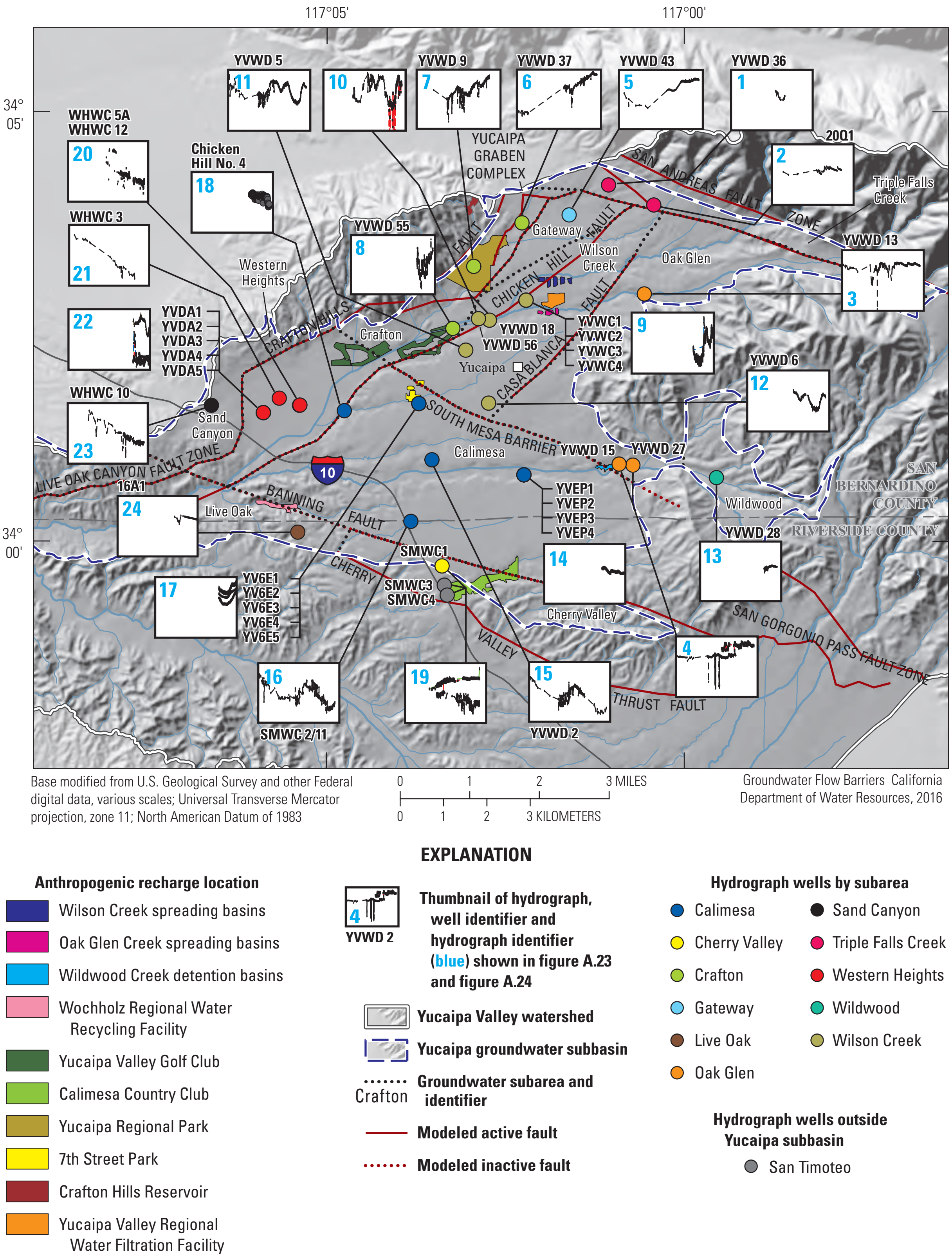


Figure A22. Location of selected wells with groundwater-level hydrographs shown in figures A23 and A24, Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Well information is summarized in table A1.1, and groundwater-level data can be accessed from the U.S. Geological Survey National Water Information System database (U.S. Geological Survey, 2018).

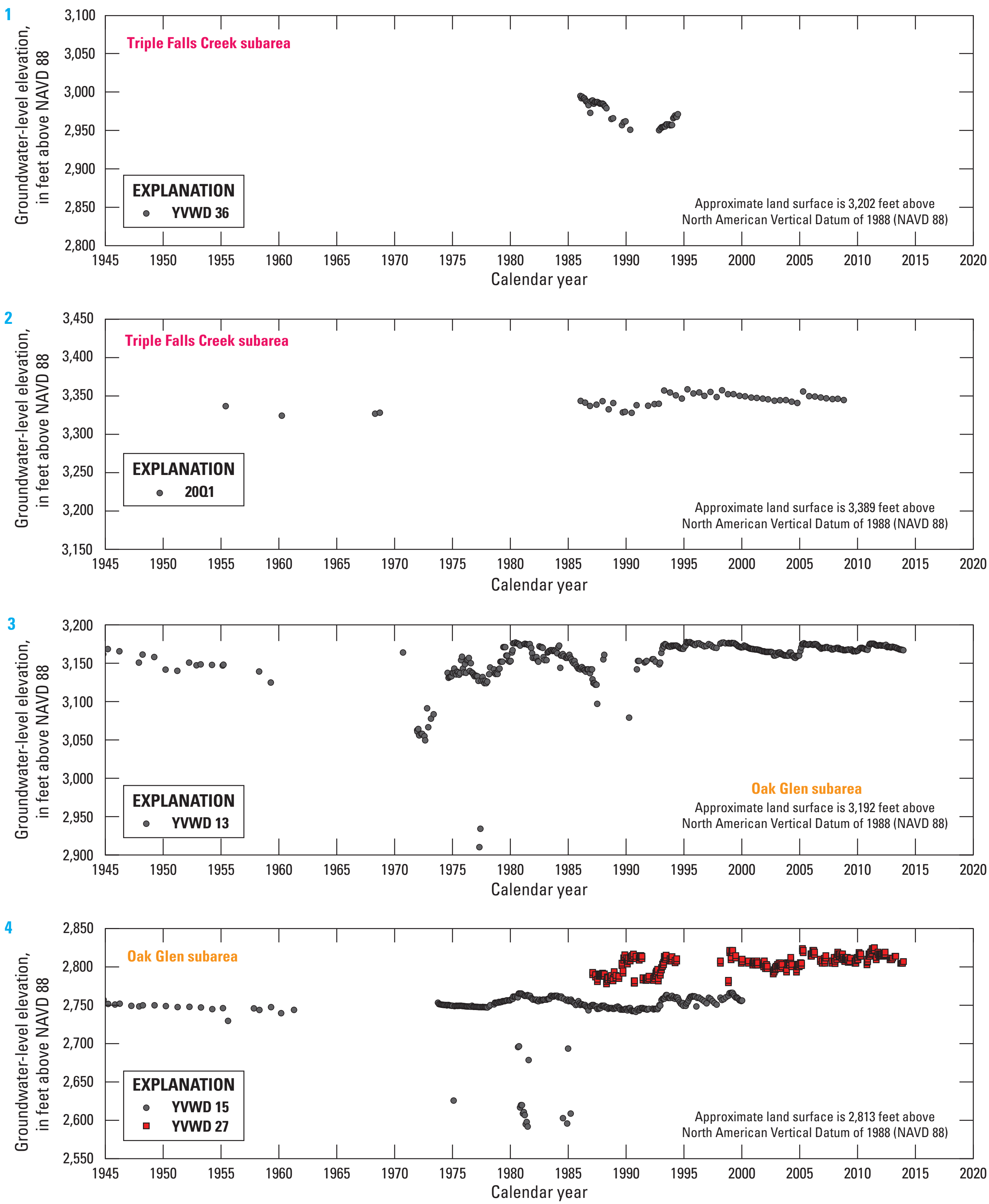


Figure A23. Measured groundwater elevations for selected wells in the Yucaipa groundwater subbasin, 1947–2014, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Figure panel numbers correspond to thumbnail panel numbers in figure A22.

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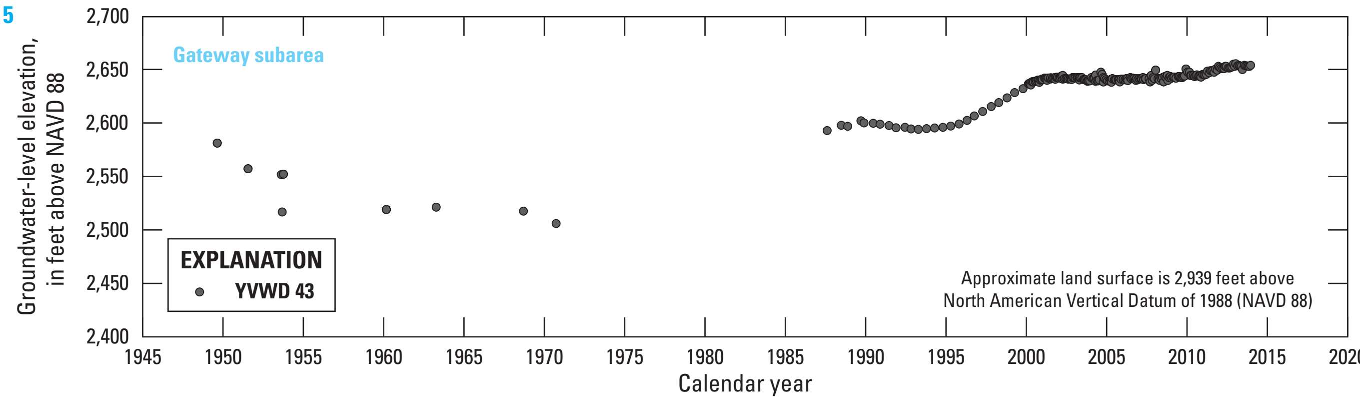

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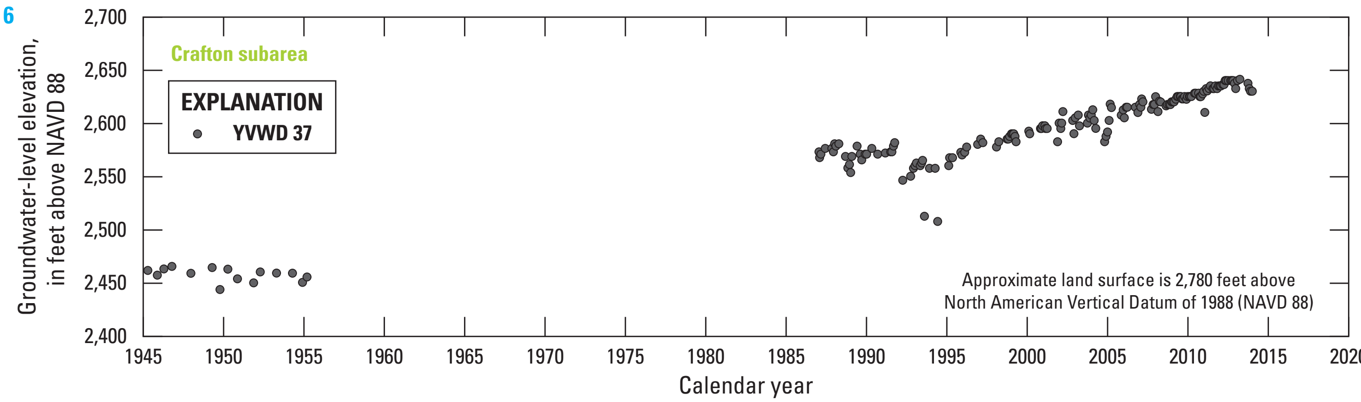

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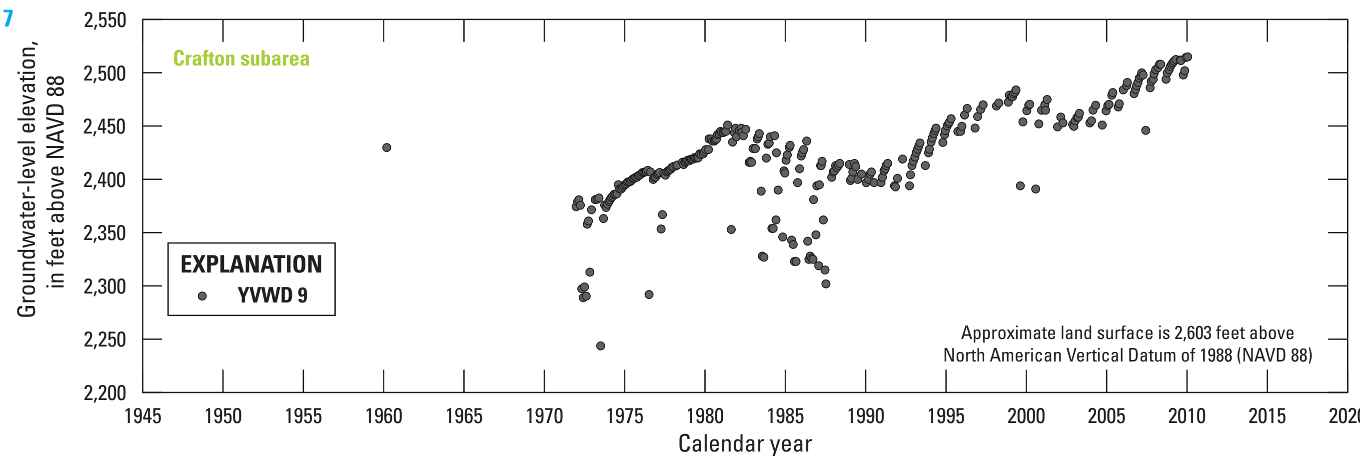

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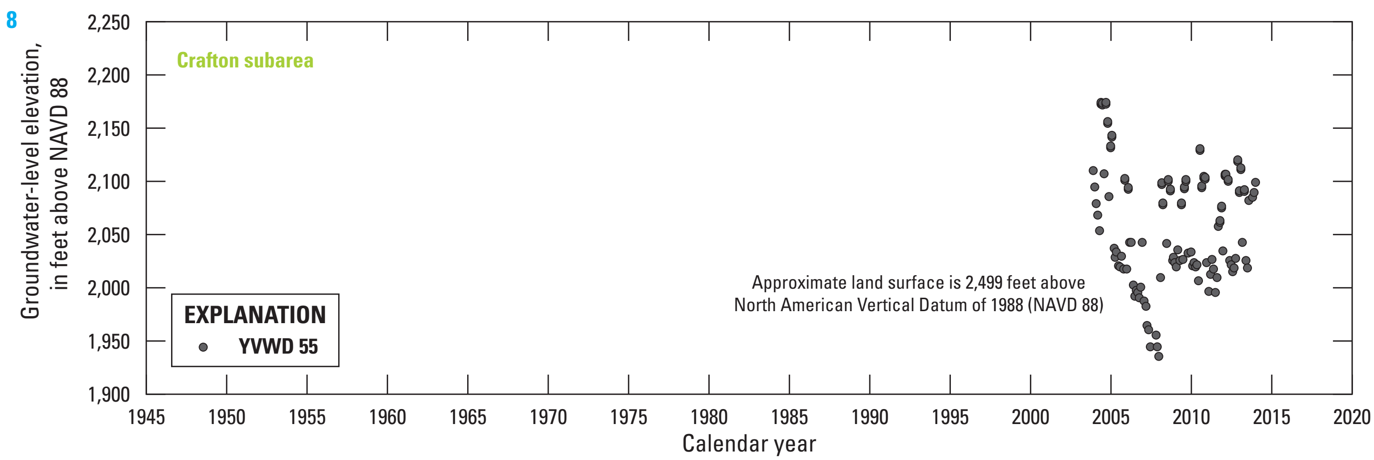

