Prepared in cooperation with the Hi-Desert Water District

# The Effects of Artificial Recharge on Groundwater Levels and Water Quality in the West Hydrogeologic Unit of the Warren Subbasin, San Bernardino County, California

Scientific Investigations Report 2013–5088


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

**Cover:** Water being released into a recharge pond, Yucca Valley, California. Photograph by David O'Leary, U.S. Geological Survey.

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SALLY JEWELL, Secretary

**U.S. Geological Survey**
Suzette M. Kimball, Acting Director

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# Contents—Continued

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## Figures—Continued

# Tables

# Conversion Factors

Inch/Pound to SI

| 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 ($hm^3$) |
| | **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) |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| foot per year (ft/yr) | 0.3048 | meter per year (m/yr) |

SI to Inch/Pound

| Multiply | By | To obtain |
|---|---|---|
| | **Length** | |
| centimeter (cm) | 0.3937 | inch (in.) |
| meter (m) | 1.094 | yard (yd) |
| millimeter (mm) | 0.03937 | inch (in.) |
| | **Mass** | |
| gram (g) | 0.03527 | ounce, avoirdupois (oz) |
| kilogram (kg) | 2.205 | pound avoirdupois (lb) |
| | **Pressure** | |
| kilopascal (kPa) | 0.009869 | atmosphere, standard (atm) |
| kilopascal (kPa) | 0.01 | Bar |
| kilopascal (kPa) | 0.2961 | inch of mercury at 60°F (in Hg) |
| kilopascal (kPa) | 0.1450 | pound-force per inch (lbf/in) |
| kilopascal (kPa) | 20.88 | pound per square foot (lb/$ft^2$) |
| kilopascal (kPa) | 0.1450 | pound per square inch (lb/$ft^2$) |
| | **Volume** | |
| cubic centimeter ($cm^3$) | 0.06102 | cubic inch ($in^3$) |
| cubic meter ($m^3$) | 264.2 | gallon (gal) |

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

$$°C=(°F-32)/1.8$$

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

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

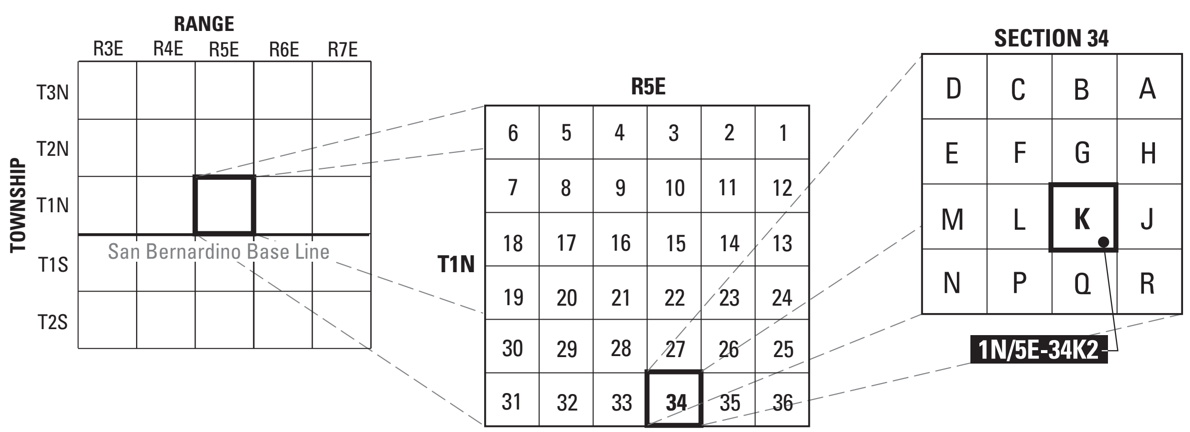
Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

# Abbreviations

| | |
|---|---|
| ‰ | parts per thousand |
| $^{18}O$ | oxygen-18 |
| ASTM | American Society for Testing and Materials |
| AT | advanced tensiometers |
| bls | below land surface |
| CAWSC | California Water Science Center |
| D or $^{2}H$ | deuterium |
| DOC | dissolved organic carbon |
| H | Hydrogen |
| HDP | Heat-Dissipation probes |
| HDWD | Hi-Desert Water District |
| MCL | maximum contaminant level |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| mil | million |
| mL | milliliter |
| MPN | most probable number |
| MWL | meteoric water line |
| N | nitrogen |
| $NO_3$ | nitrate |
| $NO_3$-N | nitrate concentrations |
| NWIS | National Water Information System |
| NWISWeb | National Water Information System web page |
| NWQL | National Water Quality Laboratory |
| O | oxygen |
| PVC | polyvinyl chloride |
| rpm | revolutions per minute |
| SWP | State Water Project |
| THM | trihalomethane |
| THMFP | trihalomethane formation potential |
| USEPA | U.S. Environmental Protection Agency |
| USGS | U.S. Geological Survey |
| VSMOW | Vienna standard mean ocean |
| YVUZ | Yucca Valley unsaturated zone |
| $\delta$ | delta notation |
| $\delta^{18}O$ | delta oxygen-18 |
| $\delta D$ | delta deuterium |
| µg/L | micrograms per liter |

## Well-Numbering System

Wells and any other monitoring devices at each site were identified and given a unique Station number according to their location in the rectangular system for the subdivision of public lands and type of instrumentation. Each name consists of the township number, north or south; the range number, east or west; and the section number. Each section is divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with “A” in the northeast corner of the section and progressing in a sinusoidal manner to “R” in the southeast corner. Within the 40-acre tract, the instruments are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. In California, there are three base lines and meridians; Humboldt (H), Mount Diablo (M), and San Bernardino (S). All instruments in the study area are referenced to the San Bernardino base line and meridian (S). Station numbers consist of 15 characters for wells and follow the format 001N005E34K002S; station numbers for other monitoring devices consist of the 15 characters followed by the three letter abbreviation indicating the type of instrumentation described previously. In this report, well numbers are abbreviated and written 1N/5E-34K2. Wells in the same township and range are referred to only by their section designation, 34K2. The following diagram shows how the number for well 1N/5E-34K2 is derived.




**Well-numbering diagram** (Note: maps in this report use abbreviated well numbers such as **"34K2"**)

## Acknowledgements

The authors thank the Hi-Desert Water District for providing funding, data, access to property, and permission for conducting drilling and monitoring activities. The authors also thank The Benevolent & Protective Order of Elks of the U.S.A. Lodge #2314 and Blue Skies Country Club, for providing access to their property for conducting drilling and monitoring activities.

Numerous USGS staff assisted with this project, including Allen H. Christensen, Dennis A. Clark, Kevin M. Ellet, David R. O’Leary, and Russell Johnson.

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## Abstract

Between the late 1940s and 1994, groundwater levels in the Warren subbasin, California, declined by as much as 300 feet because pumping exceeded sparse natural recharge. In response, the local water district, Hi-Desert Water District, implemented an artificial-recharge program in early 1995 using imported water from the California State Water Project. Subsequently, the water table rose by as much as 250 feet; however, a study done by the U.S. Geological Survey found that the rising water table entrained high-nitrate septic effluent, which caused nitrate (as nitrogen) concentrations in some wells to increase to more than the U.S. Environmental Protection Agency maximum contaminant level of 10 milligrams per liter.

A new artificial-recharge site (site 3) was constructed in 2006 and this study, which started in 2004, was done to address concerns about the possible migration of nitrates in the unsaturated zone. The objectives of this study were to: (1) characterize the hydraulic, chemical, and microbiological properties of the unsaturated zone; (2) monitor changes in water levels and water quality in response to the artificial-recharge program at site 3; (3) determine if nitrates from septic effluent infiltrated through the unsaturated zone to the water table; (4) determine the potential for nitrates within the unsaturated zone to mobilize and contaminate the groundwater as the water table rises in response to artificial recharge; and (5) determine the presence and amount of dissolved organic carbon because of its potential to react with disinfection byproducts during the treatment of water for public use.

Two monitoring sites were installed and instrumented with heat-dissipation probes, advanced tensiometers, suction-cup lysimeters, and wells so that the arrival and effects of recharging water from the State Water Project through the 250 to 425 foot-thick unsaturated zone and groundwater system could be closely observed. Monitoring site YVUZ-1 was located between two recharge ponds in the middle of site 3, and YVUZ-2 was located approximately 1,200 feet down-gradient and to the southeast in an area where septic systems have been in use since about 1960. Site YVUZ-3 only went to a depth of 42 feet and was used to sample the upper part of the unsaturated zone near a golf course.

Prior to the start of artificial recharge at site 3, nitrate concentrations reported as nitrogen from the soil leachate below YVUZ-1 did not exceed 1.58 milligrams per kilogram. Nitrate-reducing bacteria concentrations of 4,300 most probable number were found at about 220 feet below land surface and at the top of the water table at YVUZ-1. Nitrate concentrations at YVUZ-2 reached a maximum concentration of about 25 milligrams per kilogram between about 100 and 121 feet below land surface; concentrations of nitrate-reducing or denitrifying bacteria were as high as 21,000 most probable number at 36 feet below land surface but did not exceed 40 most probable number below about 150 feet below land surface.

Between June 2006 and September 2009, more than 9,800 acre feet of water from the State Water Project was released to site 3 ponds. The infiltration of the recharge water was predominantly vertical with limited lateral spreading to a depth of about 200 feet below land surface at YVUZ-1. Lateral spreading of the recharge water with depth was caused by geologic heterogeneities within the unsaturated zone, and resulted in varied arrival times of the recharge water to the instruments and slower rates of vertical movement with depth. No abrupt changes in soil moisture were observed at YVUZ-2, indicating that the recharge water had not reached that site by September 2009. Water levels from the monitoring wells at both sites and from five production wells nearby showed that the water table rose at a mean rate of about 0.08 feet per day between June 2006 and January 2009.

The arrival of the water from the State Water Project caused relatively rapid changes in the stable-isotopic ratios from the lysimeters at YVUZ-1. The estimated average rate of infiltration of the recharge water through the unsaturated zone ranged from 3.7 to 25 feet per day. The recharge water arrived at the monitoring well below the recharge ponds between August 2007 and March 2008; the rate of vertical movement to the monitoring well was between 0.6 and 0.9 feet per day. By September 2008, a production well located 375 feet west of site 3 was producing almost 100 percent infiltrated recharge water. By contrast, the stable-isotope data from the lysimeters at YVUZ-2 showed that the recharge water had not reached this site by September 2009, but that septic effluent in the unsaturated zone likely had mixed with the native pore water

to at least 154 feet below land surface. Assuming vertical infiltration, the minimum rate of infiltration of septic effluent since 1960 was about 3 feet per year. The isotopic data from the lysimeters at YVUZ-3 indicated two different sources of water to the upper 43 feet–irrigation-return flow and precipitation.

Nitrate concentrations of the water from the State Water Project did not exceed 1 milligram per liter. Prior to artificial recharge, nitrate concentrations of the pore water at YVUZ-1 ranged between 6 to 18.2 milligrams per liter. After the arrival of the recharge water, the nitrate concentrations from the lysimeters and well at YVUZ-1 decreased to less than 1 milligram per liter, with the exception of samples collected at 205.5 feet, which did not exceed 4.12 milligrams per liter. The decrease in nitrate concentrations after artificial recharge indicated that the rising water table did not result in an increase of nitrates below YVUZ-1. At YVUZ-2, nitrate concentrations ranged between 12 to 479 milligrams per liter. The highest nitrate concentrations were at 92 feet below land surface and were almost seven times that of samples collected from a nearby septic tank. Nitrate concentrations from the lysimeter at 273 feet below land surface increased from 6 to almost 58 milligrams per liter after it was saturated by the rising water table in December 2007. These increases could be the result of the mobilization of high-nitrate water from regional sources of septic effluent after saturation, or the result of high-nitrate water present at the top of the water table that may be diluted deeper in the aquifer.

Nitrate concentrations in groundwater from five nearby production wells and from both monitoring wells were less than 5 milligrams per liter before artificial recharge started. Nitrate concentrations decreased to less than 3 milligrams per liter in three of the production wells and the monitoring well below the recharge ponds after artificial recharge.

Dissolved organic carbon concentrations were measured in the recharge water and groundwater because of the potential for dissolved organic carbon to react with chlorine to form trihalomethanes during the water-treatment process. The dissolved organic carbon concentrations of the recharge water were 3.1 milligrams per liter or less, and dissolved organic carbon concentrations of the groundwater were less than 1 milligram per liter. Even though recharge water was present in some of the wells by September 2008, the concentrations of both dissolved organic carbon and trihalomethane formation potential in the groundwater did not increase. Interpretation of these data suggests that the dissolved organic carbon from the recharge water is altered or metabolized in the unsaturated zone, either by absorption to the grain particles in the soil or by microbiological processes.

# Introduction

Historically, groundwater was the sole source of water supply, and septic tanks were the primary method for wastewater treatment, for the town of Yucca Valley, California, located in the Warren subbasin of the Morongo groundwater basin (fig. 1). An imbalance between the amount of natural recharge and groundwater pumpage in the subbasin since the late 1940s caused groundwater levels to decline by as much as 300 feet (ft) by 1994 (Nishikawa and others, 2003). In response, the local water district, Hi-Desert Water District (HDWD), implemented an artificial-recharge program in 1995, which consisted of applying imported water from the California State Water Project (SWP) to two recharge ponds (sites 6 and 7) near the center of the subbasin (fig. 1). Groundwater levels recovered by as much as 250 ft beneath the recharge ponds between February 1995 and December 2001 as a result of the artificial-recharge program; however, nitrate ($NO_3$) concentrations, reported as nitrogen (N), and referred to in this report as $NO_3$-N, in water from some production wells near the recharge ponds increased from about 2 milligrams per liter (mg/L) to more than the U.S. Environmental Protection Agency (USEPA) water-quality maximum contaminant level (MCL) of 10 mg/L (U.S. Environmental Protection Agency, 2002; fig. 2).

In 1997, the U.S. Geological Survey (USGS) initiated a cooperative study with the HDWD to evaluate the source of nitrates and the potential effects of present and future artificial-recharge programs in the Warren subbasin (Nishikawa and others, 2003). Prior to the artificial recharge, most of the septic effluent accumulated in the more than 300-ft-thick unsaturated zone. Groundwater-flow and solute-transport models were developed as part of the study to evaluate the effect of artificial recharge on water levels and nitrate concentrations in the subbasin. The conclusions drawn from that study were that septic effluent was the primary source of high nitrate to the groundwater system, and that rising groundwater levels, resulting from the artificial-recharge program, entrained high-nitrate septic effluent stored in the unsaturated zone (fig. 3). Model results indicated that most of the applied artificial-recharge water remained near where it was applied because extensive faulting in the subbasin effectively compartmentalizes the groundwater system into five separate hydrogeologic units. In addition, the model simulated that the proposed artificial recharge of 3,300 acre-feet per year (acre-ft/yr) in the west hydrogeologic unit at site 3 (fig. 1) could result in a water-level rise of 75 ft near the site and an increase in nitrate concentrations of about 30–35 mg/L (Nishikawa and others, 2003). Although the model provided a tool to help evaluate and manage artificial recharge in the subbasin, there is a need to monitor the distribution of nitrate in the unsaturated zone in the west hydrogeologic unit to help water managers ensure that the proposed artificial recharge will not result in nitrate concentrations exceeding USEPA MCLs in the HDWD production wells.

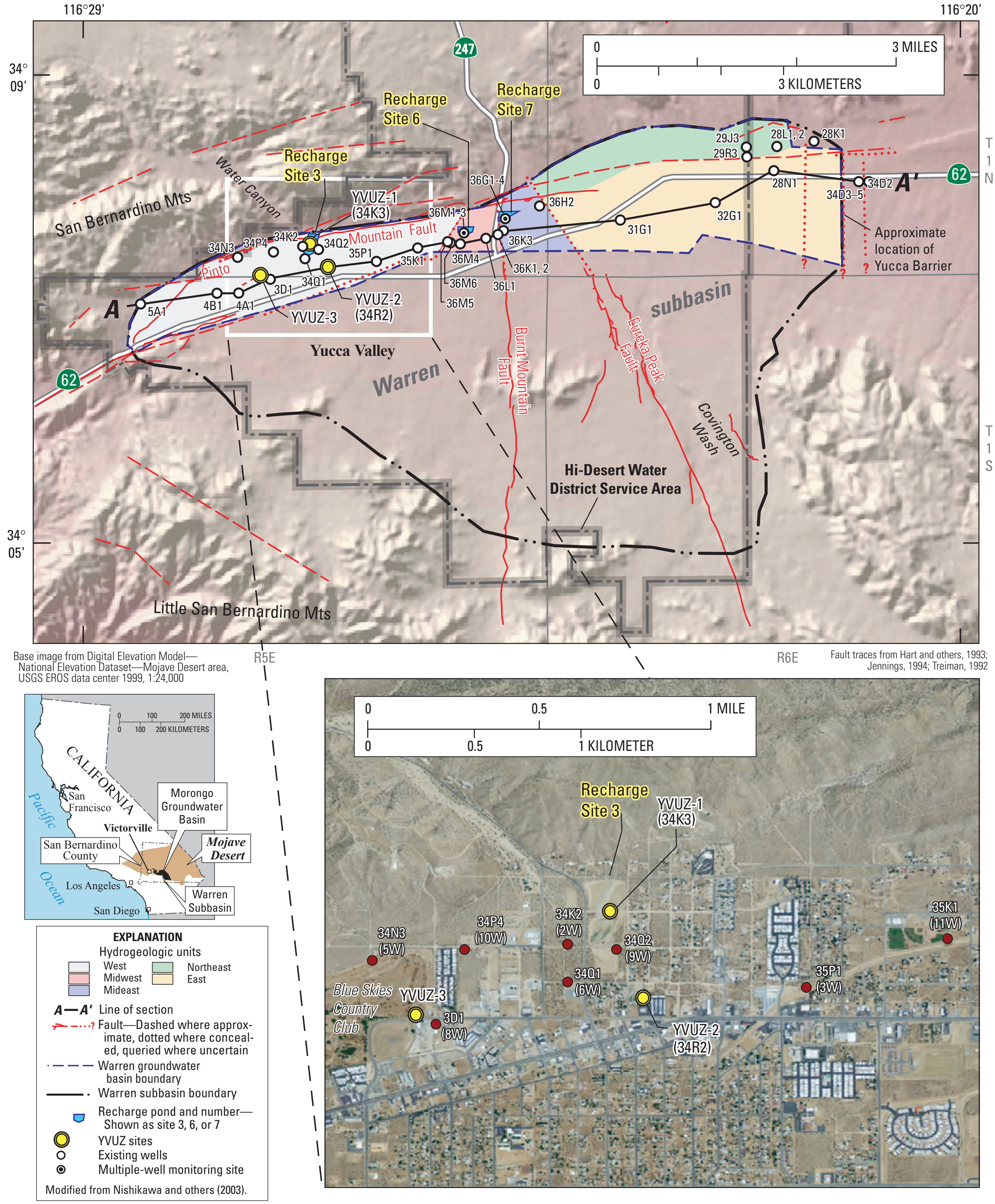



**Figure 1.** Location of study area, hydrogeologic units, artificial-recharge sites, and unsaturated-zone monitoring sites in Warren subbasin, San Bernardino County, California.

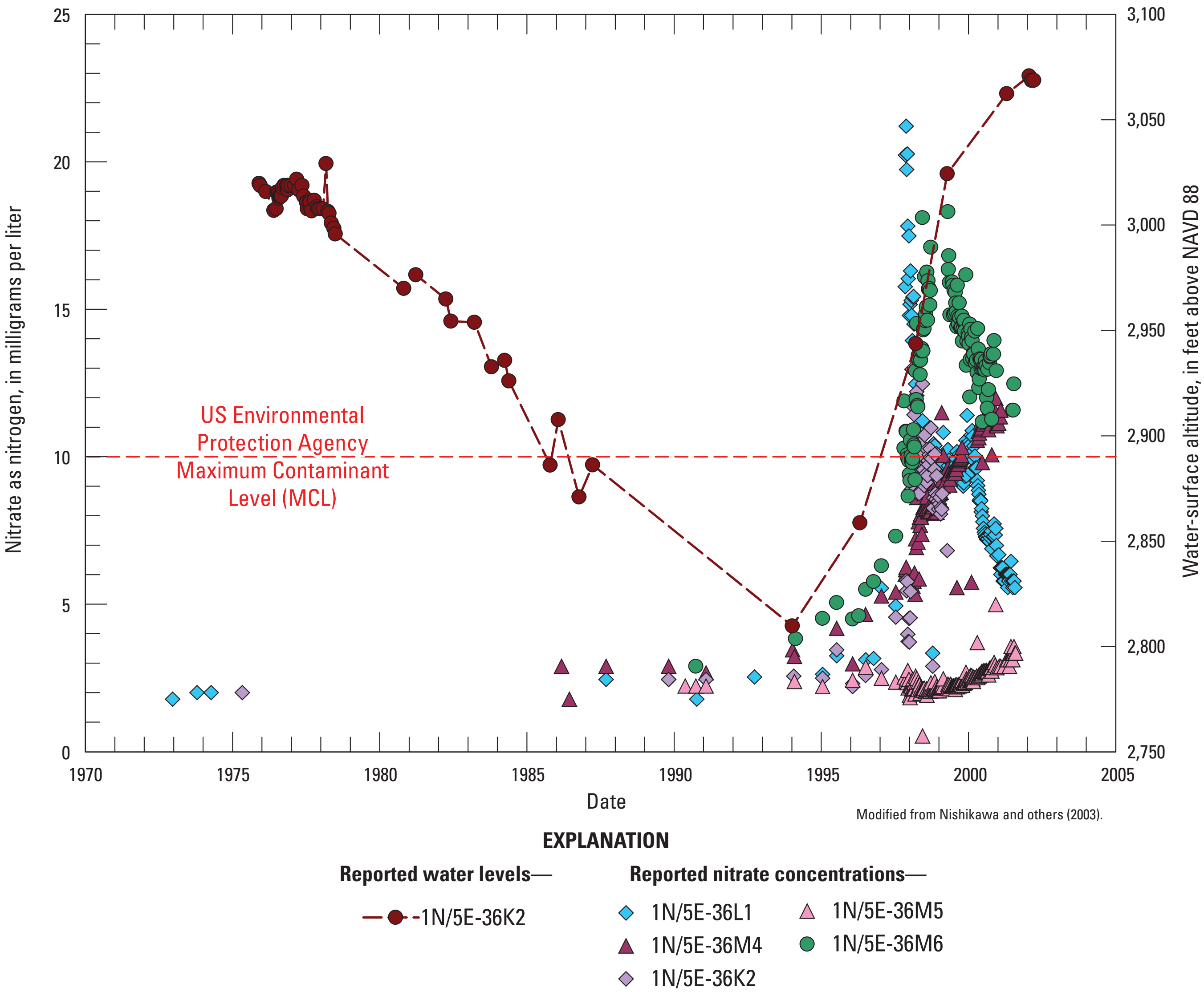
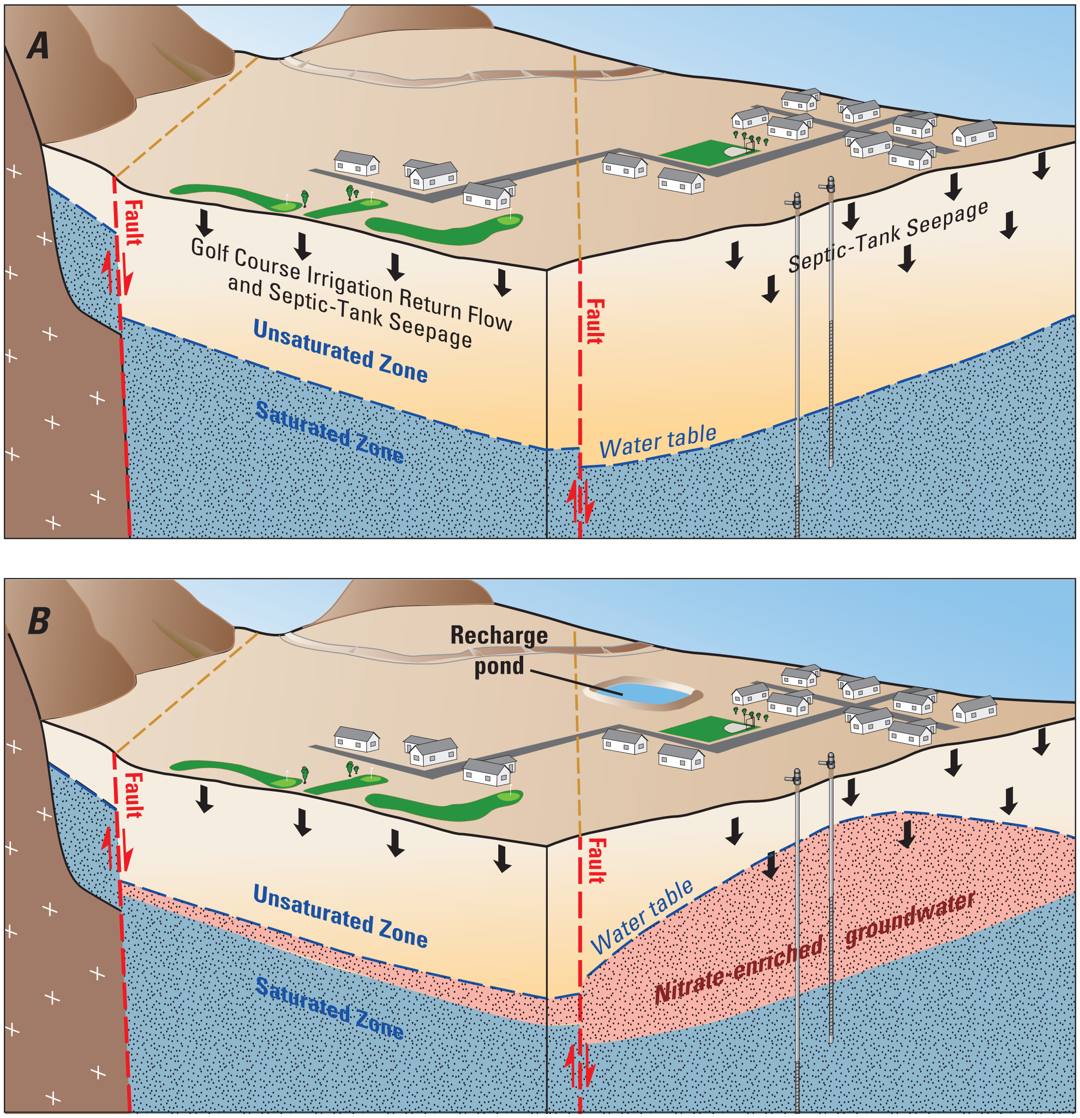



**Figure 2.** Nitrate concentrations, reported as nitrogen, from selected Hi-Desert Water District production wells and water levels from well 1N/5E-36K2 in the midwest hydrogeologic unit, 1972–2002, Warren subbasin, San Bernardino County, California.




Modified from Nishikawa and others (2003).

**Figure 3.** Conceptual model of septic effluent entrainment and downward migration of effluent in the unsaturated zone *A*, prior to application of artificial recharge, and *B*, after artificial recharge, Warren subbasin, San Bernardino County, California (from Nishikawa and others, 2003).

In 2004, the USGS began a cooperative study with HDWD to develop a monitoring network to evaluate the effects of planned artificial recharge on groundwater levels and water quality at site 3 in the west hydrogeologic unit of the Warren subbasin. Three unsaturated-zone monitoring sites were installed near recharge site 3 to augment available groundwater data from HDWD production wells and enabled depth-dependent monitoring of the artificial recharge in the unsaturated zone and groundwater system. Various instruments were installed to monitor the effects of the artificial recharge in the unsaturated zone, including heat-dissipation probes, advanced tensiometers (ATs), and suction-cup lysimeters. Two monitoring wells were installed to monitor changes in the saturated zone.

## Purpose and Scope

This report contains the data collected during this study and discusses the potential effects of recharge starting in June 2006 to the unsaturated zone, groundwater levels, and groundwater quality near and below the recharge ponds. The objectives of this study were to (1) characterize the hydraulic, chemical, and microbiological properties of the unsaturated zone; (2) monitor changes in water levels and water quality in response to the artificial-recharge program; (3) determine if nitrates from septic effluent infiltrated through the unsaturated zone to the water table; (4) determine the potential for nitrates within the unsaturated zone to mobilize and contaminate the groundwater as the water table rises in response to artificial recharge; and (5) determine the potential for the formation of trihalomethanes during the water-treatment process as a result of mixing SWP water and native groundwater. The scope of the work for this study included the collection of field and laboratory analyses of drill cuttings and core material from the monitoring sites to better define the physical and hydraulic properties of the underlying sediment. Analyses of the chemical composition of leachate from selected drill cuttings and core samples, as well as the chemical and isotopic composition of soil moisture from the unsaturated zone and groundwater, were also done. This investigation continues cooperation between the Hi-Desert Water District and the U.S. Geological Survey and discusses findings made from the evaluation of artificial recharge on groundwater levels and water quality in the west hydrogeologic unit of the Warren subbasin from September 2004 to September 2009.

## Accessing Data

Users of the data presented in this report are encouraged to access information through the USGS National Water Information System Web page (NWISWeb) located at *http://waterdata.usgs.gov/nwis/*. NWISWeb serves as an interface to a database network of site information, real-time, groundwater, surface-water, and water-quality data collected from locations throughout the 50 states and elsewhere. Data are updated from the database network on a regularly scheduled basis. Data are retrieved by category and geographic area and can be selectively refined by specific location or parameter field. NWISWeb can output water-level and water-quality graphs, site maps, data tables (in HTML and ASCII format) and develop site-selection lists.

# Description of the Study Area

The Warren subbasin is located approximately 100 miles (mi) east of Los Angeles on the southwestern edge of the Mojave Desert and includes the town of Yucca Valley, California, and is part of the Morongo groundwater basin (fig. 1). The Warren subbasin is bounded on the north by the San Bernardino Mountains and the Pinto Mountain Fault, on the south by the Little San Bernardino Mountains, on the west by a natural topographic and groundwater divide, and on the east by a series of faults that make up the Yucca Barrier. The areal extent of the subbasin is about 19 square miles ($mi^2$), but the extent of the water-bearing deposits in the subbasin is much smaller. Extensive faulting has compartmentalized the 5.5 $mi^2$ groundwater basin into five hydrogeologic units, referred to as the west, midwest, mideast, east, and northeast hydrogeologic units (Nishikawa and others, 2003; fig. 1).

The climate of the area is typical of the southern Mojave Desert and is characterized by low precipitation, hot summers, and relatively cool winters. Most precipitation in this part of the Morongo groundwater basin falls during the winter rainy season from November through March (Izbicki and Michel, 2004). From 1957 through 2010, the average annual precipitation at Yucca Valley was about 6.3 inch (in.; Hi-Desert Water District, 2010), most of which was lost through evaporation and soil-moisture requirements. The total average monthly evapotranspiration rate of a highdesert valley is 66.5 inches per year (in./yr; California Irrigation Management Information System, 2010).

The geohydrology of the Warren subbasin has been described previously by Dibblee (1967), Lewis (1972), and Nishikawa and others (2003). A summary of the geologic framework, the stratigraphic units that compose the aquifer system, and the stresses that affect the groundwater system in the subbasin is presented in the following sections.

## Geology

The Warren subbasin is surrounded by mountains and uplands, which consist of a nearly impermeable complex of igneous and metamorphic rocks of pre-Tertiary age. These rocks are the oldest geological materials in the study area and are referred to as basement complex in this report. The basement complex was uplifted millions of years ago, forming the mountains, and throughout most of the Morongo groundwater basin, it is buried by younger alluvial deposits (fig. 4). During the last several million years, the lowland valleys of the

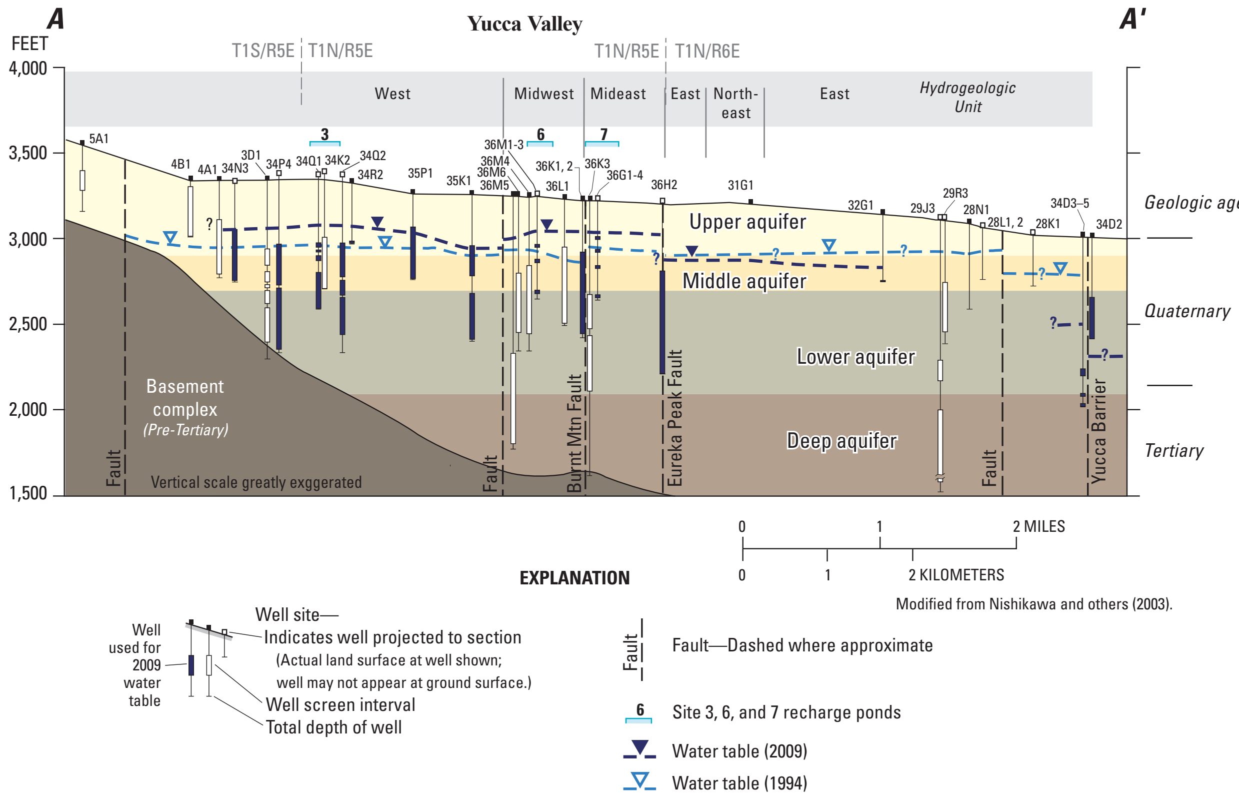



**Figure 4.** Hydrogeologic section along section A–A′ showing locations and depths of production and monitoring wells, locations of the recharge sites, and the upper, middle, lower, and deep aquifer systems of the Warren subbasin, San Bernardino County, California.

groundwater basin have been accumulating gravel, sand, silt, and clay primarily deposited by streams flowing from the surrounding mountains. The subbasin, from the bottom to the top, is filled with older sedimentary deposits of Tertiary age, older alluvial-fan deposits of Tertiary to Quaternary age, and alluvial deposits of Quaternary age. The deposits are unconsolidated at land surface and become more consolidated with depth. The unconsolidated alluvial deposits were eroded from the granitic rocks of the San Bernardino Mountains to the north and west, and from metamorphic rocks of the Little San Bernardino Mountains to the south (figs. 1 and 4).

Several faults cross the subbasin and are barriers to the lateral movement of groundwater flow as a result of the juxtaposition of the basement complex against the alluvial deposits or the displacement of preferential flow paths within the aquifers. The most prominent of these faults is the Pinto Mountain fault (fig. 1), which trends east-west along the entire northern boundary of the subbasin and is a barrier to groundwater flow from the north. An unnamed east-west fault forms the southern boundary of the west hydrogeologic unit, and an unnamed northeast-southwest trending fault forms the eastern boundary between the west and midwest hydrogeologic units. The north-south trending Burnt Mountain fault separates the midwest and mideast hydrogeologic units, and the Eureka Peak fault separates the mideast, the east, and northeast hydrogeologic units (fig. 1).

## Aquifer System

Nishikawa and others (2003) used information from lithologic and geophysical logs to divide the deposits that fill the Warren subbasin into four aquifers, referred to as the upper, middle, lower, and deep aquifers (fig. 4). Most wells are perforated in the unconsolidated deposits of the upper, middle, and lower aquifers. The upper aquifer consists of the saturated part of the alluvium and the upper part of the alluvial-fan deposits, and extends from about 2,900 ft above sea level to the water table. This aquifer is mainly fine-to-coarse grained sand with occasional gravel. The middle aquifer is contained in the alluvial-fan deposit, about 200 ft thick, and consists mainly of silty sand. The lower aquifer is contained within the lower part of the alluvial fan deposits, is about 600 ft thick, and consists mainly of indurated silty sand. The deep aquifer is contained within the Tertiary deposits, is as much as 2,000 ft thick, and consists mainly of semi-consolidated fanglomerates.

## Recharge

Natural recharge to the groundwater basin is primarily runoff from the surrounding mountains and highlands during storm events. On the basis of tritium (a naturally occurring radioactive isotope of hydrogen) in groundwater samples, it can be inferred that recent recharge has occurred along Water

Canyon (fig. 1), predominantly from storms during the winter months (Izbicki and Michel, 2004). However, recharge from the direct infiltration of precipitation, which averages about 6.3 in./yr, is generally not enough to meet evapotranspiration and soil-moisture requirements. Lewis (1972) estimated natural recharge to be less than 200 acre-ft/yr, and Nishikawa and others (2003) reduced this value to 83 acre-ft/yr on the basis of results from the calibrated groundwater-flow model.

After World War II, development in the subbasin began in earnest, and in the 1950s, septic effluent, infiltration of irrigation-return flow from the Blue Skies Country Club golf course (fig. 1), and other irrigated fields became sources of recharge in the subbasin. Nishikawa and others (2003) reported that the simulated recharge from septic effluent and irrigation-return flows was about 1,750 acre-ft/yr in 2001.

## Discharge

Natural discharge from the groundwater basin is predominantly groundwater underflow across the Yucca Barrier (fig. 1) to the Joshua Tree subbasin to the east. Under predevelopment conditions, the quantity of groundwater underflow was equal to the natural recharge (83 acre-ft/yr; Nishikawa and others, 2003).

The first public water-supply wells were drilled in the Warren subbasin in 1949 (Lewis, 1972). However, significant groundwater development did not take place until 1956, when pumpage equaled about 650 acre-ft/yr (Lewis, 1972); by 2009, pumpage had increased to about 2,600 acre-ft/yr (Hi-Desert Water District, 2010); (fig. 5). Between 1956 and 2009, a cumulative total volume of about 103,000 acre-feet (acre-ft)

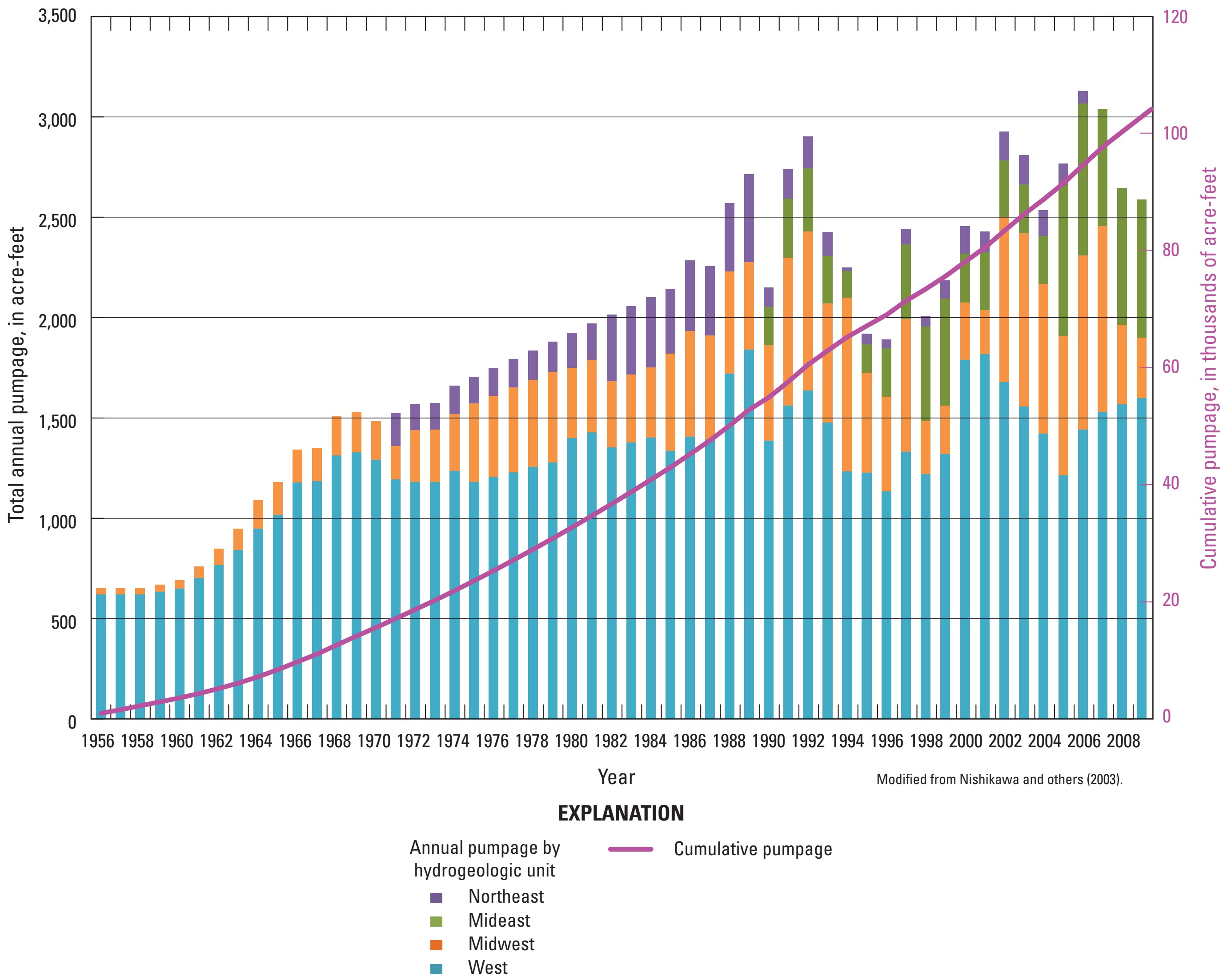



**Figure 5.** Total annual pumpage by hydrogeologic unit and cumulative pumpage, 1956–2009, Warren subbasin, San Bernardino County, California.

of water had been pumped from the groundwater system (Hi-Desert Water District, 2010). Because of the imbalance between recharge to, and discharge from, the subbasin, there have been large water-level declines in some areas. For example, the long-term hydrograph for well 1N/5E-34N3 (5W), located in the west hydrogeologic unit (fig. 1), shows that water levels declined about 180 ft between the late 1950s and 1994 (fig. 6*A*). Wells 1N/5E-36K1 and -36K2, which are in the midwest hydrogeologic unit, show water-level declines of more than 300 ft between the late 1940s and 1994 (fig. 6*B*).

## Artificial Recharge

In response to the large water-level declines, HDWD began to artificially recharge the Warren subbasin in February 1995 by spreading SWP water in recharge ponds in the midwest (site 6) and mideast (site 7) hydrogeologic units (figs. 1 and 7). The HDWD began construction of another artificial-recharge site (site 3) in 2004 and completed construction in 2006. At the time of completion, site 3 was composed of three recharge ponds with an average area of about 2.3 acres (fig. 1). In June 2006, HDWD began applying water to ponds in the west hydrogeologic unit at site 3. By September 2009, more than 51,000 acre-ft of water had been released to all three sites (Hi-Desert Water District, 2010). Comparisons of the water-table elevations in 1994 and 2009 (fig. 4) show that these recharge operations have affected water levels in the west, midwest, and mideast hydrogeologic units since 1995. The long-term hydrographs show increases in the water levels in the west and midwest hydrogeologic units since 1995; for example, water levels in well 1N/5E-36K2 in the midwest hydrogeologic unit increased by as much as 260 ft from 1995 through 2001 (fig. 6*B*).

# Monitoring-Site Construction and Installation

Three unsaturated-zone monitoring sites were installed in September and October 2004 near or down-gradient from site 3 as part of this study, prior to the construction and implementation of the three recharge ponds at site 3 in 2006 (fig. 1). Data collected from these monitoring sites were used to characterize the hydraulic, chemical, and microbiological properties of the unsaturated zone. The first monitoring site, YVUZ-1, was constructed on the berm between the two northern ponds of recharge site 3 (fig. 1). The second monitoring site, YVUZ-2, was installed approximately 1,200 ft down gradient and southeast of the recharge ponds, in an area of long-term septic usage. The third, shallow monitoring site, YVUZ-3, was installed next to a golf course, about 0.5-mi southwest of the ponds, to monitor the infiltration of golf-course irrigation-return flows in the upper part of the unsaturated zone in that area.

## Drilling Procedures

The boreholes were drilled by using an ODEX air-hammer and casing-advance system to ensure no foreign fluids were introduced to the unsaturated zone. The ODEX method, which consists of a percussion hammer and an eccentric reamer, allows a casing to follow the reamer as the hole is drilled. When the completion depth is reached, the drill stem, percussion hammer, and reamer are pulled up through the casing, the instruments are installed, and then the casing is pulled from the borehole. Drill cuttings were collected at one-ft intervals throughout the drilling process, and cores were collected at selected depths.

Detailed lithologic logs were compiled from descriptions of drill cuttings collected at each site and from observations recorded during the drilling process (appendices 1–3). In the field, drill cuttings were described by grain size, texture, sorting, rounding, and color. The drill cuttings were later examined under a binocular microscope to verify and amend the field descriptions. Texture was determined on all cuttings by using a method developed by Folk (1954), and particle-size description followed the National Research Council (1947) classification. This classification allows for correlation of grain-sized terms (such as “sand”) to size limits in millimeters or inches. For samples containing fine-grained material, the terms “silt” and (or) “clay” are used in lieu of “mud.” Color follows the numerical color designations in Munsell Soil Color Charts (Munsell Color, 1994).

Cores were collected in aluminum sleeves measuring 4-in. in diameter by 6-in. long. Four sleeves were loaded into the core barrel to allow for a 2-ft core to be collected at one time. Once the core was retrieved, the liners were removed from the barrel, labeled with the appropriate depth, wrapped in plastic, placed inside an aluminum heat-sealable pouch, and partially sealed. The partially sealed bag was then deflated as much as possible and helium was released into the bag via a tube inserted to the back of the bag to purge as much oxygen as possible. The bag was then heat-sealed to preserve the core.

At the time of construction, only neutron and natural gamma borehole geophysical logs were collected because the ODEX drilling method was used. These geophysical logs were used to determine the placement of the instruments and monitoring wells in the boreholes. A summary of the construction, instrumentation, geophysical and lithologic data, and selected soil chemistry for the three monitoring sites is shown in figures 8–10.

Neutron logs measure the backscattering of neutrons generated from a nuclear source in the borehole. In media with generally uniform properties, a direct relation exists between the water content and the back scatter neutron measurement (Schlumberger, 1972; Troxler, 1994). Prior to installation of the instruments, neutron logs were collected from within the 8-in. diameter ODEX pipe in the borehole. The logs were affected by the ODEX pipe and by differences in the position of the neutron source within the pipe. As a result, the neutron log data were collected only for site construction

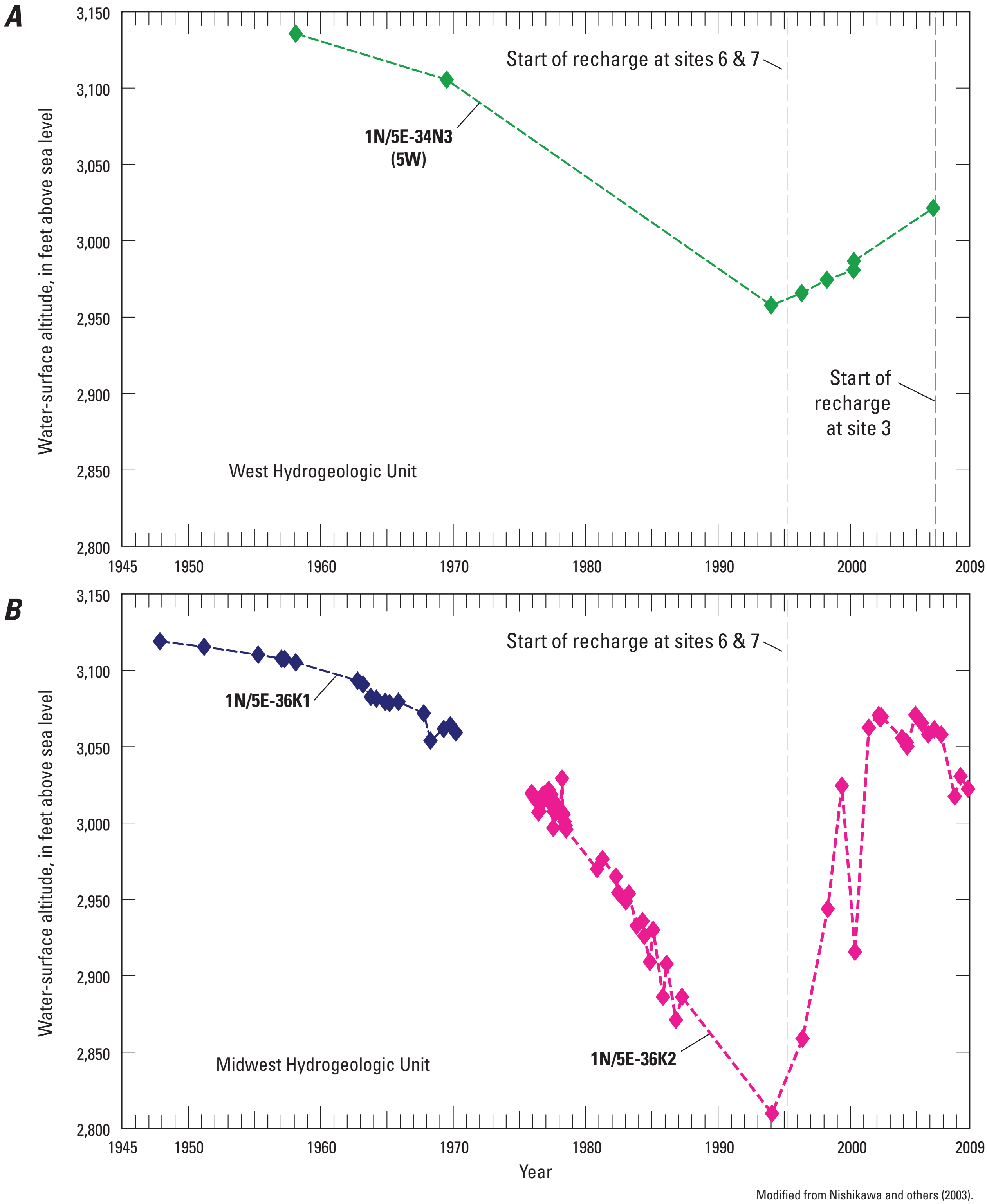



**Figure 6.** Water-level hydrographs for well *A,* 1N/5E-34N3 in the west hydrogeologic unit, and *B,* 1N/5E-36K1 and -36K2 in the midwest hydrogeologic unit, 1947-2009, Warren subbasin, San Bernardino County, California.

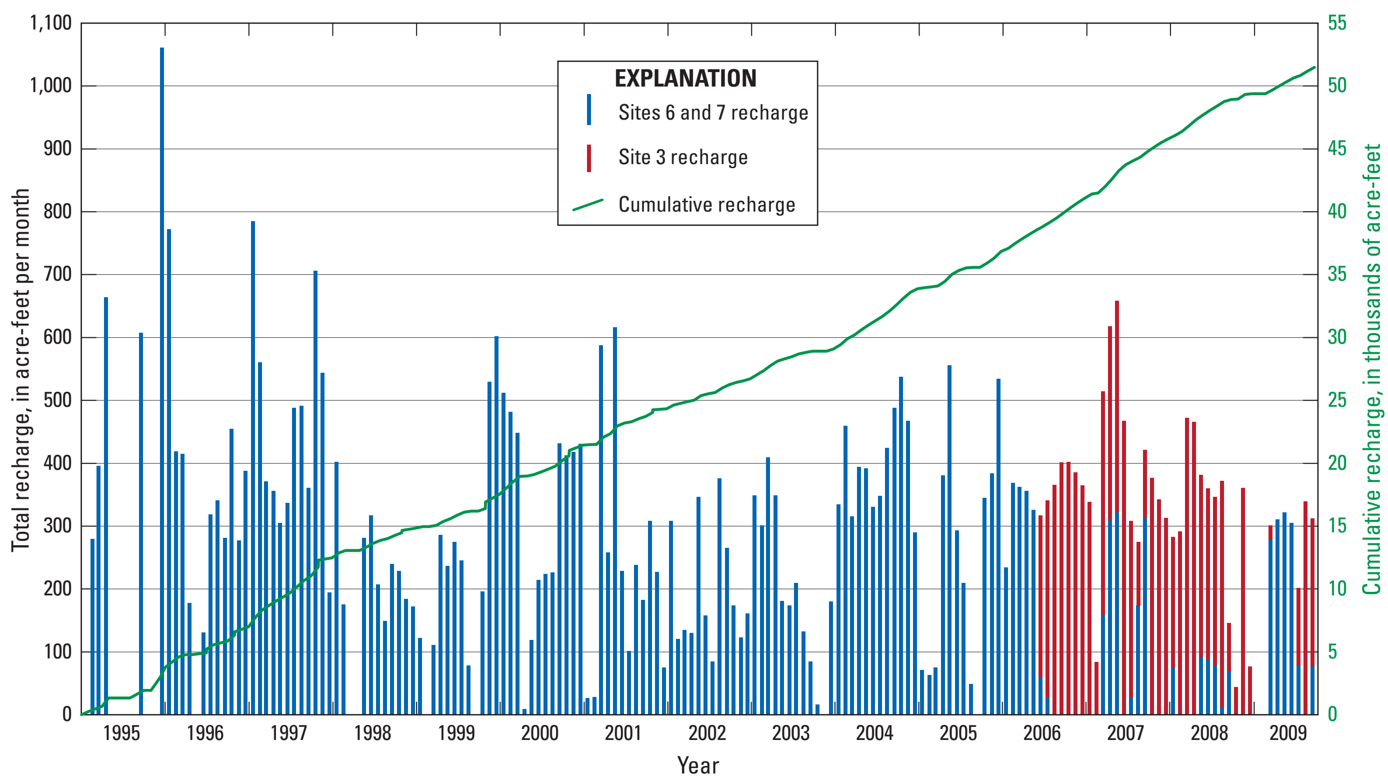



**Figure 7.** Total monthly and cumulative artificial recharge applied to Hi-Desert Water District recharge ponds at sites 3, 6, and 7, January 1995 to September 2009, Warren subbasin, San Bernardino County, California.