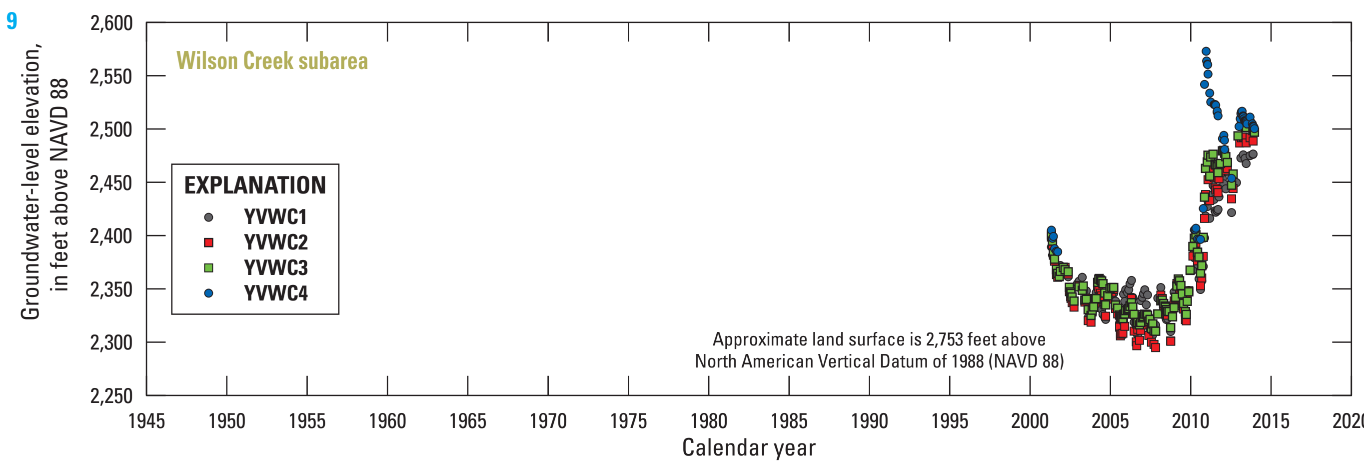

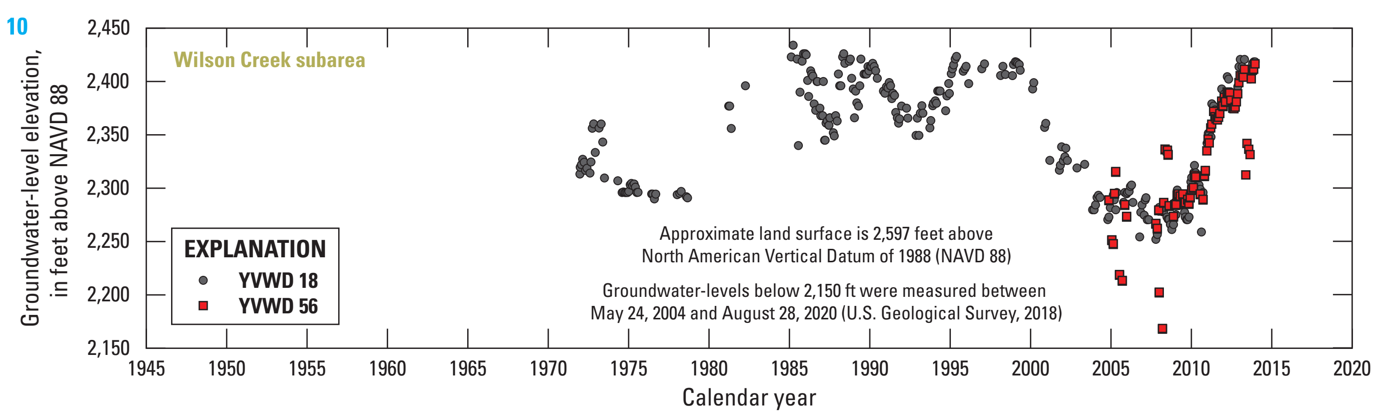

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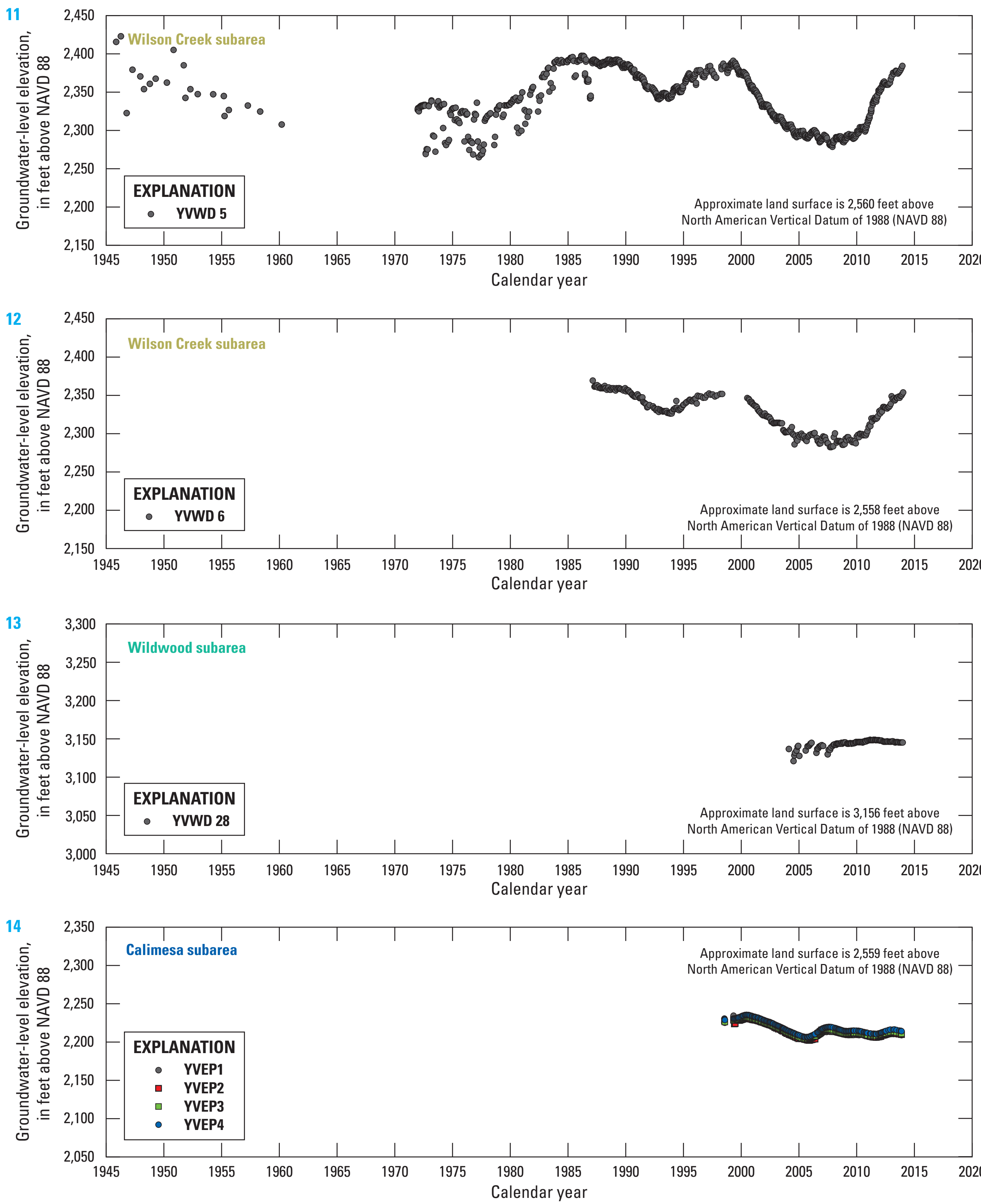

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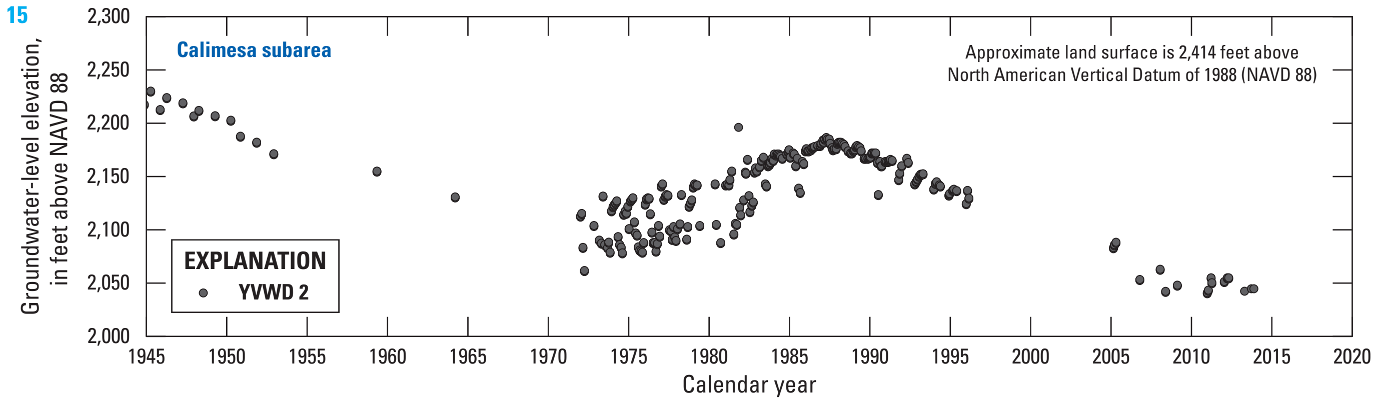

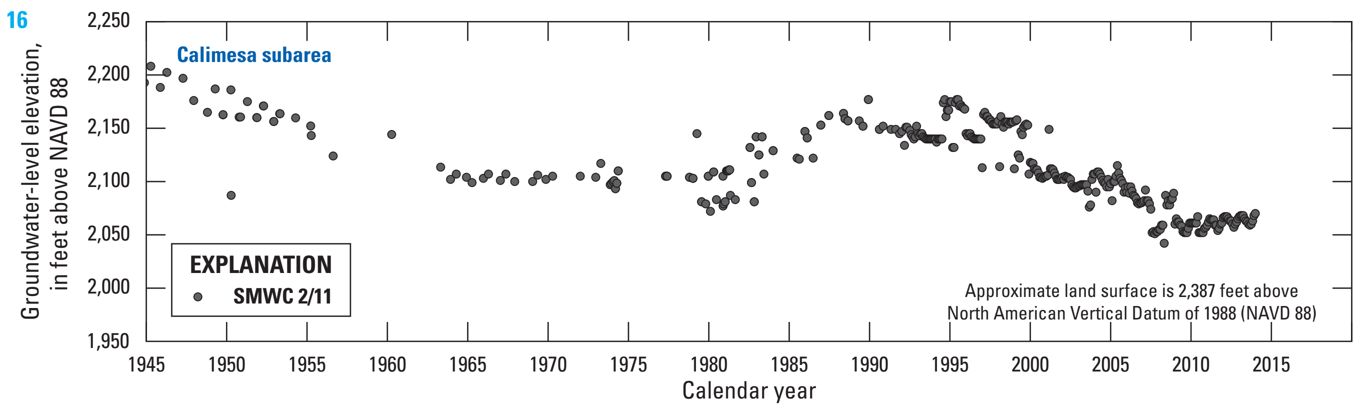

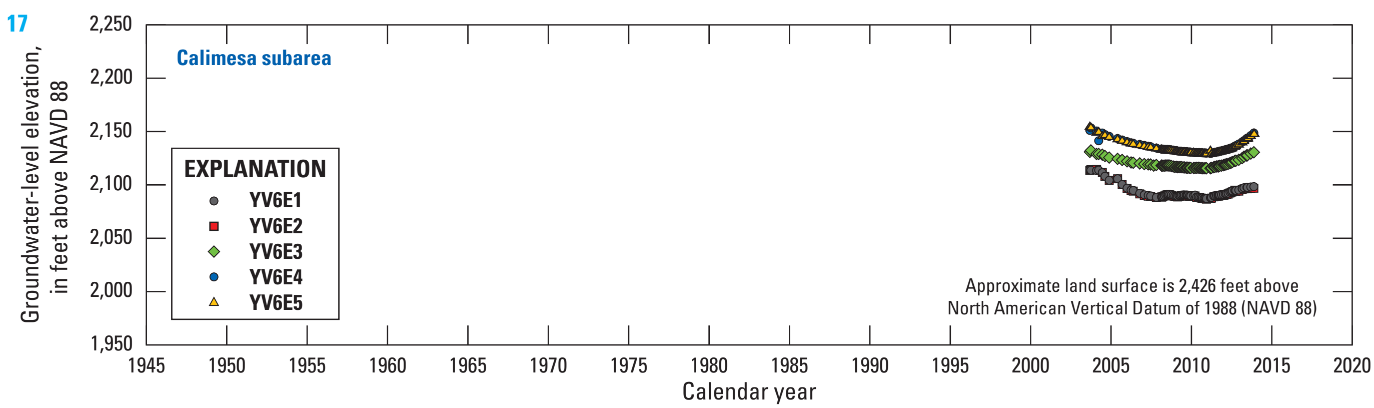

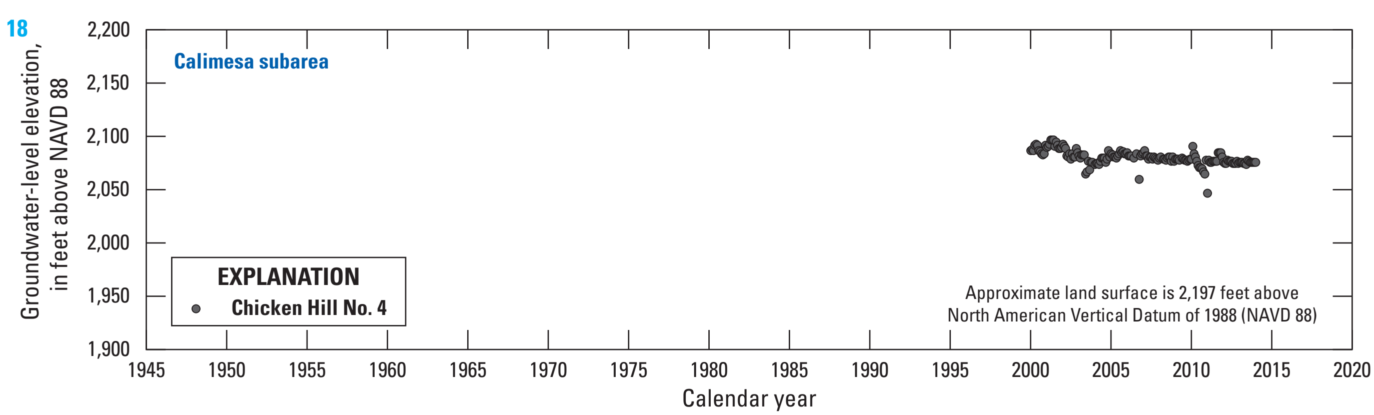

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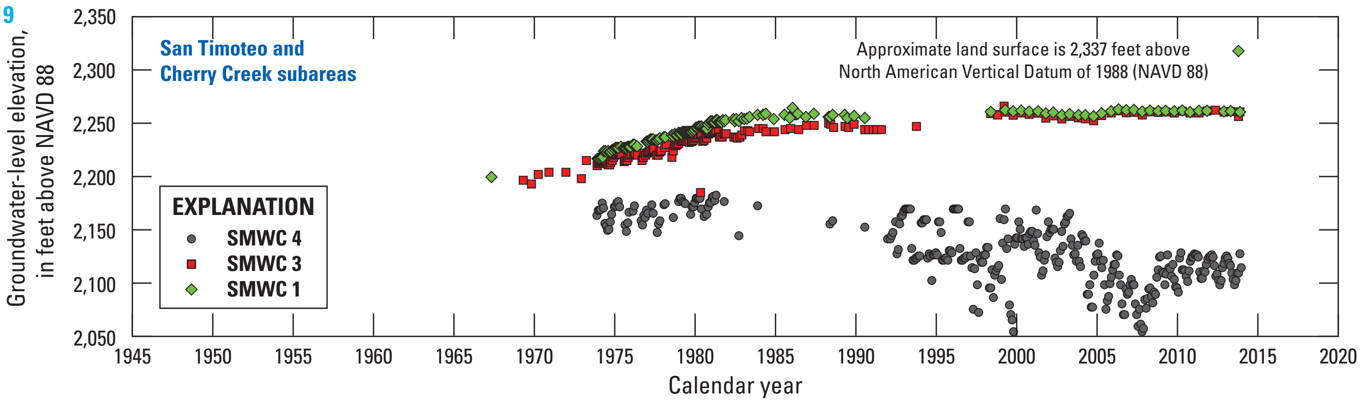