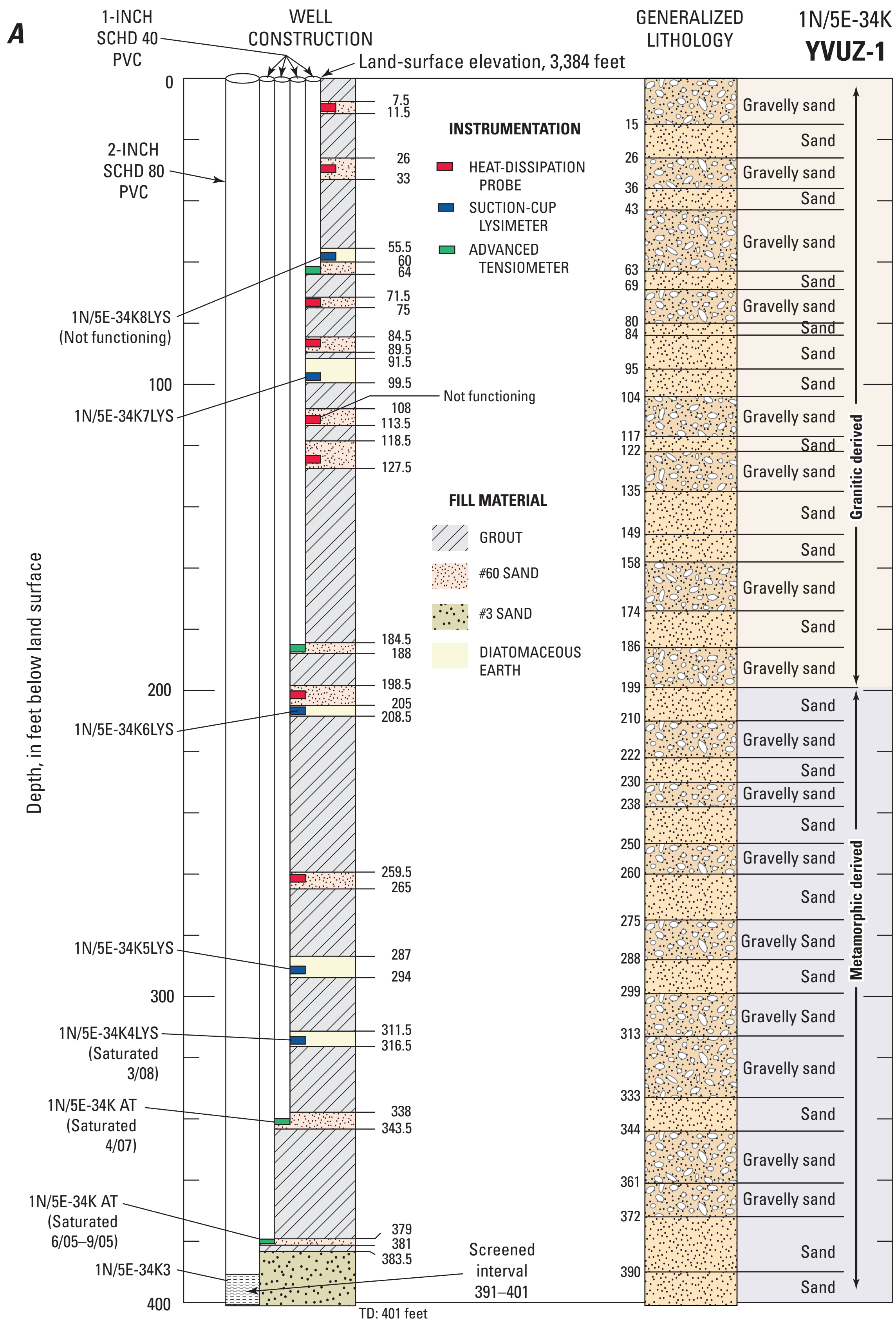



**Figure 8.** Summary of data collected for monitoring site YVUZ-1 *A,* well construction and generalized lithology, *B,* geophysical logs and selected water-quality data, Warren subbasin, San Bernardino County, California.

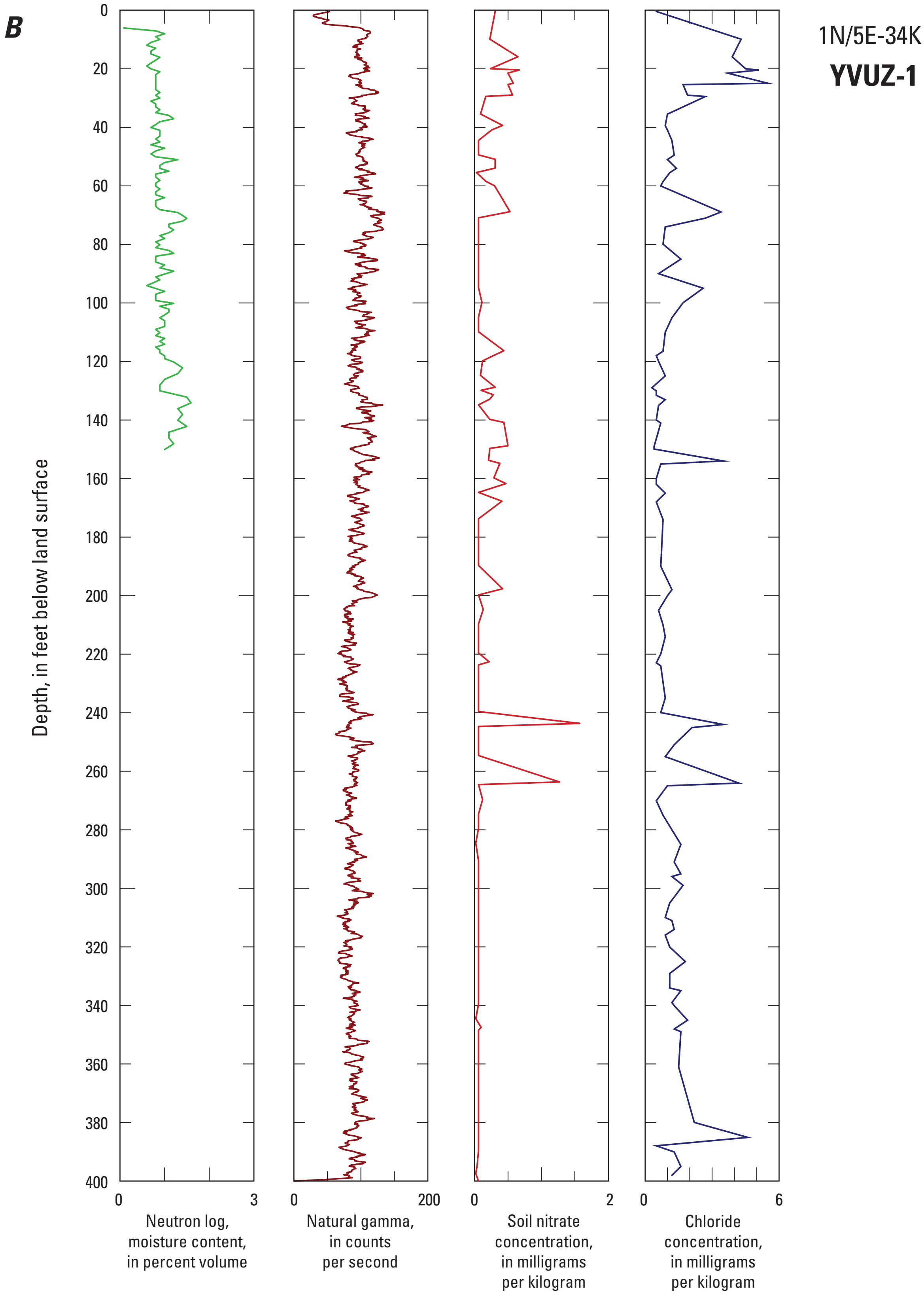



**Figure 8.** Continued.

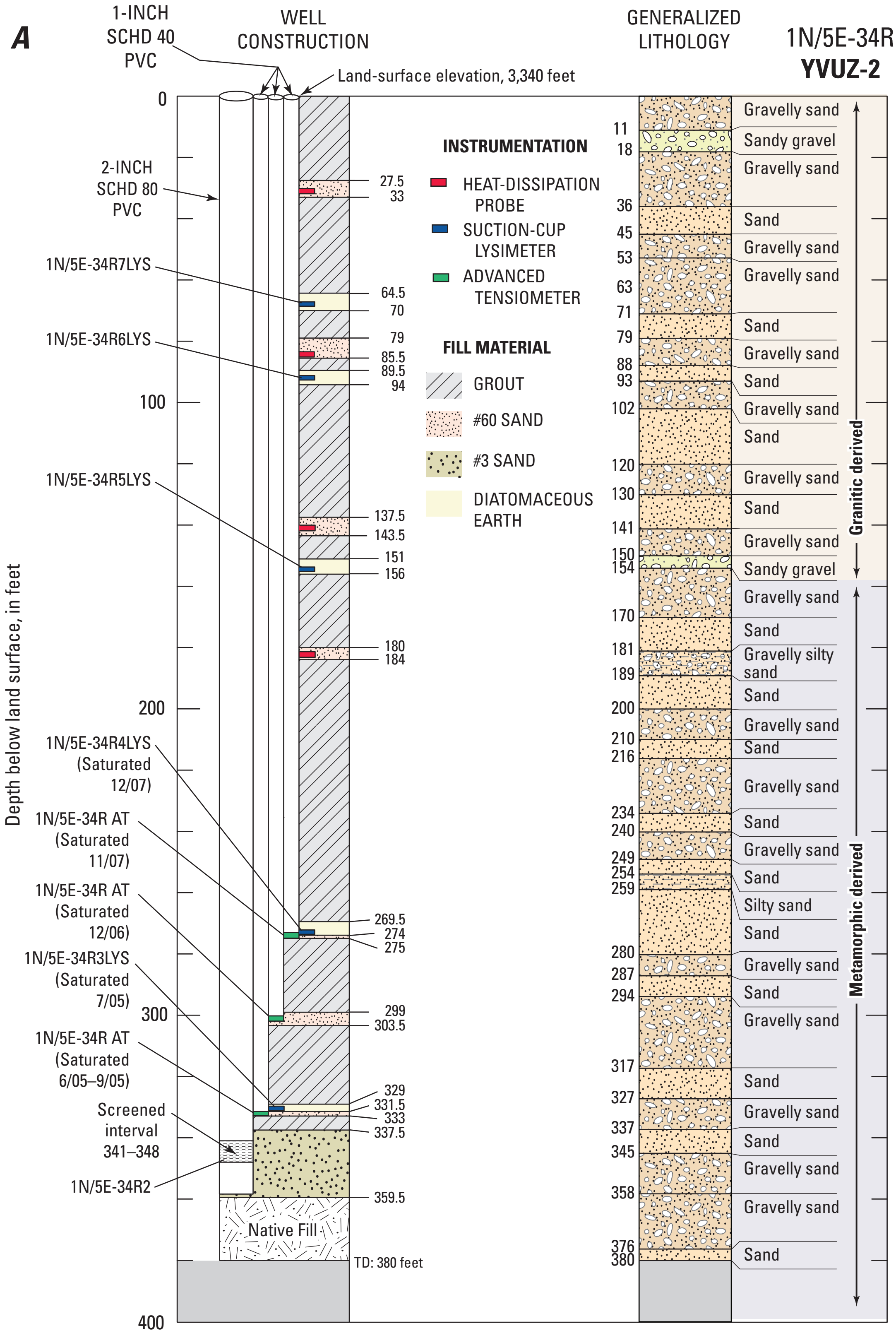



**Figure 9.** Summary of data collected for monitoring site YVUZ-2 *A,* well construction and generalized lithology, *B,* geophysical logs and selected water-quality data, Warren subbasin, San Bernardino County, California.

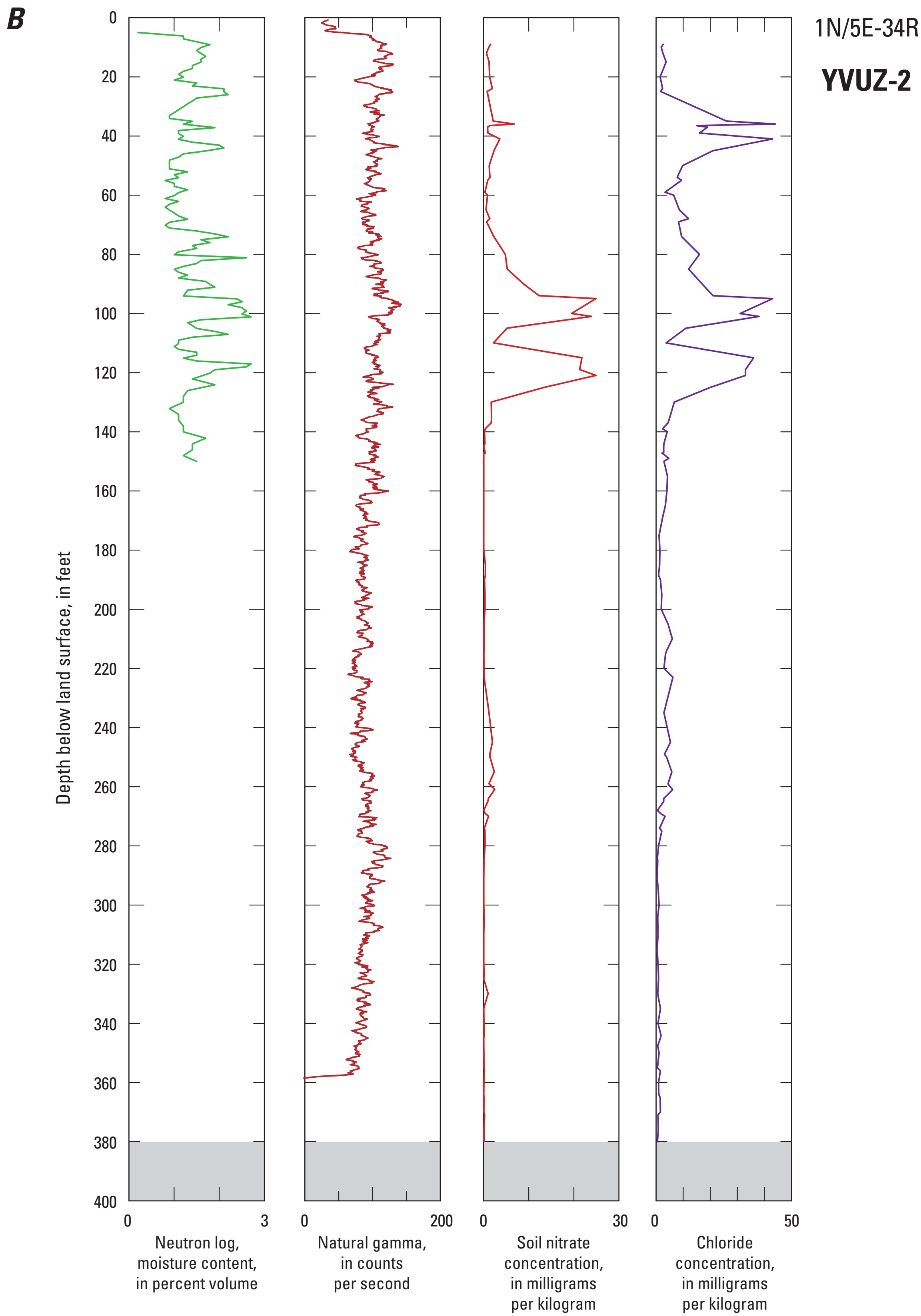



**Figure 9.** Continued.

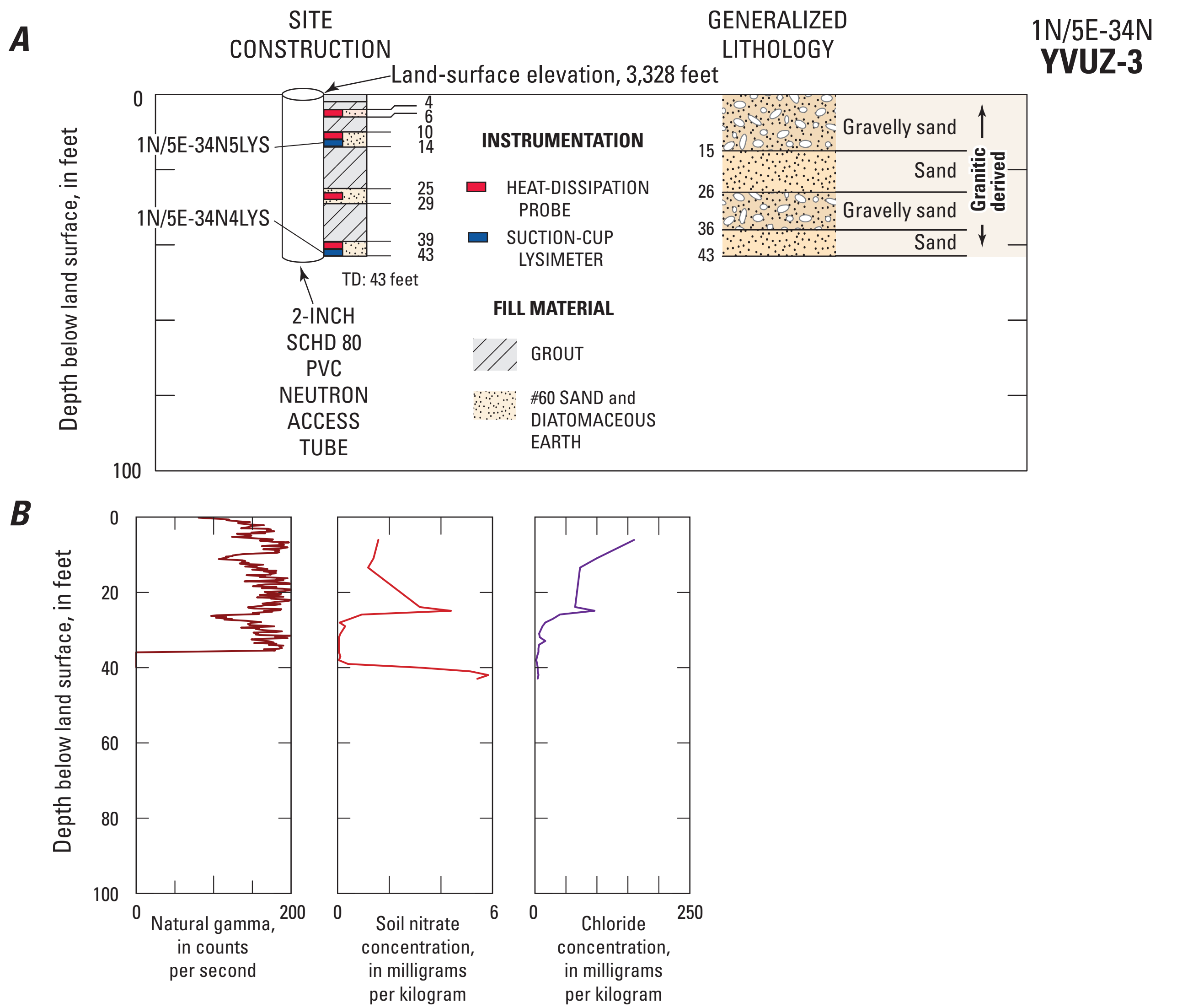



**Figure 10.** Summary of data collected for monitoring site YVUZ-3 *A,* site construction and generalized lithology, *B,* natural gamma log and selected water-quality data, Warren subbasin, San Bernardino County, California.

and instrumentation placement and were not used to estimate moisture content of the unsaturated zone. Because of the limited length of the cable attached to the probe, only the upper 150 ft of the boreholes were able to be logged.

Natural-gamma logs measure the intensity of gamma-ray emissions resulting from the decay of potassium-40 and the daughter products of uranium and thorium (Schlumberger, 1972). These logs are used primarily to define lithologic indicators and for geologic correlation. In general, clays and feldspar-rich gravels have more intense gamma-ray emissions.

## Site Instrumentation

The design and instrumentation installed at each monitoring site was determined on the basis of the cuttings, lithology, specific conductance of soil leachate, and natural gamma and neutron geophysical logs at each site. All three sites were instrumented with heat-dissipation probes (HDPs) and suction-cup lysimeters (figs. 8–10). Sites YVUZ-1 and YVUZ-2 also were instrumented with advanced tensiometers and with a 2-in. monitoring well. The monitoring wells consist of a 2-in. diameter, flush-threaded schedule-80 polyvinyl chloride (PVC) pipe. Each well has a section of PVC screen at the bottom with a slot size of 1.5 in. by 0.020 in. As the casing for the monitoring well was lowered into the borehole, the ATs, HDPs, and suction-cup lysimeters were attached to the outside of the well casing to ensure they were installed at the appropriate depths. No monitoring well was installed at YVUZ-3 (fig. 10), but the 2-in. diameter flush-threaded schedule-80 PVC pipe used to install the lysimeters and HDPs is capped at the bottom and can be used as a neutron access tube.

The HDPs and ATs were installed to measure the matric potential of the soil. When soil water is at a pressure lower than atmospheric, the pressure is negative and is referred to as the matric potential. In general, the HDPs were installed where conditions were expected to remain dry during artificial recharge. The probes measure the rate of movement of heat in a calibrated ceramic capsule, which varies with water content. The range of soil-water matric potential for the probes is from about 0 to about –840 ft (Campbell Scientific, Inc., 2006). The commercially available HDPs consist of a heating element and an electric thermometer enclosed in a ceramic capsule. Prior to installation, the HDPs were enclosed in a sheer cloth bag filled with diatomaceous earth and allowed to soak in deionized water until thoroughly saturated. The HDPs were calibrated at the USGS-California Water Science Center (CAWSC) Hydrologic Research Laboratory Sacramento, California.

The ATs were installed where wetter, or even saturated, conditions were expected to develop as a result of artificial recharge. The ATs measure matric potential between 0 and about −26 ft (Cassell and Klute, 1986) and also measure positive pressures (indicating saturation) as great as 26 ft. The commercially available ATs that were installed at sites YVUZ-1 and YVUZ-2 consisted of a porous cup connected to a 1.5-in. diameter PVC pipe by a short adapter. The transducer was set in the cup at the bottom, and the reservoir was filled with a small amount of deionized water. The ATs were calibrated prior to installation at the USGS-CAWSC Hydrologic Research Laboratory, Sacramento, California.

In general, the suction-cup lysimeters were installed at depths at which the neutron-log data, where available, indicated that the soil moisture was relatively high, especially above fine-grained layers that can act to slow infiltration or create a perched condition. Two types of commercially available suction-cup lysimeters were used in this study in order to sample the unsaturated-zone pore water. Both types were made of 1.5-ft long, 1.5-in. diameter PVC with porous ceramic cups and were installed in a diatomaceous earth to ensure good contact between the porous cup and the unsaturated-zone materials. The lysimeters used at shallow depths had a single chamber with pressure/vacuum and sample tubes at different depths in the same chamber. The lysimeters used at greater depths were equipped with two chambers separated by stainless steel one-way valves. These lysimeters were designed to withstand the higher pressures needed to lift sample water from greater depths (over 300 ft) by having the pressure/vacuum and sample tubes located in different chambers. The pressure/vacuum tubes connecting the lysimeter to the surface were 0.25-in. diameter nylon tubing; the sample tubes were 0.25-in. diameter Teflon tubing.

After all instruments were set at the proper depth, the borehole was backfilled with diatomaceous earth, bentonite grout chips, or sand, depending on each instrument's requirements. All materials were poured from the surface down the dry ODEX casing as it was pulled out of the borehole. The borehole around the screened interval of the monitoring well was backfilled with no. 3 sand; the borehole around the ATs and HDPs was backfilled with no. 60 sand. Bentonite grout chips were used to isolate the instruments vertically and prevent the downward movement of water through the borehole (figs. 8–10). The elevation of the backfilled material was measured frequently to monitor the placement and elevation of the material and to ensure that there was no bridging of the material.

## Site Names and Numbering System

Each monitoring site and instrument has a name assigned by the USGS at the time the site was constructed, a State well number based on the rectangular system for the subdivision of public lands (see "California State Well-Numbering System" at the beginning of this report for an explanation of how State well numbers for the sites are derived), and a unique USGS site number (table 1).

The monitoring sites were assigned names according to the acronym Yucca Valley Unsaturated Zone (YVUZ) and the order in which they were installed: YVUZ-1, YVUZ-2, or YVUZ-3 (table 1). The State Well number for each piece of instrumentation describes the instrument's location and type. Suction-cup lysimeters were abbreviated as "LYS," heat-dissipation probes were abbreviated "HDP," and advanced tensiometers were abbreviated as "AT." Throughout this report, the names of the instruments were abbreviated by using the State well number quarter-quarter section designation and sequence number. For example, the well at YVUZ-1, 001N005E34K003S, was abbreviated as 34K3, and the lysimeter at 381.5 ft, 001N005E34K004LYS, was abbreviated as 34K4LYS (table 1).

In addition to the site names and State well numbers, each instrument was also assigned a 15-digit unique USGS site number. Site numbers assigned by the USGS consist of 15 characters and follow the format 340734116264301, where the first 6 digits correspond to the site's location in degrees, minutes, and seconds of latitude; the next 7 digits correspond to the degrees, minutes, and seconds of longitude; and the last 2 digits signify the sequence number; instruments in the same borehole are numbered sequentially from deepest to shallowest (table 1). Once assigned, the USGS site number does not change even if the well is more accurately located, and should not be used to geographically locate the well. Either the State well numbers or the USGS site number can be used to access the data in the USGS's web site for National Water Information System (NWIS; *http://waterdata.usgs.gov/nwis)*.