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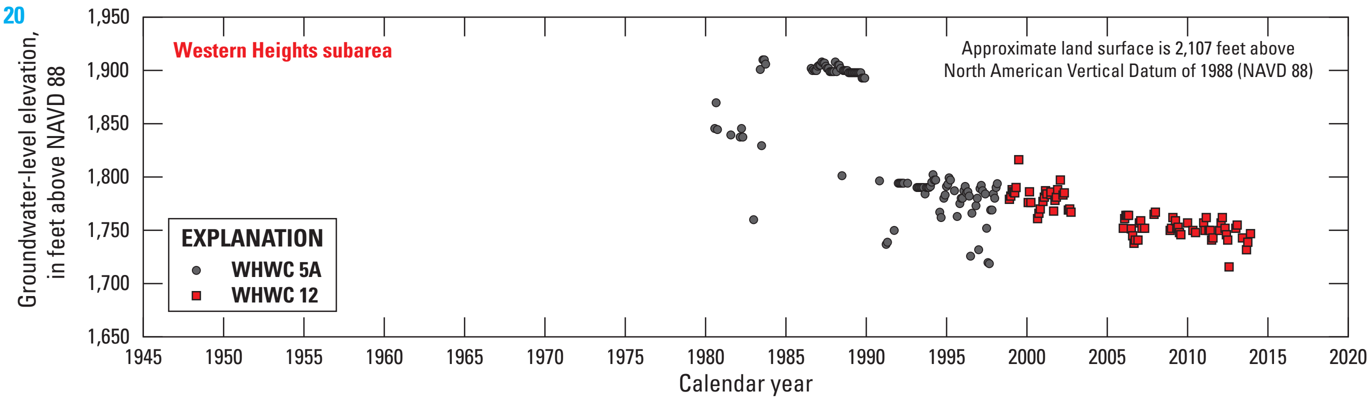

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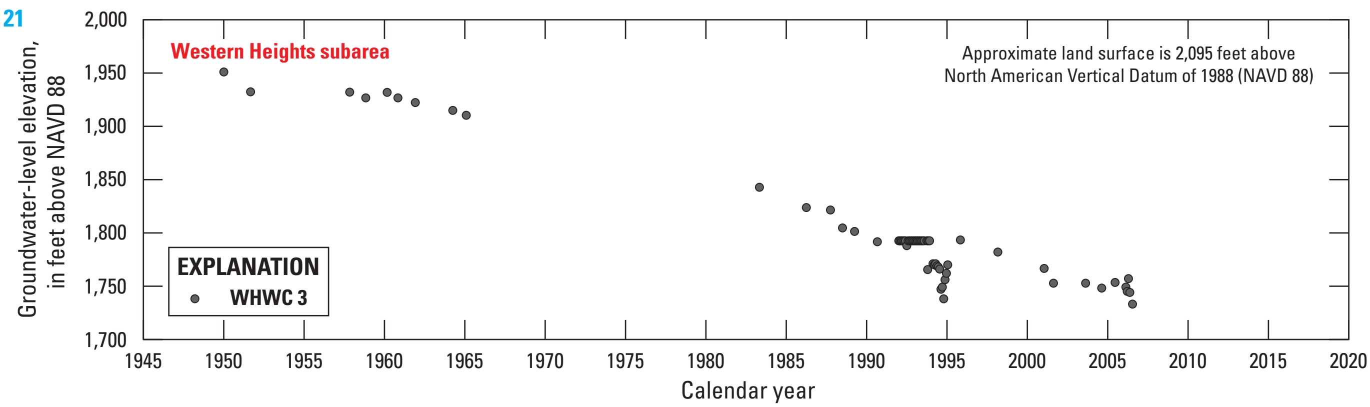

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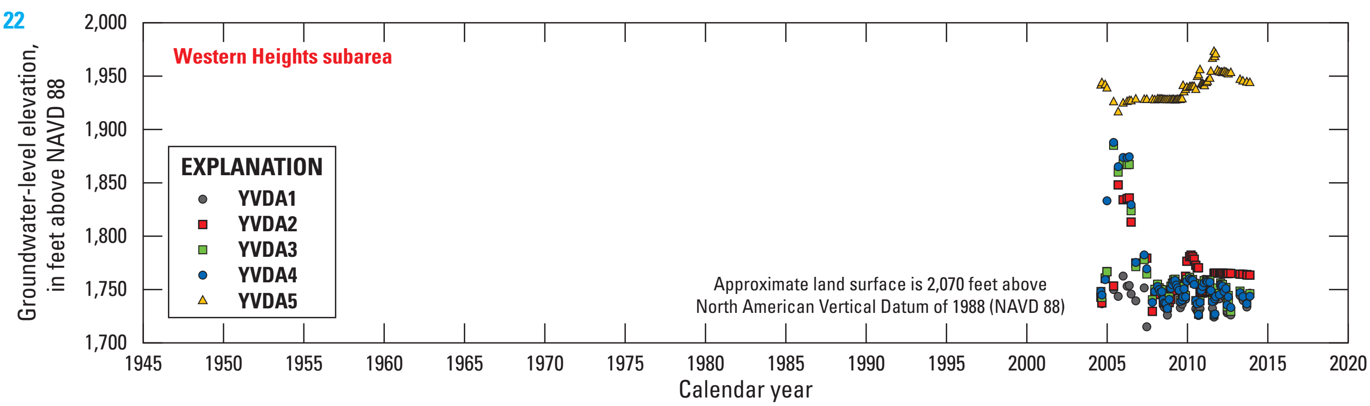

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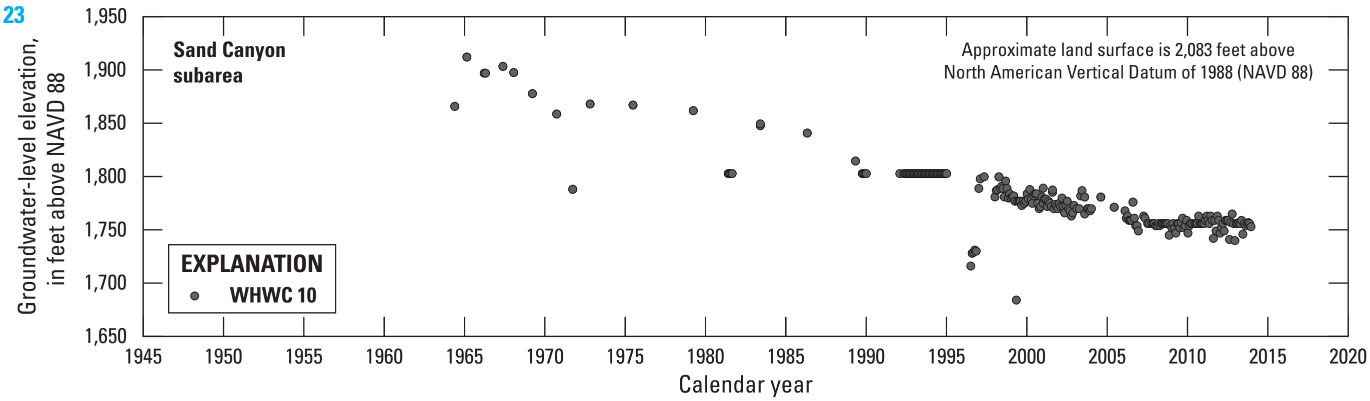


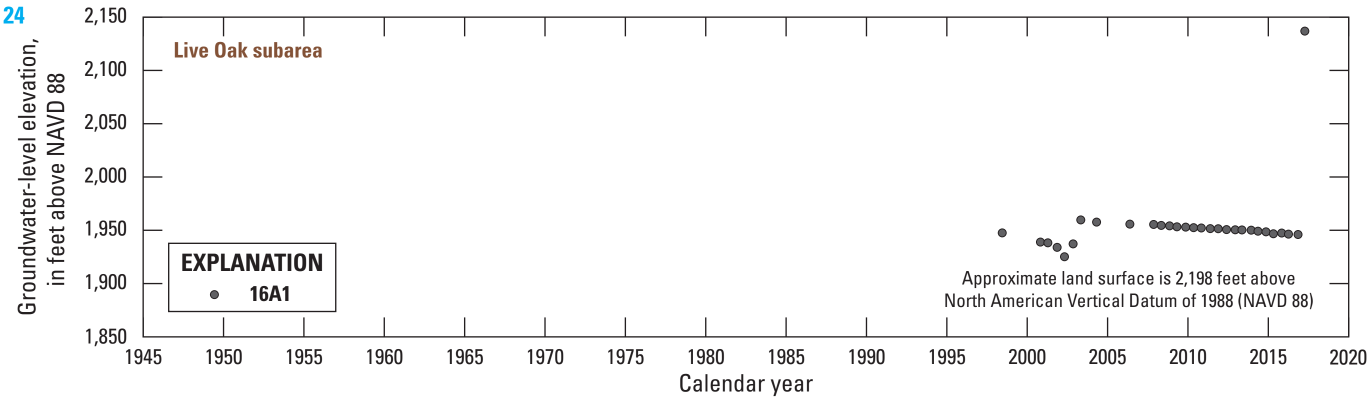


Figure A23.—Continued

Groundwater levels in the Yucaipa subbasin are generally sensitive to changes in climate. Groundwater levels generally increased during wet periods and declined during dry periods and intervening periods with average precipitation (fig. A5). Individual subareas have variable responses to climate that generally depend on local pumpage and hydrogeologic conditions. In general, groundwater levels declined until about the mid-1970s, increased during wet periods from 1978 to 1983 and 1991 to 1998, and declined from the late-1990s until about 2008. After 2008, groundwater levels generally stabilized or increased in conjunction with imported water deliveries of more than about 8,000 acre-ft/yr and a corresponding subbasin-wide decrease in pumpage.

Triple Falls Creek and Oak Glen Groundwater Subareas

Wells in the Triple Falls Creek and Oak Glen subareas are near sources of natural recharge: deep percolation of mountain-front runoff, streamflow, and precipitation from the San Bernardino Mountains and Yucaipa hills. These wells include YVWD 36, 20Q1, YVWD 13, YVWD 15 and YVWD 27 (hydrographs 1–4, respectively; figs. A22, A23; table A1.1; U.S. Geological Survey, 2018). The data from these five wells generally show relatively constant groundwater levels throughout the period of record, indicative of the relatively constant annual recharge rates. Most variations in groundwater levels are associated with periods of increased pumpage during years with low precipitation or years with greater than average recharge (hydrographs 1–4, respectively; figs. A22, A23).

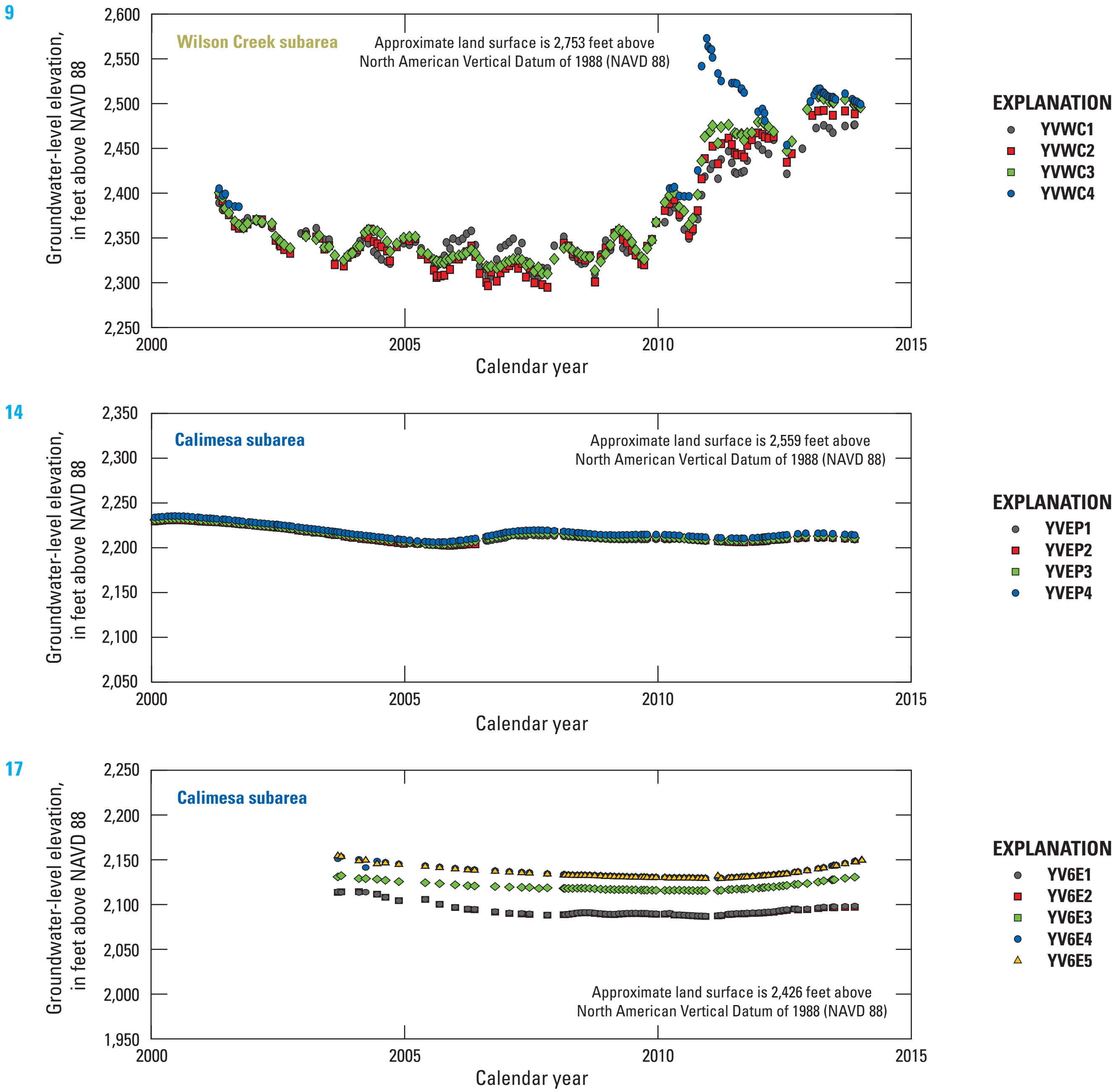
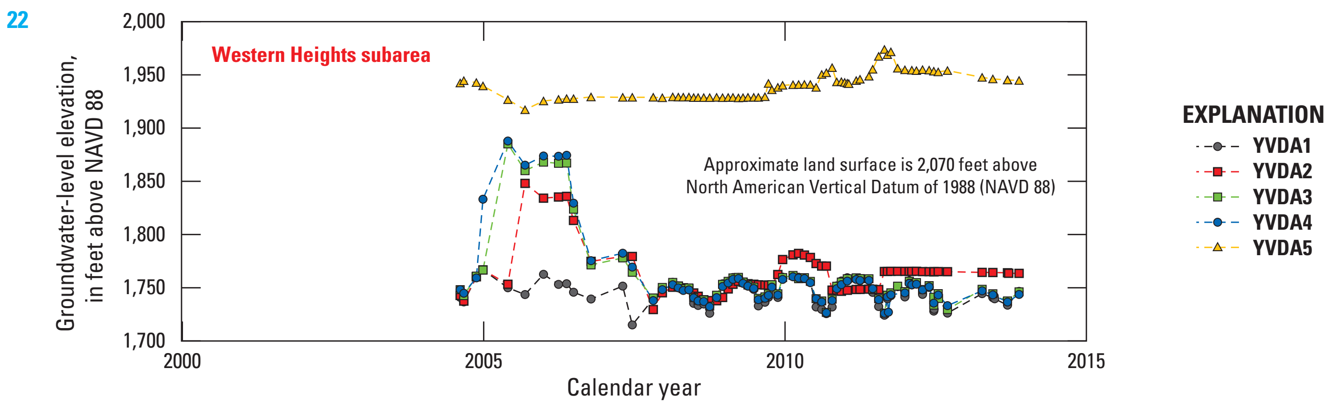


Figure A24. Measured groundwater elevations for U.S. Geological Survey multiple-depth, monitoring-well sites YVWC, YVEP, YV6E, and YVDA, 1998–2014, Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Figure panel numbers correspond to thumbnail panel numbers in figure A22.