# Methods of Data Collection

Physical, hydraulic, chemical, isotopic, and bacterial data were collected with various methods during the construction of the monitoring sites and after the installation of the instruments to determine the hydrologic properties of the unsaturated zone at different locations near recharge site 3. Physical and hydraulic properties, such as particle size, water content (gravimetric and volumetric), bulk density, water potential, and saturated hydraulic conductivity values were determined on selected cores collected from the three monitoring sites. Matric potential data from the unsaturated zone, collected from HDPs and ATs at the monitoring sites, were used to help determine the vertical movement of natural and artificial recharge. Selected cores and collected drill cuttings were used

**Table 1.** Site names, description of instruments at monitoring sites, and selected Hi-Desert Water District production wells in the west hydrogeologic unit, Warren subbasin, San Bernardino County, California.

[Site locations are shown in fig. 1. Depths are below land surface. **Abbreviations**: AT, advanced tensiometer; ft, foot; HDP, heat-dissipation probe; LYS, suction-cup lysimeter; NAVD, North American Vertical Datum]

| State well number | Abbreviated number | USGS site number | Altitude of land surface (ft) (NAVD 1988) | Description of instrument or well |
|---|---|---|---|---|
| | | YVUZ-1 | | |
| 1N/5E-34K3 | 34K3 | 340734116264301 | 3,378 | Well depth 401 ft; perforations 391–401 ft. |
| 1N/5E-34K AT @ 381.5 | AT @ 381.5 | 340734116264302 | 3,378 | Advanced tensiometer at 381.5 ft. |
| 1N/5E-34K AT @ 341.5 | AT @ 341.5 | 340734116264303 | 3,378 | Advanced tensiometer at 341.5 ft. |
| 1N/5E-34K4LYS | 34K4LYS | 340734116264304 | 3,378 | Suction-cup lysimeter at 314.5 ft. |
| 1N/5E-34K5LYS | 34K5LYS | 340734116264305 | 3,378 | Suction-cup lysimeter at 291.5 ft. |
| 1N/5E-34K HDP @ 261.5 | HDP @ 261.5 | 340734116264306 | 3,378 | Heat-dissipation probe at 261.5 ft. |
| 1N/5E-34K6LYS | 34K6LYS | 340734116264307 | 3,378 | Suction-cup lysimeter at 205.5 ft. |
| 1N/5E-34K HDP @ 201.5 | HDP @ 201.5 | 340734116264308 | 3,378 | Heat-dissipation probe at 201.5 ft. |
| 1N/5E-34K HDP @ 187.5 | HDP @ 187.5 | 340734116264309 | 3,378 | Advanced tensiometer at 187.5 ft. |
| 1N/5E-34K HDP @ 124.5 | HDP @ 124.5 | 340734116264310 | 3,378 | Heat-dissipation probe at 124.5 ft. |
| 1N/5E-34K HDP @ 111.5[1] | HDP @ 111.5 | 340734116264311 | 3,378 | Heat-dissipation probe at 111.5 ft. |
| 1N/5E-34K7LYS | 34K7LYS | 340734116264312 | 3,378 | Suction-cup lysimeter at 97.5 ft. |
| 1N/5E-34K HDP @ 86.5 | HDP @ 86.5 | 340734116264313 | 3,378 | Heat-dissipation probe at 86.5 ft. |
| 1N/5E-34K HDP @ 73.5 | HDP @ 73.5 | 340734116264314 | 3,378 | Heat-dissipation probe at 73.5 ft. |
| 1N/5E-34K AT @ 61.5 | AT @ 61.5 | 340734116264315 | 3,378 | Advanced tensiometer at 61.5 ft. |
| 1N/5E-34K8LYS[1] | 34K8LYS | 340734116264316 | 3,378 | Suction-cup lysimeter at 60.5 ft. |
| 1N/5E-34K HDP @ 29.5 | HDP @ 29.5 | 340734116264317 | 3,378 | Heat-dissipation probe at 29.5 ft. |
| 1N/5E-34K HDP @ 9.5 | HDP @ 9.5 | 340734116264318 | 3,378 | Heat-dissipation probe at 9.5 ft. |
| HI-DESERT WD RECHARGE PIPE A POND A YUCCA VALLEY | Not available | 340734116264501 | 3,383 | California State Water Project discharge pipe at site 3 ponds. |
| | | YVUZ-2 | | |
| 1N/5E-34R2 | 34R2 | 340718116263701 | 3,325 | Well depth 358 ft; perforations 341–348 ft. |
| 1N/5E-34R AT @ 332 | AT @ 332 | 340718116263702 | 3,325 | Advanced tensiometer at 332 ft. |
| 1N/5E-34R3LYS | 34R3LYS | 340718116263703 | 3,325 | Suction-cup lysimeter at 331 ft. |
| 1N/5E-34R AT @ 301 | AT @ 301 | 340718116263704 | 3,325 | Advanced tensiometer at 301 ft. |
| 1N/5E-34R AT @ 274 | AT @ 274 | 340718116263705 | 3,325 | Advanced tensiometer at 274 ft. |
| 1N/5E-34R4LYS | 34R4LYS | 340718116263706 | 3,325 | Suction-cup lysimeter at 273 ft. |
| 1N/5E-34R HDP @ 182 | HDP @ 182 | 340718116263707 | 3,325 | Heat-dissipation probe at 182 ft. |
| 1N/5E-34R5LYS | 34R5LYS | 340718116263708 | 3,325 | Suction-cup lysimeter at 154 ft. |
| 1N/5E-34R HDP @ 141 | HDP @ 141 | 340718116263709 | 3,325 | Heat-dissipation probe at 141 ft. |
| 1N/5E-34R6LYS | 34R6LYS | 340718116263710 | 3,325 | Suction-cup lysimeter at 92 ft. |
| 1N/5E-34R HDP @ 84 | HDP @ 84 | 340718116263711 | 3,325 | Heat-dissipation probe at 84 ft. |
| 1N/5E-34R7LYS | 34R7LYS | 340718116263712 | 3,325 | Suction-cup lysimeter at 68 ft. |

**Table 1.** Site names, description of instruments at monitoring sites, and selected Hi-Desert Water District production wells in the west hydrogeologic unit, Warren subbasin, San Bernardino County, California.—Continued

[Site locations are shown in fig. 1. Depths are below land surface. **Abbreviations**: AT, advanced tensiometer; ft, foot; HDP, heat-dissipation probe; LYS, suction-cup lysimeter; NAVD, North American Vertical Datum]

| State well number | Abbreviated number | USGS site number | Altitude of land surface (ft) (NAVD 1988) | Description of instrument or well |
|---|---|---|---|---|
| | | YVUZ-3 | | |
| 1N/5E-34R HDP @ 31 | HDP @ 31 | 340718116263713 | 3,325 | Heat-dissipation probe at 31 ft. |
| 1N/5E-34N TEST HOLE | 34N | 340715116271901 | 3,328 | Neutron Access Tube. |
| 1N/5E-34N4LYS | 34N4LYS | 340715116271902 | 3,328 | Suction-cup lysimeter at 42 ft. |
| 1N/5E-34N HDP @ 41 | HDP @ 41 | 340715116271903 | 3,328 | Heat-dissipation probe at 41 ft. |
| 1N/5E-34N HDP @ 27 | HDP @ 27 | 340715116271904 | 3,328 | Heat-dissipation probe at 27 ft. |
| 1N/5E-34N5LYS | 34N5LYS | 340715116271905 | 3,328 | Suction-cup lysimeter at 13 ft. |
| 1N/5E-34N HDP @ 11[1] | HDP @ 11 | 340715116271906 | 3,328 | Heat-dissipation probe at 11 ft. |
| 1N/5E-34N HDP @ 5 | HDP @ 5 | 340715116271907 | 3,328 | Heat-dissipation probe at 5 ft. |
| | | 2W | | |
| 1N/5E-34K2 | 34K2 | 340729116264702 | 3,381 | Well depth 640 ft; perforations 340–640 ft. |
| | | 3W | | |
| 1N/5E-35P1 | 35P1 | 340722116260301 | 3,280 | Well depth 504 ft; perforations 194–494 ft. |
| | | 5W | | |
| 1N/5E-34N3 | 34N3 | 340725116272402 | 3,324 | Well depth 548 ft; perforations 245–545 ft. |
| | | 6W | | |
| 1N/5E-34Q1 | 34Q1 | 340724116264801 | 3,357 | Well depth 757 ft; perforations 370–396 ft, 410–421 ft, 445–475 ft, 540–751 ft. |
| | | 8W | | |
| 1S/5E-3D1 | 3D1 | 340717116271001 | 3,343 | Well depth 940 ft; perforations 400–500 ft, 520–590 ft, 608–620 ft, 640–720 ft, 740–940 ft. |
| | | 9W | | |
| 1N/5E-34Q2 | 34Q2 | 340727116263801 | 3,357 | Well depth 990 ft; perforations 360–560 ft, 580–665 ft, 680–900 ft. |
| | | 10W | | |
| 1N/5E-34P4 | 34P4 | 340727116270801 | 3,369 | Well depth 1,020 ft; perforations 398–640 ft, 650–1,010 ft. |
| | | 11W | | |
| 1N/5E-35K1 | 35K1 | 340729116253701 | 3,261 | Well depth 860 ft; perforations 300–480 ft, 580–850 ft. |

[1] Instrument not functioning; no data available.

to determine the chemical properties of the soil leachate and to detect the presence of nitrate-reducing and denitrifying bacteria. Pore-water samples were collected from suction-cup lysimeters to determine the chemical and isotopic composition of pore water in the unsaturated zone. Water samples were collected from monitoring wells and long-screened production wells to determine the chemical and isotopic composition of water in the saturated zone.

## Physical and Hydraulic Properties

Particle-size analyses were conducted on 19 cores collected at the three unsaturated zone monitoring sites (12 at YVUZ-1, six at YVUZ-2, and one at YVUZ-3). The tests were performed at the USGS- CAWSC Hydrologic Research Laboratory, Sacramento, California, in accordance with American Society for Testing and Materials (ASTM) C136 procedures (American Society for Testing and Materials, 1987). Water content was measured by using ASTM (1987) methods on selected cores from all three sites. Water-potential was measured by using the filter-paper method (Campbell and Gee, 1986).

Saturated hydraulic conductivity tests were conducted on two cores collected at YVUZ-1. The tests were performed at the USGS-CAWSC Hydrologic Research Laboratory, Sacramento, California, in accordance with ASTM Procedure D5084 (American Society for Testing and Materials, 1987).

## Chemical Analyses of Soil Extractions

Water was extracted from selected core materials and drill cuttings in the field to determine the specific conductance of the cores and later in the laboratory to determine the chemical composition. Field extractions were prepared by mixing approximately 50 grams (g) of drill cuttings with 50 milliliter (ml) of deionized water and then shaking the mixture by hand for 60 seconds. The specific conductance of the solution was then measured and recorded.

Laboratory soil extracts were prepared on drill cuttings and core material collected from the three sites. Prior to extraction, core material and cuttings were oven-dried and then sieved to obtain 50 ± 0.005 g of material having particles less than 1 millimeter (mm) in diameter. The sieved sample was mixed with 50 mL of distilled water. The mixture was shaken vigorously for 30 seconds, allowed to stand with occasional shaking for about 24 hours, and centrifuged at 4,000 revolutions per minute (rpm) for 20 minutes to allow the remaining solids to settle. The supernatant was pressure filtered through a 0.45-mm pore-sized disk-filter by using a syringe. The first 10 mL of sample was used to rinse the filter and discarded. The remaining sample was filtered and analyzed for chloride, sulfate, nitrate, and nitrite ions by ion chromatography (American Public Health Association, 2005) at the USGS laboratory in San Diego, California. The laboratory extractions are based on a weight per volume ratio and are reported as mg of solute per kg of soil (mg/kg).

## Bacterial Analyses of Soil Extractions

Bacterial analyses of selected samples collected throughout the borehole at sites YVUZ-1 and YVUZ-2 were performed to detect the presence of nitrate-reducing and denitrifying bacteria with depth. Cuttings and core material that were collected for the analysis of bacterial data were stored immediately after collection in the field in heat-sealable aluminum pouches after the ambient atmosphere was displaced from the pouches by using nitrogen gas prior to sealing. Core liners, implements used to handle the sample material, and the cannula used to inject nitrogen gas into the aluminum pouch were flame sterilized prior to use. Sealed pouches were placed in a cool container and transported to the USGS laboratory in San Diego, California, at the end of the day's drilling for analysis the next day.

Prior to analysis in the lab, samples were sieved to remove gravel, thereby creating a more uniform sample medium for analysis and to facilitate comparison of data from different samples with similar particle-size distributions. Denitrifying and nitrate-reducing bacteria abundance as most probable number (MPN) were determined on 10 g of material incubated at 28 degrees Celsius in a nutrient broth containing 0.1 percent potassium nitrate by using methods described by Britton and Greeson (1987). When using this method, the production of nitrogen gas by denitrifying bacteria is determined visually after the 14-day incubation period by nitrogen gas accumulated in an inverted tube (Durham Tube) within the culture tube. Nitrite produced by nitrate-reducing bacteria is identified by a deep red color produced upon addition of a nitrite-test reagent to the culture tube. Nitrate remaining within the culture tube, indicative of incomplete or the absence of nitrate reduction, is identified through the addition of a zinc copper manganese dioxide mixture and the subsequent production of a deep red color. Bacteria were enumerated over a range from 30 to 21,000 MPN per sample through five serial dilutions from the initial culture tubes by using procedures described by American Public Health Association (2005). All bottles, test tubes, sample containers, and sample handling implements were autoclaved prior to use. Implements used to handle cutting and core material were flame sterilized between samples. All equipment and sample media were cleaned and autoclaved after use prior to storage or disposal.

## Sampling of Pore Water

Suction-cup lysimeters were used to sample pore water from the unsaturated zone at all three monitoring sites. The lysimeters were sampled by applying a vacuum (about 60 centibars), which induces water to flow from the unsaturated zone into the lysimeters. Once in the lysimeters, the water was forced to land surface by applying nitrogen-gas pressure to one tube of the two-tube system. The volume of water collected from each lysimeter is shown in figure 11. Determination of specific conductance and pH was done in the field immediately after sample collection. Possible

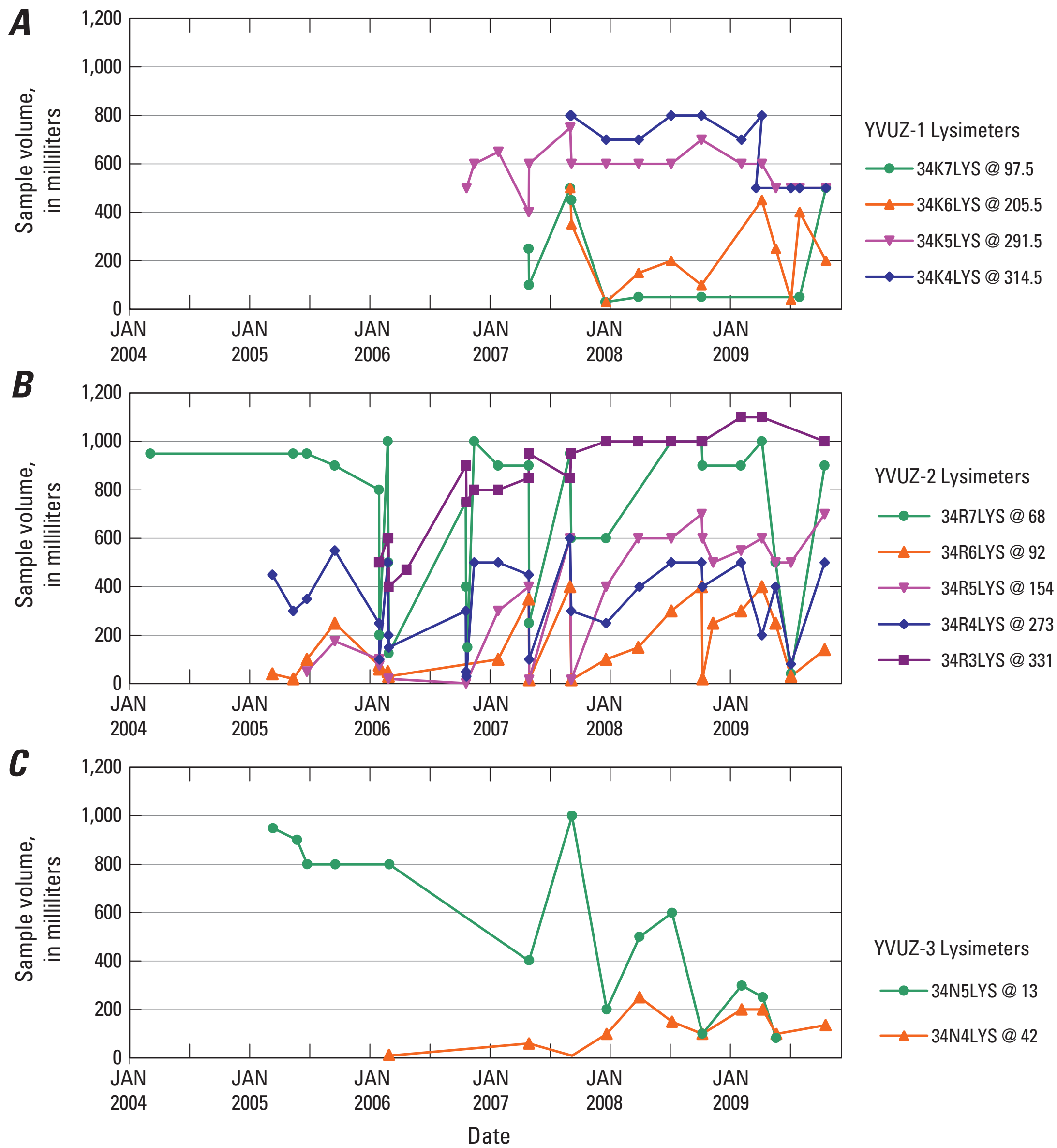



**Figure 11.** Volume of pore water captured during sampling events from lysimeters at sites *A,* YVUZ-1, *B,* YVUZ-2, and *C,* YVUZ-3, Warren subbasin, San Bernardino County, California, 2004–09.

problems with the collection of water from suction-cup lysimeters include the contamination of samples by lysimeter materials, the variability of intake rates of the lysimeters, inhomogeneities in the flow regime, the effects of chemical-disequilibrium conditions, and the inability to collect sufficient sample volume (Umari and others, 1995). About 2 to 4 weeks were required after the application of a vacuum to ensure maximum accumulation of water within most lysimeter cups. Umari and others (1995) found that shorter sampling periods resulted in incomplete water recovery, and longer sampling periods resulted in partial loss of the sample through leakage back into the soil.

## Sampling of Groundwater, State Water Project (SWP) Water, and Septic-Tank Effluent

To quantify changes in groundwater quality as a result of artificial recharge, water samples were collected prior to recharge and intermittently between 2005 and 2009 from the monitoring wells at YVUZ-1 and YVUZ-2, selected HDWD production wells, and suction-cup lysimeters (when saturated) in the west hydrogeologic unit. To determine the chemical and isotopic signature of the SWP water applied to the ponds, water samples were collected directly from the discharge pipe during periods of recharge. Samples also were collected from a septic tank located near YVUZ-2, southeast of the ponds.

Groundwater samples were collected from the monitoring wells after they were purged for three casing volumes by using a small-diameter positive displacement-piston pump. The public-supply wells were sampled while being pumped. Field parameters (temperature, specific conductance, pH, alkalinity, and dissolved oxygen) were measured repeatedly prior to sample collection on water from the wells and to ensure field values were stable prior to sample collection. If required, samples were field filtered and preserved at the time of collection. Selected samples were analyzed for major ions, minor ions, selected trace elements (iron, manganese, arsenic, and chromium), and nutrients at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Samples for the stable isotopes of oxygen and hydrogen were analyzed at USGS Stable Isotope Laboratory in Reston, Virginia.

Trihalomethane (THM) samples were collected in glass bottles and analyzed separately at the USGS Laboratory in Sacramento, California, by using a gas chromatograph with an electron capture detector according to a modified version of the USEPA method 502.2 (U.S. Environmental Protection Agency, 1995) described by Crepeau and others (2004). Samples for trihalomethane formation potential (THMFP) were dosed and incubated using methods described by Crepeau and others (2004).

# Results of Data Collection

## Lithology of Monitoring Sites

The upper 200 ft of the unsaturated zone at YVUZ-1 is characterized by interbedded sands and gravels that originated from granitic rocks of the San Bernardino Mountains to the north and west; in contrast, the sediments from the borehole below a depth of about 200 ft are characterized by sands and gravels that originated from the metamorphic rocks of the Little San Bernardino Mountains to the south (fig. 8*A*). At YVUZ-2, the boundary between the sediments originating from the granitic and metamorphic rocks was about 154 ft below land surface (bls; fig. 8*B*).

## Physical and Hydraulic Properties

Particle-size analyses completed for the cores collected at the three unsaturated zone monitoring sites are presented in table 2. The cumulative silt and clay fractions (passing the 53 microns sieve size) of the 19 cores collected for this study ranged from 3 to 11 percent in YVUZ-1 and 9 to 52 percent in YVUZ-2, and were 21 percent in YVUZ-3.

**Table 2.** Particle-size analyses, done by using the dry-sieve method, for selected core material from unsaturated-zone monitoring sites in Warren subbasin, San Bernardino County, California.

[**Abbreviations**: ft, foot; <, less than; mm, millimeter]

| Depth interval (ft) | Overall sample percentages | | | | <2mm percentages | | | Cumulative percentage passing | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel | Sand | Silt | Clay | Sand | Silt | Clay | 19 mm | 9.5 mm | 4.75 mm | 2 mm | 1 mm | 0.5 mm | 0.25 mm | 0.125 mm | 53 microns | 2 microns | <2 microns |
| YVUZ-1 | | | | | | | | | | | | | | | | | | |
| 34–35 | 17 | 80 | 2 | 2 | 96 | 2 | 2 | 100 | 100 | 100 | 83 | 65 | 38 | 18 | 7 | 4 | 2 | 0 |
| 67–68 | 15 | 79 | 5 | 2 | 92 | 5 | 2 | 100 | 100 | 99 | 85 | 66 | 49 | 27 | 13 | 7 | 2 | 0 |
| 79–80 | 13 | 82 | 4 | 1 | 94 | 5 | 1 | 100 | 100 | 100 | 87 | 62 | 39 | 20 | 10 | 5 | 1 | 0 |
| 92–93 | 6 | 91 | 1 | 2 | 97 | 1 | 2 | 100 | 100 | 100 | 94 | 64 | 35 | 16 | 6 | 3 | 2 | 0 |
| 117–117.5 | 34 | 62 | 3 | 2 | 93 | 4 | 3 | 99 | 99 | 94 | 66 | 32 | 18 | 10 | 6 | 4 | 2 | 0 |
| 130–131 | 3 | 91 | 3 | 3 | 94 | 3 | 3 | 100 | 100 | 100 | 97 | 64 | 43 | 25 | 11 | 6 | 3 | 0 |
| 193-194 | 43 | 51 | 3 | 3 | 90 | 5 | 5 | 100 | 100 | 99 | 57 | 33 | 21 | 13 | 9 | 6 | 3 | 0 |
| 207–208 | 34 | 59 | 4 | 3 | 89 | 6 | 5 | 100 | 100 | 100 | 66 | 33 | 19 | 12 | 9 | 7 | 3 | 0 |
| 208–209 | 2 | 87 | 5 | 6 | 89 | 6 | 6 | 100 | 100 | 100 | 98 | 75 | 44 | 26 | 16 | 11 | 6 | 0 |
| 267–267.5 | 41 | 52 | 4 | 3 | 89 | 6 | 5 | 98 | 96 | 90 | 59 | 38 | 25 | 15 | 9 | 6 | 3 | 0 |
| 347–347.5 | 19 | 70 | 6 | 4 | 87 | 8 | 6 | 100 | 99 | 97 | 81 | 65 | 47 | 33 | 18 | 11 | 4 | 0 |
| 387–387.5 | 34 | 62 | 2 | 1 | 94 | 4 | 2 | 100 | 100 | 91 | 66 | 34 | 19 | 10 | 5 | 4 | 1 | 0 |
| YVUZ-2 | | | | | | | | | | | | | | | | | | |
| 36.0–36.5 | 22 | 65 | 7 | 5 | 84 | 9 | 7 | 100 | 100 | 95 | 78 | 63 | 51 | 40 | 25 | 12 | 5 | 0 |
| 89–90 | 17 | 72 | 6 | 6 | 86 | 7 | 8 | 100 | 100 | 96 | 83 | 67 | 52 | 38 | 21 | 12 | 6 | 0 |
| 145.67–146.17 | 7 | 79 | 5 | 8 | 85 | 6 | 9 | 100 | 100 | 100 | 93 | 93 | 73 | 50 | 26 | 14 | 9 | 1 |
| 187–187.5 | 41 | 50 | 4 | 5 | 85 | 7 | 8 | 100 | 100 | 92 | 59 | 45 | 36 | 27 | 16 | 9 | 5 | 0 |
| 277–280 | 14 | 33 | 34 | 18 | 39 | 40 | 21 | 100 | 100 | 97 | 86 | 83 | 81 | 78 | 70 | 52 | 18 | 0 |
| 337–338 | 3 | 74 | 16 | 7 | 76 | 17 | 7 | 100 | 100 | 100 | 97 | 95 | 89 | 69 | 39 | 23 | 7 | 0 |
| YVUZ-3 | | | | | | | | | | | | | | | | | | |
| 41-43 | 20 | 59 | 13 | 8 | 74 | 16 | 10 | 100 | 99 | 97 | 80 | 70 | 61 | 51 | 34 | 21 | 8 | 0 |

With the exception of one core collected at YVUZ-2 from 277–280 ft bls, all of the cores had sand percentages of 50 percent or greater (table 2). No clay layers that could substantially impede the vertical migration of SWP water were identified in the cores or cuttings from any of the three monitoring sites.

In general, water content and water potential in the core samples from the sites increased with depth in the unsaturated zone (table 3). Measured values of saturated, vertical hydraulic conductivity for the two cores tested from YVUZ-1 (117–117.5 ft and 267–267.5 ft bls) ranged from 3.25 to 3.92 feet per day (ft/d; table 4).

## Measurement of Matric Potential in the Unsaturated Zone

The HDPs and ATs were installed at varying depths at the monitoring sites to detect changes in the soil-matric potential at specific depths in the unsaturated zone. Decreases in matric potential (less negative values or increases in pressure) measured by the HDPs and ATs were an indication of when the moisture content increased either by infiltration of the SWP water or by the rising water table. Because the HDPs and ATs are surrounded by non-native backfill, it takes several months for the probes to equilibrate with the surrounding soil.

### Heat-Dissipation Probe Measurements

Prior to the application of artificial recharge at site 3 in June 2006, the matric potential measured by the HDPs at YVUZ-1 at 9.5 ft and 261.5 ft bls were near zero, indicating that the soils had a high water content; whereas, the matric potential measured by the HDPs at 29.5, 73.5, 86.5, 124.5, and 201.5 ft bls were more negative, between −18 and −25 ft, indicating drier conditions (fig. 12*A*). At different times after recharge was applied, the matric potential measured at the HDPs at 73.5, 86.5, 124.5, and 201.5 ft bls changed abruptly in response to the vertical migration of the wetting front. The matric potential measured from the HDP at 29.5 ft bls varied only slightly between −28 and −35 ft after it stabilized, but the HDP at 73.5 ft bls recorded a change in matric potential in March 2008, and the HDP at 86.5 ft bls recorded a change in matric potential in November 2008 (fig. 12*A*).