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Gateway and Crafton Groundwater Subareas

Wells with long-term groundwater data in the Gateway and Crafton subareas include wells YVWD 43, YVWD 37, YVWD 9, and YVWD 55 (figs. A22, A23; table A1.1; U.S. Geological Survey, 2018). These wells are located near sources of natural recharge. Groundwater-level data from wells in these subareas showed a decline until about 1970, similar to wells in most other areas in the Yucaipa subbasin; however, unlike wells in other subareas, groundwater levels in wells from the Gateway and Grafton subareas increased through 2014 (hydrographs 5–8, respectively; figs. A22, A23). The steepest increases in groundwater-levels in the Gateway and Crafton subareas followed the period when annual pumpage in the subareas declined from historical highs in the 1950s and 1960s to historical lows in subsequent decades (fig. A19; table A1.2). Beginning in the 1990s when the Yucaipa Regional Park was constructed, groundwater levels in the Crafton subarea may have responded to infiltration of irrigation return or to leakage or seepage from holding ponds in the park (fig. A22).

Wilson Creek Groundwater Subarea

Long-term wells in the Wilson Creek subarea are located proximal to and downgradient of the Wilson Creek and Oak Glen Creek spreading basins and include the USGS multiple-depth, monitoring-well site YVWC (wells YVWC1–4) and wells YVWD 18, YVWD 56, YVWD 5, and YVWD 6 (hydrographs 9–12, respectively; figs. A22, A23, A24; table A1.1; U.S. Geological Survey, 2018). Groundwater-level data from wells in the Wilson Creek subarea show the same general trend as wells in most other areas in the Yucaipa subbasin. Beginning in 2008, the application of imported water to the Wilson Creek and Oak Glen Creek spreading basins for MAR exceeded more than about 8,000 acre-ft/yr (fig. A16), and groundwater levels in the Wilson Creek subarea rose as much as 80–190 ft since 2009 (figs. A23, A24) in response to a reduction in pumpage (fig. A19) and application of MAR water.

The combined effects of reduction in pumpage and of the MAR water on groundwater levels is shown at the USGS multiple-depth, monitoring-well site YVWC (figs. A22, A23, A24; table A1.1; U.S. Geological Survey, 2018). The shallowest well (YVWC4), installed to a depth of about 370 ft, had become dry in late 2001 but became saturated again in 2010 after application of MAR water (fig. A24; see the "Water Chemistry" section). In addition to increasing groundwater levels, the occasionally upward vertical gradient, prior to about 2009, from the deeper wells, YVWC1 and YVWC2 (838 and 658 ft bls, respectively), to the shallower wells, YVWC3 and YVWC4 (515 and 370 ft bls, respectively), was reversed (fig. A24). After 2009, groundwater levels in the shallower wells were consistently higher than those in the deeper wells, indicating a downward vertical gradient.

Calimesa Groundwater Subarea

Long-term wells located throughout the Calimesa subarea include USGS multiple-depth, monitoring-well sites YVEP and YV6E (wells YVEP1–4 and YV6E1–5), wells YVWD 2 and SMWC 2/11, and Chicken Hill No. 4 (hydrographs 14–18; figs. A22, A23, A24). Groundwater levels in the Calimesa subarea declined until about the mid-1970s, increased from the mid-1970s to the late 1980s, and then declined again until about 2008, after which time groundwater levels stabilized or gradually increased. Groundwater levels did not appear to increase during the wet period of 1991–98, which was a notable departure from other subareas in the Yucaipa subbasin. After 1984, pumpage rates in the Calimesa subarea increased to historical highs and averaged more than 5,500 acre-ft/yr from 1984 to 2007; cumulative pumpage during this period overwhelmed any increased recharge during the 1991–98 wet years, and groundwater levels declined to historical lows. The decline in groundwater levels continued until about 2008 when pumpage in the subarea decreased and groundwater levels partially recovered in some areas (figs. A23, A24).

The USGS multiple-depth, monitoring-well sites YVEP and YV6E are located in the eastern and northern parts of the Calimesa subarea, respectively (hydrographs 14 and 17; figs. A22, A23, A24; table A1.1; U.S. Geological Survey, 2018). Groundwater levels in all four wells at site YVEP (849–400 ft bls) were similar, indicating that there is little, if any, vertical gradient in this part of the subarea (fig. A24). In contrast, the groundwater levels at site YV6E show a downward vertical gradient from shallower wells YV6E4 and YV6E5 (399 and 309 ft bls, respectively) to deeper wells YV6E1 and YV6E2 (884 and 747 ft bls, respectively); differences of about 50–60 ft were observed between the shallow and deep wells. The result is a downward vertical gradient of about 0.1 ft/ft (50–60 ft groundwater level difference over 575 ft of depth). This downward vertical gradient could be caused by localized infiltration from irrigation return at 7th Street Park (fig. A15).

Western Heights and Sand Canyon Groundwater Subareas

Long-term wells in the Western Heights and Sand Canyon subareas include USGS multiple-depth, monitoring-well sites YVDA and wells WHWC 5A and WHWC 12, WHWC 3, and WHWC 10 (hydrographs 20–23; figs. A22, A23, A24; table A1.1; U.S. Geological Survey, 2018). Groundwater-level data from these wells showed continuous groundwater-level declines from 1947 to about 2008, after which time groundwater levels slightly recovered. The continuous decline in groundwater levels can be attributed to (1) consistent pumpage in the Western Heights subarea from 1947 to 2008 (about 2,600 acre-ft/yr; fig. A19; table A1.2), (2) relatively limited recharge to the subarea caused by a layer of fine-grained material that may have limited infiltration of natural water sources to the aquifer system (Moreland, 1970), and (3) the presence of the Chicken Hill fault that restricted groundwater flow into the subarea (see the “Hydrologic Flow Barriers” section). The recovery of groundwater-levels after about 2008 likely was a result of reduced pumpage across the Yucaipa subbasin because of the addition of imported water to the municipal water supply.

Groundwater levels for wells YVDA1–4 at the USGS multiple-depth, monitoring-well site YVDA (figs. A22, A23, A24; table A1.1; U.S. Geological Survey, 2018) showed seasonal responses to pumping after 2008 and were likely influenced by nearby pumping wells. Groundwater levels for the shallowest well, YVDA5 (246 ft bls) were about 200 ft higher than the deeper wells YVDA1–4 (1,053–446 ft bls), supporting the observed presence of a perched aquifer in the Western Heights subarea caused by a fine-grained layer at about 270–300 ft bls (about 1,770–1,800 ft above NAVD 88; Moreland, 1970; Mendez and others, 2018; also see the “Hydrogeologic Units” section).

Hydrologic Flow Barriers

Hydrologic flow barriers affect groundwater by causing groundwater-level differences across the barrier when they are oriented oblique to groundwater flow. Variable groundwater-flow directions and groundwater levels among groundwater subareas indicate different amounts of recharge and pumping and illustrate how subsurface structures have compartmentalized the Yucaipa subbasin. The degree of offset of long-term groundwater levels in wells across geologic structures such as faults and folds indicate the effects these structures have on groundwater flow. These effects are indicated by the groundwater-level data from wells on opposite sides of known structures, such as the Chicken Hill fault, South Mesa barrier, Banning fault, Cherry Valley thrust fault, and San Andreas fault zone. Other barriers suggested by previous researchers include the Yucaipa barrier, the Gateway barrier, and the Casa Blanca fault (fig. A22; Eckis, 1934; Burnham and Dutcher, 1960; Moreland, 1970).

The northeast-southwest trending Chicken Hill fault in the Yucaipa subbasin is a prominent hydrologic flow barrier that illustrates the control that geologic structures have on groundwater levels. The Chicken Hill No. 4 well in the Calimesa subarea and WHWC 12 well in the Western Heights subarea (hydrographs 18 and 20, respectively; figs. A22, A23; table A1.1; U.S. Geological Survey, 2018) are located on opposite sides of the southern segment of the Chicken Hill fault. Groundwater levels in well Chicken Hill No. 4 are about 360 ft higher than groundwater levels in well WHWC 12 during the same period of record, and both wells have different patterns of observed groundwater-levels, indicating that the southern part of the Chicken Hill fault restricts groundwater flow. In contrast, wells YVWD 18 and YVWD 56 (hydrograph 10; fig. A23) are located on opposite sides of the northern segment of the Chicken Hill fault in the Wilson Creek subarea (fig. A22). Groundwater levels in both wells have similar levels and similar responses to pumping, indicating that the northern segment of the Chicken Hill fault has little restriction on groundwater flow.

The South Mesa barrier probably is a fault, and its vertical displacement likely affects groundwater flow (Moreland, 1970). This restriction in groundwater flow is indicated by the observed differences in the groundwater levels in well YVWD 6 (hydrograph 12; fig. A22) in the Wilson Creek subarea and USGS multiple-depth, monitoring-well site YV6E (hydrograph 17; fig. A24) in the Calimesa subarea. The reported depth of well YVWD 6 (629 ft bls) was between the reported depths of wells YV6E2 and YV6E3 (747 and 547 ft bls, respectively). Groundwater levels in upgradient YVWD 6 were about 200–250 ft higher than the groundwater levels in downgradient wells YV6E2 and YV6E3 during the same period, although the difference in location of the wells may account for some of the observed differences in groundwater levels. The South Mesa barrier, or the fold structure associated with the South Mesa barrier (see the “Hydrogeologic Units” section), may restrict groundwater flow.

Previous studies considered the Banning fault to have a slight effect on groundwater flow; groundwater-level displacements across the fault were generally small, and barrier effects were inferred from differences in hydrographs on either side of the fault (Moreland, 1970). Wells SMWC 2/11 in the Calimesa subarea and 16A1 in the Live Oak subarea (hydrographs 16 and 24, respectively; figs. A22, A23) are located north and south of the Banning fault, respectively. Groundwater levels in the upgradient well SMWC 2/11 are about 100 ft higher than groundwater levels in the downgradient well 16A1 during the same period. The 1.5 mi difference in location of the wells may account for some of the observed differences in groundwater levels. Therefore, the Banning fault, or more accurately, the fold structure associated with the Banning fault (see “Hydrogeologic Units” section), may affect groundwater flow.

The Cherry Valley thrust fault was believed to be at least a partial barrier to groundwater flow. Groundwater levels were observed to be higher in in wells on the north side of the fault trace in the Yucaipa subbasin (Burnham and Dutcher, 1960) and near the Beaumont plain, east of the Yucaipa subbasin (Rewis and others, 2006). Differences in drawdown in wells across the fault trace during aquifer pump tests were also observed in wells near the Beaumont plain (Rewis and others, 2006). The plane of the fault dips north-northeast at a shallow angle (between 8 and 39 degrees; Matti and others, 2015), plunging from the mapped fault trace into the Yucaipa subbasin to the northeast. Wells SMWC 3 and SMWC 1 are completed above the projected plane of the Cherry Valley thrust fault and have groundwater levels that are about 50–150 ft higher than groundwater levels in well SMWC 4 (hydrograph 19; figs. A22, A23), which is completed below the projected fault plane. Groundwater levels in wells SMWC 3 and SMWC 1 increase throughout the period of record; in contrast, groundwater levels in well SMWC 4 decrease throughout the period of record and show substantial variations due to groundwater pumping. The elevation and observed patterns of groundwater levels in wells completed above and below the projected plane of the Cherry Valley thrust fault indicate that the fault is a barrier to groundwater flow at least in the vicinity of the Yucaipa subbasin.

Individual faults of the San Andreas fault zone are believed to be barriers to groundwater flow, especially where the faults represent the contact between basin-fill sediment and crystalline basement; springs and heavy vegetation were observed where the fault strands crossed canyon mouths (Burnham and Dutcher, 1960; Moreland, 1970). Wells drilled in the fault zone were reported to have encountered fault-gouge material, which can inhibit groundwater flow; and tunnels dug across the fault zone reportedly resulted in depletion of groundwater storage on the upgradient side of the fault (Burnham and Dutcher, 1960).

Water Chemistry

Water chemistry data provided information on the general groundwater quality, including type, source, and age of groundwater in the Yucaipa subbasin. The groundwater-quality analyses were used to evaluate the vertical and geographic chemical variability within the aquifer system. Groundwater-quality data compiled for this report and described in this section were sampled and reported by Mendez and others (2001), Rewis and others (2006), and Mendez and others (2018) and include analyses of major ions, nutrients, stable isotopes of oxygen and hydrogen (oxygen-18 and hydrogen-2, respectively), tritium, and carbon-14 (^{14}C), a radioactive isotope of carbon that occurs naturally and was also produced by atmospheric bomb explosions. Complete analyses of all samples can be retrieved from the USGS National Water Information System database (U.S. Geological Survey, 2018). The chemical data compiled for this report were used to characterize the areal, vertical, and temporal variations in groundwater quality in the Yucaipa subbasin, and the type, source, and age of groundwater. These data were compiled for monitoring wells and production wells primarily within the Yucaipa subbasin (fig. A25; table A1.1; U.S. Geological Survey, 2018). Unless otherwise stated, wells with multiple chemical analyses are represented in the following water chemistry figures by a single value corresponding to the most recent sample with select constituents within the study period (1947–2014).

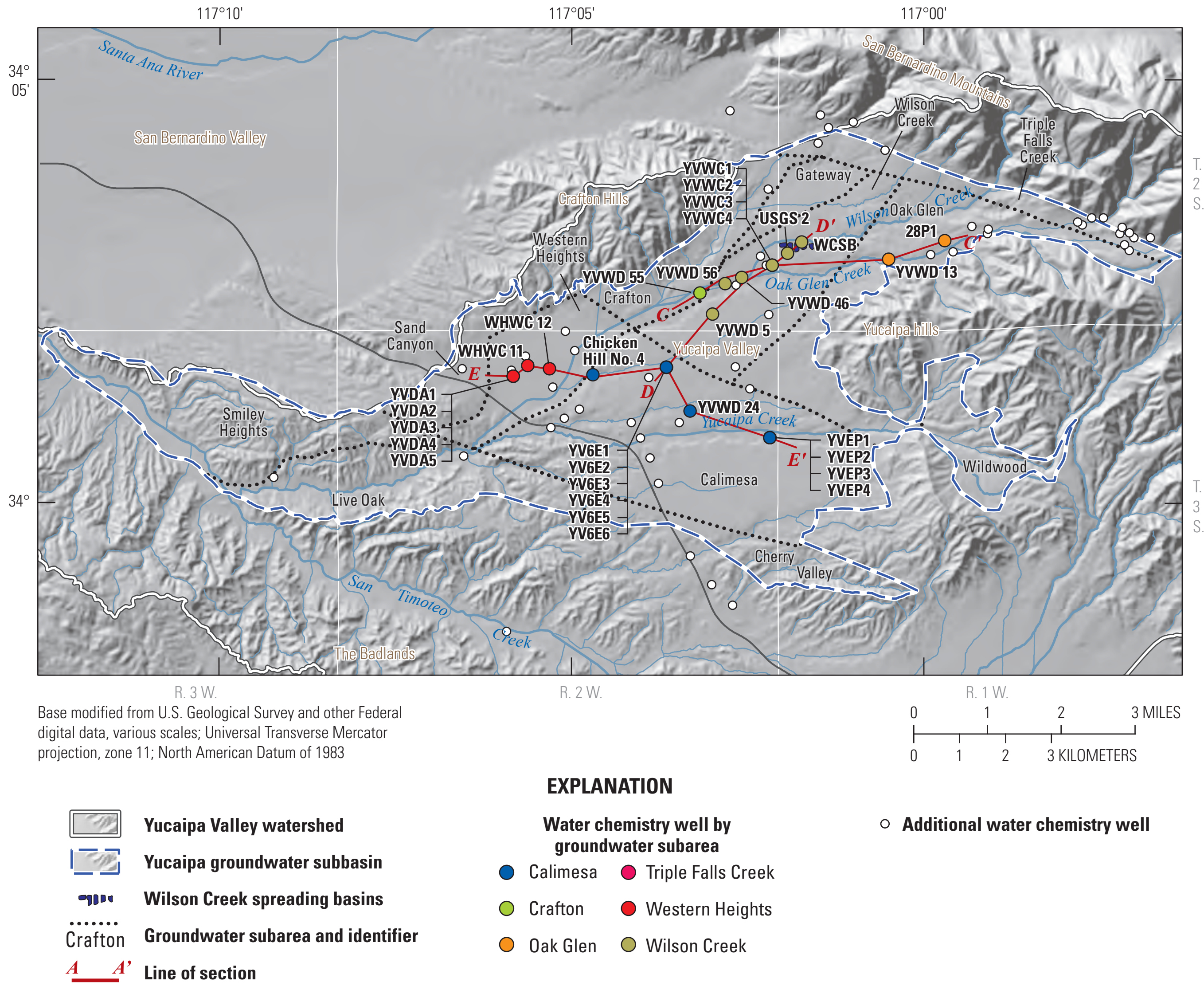

Figure A25. Location of select wells with groundwater-quality data shown in figures A26–A28, Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Chemical Character of Groundwater

The chemical character of groundwater in the Yucaipa subbasin was determined using analyses of major and minor ion concentrations, nutrient concentrations, and dissolved total solids concentrations (TDS) for depth-dependent and bulk samples collected from USGS multiple-depth, monitoring-well sites, and other monitoring and productions wells, located throughout the Yucaipa subbasin. The major ion composition of groundwater in the Yucaipa subbasin shows that TDS ranged from about 225 to 1,120 milligrams per liter (mg/L; U.S. Geological Survey, 2018). Groundwater samples with lower TDS concentrations generally were collected from wells near sources of natural recharge; samples with the highest TDS concentrations were collected from deep wells near the contact with the crystalline basement. In the Western Heights subarea, the perched aquifer above the fine-grained layer at about 270–300 ft bls showed a unique chemical character compared to groundwater from the rest of subbasin. Groundwater data from USGS multiple-depth, monitoring well site YVDA indicated that the shallowest well, YVDA5 (in the perched aquifer) had TDS concentrations that were about 200 mg/L greater than concentrations in the deeper wells YVDA1–4, where TDS concentrations did not exceed about 320 mg/L.

The four water types observed in the Yucaipa subbasin based on the major ion composition were (1) calcium-bicarbonate-type present across the subbasin, which originates from local recharge areas to the northeast; (2) sodium-sulfate-type that likely flows through long pathways through the crystalline basement; (3) sulfate-rich, calcium-bicarbonate-type in a perched aquifer in the Western Heights subarea; and (4) chloride-type, imported water from northern California that is elevated compared to the chloride in native groundwater and is recharged at the Wilson Creek and Oak Glen Creek spreading basins (fig. A26).

The chemical character of groundwater is illustrated for the aquifer system on a Piper diagram (Piper, 1944; fig. A26) and using Stiff diagrams on three sections through the Yucaipa subbasin (fig. A27). Piper diagrams are useful to determine if simple mixing between chemically different water has occurred (Hem, 1985) and show the relative contribution of major cations and anions, on a charge-equivalent basis, to the ionic content of the water (Piper, 1944). Stiff diagrams depict the concentrations of major ions in milliequivalents per liter (meq/L) and indicate relative proportions of major ions (Stiff, 1951). Analyses with similarly shaped diagrams represent groundwater with similar chemical characteristics with respect to major ions. Changes in the width of the diagrams indicate differences in the concentrations of dissolved constituents. Water that contains higher concentrations of major ions has a wider diagram than a diagram for water with lower concentrations. The left side of the diagram shows the major cations: sodium plus potassium (Na^{+}+K^{+}) at the top, calcium (Ca+) in the middle, and magnesium (Mg^{++}) at the bottom. The right side of the diagram shows the major anions: chloride plus fluoride (Cl^{-}+F^{-}) at the top, carbonate plus bicarbonate (CO_3^{--}+HCO_3^{-}) in the middle, and sulfate (SO_4^{--}) on the bottom. Figures A26 and A27 show the chemical character of the same set of samples from selected groundwater wells, including bulk and depth-dependent samples. Stiff diagrams representing bulk samples are placed at the top of a well's perforated interval, and diagrams representing depth-dependent samples are shown at the depth from which the samples were analyzed for each well (fig. A27). Also shown are hydrogeologic units and faults from the HFM and model layers used in the YIHM (chapter B).

Groundwater sampled from most wells indicated mostly homogeneous native water types throughout the Yucaipa subbasin. Stiff diagrams were used to characterize groundwater sampled from most wells as calcium-bicarbonate-type water that was sourced from areas of natural recharge in the northeastern part of the Yucaipa subbasin (brown Stiff diagrams in fig. A27). Three additional groundwater types with distinct characteristics that indicate different sources of recharge were evident in some wells in the Calimesa, Western Heights, and Wilson Creek subareas. These groundwater types reflect sources of groundwater recharged from subsurface flow through crystalline basement (gray Stiff diagrams in figs. A27*B*, A27*C*), groundwater in the perched aquifer in the Western Heights groundwater subarea (red Stiff diagram in fig. A27*C*), and imported water from northern California (light blue Stiff diagrams in figs. A27*A*, A27*B*).

Most wells in the Yucaipa subbasin have groundwater quality that reflects the chemical character of locally recharged water from deep percolation of mountain-front runoff, streamflow, and precipitation. The chemical characters of groundwater in the Oak Glen and Triple Falls Creek subareas likely are representative of locally recharged water because water in these subareas is likely only recharged from local sources (see the "Natural Recharge" section). A Stiff diagram was used to characterize groundwater from wells 28P1 and YVWD 13 in the Oak Glen subarea as calcium-bicarbonate-type water with TDS concentrations of less than 300 mg/L (fig. A27*A*; U.S. Geological Survey, 2018). The chemical characters of most other wells in the Yucaipa subbasin were similar, indicating that most groundwater is locally recharged.

Groundwater recharged through crystalline basement is evident in the Calimesa subarea from deep wells at USGS multiple-depth, monitoring-well site YV6E, wells YVWD 24 and 1K1, and possibly from deep wells at USGS multiple-depth, monitoring-well site YVEP (figs. A27*B*, A27*C*, A28; U.S. Geological Survey, 2018). A Stiff diagram was used to characterize groundwater in these wells as sodium-sulfate-type water with concentrations of sodium plus potassium and sulfate that were greater than samples from shallower wells at the same location. At well site YV6E, sodium plus potassium and sulfate concentrations from the deepest well, YV6E1, were greater than 310 and 630 mg/L, respectively, or about 6 and 15 times greater than respective concentrations in the shallowest well, YV6E5 (figs. A27*B*, A27*C*). This elevated sodium plus potassium and sulfate chemical signature is consistent with observations of groundwater quality sampled from wells near the Beaumont plain and indicates groundwater had recharged through crystalline rock (Rewis and others, 2006, well 22G3, figs. 31, 32; fig. A26).

The two deep wells at well site YV6E (about 885 and 750 ft bls, respectively; table A1.1) are completed in, or very near, crystalline basement (Mendez and others, 2016, 2018). However, the crystalline basement surface was projected below the total depth of the well site (Cromwell and Matti, 2022). The groundwater chemistry from these wells indicated that the source of the groundwater at these great depths was mainly from the weathered saprolitic material or fractured crystalline basement. Samples at well YVWD 24 have similar depth-dependent concentrations of sodium plus potassium and sulfate; deeper samples (about 540 ft bls) have sodium plus potassium and sulfate concentrations of about 145 and 370 mg/L, respectively, while shallower samples (about 420 ft bls) have concentrations of about 30 and 28 mg/L, respectively (fig. A27*C*; U.S. Geological Survey, 2018). The three deeper wells at YVEP also were completed in or very near crystalline basement (Mendez and others, 2016, 2018), however. The crystalline basement surface is projected below the total depth of the well site similar to wells at site YV6E (Cromwell and Matti, 2022). Deeper wells at site YVEP had sodium plus potassium and sulfate concentrations that ranged from 100 to 150 mg/L and 120 to 190 mg/L, respectively. Duplicate samples from the shallowest well, YVEP4, had sodium plus potassium and sulfate concentrations that were less than or equal to 33 and 25 mg/L, respectively. Measured concentrations of sodium plus potassium and sulfate at well

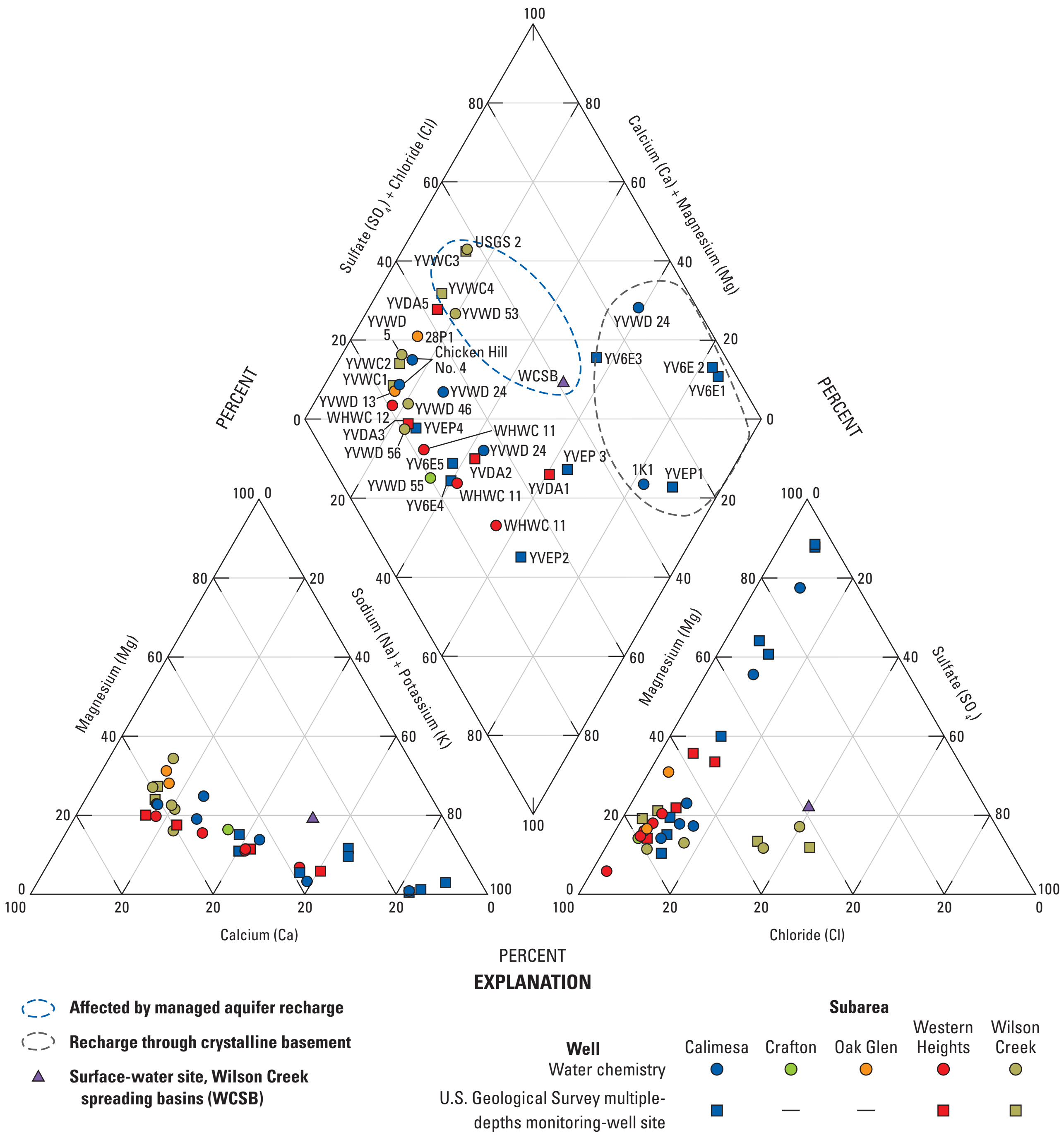

Figure A26. Major ion concentrations of groundwater from selected wells and imported water from northern California applied to the Wilson Creek spreading basins, Yucaipa groundwater subbasin, San Bernardino and Riverside Counties, California.

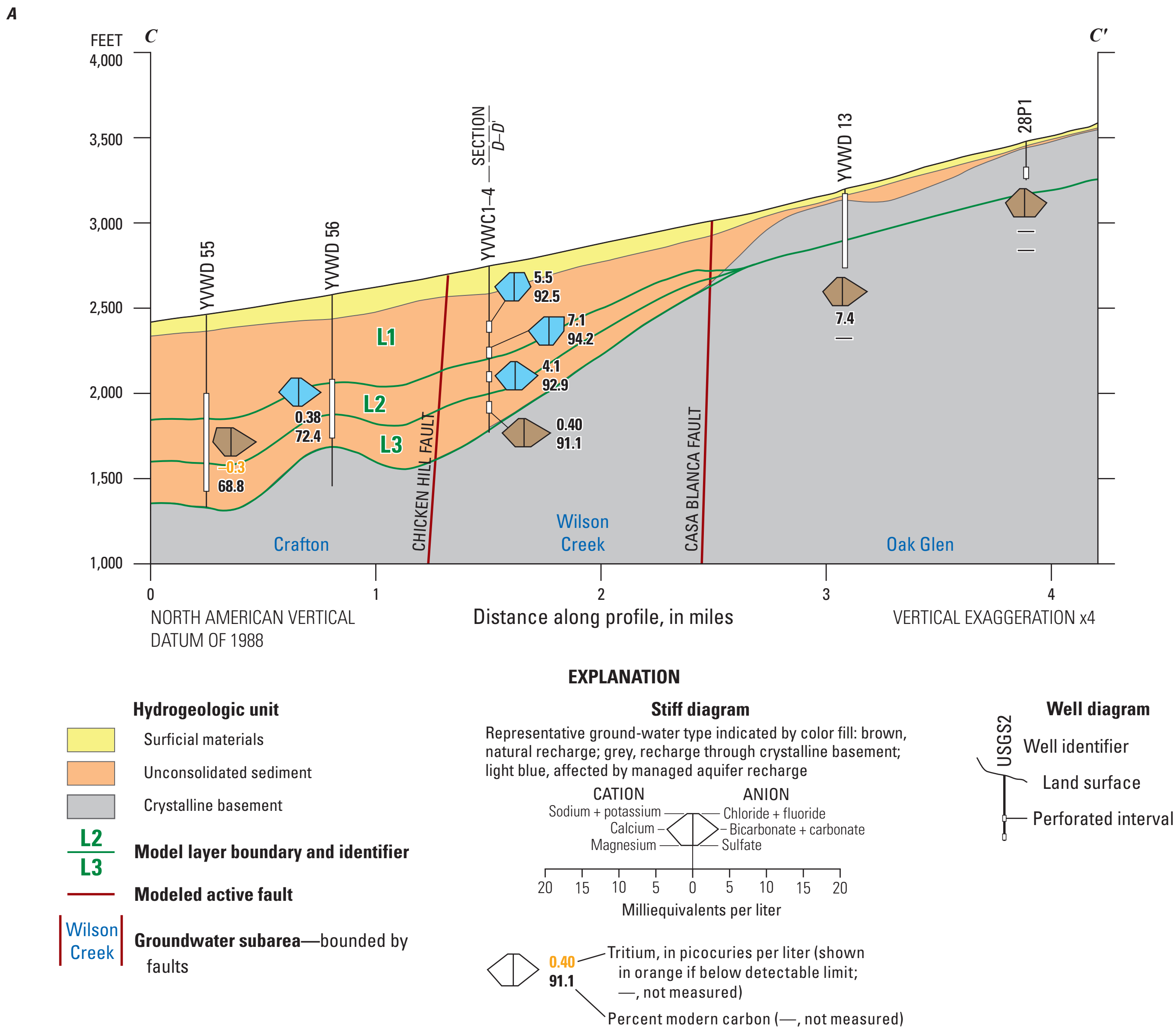

Figure A27. Sections showing major ion concentrations of select wells as Stiff diagrams, hydrogeologic units and faults from the three-dimensional hydrogeologic framework model of Cromwell and Matti (2022), and model layers of the Yucaipa Integrated Hydrologic Model, Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. Refer to figure A25 for locations of sections. *A*, section through the Crafton, Wilson Creek, and Oak Glen groundwater subareas; *B*, section through the Calimesa and Wilson Creek groundwater subareas; and *C*, section through the Western Heights and Calimesa groundwater subareas.