**Table 3.** Water content, bulk density, and water-potential data for selected core material from unsaturated-zone monitoring sites in the Warren subbasin, Yucca Valley, San Bernardino County, California.

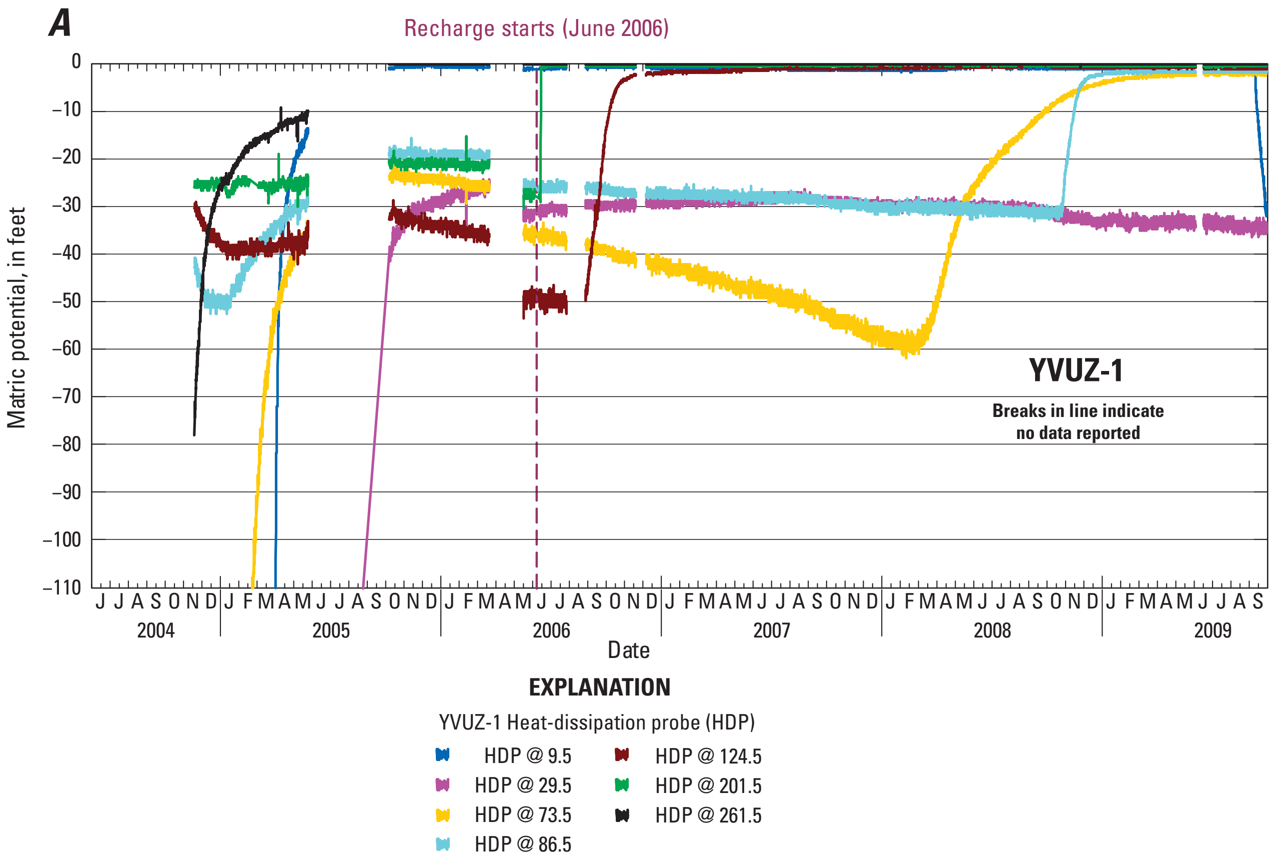
[**Abbreviations**: $cm^3$, cubic centimeter; ft, foot; g, gram; kPa, kilopascal; $m^3$, cubic meter; –, no data]

| Depth interval (ft) | Volumetric water content ($m^3/m^3$) | Bulk density ($g/cm^3$) | Water potential (kPa) | |
|---|---|---|---|---|
| | | | Water activity meter | Filter paper |
| | | YVUZ-1 | | |
| 117–117.5 | 0.034 | 1.78 | –0.56 | –2.08 |
| 267–267.5 | 0.076 | 1.94 | –0.41 | –0.09 |
| 347–347.5 | – | – | – | 0.00 |
| 387–387.5 | 0.113 | 1.76 | –0.31 | 0.00 |
| | | YVUZ-2 | | |
| 36–36.5 | – | – | –0.4 | –0.14 |
| 145.67–146.17 | 0.067 | 1.78 | –0.46 | –0.05 |
| 187–187.5 | 0.100 | 1.92 | –0.79 | –0.03 |
| | | YVUZ-3 | | |
| 41–43 | 0.032 | 1.66 | –0.68 | –0.79 |

**Table 4.** Saturated vertical hydraulic conductivity values for two cores from unsaturated-zone monitoring site YVUZ-1, Warren subbasin, San Bernardino County, California.

[**Abbreviations**: cm/s, centimeter per second; ft, foot; ft/d, feet per day; psi, pounds per square inch]

| Sample interval (ft) | Saturated hydraulic conductivity (cm/s) | Saturated hydraulic conductivity (ft/d) | Pressure gradient (psi) |
|---|---|---|---|
| 117–117.5 | 1.2E-03 | 3.35 | 1 |
| 117–117.5 | 1.3E-03 | 3.78 | 2 |
| 267–267.5 | 1.4E-03 | 3.92 | 1 |
| 267–267.5 | 1.1E-03 | 3.25 | 2 |



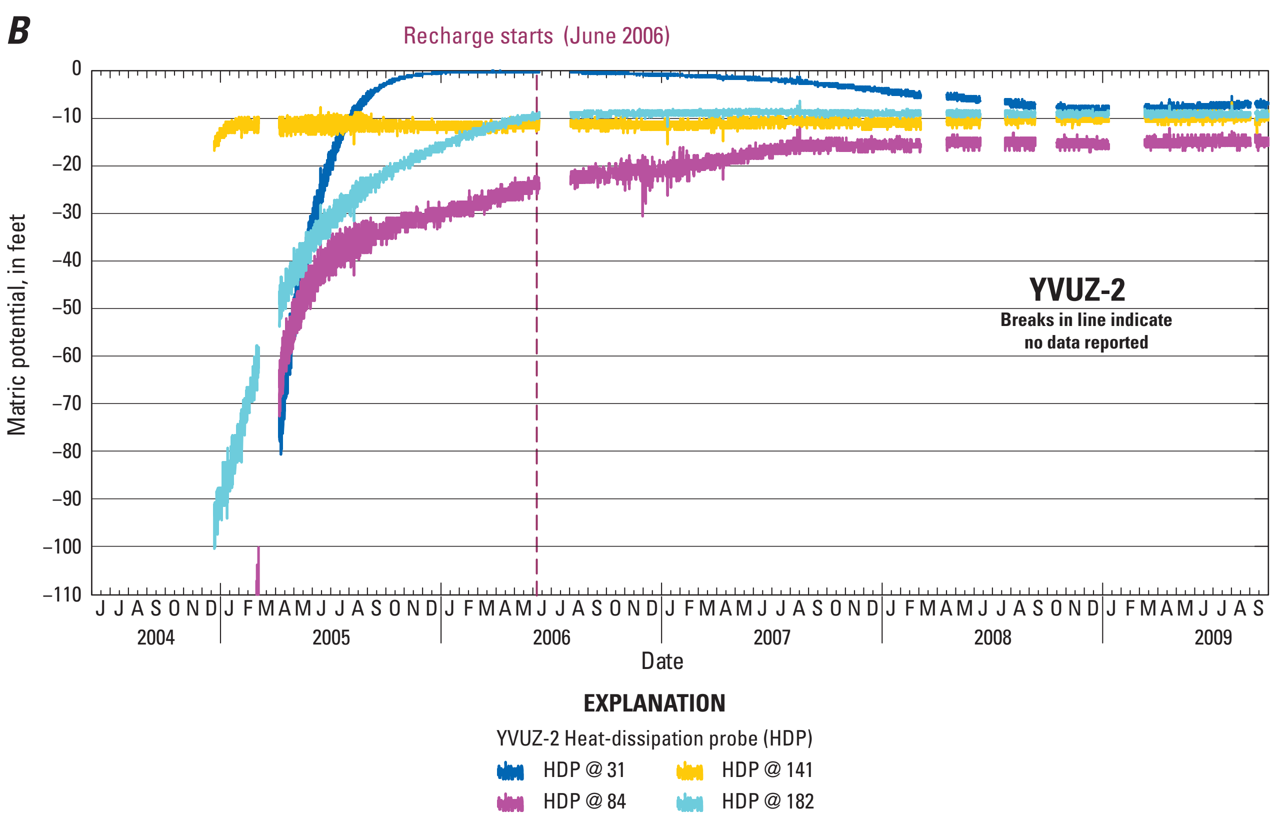




**Figure 12.** Matric potential from heat-dissipation probes in the unsaturated zone at sites *A,* YVUZ-1, *B,* YVUZ-2, and *C,* YVUZ-3 in the Warren subbasin, San Bernardino County, California, 2004–09.

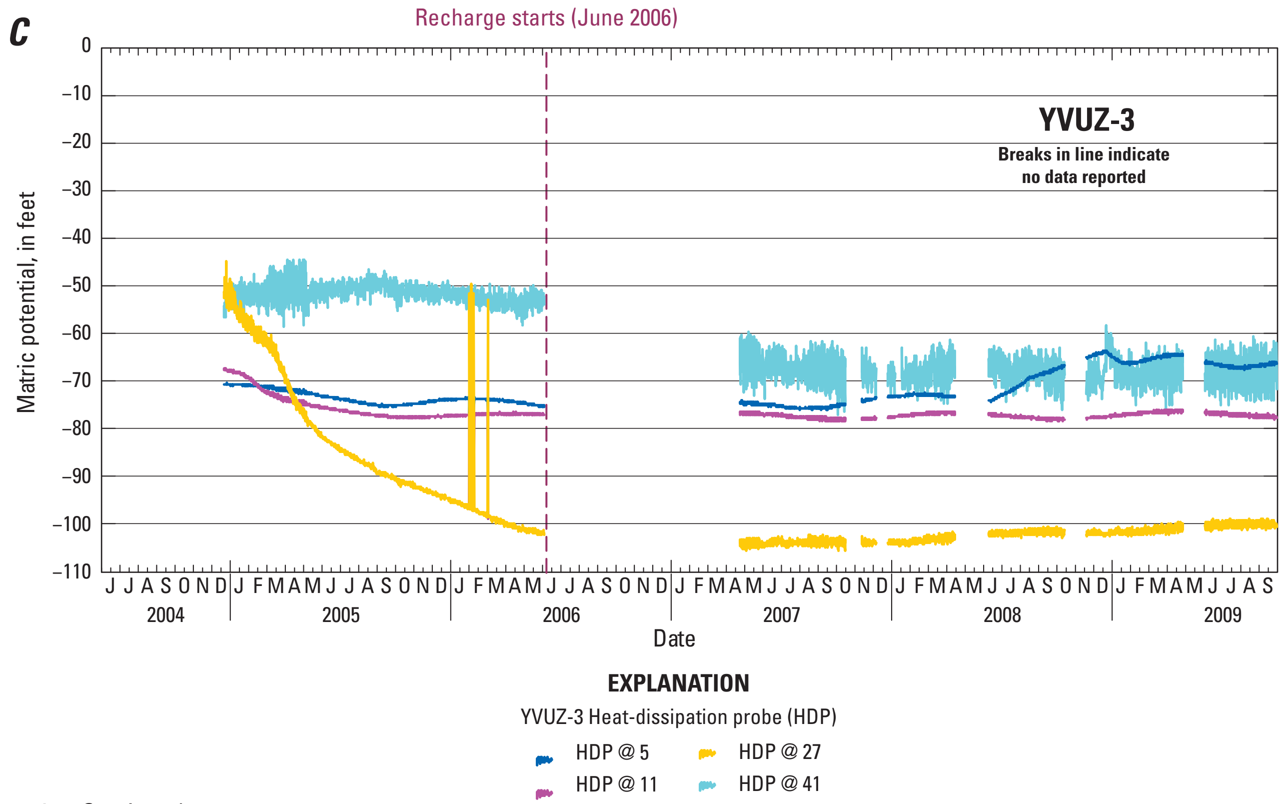



**Figure 12.** Continued.

The matric potential measured from the HDPs at YVUZ-2 was more than −15 ft, after the instruments reached equilibrium in late 2007 (fig. 12*B*). In general, the matric potential measured from the HDPs at YVUZ-2 was less negative than the matric potential measured at YVUZ-1, reflecting moister conditions from the infiltration of nearby septic-tank seepage at YVUZ-2.

The matric potentials measured from the HDPs at YVUZ-3 were less than about −45 ft, indicating drier conditions than measured at YVUZ-1 and YVUZ-2 (fig. 12*C*). This site is about 2,800 ft southwest of site 3 and next to a green on the golf course at Blue Skies Country Club (fig. 1). This site was irrigated with groundwater until 2007, after which time the irrigation of the golf course was terminated.

## Advanced Tensiometer Measurements

The ATs were placed at depths that were anticipated to be wetter, and possibly saturated, by the rising water table. Positive pressures from these instruments represented the onset of saturated conditions. In general, the matric potential measured by the AT at YVUZ-1 at 61.5 ft bls became less negative (decreased) after recharge was initiated at site 3 in June 2006 (fig. 13*A*). The data also showed a seasonal pattern in the AT at 61.5 ft bls, with less negative values in the winter months and more negative values in the drier, summer months. The matric potential measured by the AT at 187.5 ft bls remained relatively constant throughout the study period and the AT at 341.5 ft bls stopped recording in March 2005. The AT at 381.5 ft bls also had intermittent recording problems, however, the matric potential measured by this AT changed from negative values (unsaturated conditions) in June 2005, to positive values (saturated conditions) when the instrument started to record again in October 2005 (fig. 13*A*). Based on the water-level measurements from the monitoring well at YVUZ-1, the water table had reached the AT at 381.5 ft bls sometime between June and September 2005 (fig. 13*A*) and saturated the instrument. The pressure measured at this AT continued to rise in response to recharge from site 3 until the pressure exceeded the instrument's capacity of 26 ft in early 2007 (fig. 13*A*).

At YVUZ-2, the rising of the water table was readily recognized and recorded by the rapid changes in matric potential at each of the ATs (fig. 13*B*). In December 2004, the matric potential measured by the ATs at 274 ft and 301 ft bls at YVUZ-2 were negative, indicating drier conditions than those measured by the AT at 332 ft bls, which indicated wetter conditions (fig. 13*B*). The matric potential at this deepest AT abruptly decreased in July 2005, and the water-level data from the monitoring well showed that the water table had reached this AT sometime between June and September 2005. The pressure measured by this AT exceeded the instrument's capacity of 26 ft by December 2006.

The AT at 301 ft bls began to record positive values beginning in January 2007, corresponding to when the water table reached the AT. The pressure measured by this AT continued to rise until the pressure exceeded the instrument's capacity of 26 ft in December 2007. By November 2007, the AT at 274 ft bls began to measure positive values, corresponding to the arrival of the water table at this depth in the monitoring well.

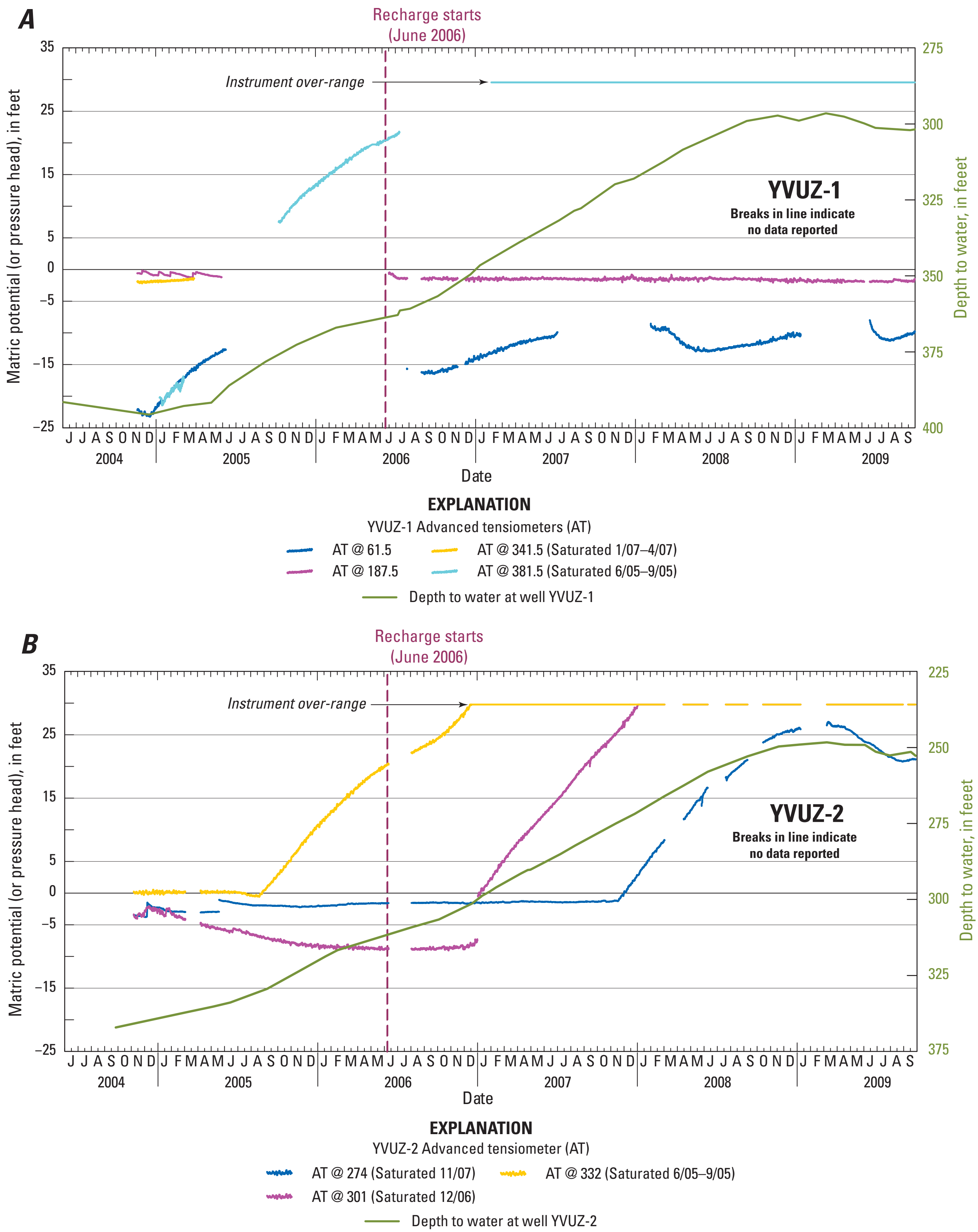



**Figure 13.** Matric potential from advanced tensiometers in the unsaturated zone at sites *A,* YVUZ-1 and *B,* YVUZ-2 in the Warren subbasin, San Bernardino County, California, 2004–09.

### Chemical Analyses of Soil Extractions

The chemical analyses of the soil leachate extracted from the cores and cuttings are given in appendices 4–6. Vertical distributions of the $NO_3$-N concentrations of the soil leachate at monitoring sites YVUZ-1, YVUZ-2, and YVUZ-3 are shown in figure 14. The $NO_3$-N concentrations in the soil leachates from YVUZ-1 were consistently low, less than 1.57 mg/kg, in samples from land surface to 404 ft bls (fig. 14*A*, appendix 4). In general, $NO_3$-N concentrations in the soil leachates from YVUZ-2 from land surface to 137 ft bls were higher than in samples collected deeper in the borehole and from YVUZ-1 (fig. 14*A* and *B*, appendix 4 and 5). The $NO_3$-N concentrations at YVUZ-2 reached a maximum concentration of about 25 mg/kg between about 100 and 121 ft bls (fig. 14*B*). The $NO_3$-N concentrations were less than 6 mg/kg at YVUZ-3 (fig. 14*C*, appendix 6).

### Bacterial Analyses of Soil Extractions

The denitrifying and nitrate-reducing bacteria abundances determined in borehole materials from monitoring sites YVUZ-1 and YVUZ-2 are shown in figure 15. Limited funding for the project did not allow for bacteria sampling of YVUZ-3. Overall, the denitrifying and nitrate-reducing bacteria abundances were greater in YVUZ-2 than in YVUZ-1, with the greatest abundance in samples collected from YVUZ-2 above 100 ft bls. Nitrate-reducing bacteria counts above 40 MPN, slightly above the detection limit of 30 MPN, were not found below about 150 ft bls at site YVUZ-2. The highest denitrifying bacteria counts for YVUZ-2 were 21,000 MPN at about 36 ft. At YVUZ-1, the highest nitrate-reducing bacteria counts of 4,300 MPN were found at about 220 ft bls, near the contact between the granitic and metamorphic derived sediments (fig. 8*A*), and at about 400 ft bls (fig.15*A*), near the water table. Denitrifying bacteria counts did not exceed 90 MPN at YVUZ-1.

### Chemical and Isotopic Analysis of Pore Water

The chemical and isotopic composition of pore water was determined on samples collected from suction-cup lysimeters at all three monitoring sites. Frequent sampling over an almost 5-year period resulted in time-series water-quality data in the unsaturated zone. The water-quality data, including the stable isotopes of oxygen and hydrogen, collected from the lysimeters are shown in appendix 7. Although the volume of pore water captured from each lysimeter in this study varied considerably with each sampling event (fig. 11), the high-frequency and relatively long-term sampling of the lysimeters was considered to yield samples representative of the unsaturated zone chemistry. Figure 14 shows the average nitrate concentrations from the groundwater sampled from the monitoring wells and the average nitrate concentrations of the pore water sampled before and after recharge started in June 2006 for YVUZ-1 and YVUZ-2. Also shown in figure 14 is the depth of the water table at YVUZ-1 and YVUZ-2 before and after artificial recharge, and the date when individual lysimeters became saturated at each site.

### Chemical and Isotopic Analysis of Groundwater, State Water Project Water, and Septic-Tank Effluent

The chemical and isotopic composition of water samples collected from the wells at YVUZ-1 and YVUZ-2, selected HDWD production wells, SWP water from a discharge pipe at site 3, and a septic tank near YVUZ-2 (fig. 1) are presented in appendix 8. The results from the dissolved organic carbon (DOC) and THMFP analyses are also presented in appendix 8. The interpretation of the results from these analyses is discussed in the following section of the report.

## Effects of Artificial Recharge in the West Hydrogeologic Unit

Direct recharge of imported SWP water to the west hydrologic unit started in June 2006, and by September 2009, more than 9,800 acre-ft of water had been released to three ponds at site 3 (fig. 16). Matric-potential, water-level, and water-quality data were used to determine the travel time of the SWP water through the thick (250 to 425 ft) unsaturated zone beneath the ponds, the groundwater-level response to recharge, and changes to the quality of soil water and groundwater from the recharge of SWP water in the west hydrogeologic unit.

### Changes in Matric Potential of the Unsaturated Zone in Response to Artificial Recharge

Artificial recharge at site 3 began on June 7, 2006; SWP water was spread to the northern ponds on either side of monitoring site YVUZ-1 (fig. 1). Although the HDPs at YVUZ-1 showed that some discrete zones of moist soils were present before recharge (fig. 12*A*), the volumetric water content of the soils below the recharge ponds indicated that the upper 267 ft of the unsaturated zone was mostly dry, with a water content between 3.4 and 7.6 percent (table 3). Therefore, the vertical movement of the wetting front associated with the infiltrated water was expected to be evident by changes in soil-moisture content measured by the HDPs and ATs installed in YVUZ-1.

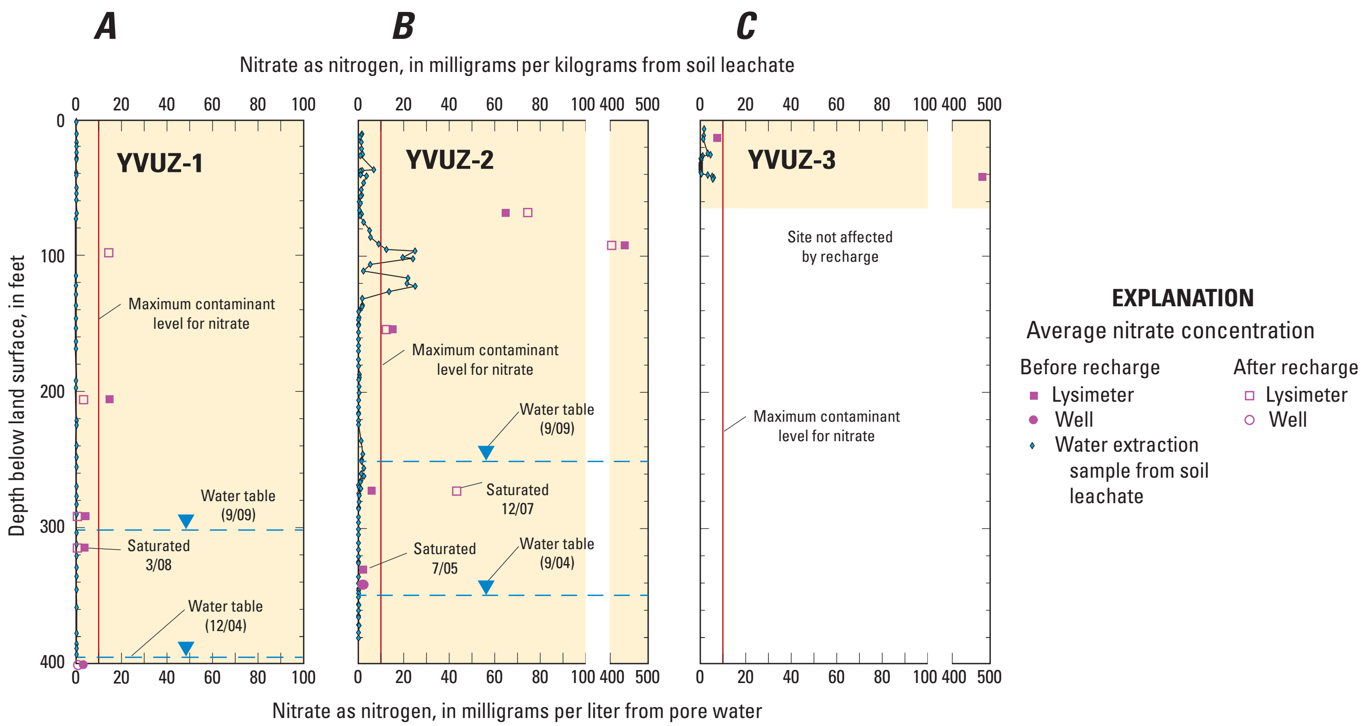



**Figure 14.** Vertical nitrate-nitrogen distribution from soil extractions, and average nitrate-nitrogen concentrations from pore water and groundwater samples, at monitoring sites *A,* YVUZ-1, *B,* YVUZ-2, and *C,* YVUZ-3, Warren subbasin, San Bernardino County, California.

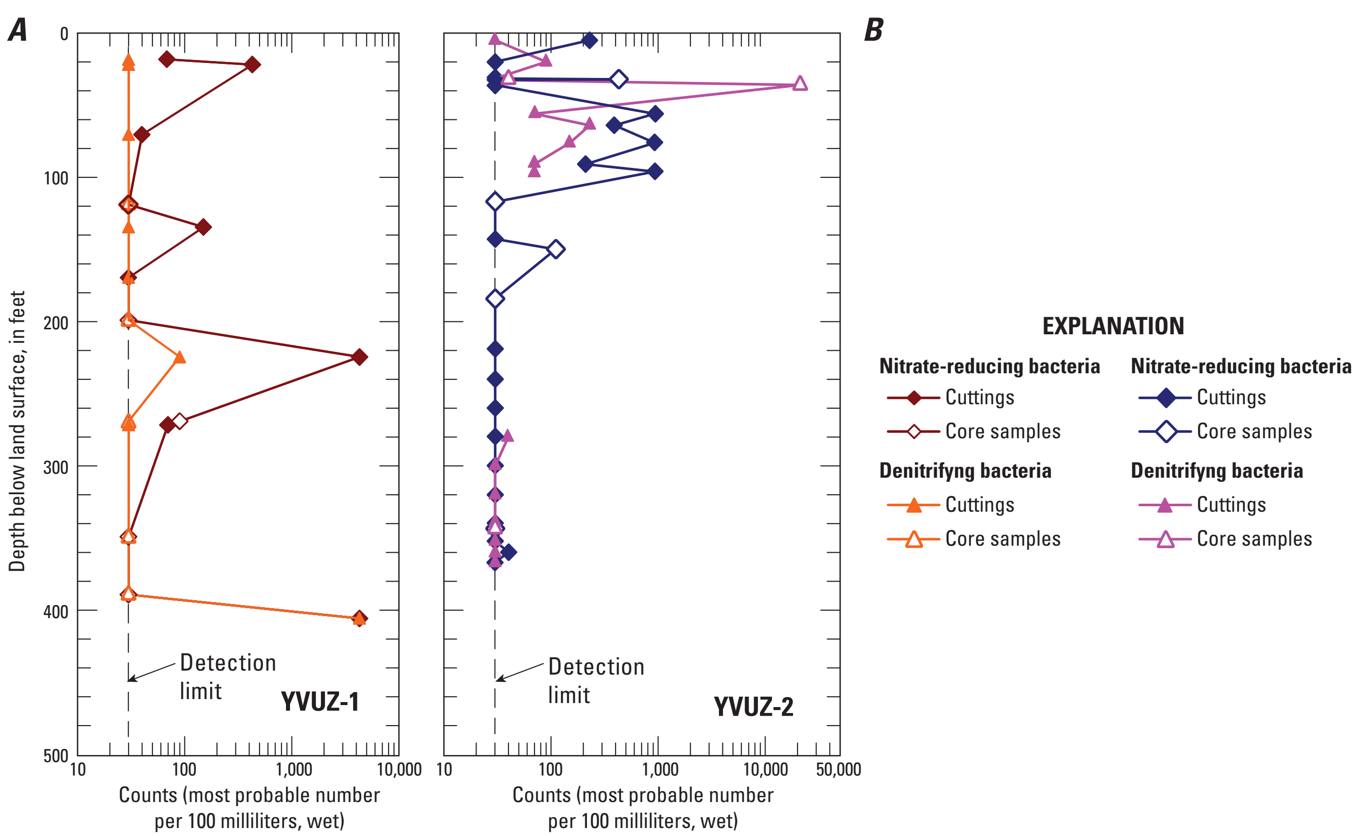



**Figure 15.** Nitrate-reducing and denitrifying bacteria from selected cores and drill cuttings collected from sites *A,* YVUZ-1 and *B,* YVUZ-2, Warren subbasin, San Bernardino County, California.

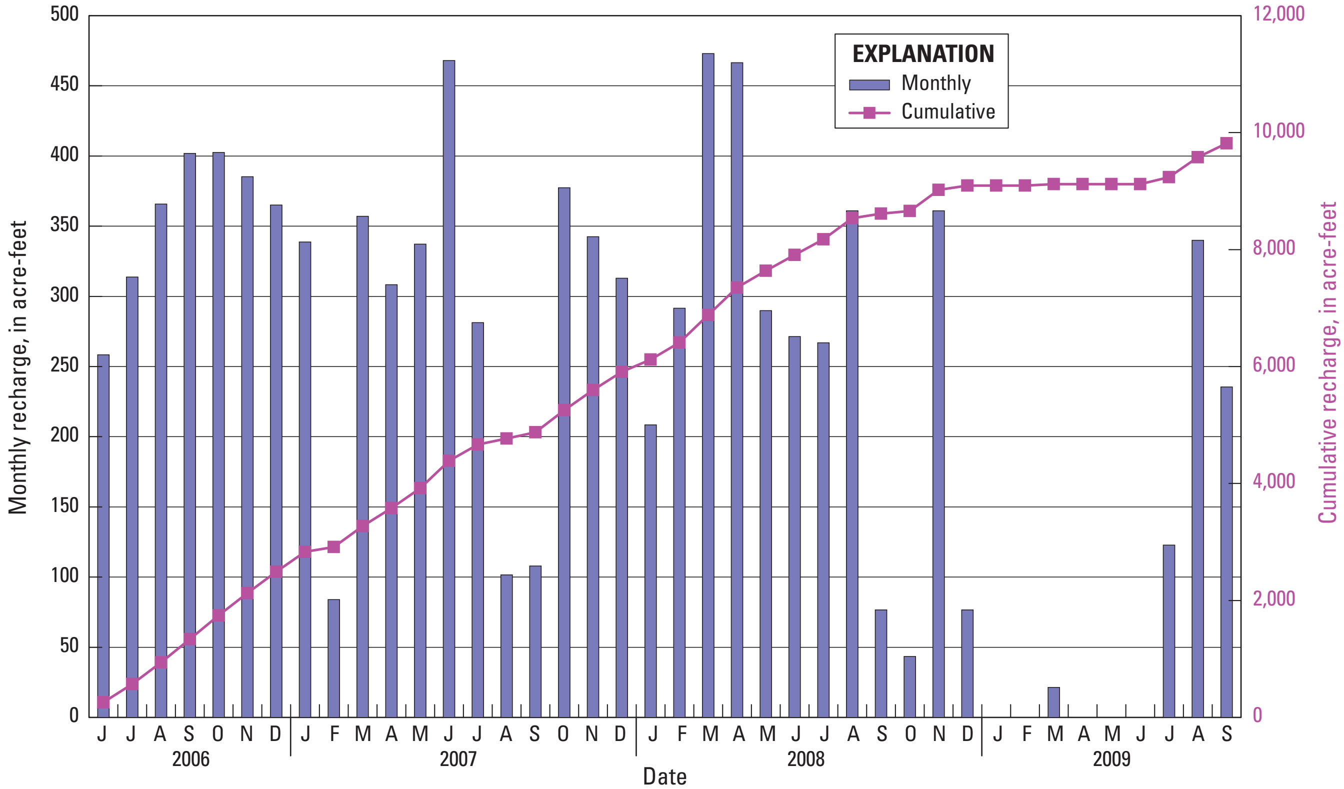



**Figure 16.** Amount of artificial recharge applied to Hi-Desert Water District recharge ponds at site 3, June 2006 to September 2009, Warren subbasin, San Bernardino County, California.

The first instrument to record a change in matric potential was the HDP at 201.5 ft bls, which abruptly changed on June 15, 8 days after recharge began (fig. 12*A*), indicating that the infiltration of the SWP water through the unsaturated zone beneath the ponds was predominantly vertical to a depth of about 200 ft bls with limited lateral spreading. The change in lithology at about 200 ft bls (fig. 8*A*) resulted in lateral spreading of the wetting front, which was observed by the change in matric potential measured from the HDP at 201.5 ft bls. On the basis of these data, it is estimated that the rate of infiltration of the initial wetting front was about 25 ft/d.

The varied arrival times of the SWP water recorded by the HDPs at YVUZ-1 indicated heterogeneities in the geologic materials of the unsaturated zone above 200 ft that caused lateral flow within the unsaturated zone, but these were minimal compared to the change in geologic materials at 200 ft bls. A conceptual model illustrating the effect of geologic heterogeneities on water movement through the unsaturated zone is presented in figure 17.

No abrupt changes were measured in the matric potential at YVUZ-2 after the application of artificial recharge at site 3, as was observed at YVUZ-1. Because the soil moisture content of the unsaturated zone at YVUZ-2 did not vary, artificial recharge at site 3 did not spread laterally as far as the YVUZ-2 site, which is 200 ft northwest of the southern extent of the recharge ponds.

## Groundwater-Level Responses to Artificial Recharge

Prior to the start of artificial recharge in the west hydrologic unit in June 2006, water levels measured in HDWD production wells were rising at a rate of about 0.05 ft/d, probably in response to reduced pumpage. Pumpage in the west hydrogeologic unit decreased from about 1,820 acre-ft in 2001 to about 1,430 acre-ft in 2009 (fig. 5), while precipitation in water year 2005 was 10.35 in., or about 164 percent greater than the long-term average of 6.3 in. (Hi-Desert Water District, 2010); (fig. 18). The rise in water levels also could be in response to the artificial recharge in the midwest and mideast hydrogeologic units (fig. 1) and (or) to an increase natural recharge. After the application of SWP water to the ponds at site 3 was initiated, most wells showed a more rapid rise in water levels (fig. 18*A*). Between June 2006 and January 2009, water levels rose at a rate of about 0.08 ft/d in the monitoring wells at sites YVUZ-1 and YVUZ-2 (34K3 and 34R2). The rise in water levels ceased between January and June 2009, corresponding to a decrease in the volume of water applied to the ponds at site 3 (fig. 18*B*). During that time, a total of only about 21 acre-ft of water was applied to the ponds (figs. 16 and 18*B*).

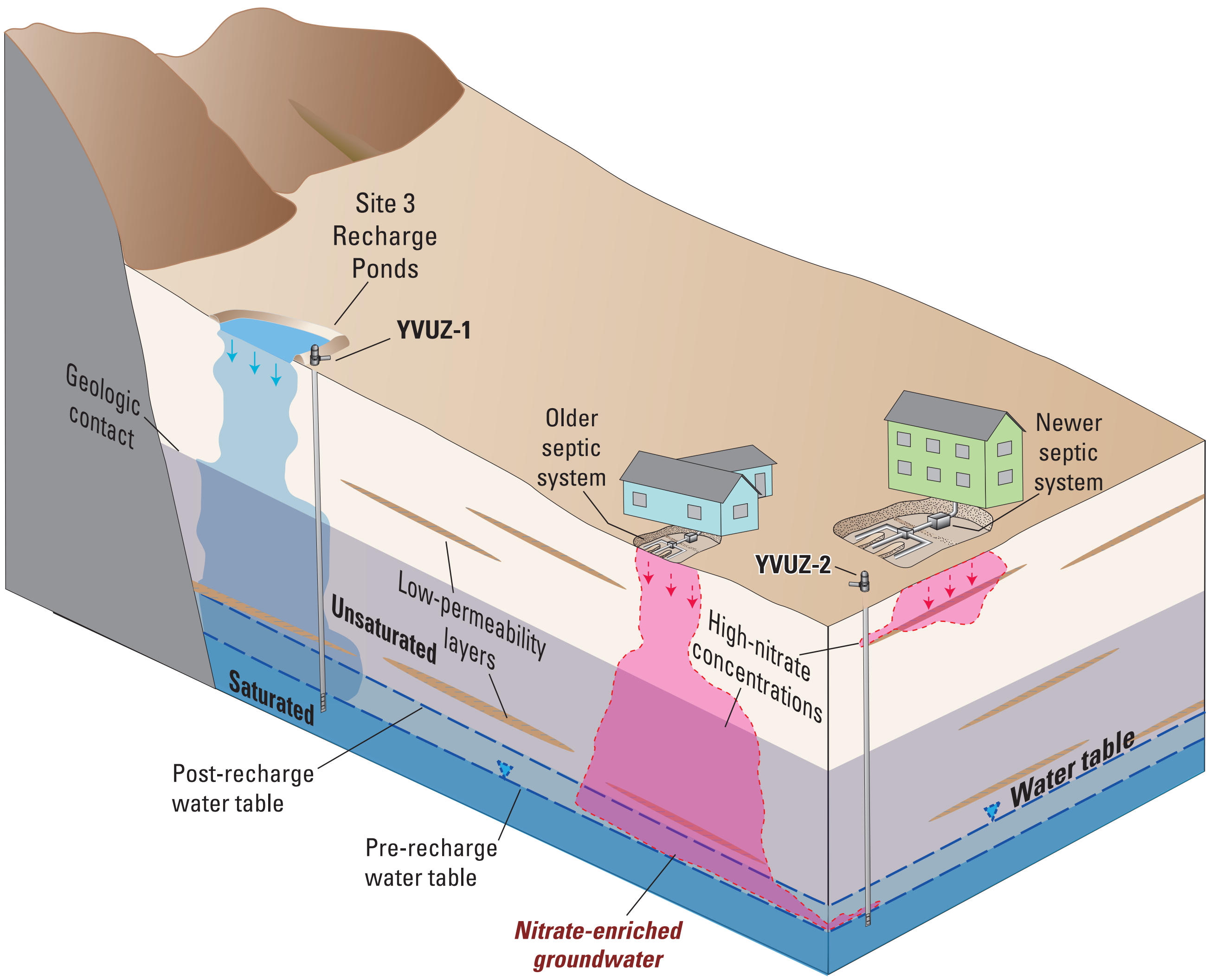



**Figure 17.** Conceptual model of geologic heterogeneities and preferential flow paths within the unsaturated zone in the west hydrogeologic unit, Warren subbasin, San Bernardino County, California.

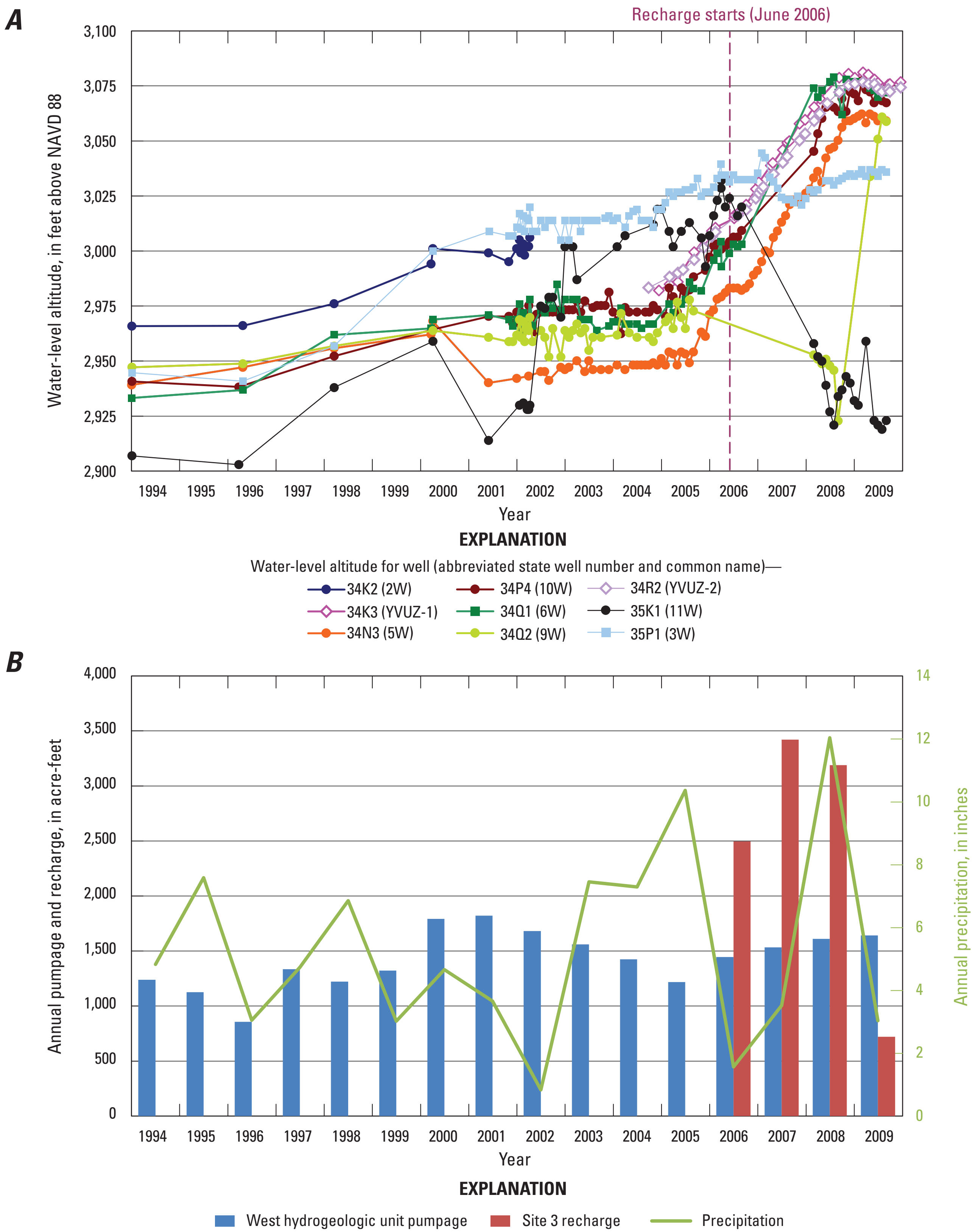



**Figure 18.** *A,* Water levels from Hi-Desert Water District production wells and from monitoring wells at sites YVUZ-1 and YVUZ-2, and *B,* annual pumpage and artificial recharge in the west hydrogeologic unit, and annual precipitation in Yucca Valley, 1994–2009, Warren subbasin, San Bernardino County, California.

Between June 2006 and September 2009 groundwater levels in the monitoring wells at YVUZ-1 and YVUZ -2 (34K3 and 34R2) and HDWD production wells 34K2 (2W), 34N3 (5W), 34P4 (10W), 34Q1 (6W), and 34Q3 (9W) in the west hydrogeologic unit rose more than 60 ft (fig. 18*A*). These wells are in close proximity or are west of site 3 (fig. 1), and the water-level rise is in response to more than 9,800 acre-ft of recharge of SWP water. Groundwater levels in HDWD production well 35K1 (11W), about 1 mi east of site 3, declined about 100 ft, however, and groundwater levels in HDWD production well 35P1 (3W), about 0.6 mi east of site 3, remained about the same between June 2006 and September 2009 (figs. 1 and 18*A*). Well 11W is the furthest HDWD production well from the recharge ponds, and a total of about 2,740 acre-ft of groundwater was pumped from well 11W between June 2006 and September 2009, which is about 51 percent of the groundwater pumped from the west hydrogeologic unit during this period (Hi-Desert Water District, 2010).

## Changes in Water Quality

Water-quality samples were collected and analyzed to determine if the SWP water had arrived at a particular lysimeter or well and, if so, the approximate time of the arrival. As mentioned in the "Sampling of Groundwater, State Water Project (SWP) Water, and Septic-Tank Effluent" section, water samples were analyzed for the stable isotopes of oxygen and hydrogen, nutrients, major and minor ions, and selected trace elements. The water-quality data also were used to indicate whether the change in some constituents, such as nitrate and organic carbon, could become public-health concerns.

### Stable Isotopes of Oxygen and Hydrogen

Oxygen-18 ($^{18}O$) and deuterium (D, or $^{2}H$) are naturally occurring stable isotopes of oxygen (O) and hydrogen (H). Changes in the values of these stable isotopes in water samples collected from the suction-cup lysimeters and wells at YVUZ-1 and YVUZ-2 and nearby HDWD production wells were used to record the arrival and presence of SWP water in the unsaturated and saturated zones beneath the ponds at site 3.

Isotopic ratios are expressed in delta notation (δ) as per mil (parts per thousand) differences relative to the standard known as Vienna Standard Mean Ocean (VSMOW; Gonfiantini, 1978). By convention, the value of VSMOW is set at 0 per mil. Because most of the world's precipitation originates as evaporation of seawater, the $\delta^{18}O$ ($^{18}O/^{16}O$ ratio) and δD ($^{2}H/^{1}H$ ratio) composition of precipitation throughout the world is linear and distributed along a line known as the meteoric water line (MWL) (Craig, 1961). Differences in the isotopic composition of precipitation along this line reflect trends with latitude and with the temperature of condensation. More negative values (depletion in the heavier relative to the lighter isotope) result when condensation takes place at colder temperatures and higher altitudes. Water that has been partly evaporated is enriched in heavier isotopes relative to its original composition; these values plot below the MWL (for δD as the vertical and $\delta^{18}O$ as the horizontal axis). The $\delta^{18}O$ and δD composition of water relative to the MWL, and relative to the isotopic composition of water from other sources, provides a record of the source of the water and can be used as a tracer of the movement of the water.

#### Isotopic Ratios from State Water Project Water

A total of about 9,800 acre-ft of SWP water was applied to site 3 between June 2006 and June 2008 (fig. 16), and water was sampled 13 times from the same discharge pipe. The $\delta^{18}O$ and δD composition of the samples ranged from –9.44 to –11.92 and –69.6 to –88.9 per mil, respectively (fig. 19; appendix 8). The isotopic ratios of the SWP water plotted below the MWL, indicating that the source SWP water may have been partly evaporated prior to delivery to the ponds at site 3, that the SWP water originated from areas with a local MWL offset from the global MWL, or both (Kendall and Coplen, 2001). When the SWP water was initially delivered in June 2006, the isotopic ratios were more negative (lighter) than samples collected later in the study, indicating that the isotopic composition of the SWP water changed during the study. Samples were collected more frequently at the beginning of the recharge period. The volume weighted $\delta^{18}O$ and δD composition of the applied SWP water during June 2006–June 2008 was −9.78 and −72.8, respectively (fig. 19).

#### Isotopic Ratios from YVUZ-1

The stable-isotopic ratios of samples collected from three of the four lysimeters (205.5, 291.5, and 314.5 ft bls) and the well (401.5 ft bls) at YVUZ-1 prior to the application of the SWP water starting on June 7, 2006, showed that the isotopic composition of the soil water and groundwater initially plotted above the MWL and that the values were less negative (heavier) than those of the initially applied SWP water (fig. 20*B*–*E*). Similar to the data from the HDPs, the isotopic ratios from the lysimeters at YVUZ-1 indicated that the applied SWP water infiltrated through the unsaturated zone in a predominantly vertical manner, with limited lateral spreading until a depth of about 200 ft bls. The geologic heterogeneities at about this depth (fig. 8*A*) caused the wetting front of the infiltrated water to get wider as it migrated through the unsaturated zone (fig. 17). Isotopic ratios changed rapidly when the SWP water reached a lysimeter; the isotopic ratios became heavier and reflected similar ratios to those analyzed in SWP water (fig. 20).

The shallowest lysimeter at 97.5 ft bls did not produce a sufficient volume of water for analysis until April 2007 because of the low water content of the soils at this depth; this lysimeter did not yield sufficient water until about 11 months after artificial recharge had been applied to the ponds. The initial isotopic ratios from this depth plotted slightly below the MWL, but by March 2008, the isotopic ratios reflected those of the SWP water (fig. 20*A*).

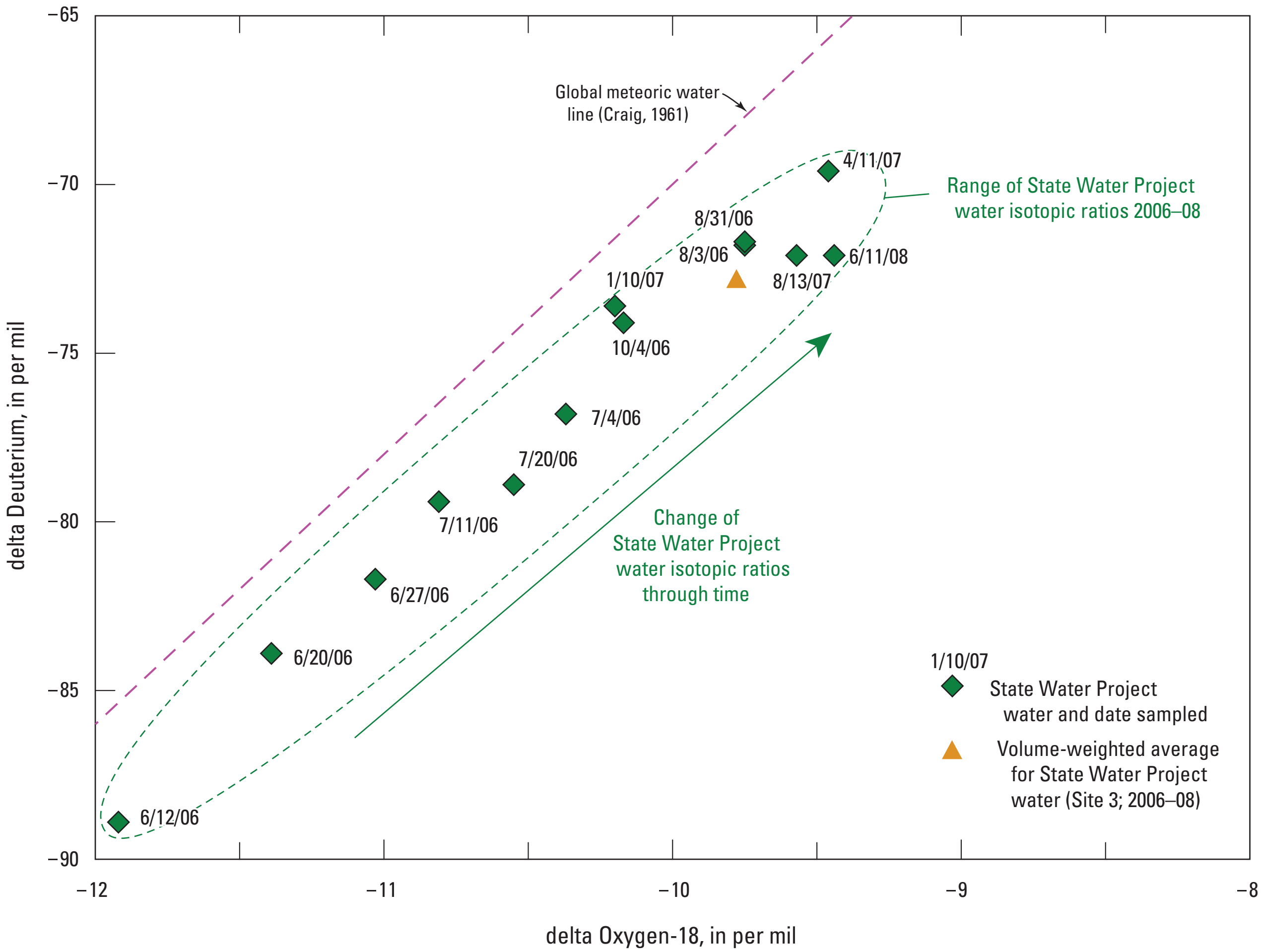



**Figure 19.** Delta oxygen-18 ($\delta^{18}O$) and delta deuterium ($\delta D$) composition of water from the California State Water Project, 2006–08, Warren subbasin, San Bernardino County, California.