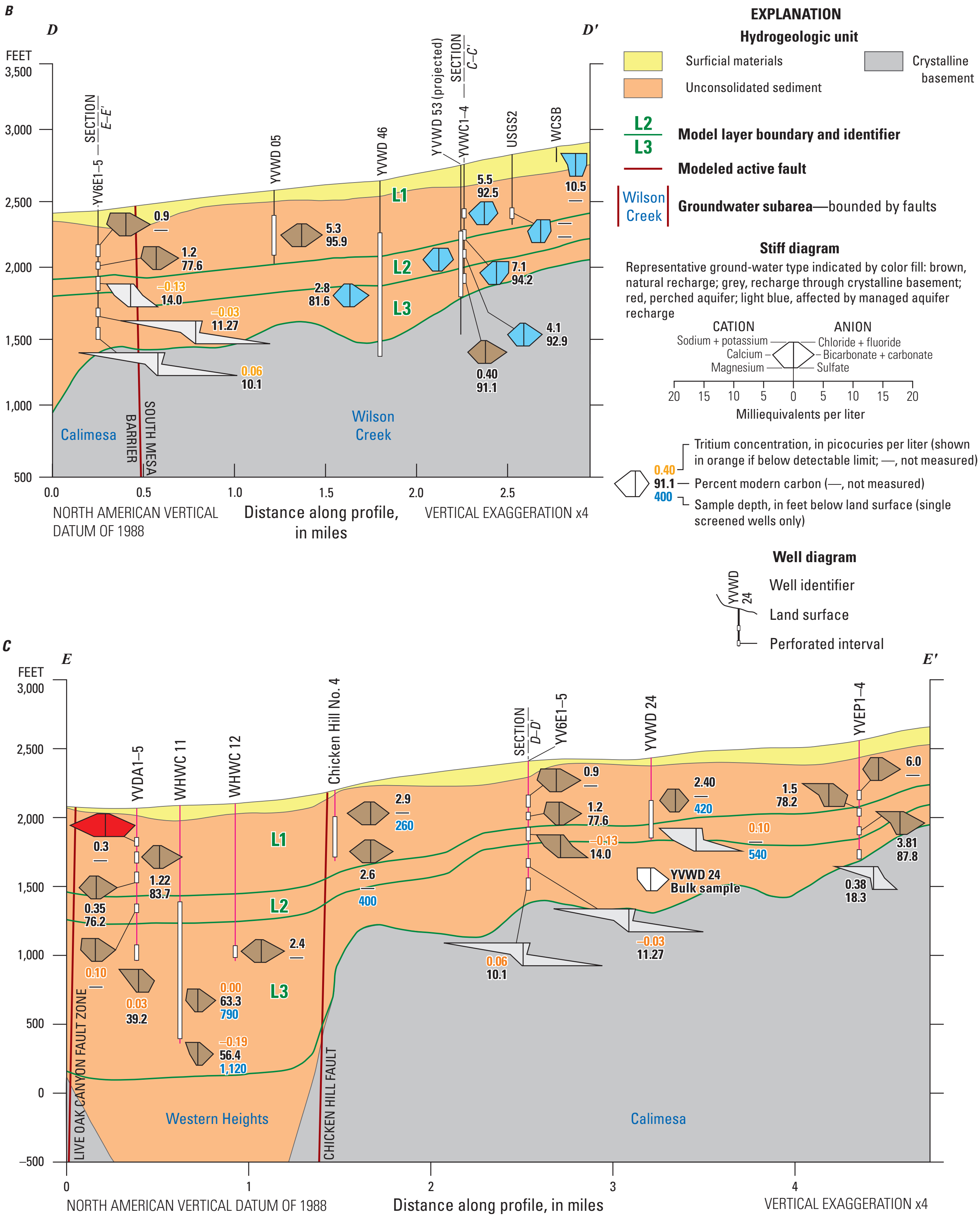

Figure A27.—Continued

sites YV6E, YVEP, and well YVWD 24, and the proximity of the deep wells in YV6E and YVEP to crystalline basement, indicate groundwater flow through crystalline basement.

Groundwater from the perched aquifer in the Western Heights subarea has higher concentrations of select major ions than naturally recharged groundwater in the Yucaipa subbasin (U.S. Geological Survey, 2018); the different groundwater type is evident in USGS multiple-depth, monitoring-well site YVDA (fig. A27*C*). The shallowest well, YVDA5 (246 ft bls; table A1.1), is located above the fine-grained layer (about 270–300 ft bls) that creates the perched aquifer in the Western Heights subarea; YVDA5 has greater concentrations of chloride, fluoride, sulfate, and bicarbonate relative to groundwater in deeper wells at well site YVDA and other wells in the subarea (figs. A26, A27*C*; U.S. Geological Survey, 2018). A Stiff diagram was used to characterize groundwater in well YVDA5 as sulfate-rich, calcium-bicarbonate-type water with TDS concentrations that ranged from 559 to 575 mg/L; in deeper wells YVDA1–4, groundwater TDS concentrations ranged from 265 to 291 mg/L (fig. A27*C*; U.S. Geological Survey, 2018). The fine-grained sediments that caused the perched aquifer inhibited the vertical downward migration of water to the deeper aquifer system. Therefore, groundwater from this shallow zone likely retained a unique chemical signature.

Signatures of locally recharged water and water imported from northern California are identifiable in samples from several wells in the Wilson Creek subarea, indicating a mixture of the two water types. Imported water from northern California applied as MAR at the Wilson Creek and Oak Glen Creek spreading basins is evident in groundwater at the USGS multiple-depth, monitoring-well site YVWC and selected wells in the Wilson Creek subarea (figs. A27*A*, A27*B*). A Stiff diagram was used to characterize imported water from northern California sampled at the Wilson Creek spreading basins as sodium chloride and potassium chloride-type water with TDS concentrations that ranged from 256 to 315 mg/L (fig. A27*B*; U.S. Geological Survey, 2018). Concentrations of sodium and chloride in imported water sampled from the Wilson Creek spreading basins ranged from 54.0 to 67.8 mg/L and 66.8 to 109.0 mg/L, respectively, and were as much as 4 and 10 times greater than the sodium and chloride concentrations from most groundwater samples in the Wilson Creek subarea (fig. A27*B*; U.S. Geological Survey, 2017). The consistent application of imported water for MAR began in 2008, and groundwater samples collected after 2008 from wells YVWC2, YVWC3, YVWC4, USGS 2, YVWD 44, YVWD 46, YVWD 53, and YVWD 56 had increased concentrations of sodium and (or) chloride (U.S. Geological Survey, 2017), meaning these wells contain some portion of imported water.

Sources and Ages of Groundwater

The ratios of stable isotopes of oxygen and hydrogen have become standard hydrologic tools for the analysis of groundwater recharge sources and movement (International Atomic Energy Agency, 1981). Investigators also have used other isotopic data, such as the combination of the radioactive isotopes of hydrogen and carbon, to (1) effectively identify sources of recharge, (2) determine the age or the time since recharge occurred for groundwater, and (3) identify geologic controls on the movement of groundwater in arid environments (Izbicki and Michel, 2004). The isotopes of oxygen and hydrogen, and the radioactive isotopes of hydrogen (tritium) and carbon-14 from selected wells (U.S. Geological Survey, 2018), were used to help determine the sources and ages of water in the Yucaipa subbasin.

Stable Isotopes of Oxygen and Hydrogen

Oxygen-18 (^{18}O) and hydrogen-2 (^{2}H) are naturally occurring stable isotopes of oxygen and hydrogen, respectively. Atoms of ^{18}O and ^{2}H have more neutrons and a greater atomic mass than the more common isotopes of oxygen-16 (^{16}O) and hydrogen-1 (^{1}H). The differences in weight result in differences in the physical and chemical behavior of the heavier, less abundant isotopes. The isotopic ratios are expressed in delta notation (δ) as parts per thousand (per mil) differences relative to the standard known as Vienna Standard Mean Ocean Water (Gonfiantini, 1978). The average $\delta^{18}O$ and $\delta^{2}H$ composition of precipitation throughout the world is linearly correlated because most of the world's precipitation is derived originally from the evaporation of seawater. The linear relation between global $\delta^{18}O$ and $\delta^{2}H$ is known as the global meteoric water line (Craig, 1961; fig. A28).

Differences in isotopic composition can be used to help determine the general atmospheric conditions at the time of precipitation and the effects of evaporation before water entered the aquifer system. The $\delta^{18}O$ and $\delta^{2}H$ of groundwater relative to the global meteoric water line provides evidence of the source of the water and fractionation processes that have affected stable-isotope values. In some areas, fractionation during atmospheric condensation and precipitation or during evaporation prior to groundwater recharge, may result in recharge waters with different $\delta^{18}O$ and $\delta^{2}H$ values (Fournier and Thompson, 1980; Friedman and others, 1992).

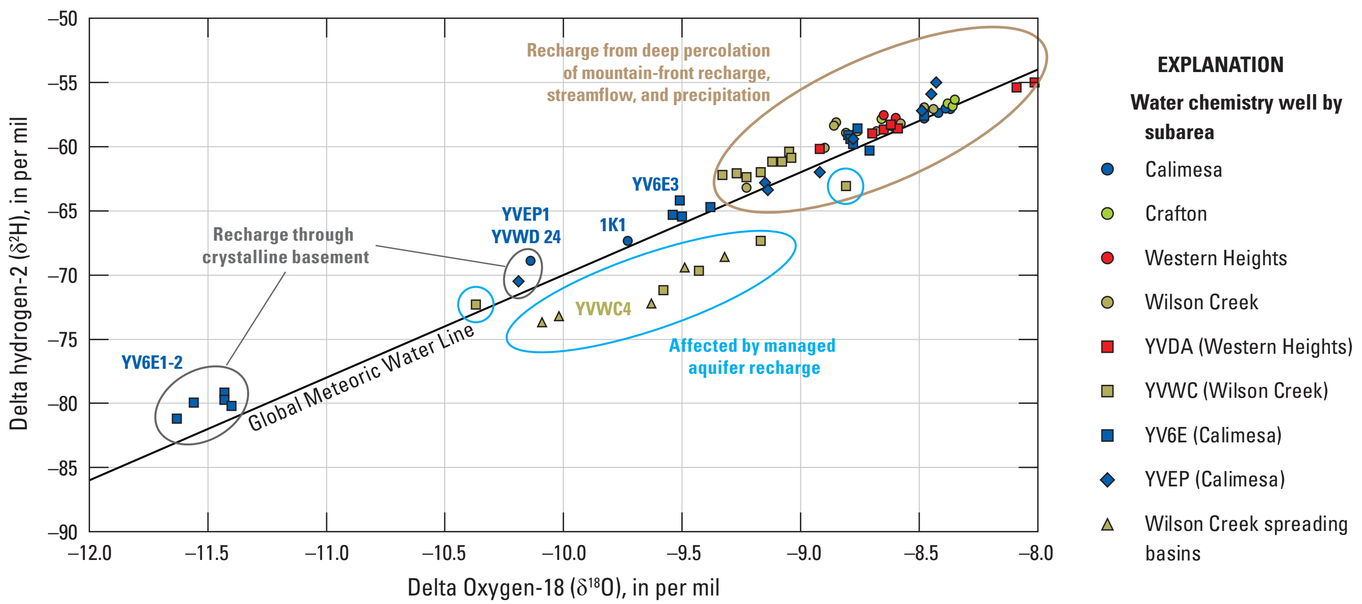

Figure A28. Stable isotope composition of groundwater for select wells in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

Information about the source and evaporative history of water can be used to evaluate the movement of water between parts of an aquifer system. Because groundwater moves slowly, isotopic data collected near the end of long flow lines typically preserve a record of groundwater recharge and movement under predevelopment conditions. This record is especially useful in aquifer systems where traditional hydrologic data, such as water levels, have been altered by pumping, by changes in recharge and discharge, or by human activities. In the Yucaipa subbasin, ratios of stable isotopes of oxygen and hydrogen were evaluated to provide insight about the source, movement, and evaporative history of water in the Yucaipa subbasin. (fig. A28).

Locally recharged groundwater from deep percolation of mountain-front runoff and infiltration of streamflow and precipitation had the heaviest stable isotopic concentrations of all groundwater types in the Yucaipa subbasin, with $\delta^{18}O$ and $\delta^{2}H$ concentrations ranging from –8.00 to –9.50 and –55.00 to –65.00, respectively (fig. A28). The consistent grouping of stable isotopic values indicated that most groundwater in the aquifer has a characteristic groundwater type and is locally recharged. Samples representing locally recharged groundwater the characteristic groundwater type generally plotted slightly to the left of the global meteoric water line, indicating that this type of groundwater quickly infiltrated into the aquifer with little evaporation. Groundwater from the perched aquifer (well YVDA5) has isotopic values within the range of other naturally recharged wells (fig. A28), indicating a similar source of recharge from deep percolation of mountain-front runoff and infiltration of streamflow and precipitation.

Imported water from northern California had lighter stable isotopic concentrations than locally recharged water. Samples from the Wilson Creek spreading basins and well YVWC4 had $\delta^{18}O$ and $\delta^{2}H$ concentrations ranging from –8.75 to –10.50 and –63.00 to –70.25, respectively. Most samples representing imported water plotted to the right of the global meteoric water line likely because of evaporation during the time required to transport imported water from northern California to the Yucaipa subbasin; that is, evaporation caused an increased enrichment of $\delta^{18}O$ and $\delta^{2}H$ prior to infiltration.

Groundwater recharged through crystalline basement has lighter stable isotopes than locally recharged water. Samples from wells YV6E1–3, YVEP1, and a deep sample from YVWD 24, have $\delta^{18}O$ and $\delta^{2}H$ concentrations ranging from –10.14 to –11.63 and –68.89 to –81.20, respectively (fig. A27). These samples plot slightly to the left of the global meteoric water line like locally recharged water, indicating that the water did not evaporate much before infiltrating into the aquifer system. Fractionation processes during atmospheric condensation may result in water with different $\delta^{18}O$ and $\delta^{2}H$ values. Water from a given air mass that condensed at higher elevations and cooler temperatures contains a greater amount of the lighter isotopes of oxygen and hydrogen and has lighter (more negative) $\delta^{18}O$ and $\delta^{2}H$ values than water that condensed from a similar air mass at lower elevations and warmer temperatures. The lighter stable isotopic concentrations in samples recharged through or influenced by water recharged through crystalline basement were indicative of groundwater recharged at higher elevations or in a cooler climate relative to characteristic groundwater in the Yucaipa subbasin (fig. A28).