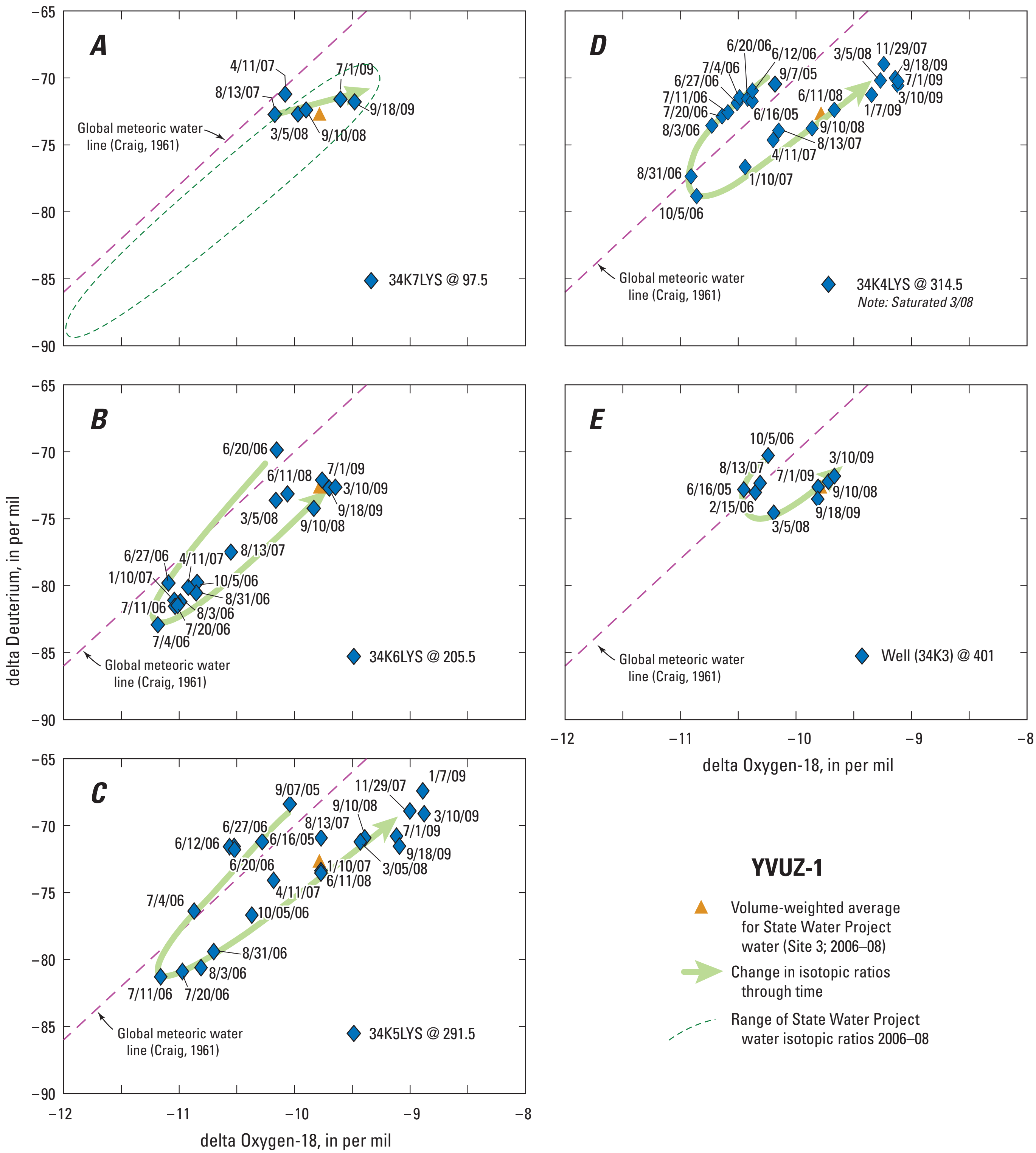



**Figure 20.** Delta oxygen-18 ($\delta^{18}O$) and delta deuterium ($\delta D$) composition of water from the California State Water Project and from lysimeters and monitoring well at site YVUZ-1, 2005–09, Warren subbasin, San Bernardino County, California.

The change in the isotopic ratios from the lysimeter at 205.5 ft bls showed that the imported SWP water was present at this depth when the lysimeter was sampled on June 27, 20 days after the initial application of water to site 3 (fig. 20*B*). Based on the change in the isotopic ratios, the estimated rate of movement of the SWP water to this lysimeter was about 10.3 ft/d. Because samples were not collected from the lysimeters on a daily basis, the actual rate of infiltration of the SWP water was faster. Estimates of rates of infiltration from the HDP data indicated that the rate of movement of the wetting front was about 25 ft/d.

The isotopic ratios showed that the wetting front of the SWP water had started to mix with the native pore water at 291.5 ft bls when the lysimeter was sampled after 27 days of artificial recharge. The sample taken on July 11, 34 days after recharge started, showed the predominance of SWP water at this depth about 14 days after the arrival at the lysimeter at 205.5 ft bls (figs. 20*B* and 20*C*). Based on when the isotopic ratios plotted below the MWL, the estimated average rate of vertical movement of the infiltrating SWP water from land surface to 291.5 ft bls was about 8.6 ft/d, and the rate of movement between the lysimeters at 205.5 ft and 291.5 ft bls (86 ft) was about 6.1 ft/d.

The sample from the lysimeter at 314.5 ft bls that showed the predominance of SWP water was taken about 85 days after recharge started and about 51 days after the change in isotopic ratios at the lysimeter at 291.5 ft bls (fig. 20*D*). Based on when the isotopic ratios plot slightly below the MWL, the estimated average rate of vertical movement of the infiltrating SWP water from land surface to 314.5 ft bls was about 3.7 ft/d, and the rate of movement between the lysimeters at 291.5 ft and 314.5 ft bls (23 ft) was about 0.45 ft/d. The slower rates of the vertical movement of the SWP water in the unsaturated zone with depth were due to the lateral movement and spreading of water as it infiltrated beneath YVUZ-1, which was caused by heterogeneities in the unsaturated zone (fig. 17).

The stable isotopes collected from the YVUZ-1 monitoring well at 401 ft bls showed the change in composition similar to the lysimeters through time and indicated the predominance of SWP water in the well by March 2008 (fig. 20E). Because samples were collected less frequently from the well than from the lysimeters, the arrival of the SWP water was estimated to have been sometime between when the samples were collected on August 13, 2007, and March 5, 2008; therefore, it took between 432 to 636 days for the imported SWP water to arrive at the YVUZ-1 monitoring well, indicating an average rate of vertical movement between 0.6 and 0.9 ft/d.

### Isotopic Ratios from YVUZ-2

The samples from all five lysimeters and the well at YVUZ-2 showed little variability in isotopic composition through time (fig. 21). However, a comparison of the data between the lysimeters and the monitoring well showed notable variations, consistent with differences in water source. All the isotopic ratios from the two shallowest lysimeters, at 68 ft and 92 ft bls, plot below the MWL, indicating evaporation of the source water (figs. 21*A* and 21*B*). Because the isotopic ratios from the shallow lysimeters plotted below the MWL prior to and after the application of SWP water at site 3, the infiltration of SWP water from site 3 was not a possible source. YVUZ-2 is located in an area of high-septic density, where septic systems have been used since the mid 1950s to mid 1960s (fig. 2 in Nishikawa and others, 2003), indicating that septic effluent is a possible source of water to the shallow lysimeters. The isotopic ratios from the lysimeters plot along an evaporative trend line from a septic-effluent sample taken in 1998 (Nishikawa and others, 2003; figs. 21*A* and 21*B*). Partial evaporation of the septic effluent in the leach fields, prior to infiltration, could explain the heavier isotopic ratios in the samples from the shallow lysimeters.

The two deepest lysimeters, at 273 ft and 331 ft bls, and the monitoring well at 348 ft bls had isotopic values that plotted close to or above the MWL, indicating that native soil water or groundwater was present below 273 ft bls (figs. 21*D*–*F*). The isotopic composition of water from the lysimeter at 154 ft bls lay between the isotopically heavier values from the shallower lysimeters and the lighter values from the deeper lysimeters and well (fig. 21*C*), which indicated that septic effluent had mixed with native soil water to at least 154 ft bls. Assuming vertical infiltration, the minimum rate of infiltration of septic effluent at this site has been about 3 ft/yr since 1960.

### Isotopic Ratios from YVUZ-3

Isotope samples were collected from YVUZ-3 at lysimeters at 13 ft and 43 ft bls (fig. 22, appendix 8). This site is adjacent to a green on the Blue Skies Country Club golf course. Irrigation of the golf course decreased from about 200 acre-ft in 2004 to about 100 acre-ft from 2005 through 2007, after which time the golf course was abandoned, and groundwater no longer was applied (Hi-Desert Water District, 2010). Once irrigation to the golf course stopped, the vegetation died, transpiration ceased, and the volume of water captured by the shallow lysimeter decreased (fig. 11*C*).

All of the isotopic ratios at this site plot to the right of the MWL, indicating that this water was partly evaporated before it infiltrated the unsaturated zone. The samples collected from the shallow lysimeter, at 13 ft bls, in 2005, while the golf course was being irrigated, and all the samples from the lower lysimeter, at 42 ft bls, from 2007 to 2009, had similar isotopic ratios (fig. 22, appendix 8). The isotopic composition of samples collected from the shallow lysimeter, at 13 ft bls, in 2007 and 2008 was lighter (more negative) than the samples collected in 2005, indicating a change in the source water (fig. 22*A*). Historically, the Blue Skies Country Club operated two wells to irrigate the golf course: wells 1S/5E-4A1 (BSGC17) and 1S/5E-4B1 (BSGC1; fig. 1), which were recharged by winter precipitation (Izbicki and Michel, 2004). The isotopic ratios from the lysimeters lay along the evaporative trend line of isotopic ratios from well BSCG17 sampled in 2001 (Nishikawa and others, 2003), which was consistent with partial evaporation of the water. Once irrigation stopped, the

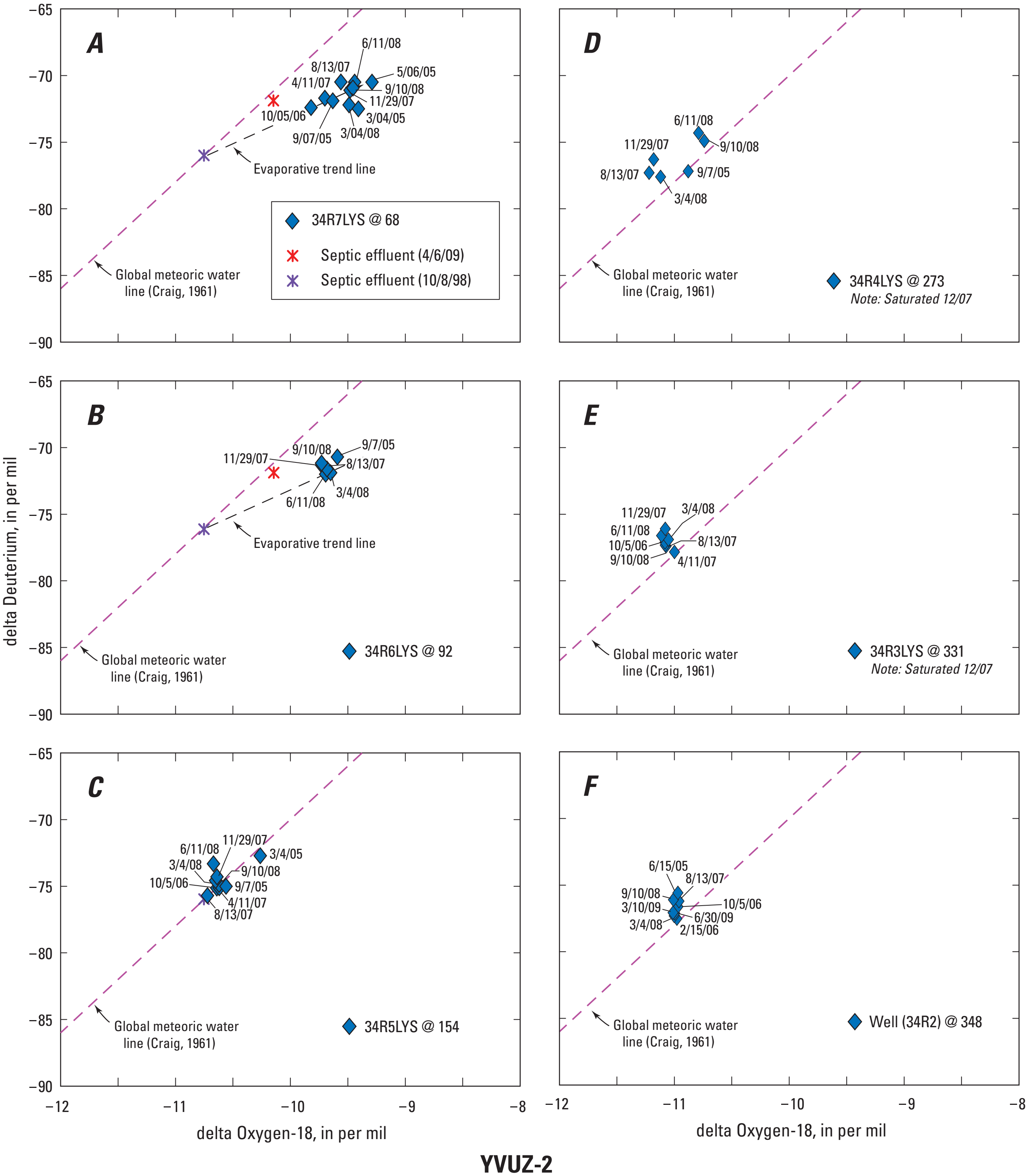



**Figure 21.** Delta oxygen-18 ($\delta^{18}O$) and delta deuterium ($\delta D$) composition of water from lysimeters and monitoring well at site YVUZ-2, 2005–09, Warren subbasin, San Bernardino County, California.

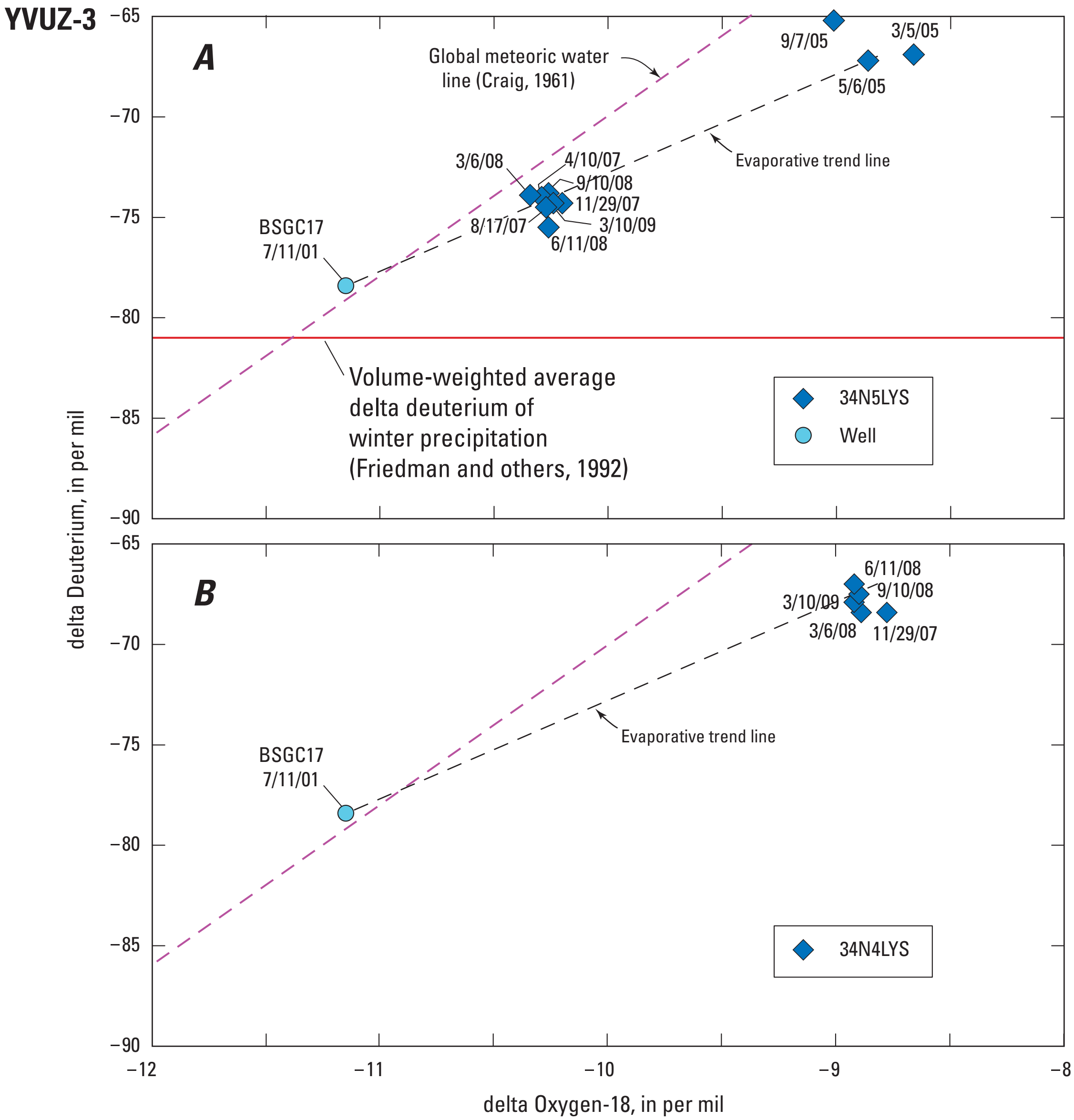



**Figure 22.** Delta oxygen-18 ($\delta^{18}O$) and delta deuterium ($\delta D$) composition of water from lysimeters at, and well near, site YVUZ-3, 2001–09, Warren subbasin, San Bernardino County, California.

only source of recharge to the site was precipitation, and the source of water to the shallow lysimeter changed. Precipitation infiltrated to a depth of 13 ft bls because there was no vegetation and, consequently, no water loss through transpiration, although there could have been evaporation, as evidenced by a slight shift to the right of the MWL (fig. 22*A*). The δD values from the shallow lysimeter were compared to the volume-weighted winter precipitation δD values reported by Friedman and others (1992) for a precipitation-collection station near Joshua Tree, California, about 17 mi to the southeast of Yucca Valley. The δD values of water from the shallow lysimeter showed a mixture of evaporated groundwater from when the golf course was irrigated and evaporated winter precipitation. The water from the deeper lysimeter did not indicate a change in source, thereby indicating that winter precipitation had not infiltrated 42 ft bls.

## Isotopic Ratios from Hi-Desert Water District Production Wells

Changes in the $\delta^{18}O$ and δD ratios of samples collected from HDWD production wells 1N/5E-34K2 (2W), 34Q1 (6W), and 34Q2 (9W) prior to and after the recharge of SWP water were used to determine if SWP water had migrated to the water table. Well 2W is 640 ft deep and is located 375 ft west of the site 3 ponds, well 6W is 751 ft deep and is located 800 ft southwest of the site 3 ponds, and well 9W is 900 ft bls and is located 275 ft south of the site 3 ponds (fig. 1). Well 2W is perforated in the upper and middle aquifers; whereas, wells 6W and 9W are perforated in the upper, middle, and lower aquifers (fig. 4).

The isotopic composition of the SWP water changed during the study period from lighter to heavier ratios (fig. 19), and the isotopic composition of the initial samples of the SWP water was lighter (more negative) than samples from the HDWD production wells. By 2007, however, most of the isotopic ratios of the SWP water were heavier (less negative) than the samples from the production wells (fig. 23). The volume weighted $\delta^{18}O$ and δD composition of the SWP water between June 2006 and June 2008 plotted below the MWL, and the $\delta^{18}O$ was heavier (less negative) than in samples collected from the HDWD production wells prior to recharge of SWP water, which plotted above the MWL (fig. 23).

Prior to artificial recharge, the samples collected from well 2W had an isotopic composition similar to the well at YVUZ-1, which was perforated solely in the upper aquifer (figs. 20*E* and 23), indicating that well 2W produced a large portion of its water from the upper aquifer. In March 2008, after less than two years of recharge of SWP water at site 3, the isotopic ratios of samples from well 2W began to plot beneath the MWL, indicating the presence of SWP water, with the exception of a sample collected in January 2009 (fig. 23).

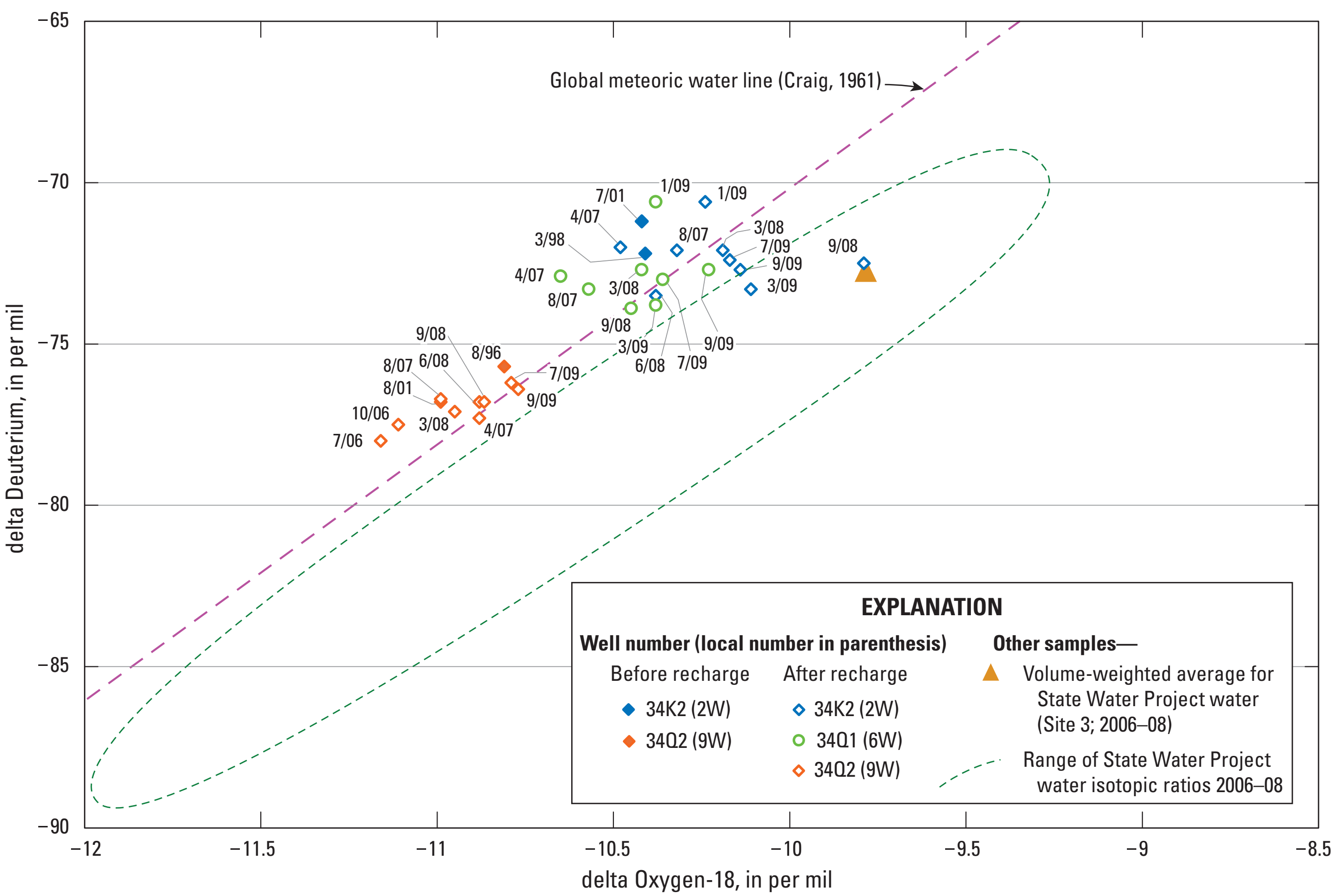



**Figure 23.** Delta oxygen-18 ($\delta^{18}O$) and delta deuterium (δD) composition of groundwater from Hi-Desert Water District production wells, 1996–2009, Warren subbasin, San Bernardino County, California.

The sample collected in September 2008 had a $\delta^{18}O$ value of −9.79, which is almost equal to the volume weighted $\delta^{18}O$ value of the SWP water applied between June 2006 and June 2008 (−9.78), indicating that the well was producing almost 100 percent SWP water at that time. The sample collected in January 2009 that plotted above the MWL was similar isotopically to native groundwater. This sample was collected at the end of the 6-month period when essentially no SWP water was applied to site 3 (fig. 16) and precipitation for the previous 12 months exceeded 12 in., or about twice the long-term average of 6.3 in. (Hi-Desert Water District, 2010).

No stable-isotope samples were collected from well 6W before the start of recharge, but the isotopic ratios in the initial sample collected from this well in April 2007 plotted above the MWL and were isotopically lighter than the isotopic ratios in samples collected from well 2W (fig. 23), indicating that the sample had little, if any, contribution from SWP water. The isotopic ratios in samples collected from this well showed a similar pattern as those from well 2W; isotopic ratios became heavier over time, and all but one of the isotopic ratios plotted below the MWL by September 2009. Similar to well 2W, the sample collected from well 6W on January 2009 plotted above the MWL, indicating minimal SWP water in the sample.

Samples were collected before and after recharge from well 9W, and the isotopic ratios of samples collected from the well prior to and after recharge were lighter (less negative) than samples from wells 2W and 6W (fig. 23). This difference in isotopic values can be explained by the differences in well construction; well 9W was 150 ft and 260 ft deeper than wells 6W and 2W, respectively, and well 9W had more screened (open) interval in the lower aquifer than the other two wells (fig. 4; table 1). The isotopic ratios in samples collected from well 9W in 2008 and 2009 showed a similar pattern as those from wells 2W and 6W; isotopic ratios became heavier over time and plotted below the MWL by September 2009 (fig. 23). Because well 9W was relatively deep and had a longer screened interval in the lower aquifer, the percentage of SWP water captured by this well likely would be less than the percentage of native groundwater captured, causing the isotopic signature to be dominated by the native groundwater.