Groundwater recharged through crystalline basement in the Yucaipa subbasin had similar δ^2H values to a volume-weighted average of precipitation of δ^2H collected near Big Bear, California (–77 per mil; Friedman and others, 1992), at an elevation of about 7,000 ft above sea level—an elevation equivalent to the San Bernardino Mountains in the northeast portion of the Yucaipa subbasin. Groundwater recharged through crystalline basement likely originated in the San Bernardino Mountains and passed through weathered saprolitic material or fractured crystalline basement until recharging the basin-fill aquifer at depth. This recharge and groundwater-flow process likely occurred throughout long periods of time as indicated by the absence of detectable tritium in most groundwater samples recharged through crystalline basement.

Samples from wells YV6E3, YVEP1, and YVWD 24 had major ion concentrations, stable isotopes ratios, and tritium concentrations (see the “Tritium and Carbon-14 Isotopes” section) that indicated a mixture of water recharged through crystalline basement, and water recharged from deep percolation of mountain-front runoff and infiltration of streamflow and precipitation. For instance, stable isotope ratios of samples in these wells are between the range of heavier ratios of locally recharged groundwater and lighter ratios of wells YV6E1 and YV6E2, which are recharged through crystalline basement (fig. A28).

Tritium and Carbon-14 Isotopes

Tritium (^3H) can be a naturally occurring or anthropogenic radioactive isotope of hydrogen and has a half-life of 12.4 years. In this report, 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 California ranged from 9.6 to 16 pCi/L (R. Michel, U.S. Geological Survey, oral commun., 2006; Borchers and Lyttge, 2007). The release of about 800 kilograms of tritium into the atmosphere from atmospheric testing of nuclear weapons from 1952 to 1962 caused tritium activity increased to greater than 2,000 pCi/L (Michel, 1989), and tritium concentrations in precipitation and groundwater recharge increased during that time. After cessation of atmospheric testing of nuclear weapons in 1962, the tritium concentration of precipitation decreased, and by 2002, tritium levels in precipitation had decreased to near pre-1952 levels (Michel, 1989). Tritium concentrations are not affected substantially by chemical reactions other than radioactive decay because tritium is part of the water molecule; therefore, tritium is an excellent tracer of the movement and relative age of water since 1952. In this report, groundwater that has detectable tritium greater than 0.3 pCi/L (Mendez and others, 2001) is interpreted to be water recharged after 1952 or recent recharge.

Carbon-14 (^{14}C) isotopes also are effective for determining the age (time since recharge) of groundwater and the potential effects of age on the movement of groundwater. Carbon-14 is a naturally occurring radioactive isotope of carbon that has a half-life of about 5,730 years (Mook, 1980). Carbon-14 data are expressed in this report as percent modern carbon (pmc) by comparing ^{14}C activities to the specific activity of National Bureau of Standards oxalic acid; 13.56 disintegrations per minute per gram of carbon in the year 1950 equals 100 pmc (Kalin, 2000). Like tritium, ^{14}C was produced by the atmospheric testing of nuclear weapons (Mook, 1980). As a result, ^{14}C activities may exceed 100 pmc in areas where groundwater contains tritium.

Carbon-14 activities are used to determine the age of groundwater samples on timescales ranging from recent to more than 20,000 years before the year 1950. Carbon-14 is not part of the water molecule; therefore, ^{14}C activities may be affected by chemical reactions that add or remove carbon to the groundwater. In addition, ^{14}C activities are affected by the mixing of younger water that has a higher ^{14}C activity with older water that has lower ^{14}C activity. Assuming an initial 100 pmc in the recharging groundwater with only radioactive decay and neglecting geochemical reactions that occur between groundwater and aquifer materials, groundwater having 90 pmc would have recharged 370 years before present, and groundwater having 50 pmc would have been recharged 5,730 years before present (Izbicki and Michel, 2004). These ages are referred to as “uncorrected ages.” In general, uncorrected ^{14}C ages are older than the actual age of the associated groundwater. For the regional aquifer in the Mojave River groundwater basin (not shown; about 40 mi northwest of the Yucaipa subbasin), ^{14}C ages are as much as 30 percent older than actual groundwater ages (Izbicki and others, 1995).

Groundwater samples with tritium concentrations above the detectable limit were found in shallow wells in the Yucaipa subbasin (fig. A27) and were associated with locally recharged water and water imported from northern California. The presence of detectable tritium indicates that these groundwater samples had some portion of recently recharged water. The highest concentrations of tritium generally were found in wells located near sources of natural recharge, such as wells YVWD 13 and YVEP4 in the Oak Glen and Calimesa subareas, respectively (figs. A27*A*, A27*C*). High concentrations of tritium also were found in wells proximal to the Wilson Creek and Oak Glen Creek spreading basins, where imported water from northern California is applied as MAR, such as well YVWC2–4 in the Wilson Creek subarea (figs. A27*A*, A27*B*). Carbon-14 concentrations in wells with detectable tritium generally ranged from about 70 pmc to more than about 95 pmc, indicating recent recharge.

Groundwater samples with tritium concentrations below the detectable limit were found in deep wells in the Calimesa and Western Heights subareas (figs. A27*B*, A27*C*) and were generally associated with locally recharged water and water recharged through crystalline basement. The absence of detectable tritium indicated that these groundwater samples were not recharged recently. In the Western Heights subarea, groundwater samples without detectable tritium have major ion and stable isotopic concentrations associated with locally recharged water and have low concentrations of ^{14}C (wells YVDA1, YVDA2, and WHWC 11; fig. A27*C*). The absence of recent recharge (as indicated by the absence of detectable tritium and low concentrations of ^{14}C) in these wells can be explained by the abundance of slow-moving, unpumped, older water at depth and by limited mixing of groundwater within the aquifer.

In the Calimesa subarea, groundwater samples without detectable tritium had major ion and stable isotopic concentrations generally associated with water recharged through crystalline basement and had low concentrations of ^{14}C (wells YV6E1, YV6E2, YV6E3, and YVWD 24; fig. A27*C*). The absence of detectable tritium and low concentrations of ^{14}C in these wells can be explained by the abundance of slow-moving, unpumped older water at depth, and long, slow travel times of groundwater that likely originated in the San Bernardino Mountains and passed through weathered saprolitic material or fractured crystalline basement before recharging the basin-fill aquifer.

Summary

To better understand the hydrogeology and water resources in the Yucaipa groundwater subbasin (hereafter referred to as “Yucaipa subbasin”), the U.S. Geological Survey (USGS) initiated a study in cooperation with the San Bernardino Valley Municipal Water District (SBVMWD) to characterize and model the hydrologic system of the Yucaipa subbasin and the surrounding Yucaipa Valley watershed (YVW). The YVW is a semiarid inland area that straddles southwestern San Bernardino County and northwestern Riverside County, about 12 miles (mi) southeast of the City of San Bernardino and about 75 mi east of Los Angeles, California. The YVW is bounded on the north by the San Bernardino Mountains, on the southeast by the San Gorgonio Pass, on the south by The Badlands, on the northwest by the San Bernardino Valley, and on the west by the Crafton Hills. The YVW is comprised of three watersheds that encompass the Yucaipa subbasin: (1) Yucaipa Creek, (2) San Timoteo Canyon—San Timoteo Wash, and (3) Little San Gorgonio Creek. The YVW is used as the active domain for the Yucaipa Integrated Hydrologic Model (YIHM) in chapter B of this report.

The Yucaipa subbasin is located within the YVW and is the area of hydrogeologic interest for this study. The subbasin encompasses 39 square miles, including the City of Yucaipa. The boundaries of the Yucaipa subbasin are (1) along geologic contacts between the sedimentary basin-fill within the Yucaipa valley and the uplands of Yucaipa hills, (2) along active faults such as the San Andreas and Crafton Hills fault zones, (3) along outcrops and partly concealed traces of the Banning fault, (4) along topographic surface divides, and (5) along locations adjudicated by the Superior Court of the State of California, Riverside County (2004).

Population growth since the 1940s and changes in water use have forced local water purveyors to adapt water infrastructure to meet demand. Groundwater historically has been the dominant source of water in the Yucaipa subbasin, but water imported via the California State Water Project has augmented the water supply since 2002. Local water managers are concerned that despite the influx of imported water, groundwater levels may decline to a point where producing water will be uneconomical, severely limiting the ability of local agencies to meet water-supply demand.

Climate in the Yucaipa subbasin is characterized by long, warm, dry summers and short, cool, wet winters. Precipitation mostly is in the form of rain, except in colder months when snow sometimes falls at higher elevations. If present, snowpack in the San Bernardino Mountains commonly lasts until April or May. Estimated average precipitation ranges from about 18 inches per year (in/yr) in the Yucaipa Valley to more than 30 in/yr in the San Bernardino Mountains. The average annual recorded precipitation during 1947–2014 was about 12.5 in/yr.

Surface-water flow in the Yucaipa subbasin occurs primarily during the wet season in intermittent or ephemeral streams. The three major streams that traverse the Yucaipa subbasin are Wilson Creek, Oak Glen Creek, and Yucaipa Creek. Perennial flow occurs in the upper reaches of the Wilson Creek and Oak Glen Creek watersheds in the San Bernardino Mountains. The direction of surface water generally flows from the San Bernardino Mountains and Yucaipa hills in the northeast, southwest toward Sam Timoteo Creek and the Santa Ana River, before eventually discharging in the Pacific Ocean about 60 mi southwest of the Yucaipa subbasin. Small springs were present historically along the Chicken Hill fault in the Western Heights groundwater subarea; these springs are no longer flowing because the groundwater table was lowered. Streamflow has been historically monitored at seven streamgages. Annual mean streamflow at the streamgages generally indicate the temporal and spatial patterns of measured average annual precipitation.

Land in the Yucaipa subbasin and encompassing YVW has been used for agriculture and developed into urban areas. Both agricultural and developed lands have been located in the Yucaipa Valley, the Beaumont plain, and in the upland areas of the Yucaipa subbasin. Detailed land-use maps of the YVW show a decrease in agricultural land and an increase in developed land through time. In the 1970s, about 20 percent of land in the YVW was used for agriculture and about 5 percent was developed. By 2014, agricultural land was almost completely absent in the YVW, and about 17 percent of land was developed.

The aquifer system in the Yucaipa subbasin consists of three basin-fill aquifer units—surficial materials, unconsolidated sediment, and consolidated sedimentary materials. Underlying the basin-fill aquifer units is crystalline basement, which includes a layer of weathered saprolitic material along and above its interpreted upper surface. Within the Yucaipa subbasin, a series of faults and groundwater barriers delineate 11 groundwater subareas (hereafter referred to as “subareas”), 7 of which comprise the majority of the aquifer system. Several faults and barriers were identified as likely to inhibit groundwater flow, including the Chicken Hill fault, the Cherry Valley thrust fault, and structural folds associated with the South Mesa barrier and the inactive strand of the Banning fault.

Recharge to the basin-fill aquifer occurs primarily as deep percolation of mountain-front runoff and infiltration of streamflow in the Oak Glen, Triple Falls Creek, and Wilson Creek groundwater subareas in the northeastern part of the Yucaipa subbasin. Underflow from crystalline basement and infiltration from precipitation are additional sources of natural recharge to the basin-fill aquifer. Estimates of historical annual recharge generally ranged from about 7,000 acre-feet per year (acre-ft/yr) to more than 13,000 acre-ft/yr. Water from northern California has been imported to the Yucaipa subbasin since 2002, applied directly as managed aquifer recharge (MAR) to the Wilson Creek and Oak Glen Creek spreading basins, and treated and used to augment the municipal water supply. During 2002–14, about 69,200 acre-ft of water was imported to the subbasin; about 17,900 acre-ft of this amount was applied as MAR. Importation of water reduced the demand for groundwater pumping in the Yucaipa subbasin. Average annual pumpage during 1947–2014 was about 12,800 acre-ft/yr and ranged from as low as about 4,000 acre-feet (acre-ft) in 1947 to as much as about 18,500 acre-ft in 2002.

The predominant direction of groundwater flow under historical and present-day conditions is from the northeastern part of the subbasin adjacent to the San Bernardino Mountains and Yucaipa hills, to the west and south to San Timoteo Creek, and eventually to the Santa Ana River west of the Yucaipa subbasin. Natural discharge of groundwater occurs as evapotranspiration and as subsurface outflow along the western margin of the Yucaipa subbasin to the adjacent San Bernardino groundwater subbasin. Estimates of subsurface outflow across the western margin range from about 2,400 to 20,000 acre-ft/yr for 1905–2014. The decline in estimated outflow values during this period likely resulted from a steady decline of groundwater levels in the Yucaipa subbasin caused by pumping. The long-term extraction of groundwater has caused groundwater levels to decrease by almost 200 feet since the 1940s in parts of the Calimesa and Western Heights groundwater subareas. In contrast, observed declines in groundwater levels were less substantial in subareas near areas of natural recharge (such as the Oak Glen, Wilson Creek, and Crafton groundwater subareas). In some locations within these subareas, water levels have increased, likely resulting from pumping reduction and MAR.

Four groundwater types were identified in the Yucaipa subbasin, and the chemical character of the four groundwater types varied depending on the source and location of recharge. Most groundwater in the Yucaipa subbasin was calcium-bicarbonate-type water that was locally recharged from deep percolation of mountain-front runoff, streamflow, and precipitation. Groundwater recharged through crystalline basement was sodium-sulfate-type water and was identified in deep wells in the Calimesa subarea. Groundwater in a perched aquifer in the Western Heights subarea was sulfate-rich, calcium-bicarbonate-type water. Water imported from northern California and applied as MAR in the Wilson Creek groundwater subarea was chloride-type water. At least some samples of all groundwater types, except for water recharged through crystalline basement, had detectable tritium, indicating that most groundwater types had modern recharge ages. The concentrations of total dissolved solids (TDS) of groundwater ranged from about 225 to 1,120 milligrams per liter; groundwater samples with lower TDS concentrations generally were collected from wells near sources of natural recharge; samples with the highest TDS concentrations were collected from deep wells near the contact with the crystalline basement.

The hydrologic characterization of the Yucaipa subbasin presented in this chapter supports development of an integrated numerical hydrologic model. The development and calibration of this model is presented in chapter B of this report. This model further refines the hydrologic understanding of the Yucaipa subbasin and the encompassing YVW.

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Appendix A1. Tables

This appendix includes two tables. Information on wells used for groundwater-level and groundwater-quality data is included in table A1.1, and annual groundwater pumpage by groundwater subarea is included in table A1.2.

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Table A1.1. Selected wells with groundwater-level and water-quality data, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

[Water quality data from National Water Information System (NWIS; U.S. Geological Survey, 2018). **Abbreviations**: NAVD 88, North American Vertical Datum of 1988; —, not applicable]

Well name	USGS site name	USGS site number	Approximate land-surface altitude, in feet (NAVD 88)	Well depth, in feet	Use of data	Groundwater subarea
1K1	002S002W01K001S	340124117021301	2,576.73	356	Water quality diagram	Calimesa
16A1	002S002W16A001S	340006117051801	2,198	—	Hydrograph[1]	Live Oak
20Q1	001S001W20Q001S	340355117001901	3,389	—	Hydrograph[1]	Triple Falls Creek
28P1	001S001W28P001S	340306116593901	3,547	223	Water quality diagram	Oak Glen
Chicken Hill No. 4	002S002W03L001S	340129117044201	2,197	505	Hydrograph[2], water quality diagram	Calimesa
SMWC 1	002S002W14J002S	335943117032001	2,418.07	400	Hydrograph[1,3]	Cherry Valley
SMWC 3	002S002W14R001S	335930117032101	2,355.99	500	Hydrograph[1,3]	San Timoteo
SMWC 4	002S002W14R003S	335924117031701	2,336.53	1,000	Hydrograph[3], water quality diagram	San Timoteo
SMWC 5	002S002W14M001S	335949117040601	2,336	1,119	Hydrograph[3]	Cherry Valley
SMWC 2/11	002S002W14C001S	340014117034301	2,387	443	Hydrograph[1,3]	Calimesa
USGS 2	001S001W30N001S	340257117015301	2,814.34	500	Water quality diagram	Wilson Creek
WCSB	Outflow into Wilson Creek Spreading Ponds nr Yucaipa CA	340305117014401	2,883	—	Water quality diagram	Wilson Creek
WHWC 10	002S002W05K001S	340135117063001	2,083	690	Hydrograph[1,4]	Sand Canyon
WHWC 11	002S002W04G004S	340137117053501	2,090	1,710	Water quality diagram	Western Heights
WHWC 12	002S002W04J003S	340135117051502	2,107	1,100	Hydrograph[1,4], water quality diagram	Western Heights
WHWC 3	002S002W04G002S	340140117053301	2,094.82	615	Hydrograph[4]	Western Heights
WHWC 5A	002S002W04J002S	340135117051601	2,107	1,100	Hydrograph[4]	Western Heights
YV6E1	002S002W02F002S	340136117033901	2,426.41	884	Hydrograph[1], water quality diagram	Calimesa
YV6E2	002S002W02F003S	340136117033902	2,426.41	747	Hydrograph[1], water quality diagram	Calimesa
YV6E3	002S002W02F004S	340136117033903	2,426.41	547	Hydrograph[1], water quality diagram	Calimesa

Table A1.1. Selected wells with groundwater-level and water-quality data, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. —Continued

[Water quality data from National Water Information System (NWIS; U.S. Geological Survey, 2018). **Abbreviations**: NAVD 88, North American Vertical Datum of 1988; —, not applicable]

Well name	USGS site name	USGS site number	Approximate land-surface altitude, in feet (NAVD 88)	Well depth, in feet	Use of data	Groundwater subarea
YV6E4	002S002W02F005S	340136117033904	2,426.41	399	Hydrograph[1], water quality diagram	Calimesa
YV6E5	002S002W02F006S	340136117033905	2,426.41	309	Hydrograph[1], water quality diagram	Calimesa
YVDA1	002S002W04L002S	340130117054901	2,069.97	1,053	Hydrograph[1], water quality diagram	Western Heights
YVDA2	002S002W04L003S	340130117054902	2,069.97	820	Hydrograph[1], water quality diagram	Western Heights
YVDA3	002S002W04L004S	340130117054903	2,069.97	593	Hydrograph[1], water quality diagram	Western Heights
YVDA4	002S002W04L005S	340130117054904	2,069.97	446	Hydrograph[1], water quality diagram	Western Heights
YVDA5	002S002W04L006S	340130117054905	2,069.97	246	Hydrograph[1], water quality diagram	Western Heights
YVEP1	002S002W12H001S	340046117020801	2,559.47	849	Hydrograph[1], water quality diagram	Calimesa
YVEP2	002S002W12H002S	340046117020802	2,559.47	655	Hydrograph[1], water quality diagram	Calimesa
YVEP3	002S002W12H003S	340046117020803	2,559.47	528	Hydrograph[1], water quality diagram	Calimesa
YVEP4	002S002W12H004S	340046117020804	2,559.47	400	Hydrograph[1], water quality diagram	Calimesa
YVWC1	001S002W36A002S	340248117020901	2,753.09	838	Hydrograph[1], water quality diagram	Wilson Creek
YVWC2	001S002W36A003S	340248117020902	2,753.09	658	Hydrograph[1], water quality diagram	Wilson Creek
YVWC3	001S002W36A004S	340248117020903	2,753.09	515	Hydrograph[1], water quality diagram	Wilson Creek
YVWC4	001S002W36A005S	340248117020904	2,753.09	370	Hydrograph[1], water quality diagram	Wilson Creek
YVWD 2	002S002W11B001S	340057117032501	2,414	638	Hydrograph[1,5]	Calimesa
YVWD 5	001S002W36N001S	340215117025701	2,560	482	Hydrograph[1,5], water quality diagram	Wilson Creek
YVWD 6	002S002W01F001S	340136117023701	2,558.27	629	Hydrograph[1,5]	Wilson Creek
YVWD 9	001S002W25M001S	340312117025001	2,602.81	506	Hydrograph[5]	Crafton
YVWD 13	001S001W32C001S	340253117002701	3,192	415	Hydrograph[1,5], water quality diagram	Oak Glen
YVWD 15	001S001W32C001S	340054117004801	2,813	129	Hydrograph[5]	Oak Glen
YVWD 18	001S002W36F001S	340233117023501	2,597	596	Hydrograph[5]	Wilson Creek
YVWD 24	002S002W11A001S	340105117031601	2,440	590	Water quality diagram	Calimesa
YVWD 27	002S001W08F001S	340054117002901	2,854	314	Hydrograph[1,5]	Oak Glen
YVWD 28	002S001W09G001S	340041117592001	3,156.00	606	Hydrograph[1,5]	Wildwood

Table A1.1. Selected wells with groundwater-level and water-quality data, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California. —Continued

[Water quality data from National Water Information System (NWIS; U.S. Geological Survey, 2018). **Abbreviations**: NAVD 88, North American Vertical Datum of 1988; —, not applicable]

Well name	USGS site name	USGS site number	Approximate land-surface altitude, in feet (NAVD 88)	Well depth, in feet	Use of data	Groundwater subarea
YVWD 36	001S001W20M001S	340409117005701	3,201.83	443	Hydrograph[5]	Triple Falls Creek
YVWD 37	001S002W25A001S	340343117021201	2,780	468	Hydrograph[1,5]	Crafton
YVWD 43	001S001W19P001S	340348117013001	2,939	350	Hydrograph[1,5]	Gateway
YVWD 46	001S002W36G001S	340236117023101	2,630	1,150	Water quality diagram	Wilson Creek
YVWD 53	001S002W25R004S	340255117021601	2,733.00	970	Water quality diagram	Wilson Creek
YVWD 55	001S002W35H003S	340223117031801	2,499	1,050	Hydrograph[1,5], water quality diagram	Crafton
YVWD 56	001S002W36F004S	340239117024801	2,573	850	Hydrograph[1,5], water quality diagram	Crafton

[1]Hydrograph data from NWIS (U.S. Geological Survey, 2018).

[2]Hydrograph data from D. Kerns, City of Redlands, written commun., 2016.

[3]Hydrograph data from D. Armstrong, South Mesa Water Company, written commun., 2016.

[4]Hydrograph data from B. Brown, Western Heights Water Company, written commun., 2016.

[5]Hydrograph data from B. Wall, Yucaipa Valley Water District, written commun., 2016.

Table A1.2. Annual groundwater pumpage by groundwater subarea in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.

[All values are in acre-ft. Values of 0 were for years with a reported pumpage of 0 acre-feet. Groundwater pumpage data was compiled from San Bernardino Valley Municipal Water District (A. Jones,, San Bernardino Valley Municipal Water District, written commun., 2016) and supplemented by additional data from Yucaipa Valley Water District (B. Brown, Yucaipa Valley Water District, written commun., 2016), South Mesa Water Company (D. Armstrong, South Mesa Water Company, written commun., 2016), Western Heights Water Company (B. Brown, Western Heights Water Company, written commun., 2016), and Geoscience Support Services, Inc. (J. Yeh, Geoscience Support Services, Inc., written commun., 2018) **Abbreviation**: —, no reported pumpage]

Year	Calimesa	Cherry Valley	Crafton	Gateway	Live Oak	Oak Glen	San Bernardino Mountains	San Timoteo	Triple Falls Creek	Sand Canyon	Western Heights	Wildwood	Wilson Creek	Yucaipa Hills	Total
1947	2,351	—	358	424	—	290	653	—	—	—	—	—	—	—	4,076
1948	2,177	—	1,022	280	—	290	638	—	—	—	102	—	412	—	4,921
1949	2,496	—	1,018	240	482	290	624	—	—	—	2,195	—	400	—	7,745
1950	3,817	157	1,000	540	557	549	616	—	340	—	2,121	—	1,695	225	11,617
1951	4,347	83	1,012	466	627	649	609	—	305	—	2,401	—	1,968	195	12,662
1952	3,624	74	998	446	355	557	602	—	380	—	2,007	—	1,339	294	10,676
1953	3,547	54	1,192	500	841	590	595	—	300	—	2,145	—	1,768	220	11,752
1954	3,781	115	1,375	480	742	548	587	—	241	—	2,149	—	1,262	229	11,509
1955	3,620	112	1,216	460	863	494	551	—	260	—	2,270	—	1,754	155	11,755
1956	4,114	113	1,237	490	1,253	495	479	123	240	—	2,345	—	1,692	131	12,712
1957	4,277	121	1,212	487	1,028	518	537	—	170	—	2,539	—	1,507	85	12,481
1958	3,311	941	1,373	462	878	404	448	169	255	—	2,206	—	1,715	170	12,332
1959	2,921	1,124	1,117	521	904	624	583	169	378	—	2,549	—	1,974	248	13,112
1960	3,175	1,287	891	353	983	723	639	171	384	—	2,539	—	1,583	152	12,880
1961	3,720	1,201	1,091	342	984	793	611	—	311	—	2,774	—	1,941	110	13,878
1962	3,686	976	891	297	1,165	936	613	—	353	—	2,596	—	1,831	122	13,466
1963	3,985	696	349	343	1,155	720	612	—	385	—	2,839	—	1,477	131	12,692
1964	4,347	689	695	39	1,138	500	612	—	412	124	3,305	—	1,689	116	13,666
1965	2,747	784	601	71	921	509	612	—	382	258	2,490	—	1,483	88	10,946
1966	3,773	1,487	643	200	954	801	636	—	404	252	2,815	114	1,465	106	13,650
1967	3,891	1,462	490	513	544	865	636	—	464	215	2,210	114	972	130	12,506
1968	4,201	937	558	69	286	749	680	—	461	189	2,685	114	1,579	117	12,625
1969	3,859	293	397	131	2,364	530	709	—	726	530	1,821	114	1,672	100	13,246
1970	4,319	360	495	80	173	799	709	—	522	435	2,276	114	1,474	20	11,776
1971	4,313	603	267	51	183	983	506	0	550	364	2,256	114	1,391	0	11,581
1972	4,828	454	433	39	185	751	680	0	425	112	3,301	114	1,511	0	12,833
1973	4,084	486	316	60	193	870	680	—	530	179	2,661	114	2,155	0	12,328
1974	4,410	445	285	69	186	1,106	680	—	503	52	2,869	114	3,003	64	13,786

Table A1.2. Annual groundwater pumpage by groundwater subarea in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.—Continued

[All values are in acre-ft. Values of 0 were for years with a reported pumpage of 0 acre-feet. Groundwater pumpage data was compiled from San Bernardino Valley Municipal Water District (A. Jones,, San Bernardino Valley Municipal Water District, written commun., 2016) and supplemented by additional data from Yucaipa Valley Water District (B. Brown, Yucaipa Valley Water District, written commun., 2016), South Mesa Water Company (D. Armstrong, South Mesa Water Company, written commun., 2016), Western Heights Water Company (B. Brown, Western Heights Water Company, written commun., 2016), and Geoscience Support Services, Inc. (J. Yeh, Geoscience Support Services, Inc., written commun., 2018) **Abbreviation**: —, no reported pumpage]

Year	Calimesa	Cherry Valley	Crafton	Gateway	Live Oak	Oak Glen	San Bernardino Mountains	San Timoteo	Triple Falls Creek	Sand Canyon	Western Heights	Wildwood	Wilson Creek	Yucaipa Hills	Total
1975	4,216	403	311	6	190	878	680	—	453	47	2,641	112	1,748	175	11,860
1976	4,131	437	263	52	186	804	680	—	483	62	2,804	126	1,953	171	12,152
1977	4,201	202	195	110	191	680	680	—	447	94	2,668	120	1,769	158	11,515
1978	4,546	251	197	49	229	861	680	—	962	79	2,815	151	1,372	29	12,221
1979	4,257	248	369	1	210	816	680	—	1,058	45	2,847	114	1,212	73	11,930
1980	4,307	219	298	6	350	991	680	—	1,106	177	2,328	142	1,527	78	12,209
1981	4,243	349	277	29	249	809	680	—	1,091	235	2,246	165	1,380	225	11,978
1982	3,694	106	127	65	223	744	680	—	941	135	2,095	123	1,025	395	10,353
1983	4,031	51	130	16	185	1,042	680	—	1,057	64	1,926	97	742	117	10,138
1984	5,636	105	177	40	140	944	711	—	910	163	2,555	127	1,037	113	12,658
1985	5,501	126	172	34	118	936	174	—	497	162	2,531	140	1,038	191	11,620
1986	4,446	81	96	40	121	960	175	—	467	95	2,652	169	1,188	153	10,643
1987	5,184	191	179	0	95	912	175	—	357	271	2,418	178	1,099	126	11,185
1988	5,840	73	249	0	145	858	175	326	334	227	2,638	194	1,201	99	12,359
1989	5,822	54	226	40	165	937	175	384	219	121	2,647	198	1,425	121	12,534
1990	5,513	113	357	119	175	851	175	489	251	29	3,267	172	1,644	63	13,218
1991	5,514	47	229	16	180	723	175	382	306	49	2,730	112	2,354	30	12,848
1992	5,394	185	335	0	150	755	175	346	407	12	2,805	87	2,551	44	13,246
1993	5,263	442	208	1	160	911	175	434	548	0	2,944	57	1,998	6	13,147
1994	5,450	553	335	0	152	1,020	175	501	490	1	3,656	71	1,909	131	14,445
1995	5,829	543	211	0	160	1,198	175	528	315	1	3,799	76	1,599	41	14,476
1996	6,655	362	190	0	150	1,074	175	595	368	2	4,086	52	2,095	56	15,860
1997	6,371	571	150	0	157	937	175	612	254	52	3,874	38	2,434	42	15,667
1998	5,271	443	358	0	152	1,024	175	478	198	27	3,431	28	2,158	55	13,799
1999	6,656	637	226	0	154	936	175	580	241	68	2,735	25	3,422	28	15,883
2000	6,158	692	750	0	148	913	176	576	233	50	2,455	46	4,225	76	16,498
2001	6,187	440	193	0	145	709	175	1,921	112	63	2,343	45	4,355	237	16,925
2002	6,616	789	888	0	149	621	175	2,139	163	60	2,505	30	4,229	212	18,576

Table A1.2. Annual groundwater pumpage by groundwater subarea in the Yucaipa groundwater subbasin, Yucaipa Valley watershed, San Bernardino and Riverside Counties, California.—Continued

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Year	Calimesa	Cherry Valley	Crafton	Gateway	Live Oak	Oak Glen	San Bernardino Mountains	San Timoteo	Triple Falls Creek	Sand Canyon	Western Heights	Wildwood	Wilson Creek	Yucaipa Hills	Total
2003	6,289	601	748	0	153	659	175	2,082	142	63	2,307	29	3,672	164	17,085
2004	5,384	786	958	0	150	538	175	2,339	87	102	2,412	29	4,142	142	17,243
2005	5,066	679	1,172	0	25	786	175	1,917	242	63	2,376	45	3,490	167	16,203
2006	5,131	721	1,174	0	1	659	175	2,672	158	54	2,582	32	3,374	199	16,931
2007	4,708	708	957	0	0	638	176	2,349	113	49	2,809	22	3,495	183	16,207
2008	4,028	876	685	0	0	459	175	1,043	78	63	2,376	0	2,801	97	12,682
2009	3,742	708	563	0	0	546	175	886	71	61	1,865	0	2,786	131	11,533
2010	3,907	744	657	0	0	612	175	1,104	58	53	1,875	0	2,971	112	12,268
2011	3,407	648	542	0	0	545	175	945	33	34	1,963	0	2,871	111	11,274
2012	3,682	655	707	0	0	601	1	1,148	0	63	2,124	0	2,821	108	11,909
2013	4,196	663	1,037	0	0	554	3	1,343	21	75	2,071	0	2,116	170	12,248
2014	4,731	594	864	0	0	521	0	1,641	14	56	2,124	0	3,746	108	14,400

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Publishing support provided by the

U.S. Geological Survey Science Publishing Network, Sacramento Publishing Service Center

Cromwell and others—**Chapter A: Hydrogeologic Characterization of the Yucaipa Groundwater Subbasin**—SIR 2021–5118–A

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20215118A