## Nitrate Concentrations

Two of the objectives of this study were to determine if nitrates from septic effluent infiltrate through the unsaturated zone to the water table and to determine the potential for nitrates within the unsaturated zone to mobilize and contaminate the groundwater as the water table rises in response to artificial recharge. The SWP water was sampled for nitrate 12 times from the discharge pipe between June 2006 and June 2008; all nitrate concentrations ($NO_3$-N) were 1.0 mg/L or less. Two samples also were collected from a septic tank located near YVUZ-2 and had total $NO_3$-N concentrations between 50 and 60 mg/L (appendix 8).

### Nitrate Concentrations from YVUZ-1

As presented in the “Chemical Analyses of Soil Extractions” section, $NO_3$-N concentrations in the soil leachate from drill cuttings at YVUZ-1 were relatively low (less than 1.57 mg/kg) throughout the unsaturated zone (fig. 14). However, the $NO_3$-N concentration of the initial sample of pore water from the lysimeter at 205.5 ft bls was 15 mg/L, which is above the USEPA MCL for drinking water of 10 mg/L (appendix 7, fig. 24*A*). The $NO_3$-N concentrations from the two deeper lysimeters did not exceed 6 mg/L. As shown in figure 11, the shallow lysimeters sometimes did not produce a sufficient amount of pore water for analysis; therefore, they yielded fewer samples than the deeper lysimeters.

The arrival of the SWP water at each lysimeter at YVUZ-1 was indicated by an abrupt decrease in nitrate concentrations (fig. 24*A*). These decreases correlate with the change in isotopic ratios from the lysimeters discussed in the previous section and shown in figure 20. The $NO_3$-N concentrations from the two deepest lysimeters decreased to less than 1.0 mg/L after the arrival of the SWP water; however, the $NO_3$-N concentrations from the lysimeter at 205.5 ft bls decreased from 15 mg/L to about 4 mg/L; the $NO_3$-N concentrations from the lysimeter at 97.5 ft bls decreased from about 18 mg/L to about 13 mg/L (appendix 7, fig. 24*A*). Samples from the shallow lysimeters showed less influence from the SWP water because flow in the upper part of the unsaturated zone is mostly vertical and the monitoring site is about 40 ft from the edge of the pond. The elevated nitrate concentration in samples from the shallow lysimeters could be caused by the accumulation of natural soil nitrate because there are no septic tanks in the area of YVUZ-1.

The $NO_3$-N concentrations in samples from the monitoring well at YVUZ-1 increased from an initial concentration of 2.77 mg/L to a maximum of 4.15 mg/L in October 2006 (fig. 25). Between October 2006 and September 2008, however, $NO_3$-N concentrations from the well at site YVUZ-1 decreased from 4.15 to less than 1.0 mg/L and, eventually, reflected $NO_3$-N concentrations that were measured in the SWP water. In addition, the samples from the well at YVUZ-1 showed an increase in chloride concentration from less than 8 mg/L prior to the recharge of SWP water to 76.5 mg/L by the end of the study period (appendix 8). Chloride concentrations in samples from the SWP water ranged from 17.5 mg/L in June 2006 to 78 mg/L in June 2008 (appendix 8). The similarity of nitrate and chloride concentrations between samples collected from YVUZ-1 and the SWP water indicated that the SWP water was the predominant source of water to the well at YVUZ-1 after March 2008.

The presence of low-nitrate concentrations in samples from the soil extracts, lysimeters, and monitoring well at YVUZ-1 indicated that the rising water table did not result in mobilization of nitrate stored in the unsaturated zone immediately surrounding YVUZ-1. This observation was supported by the low $NO_3$-N concentrations (less than 1 mg/L) sampled in the lysimeter at 314.5 ft bls after the lysimeter was saturated

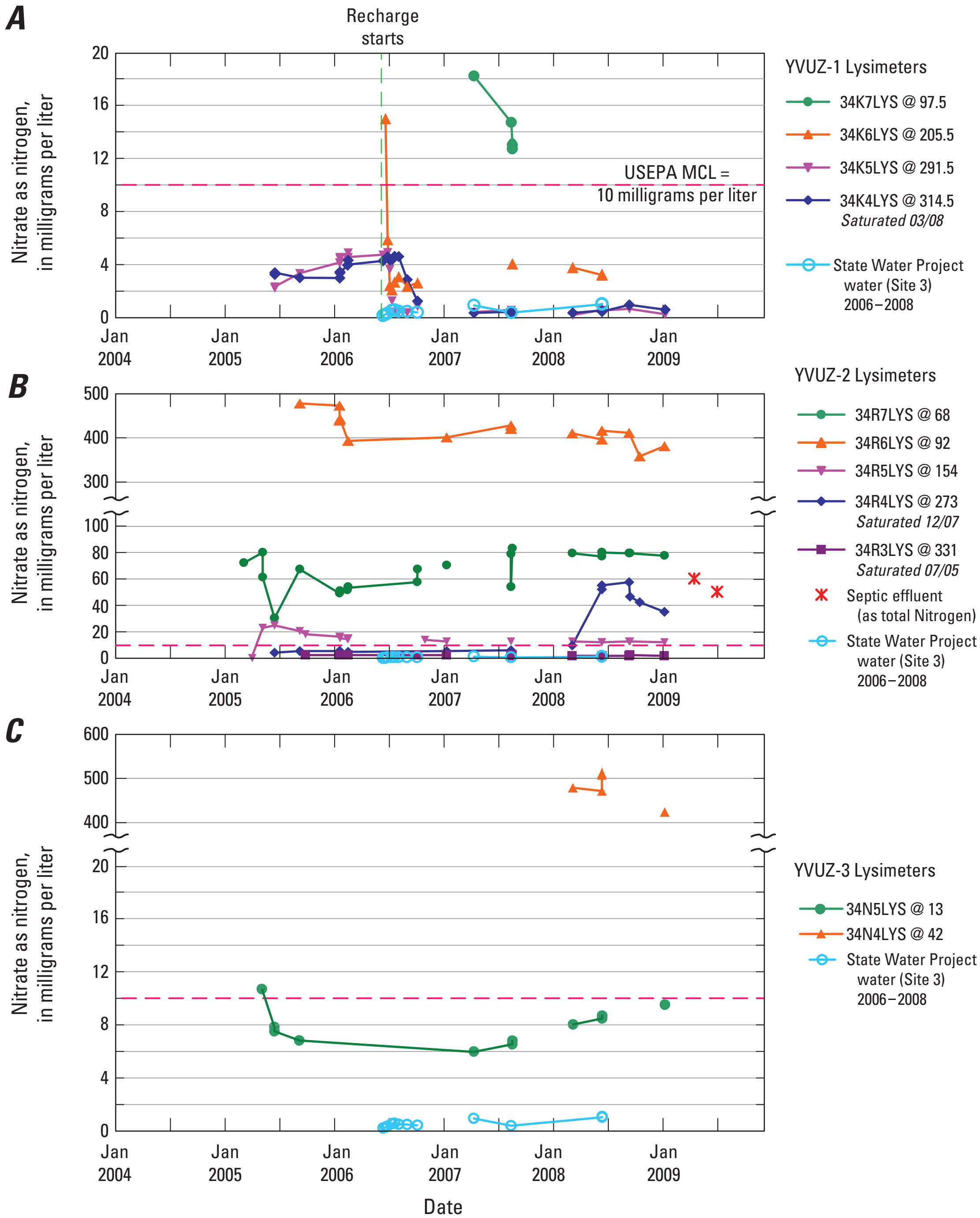



**Figure 24.** Nitrate concentrations in samples from suction-cup lysimeters at monitoring sites *A,* YVUZ-1, *B,* YVUZ-2, and *C,* YVUZ-3, Warren subbasin, San Bernardino County, California, 2005–09.

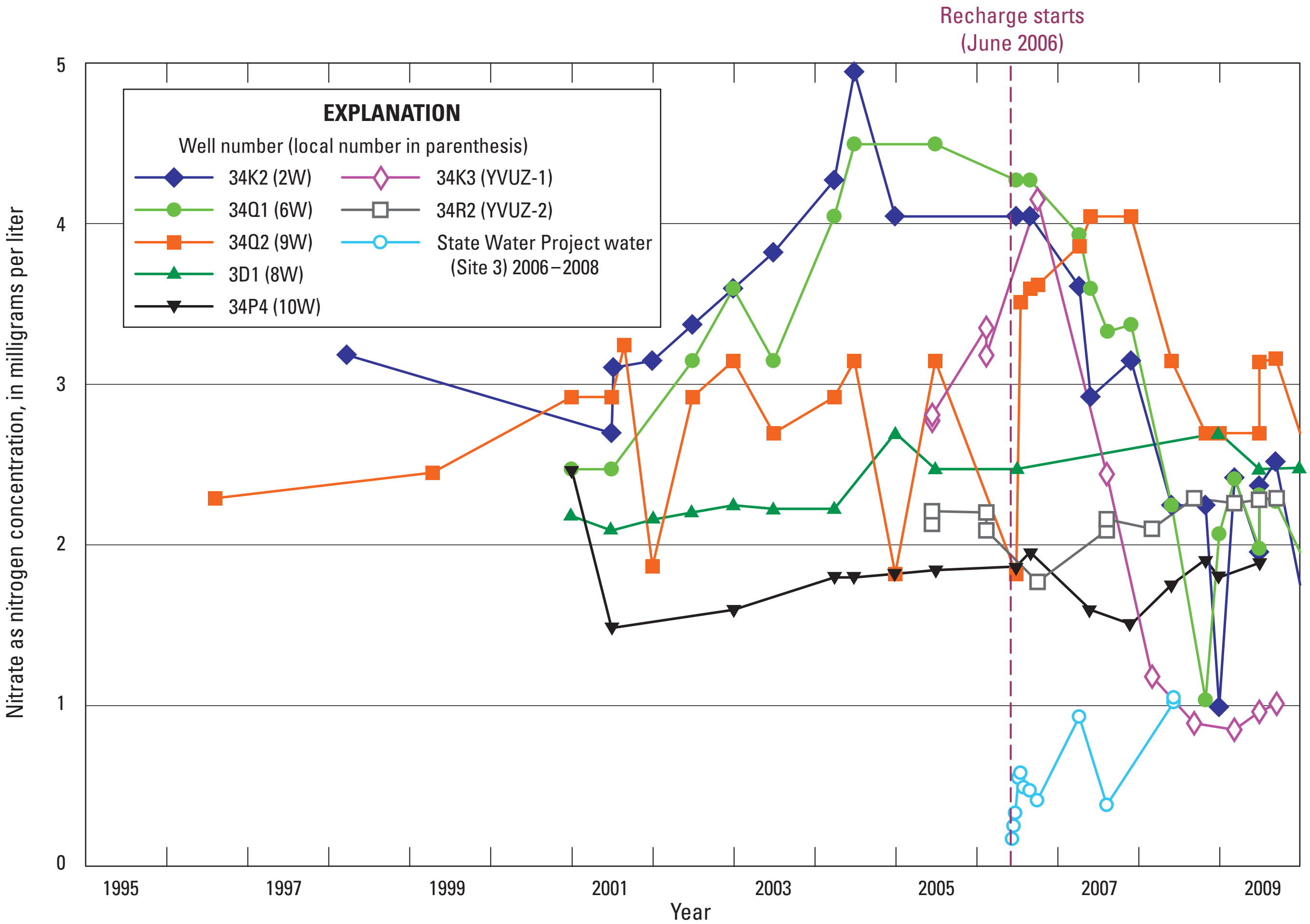



**Figure 25.** Nitrate concentrations in samples from monitoring wells and selected production wells, 1996–2009, Warren subbasin, San Bernardino County, California.

by the rising water table around March 2008 (appendix 7, figs. 14*A* and 24*A*). Possible explanations for the low-nitrate concentrations in the unsaturated zone near YVUZ-1 include the lack of septic tanks in the immediate area of site 3 and that natural soil nitrates had not been leached by natural recharge from Water Canyon (fig.1). High nitrates can accumulate in soil zone were there is not sufficient precipitation to keep the soils leached of soluble salts (Hem, 1989).

## Nitrate Concentrations from YVUZ-2

Compared to the $NO_3$-N concentrations in the soil leachate from drill cuttings at YVUZ-1 (less than 1.57 mg/kg), the $NO_3$-N concentrations in the soil leachate from drill cuttings at YVUZ-2 were relatively high between 36 and 125 ft bls, and a maximum concentration of 24.9 mg/kg was found between 101 and 121 ft bls (fig. 14*B*, appendix 5). Soil nitrate concentrations were lower below 125 ft, where they did not exceed 2.5 mg/kg, indicating that the septic effluent had infiltrated to at least a depth of about 125 ft below YVUZ-2.

Samples from the YVUZ-2 lysimeters at 68 ft, 92 ft, and 154 ft bls had $NO_3$-N concentrations ranging between 12 to 479 mg/L (appendix 7, figs. 14*B* and 24*B*) during the entire sampling period, which is in excess of the USEPA MCL of 10 mg/L. The $NO_3$-N concentrations in samples from the lysimeter at 68 ft bls ranged from 49.2 to 86.5 mg/L, which was similar to the range of total nitrogen concentrations in two samples from a nearby septic tank (50 and 60 mg/L; appendix 8). The highest $NO_3$-N concentrations were almost seven times the total nitrogen concentration of the two samples from a nearby septic tank and were measured in samples collected from the lysimeter at 92 ft. The high nitrate concentrations in the pore water from this lysimeter could be from other nearby septic sources that mobilized the natural soil nitrate. Nitrate concentrations can be high in shallow desert soils, where soil-moisture content is naturally very low and leaching is minimal (Umari and others, 1995; fig. 17).

With the exception of the initial sample, $NO_3$-N concentrations in samples from the lysimeter at 154 ft bls ranged from 12 to 24.9 mg/L (appendix 7, fig. 24B). These $NO_3$-N concentrations were lower than the concentrations in samples from the overlying lysimeters. The nitrates sampled from this lysimeter may have either originated from a different septic source or denitrification in the unsaturated zone may have reduced the nitrate concentration in samples.

Samples from the lysimeter at 273 ft bls at YVUZ-2 had lower $NO_3$-N concentrations (about 6 mg/L) until the rising water table saturated this lysimeter in December 2007 (figs. 14*A* and 24*B*). After the lysimeter was saturated, the $NO_3$-N concentrations increased to a high of 58 mg/L in September 2008. These increases could be the result of the mobilization of high-nitrate water from regional septic effluent after saturation or by high-nitrate water present at the top of the water table, but which may be diluted deeper in the aquifer.

Samples from the deepest lysimeter at 331 ft bls had the lowest $NO_3$-N concentrations at less than 3 mg/L throughout the sampling period (appendix 7, fig. 24*B*). Water levels collected from the monitoring well at YVUZ-2 indicate that this lysimeter was already saturated (beneath the water table) when the initial sample was collected in September 2005 (figs. 9*A* and 14*A*). The $NO_3$-N concentrations in samples collected from the lysimeter at 331 ft bls were almost identical to the $NO_3$-N concentrations in samples collected from the monitoring well at YVUZ-2, which was perforated from 341 to 348 ft bls (appendices 7 and 8). These data showed that there were low $NO_3$-N concentrations in the upper part of the water table near YVUZ-2 prior to the application of SWP water in 2006.

### Nitrate Concentrations from YVUZ-3

The $NO_3$-N concentrations in the soil leachate at YVUZ-3 ranged from less than 1 mg/kg to almost 6 mg/kg, with the highest concentrations at the bottom of the hole at 42 ft bls (fig. 14*C*). $NO_3$-N concentrations in pore water from the lysimeter at 13 ft bls ranged from about 6 to 11 mg/L (appendix 7, fig. 24*C*). Because YVUZ-3 is located near a golf course green that was irrigated between 1956 and 2007, the likely source of the nitrate in the samples is fertilizer. $NO_3$-N concentrations in samples from the lysimeter at 42 ft bls ranged from 424 to 512 mg/L.

### Nitrate Concentrations from Hi-Desert Water District Production Wells

The $NO_3$-N concentrations in samples from five HDWD production wells (2W, 6W, 8W, 9W, and 10W) near site 3 remained below the USEPA MCL of 10 mg/L throughout the sampling period (fig. 25). In general, $NO_3$-N concentrations in samples collected from the wells prior to artificial recharge increased slightly with time and ranged between 1.5 and 4.9 mg/L. After the application of SWP water at site 3, the $NO_3$-N concentrations in samples from the wells closest to the recharge ponds (wells 2W, 6W, and 9W) showed a decreasing trend, whereas the concentrations in wells further away from the ponds (wells 8W and 10W) remained relatively unchanged. The nitrate data supported the stable isotope results, that is, the SWP water had reached wells 2W, 6W, and 9W by September 2009. On the basis of the nitrate data, the SWP water had not reached wells 8W and 10W by the end of the study period. In addition, increases in nitrate concentrations caused by the mobilization of high-nitrate water in the unsaturated zone caused by the rising water table in septic areas, as observed in the 273 ft bls lysimeter at YVUZ-2 (fig. 24*B*), were not observed in the HDWD production wells. This probably was because the heterogeneities in the aquifer limited the vertical mixing of the nitrates through the unsaturated zone. Additional sampling would be required to determine if and when the nitrates would affect the water quality of the HDWD production wells.

## Dissolved Organic Carbon and Trihalomethanes

The presence and amount of dissolved organic carbon (DOC) in drinking water is a public-health concern because of its potential to react with disinfection byproducts during the treatment of water for public use. Specifically, trihalomethanes (THMs) can form by the reaction between DOC, either occurring naturally in groundwater or introduced through the recharge of imported surface water, and the chlorine that is added during the disinfection step of the drinking-water-treatment process. The THMs are volatile, halogenated organic compounds that are carcinogenic, and the USEPA MCL for total THMs in drinking water is 80 micrograms per liter (mg/L; *http://water.epa.gov/drink/contaminants/index.cfm*, accessed August 17, 2010).

The SWP water was sampled at the discharge pipe for DOC and THMs (fig. 26, appendix 8). The monitoring and HDWD wells near site 3 were sampled multiple times to determine if the higher DOC concentrations in the SWP water resulted in increased concentrations of DOC and THMs. The trihalomethane formation potential (THMFP) analyses were completed on the samples to determine the maximum possible amount of THM formation from a water sample, given unlimited free chlorine and fixed conditions of pH and temperature.

The DOC concentrations in the groundwater samples showed no increasing trend in concentrations through September 2009 (fig. 26*A*), even though the $\delta^{18}O$ and $\delta D$ composition and nitrate data indicated that SWP water was present in samples from wells YVUZ-1, 2W, 6W, and 9W. The THMFP concentrations in all but one of the groundwater samples ranged from 10.4 to 44.6 mg/L, which is well below the USEPA MCL of 80 mg/L for total THMs, and there was not an increasing trend during through September 2008 (fig. 26*B*). The highest THMFP concentration, 82.7 mg/L, was collected from well 6W in March 2008 and was above the USEPA MCL. The THMFP of SWP water was more than double that found in the groundwater and ranged from 178.2 to 292.6 mg/L. These differences indicated that the DOC present in the SWP water did not reach the water table, even though the SWP water infiltrated through the unsaturated zone to the water table. These data indicated that the DOC from the SWP water was altered or consumed in the unsaturated zone either by absorption to the grain particles in the soil or by microbiological processes. To more definitively address the fate of the DOC, further sampling and identification of the microbiological organisms are needed.

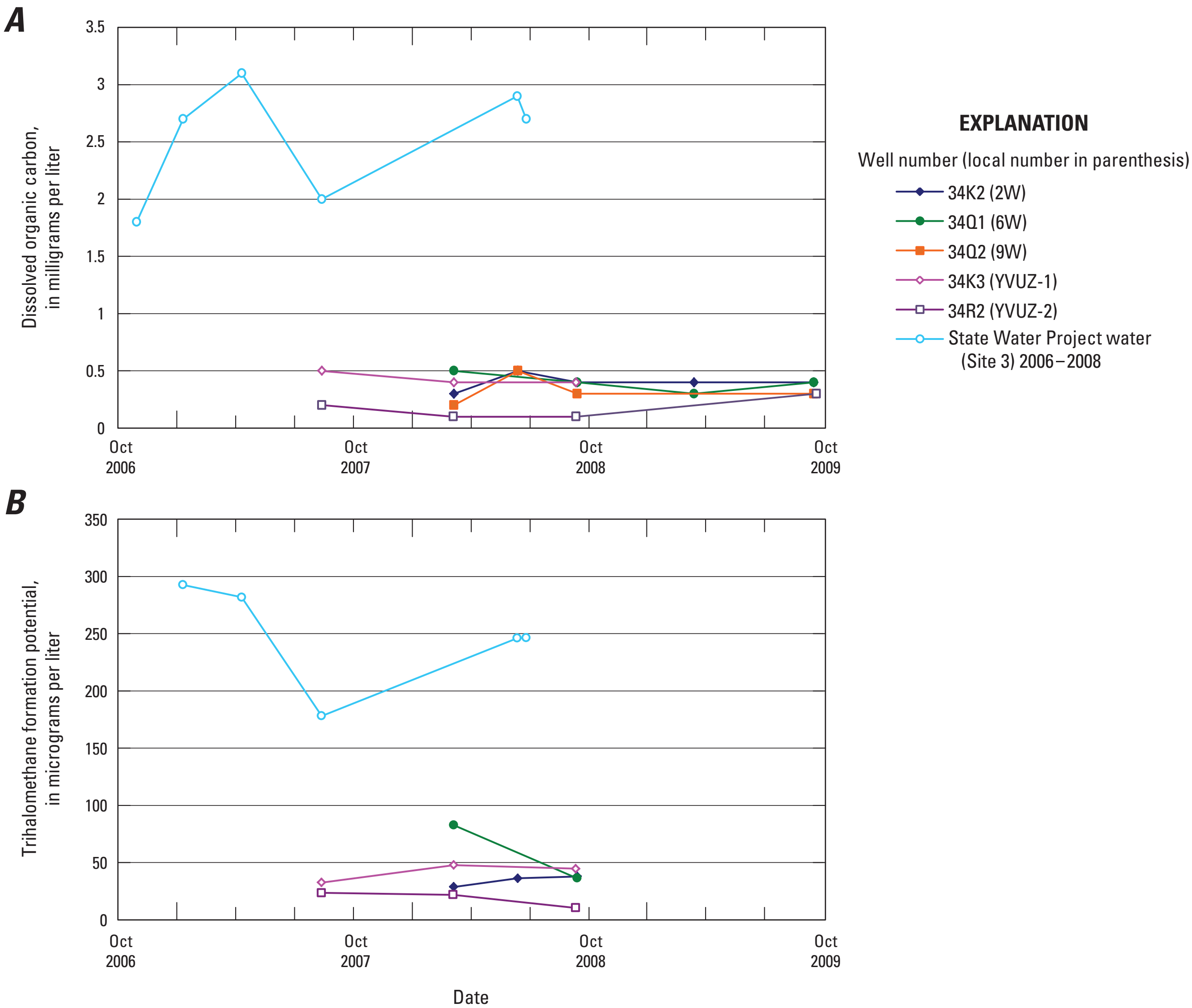



**Figure 26.** *A,* Dissolved organic carbon and *B,* trihalomethane formation potential of groundwater and applied imported surface water, Warren subbasin, San Bernardino County, California, October 2006 to September 2009.

# Summary


Historically, groundwater has been the sole source of water supply for the town of Yucca Valley in the Warren subbasin, California. An imbalance between groundwater recharge and pumpage resulted in groundwater levels in the subbasin declining by as much as 300 feet (ft) between 1940 and 1994. In response, the local water district, Hi-Desert Water District (HDWD), implemented an artificial-recharge program in early 1995 by using imported water from the California State Water Project (SWP). As a result of the artificial-recharge program, water levels rose in production wells by as much as 250 ft; however, nitrate concentrations ($NO_3$-N) in some wells increased to more than the U.S. Environmental Protection Agency (USEPA) water-quality maximum contaminant level (MCL) of 10 milligrams per liter (mg/L). Previous studies showed that the rising water levels mobilized high-nitrate septic effluent, which caused the increase in nitrate concentrations in the unsaturated zone.

Before expanding their recharge operations to the west hydrogeologic unit in 2006, the HDWD entered into a cooperative study with the U.S. Geological Survey (USGS) to determine the potential effects of the imported water on the unsaturated zone and groundwater system. Because of the mobilization of nitrates from the earlier recharge program, the fate and possible increase in nitrate concentrations in the unsaturated zone and groundwater system were of particular interest. Before artificial recharge to site 3 began, water levels in production wells in the west hydrogeologic unit had increased because of reduced pumpage since 1990 and also because of artificial-recharge operations in the midwest hydrogeologic unit since 1995. Direct recharge of imported water to the west hydrogeologic unit started in June 2006, and by September 2009, more than 9,800 acre-feet (acre-ft) of water had been released.

As part of this study, three unsaturated-zone monitoring sites (YVUZ-1, YVUZ-2, and YVUZ-3) were installed and instrumented with heat-dissipation probes, advanced tensiometers, suction-cup lysimeters, and wells so that the arrival and effects of the imported water through the thick (250 to 425 ft) unsaturated zone and groundwater system could be closely monitored. The average nitrate concentration ($NO_3$), reported as nitrogen (N), of pore water extracted from the unsaturated zone below YVUZ-1, located between the recharge ponds, ranged from 6 to 18.2 mg/L ($NO_3$-N). Overall, $NO_3$-N concentrations of pore water below YVUZ-2 were higher, and ranged from 1.9 to a maximum of 479 mg/L at 92 ft below land surface (bls). The $NO_3$-N concentrations from the monitoring and production wells in the area did not exceed 5.0 mg/L during the study.

The $NO_3$-N concentrations in the soil leachates from YVUZ-1 were consistently low, less than 1.57 milligrams per kilogram (mg/kg), from land surface to 404 ft bls. In general, $NO_3$-N concentrations in the soil leachates from YVUZ-2, from land surface to 137 ft bls, were higher than in samples collected deeper in the borehole and from YVUZ-1, and reached a maximum concentration of about 25 mg/kg between about 100 and 121 ft bls. The $NO_3$-N concentrations were less than 6 mg/kg at YVUZ-3.

Denitrifying and nitrate-reducing bacteria at YVUZ-1 were highest at about 220 ft bls, near a contact between different source materials, and at the water table. Nitrate-reducing bacteria counts were as high as 21,000 Most Probable Number (MPN) at about 36 ft bls, but bacterial counts above 40 MPN, slightly above the detection limit of 30 MPN, were not found at site YVUZ-2 below about 150 ft bls.

Matric-potential data from heat-dissipation probes at YVUZ-1 showed that the infiltration of the SWP water was rapid beneath the recharge ponds and that the velocity of the initial wetting front was about 25 ft/d. Infiltration was predominantly vertical with limited lateral spreading to a depth of about 200 ft bls, where the contact between granitic and metamorphic derived sediments caused the water to spread laterally as it migrated through the unsaturated zone. Additional inhomogeneities in the subsurface lithology resulted in lateral spreading and affected the arrival times of the SWP water with depth. No abrupt changes in soil moisture were observed at YVUZ-2, which had moister soils due to the infiltration of nearby septic-tank effluent. Advanced tensiometers at both sites recorded the rise in the water table; water levels from the monitoring wells at both sites showed that the water table increased at a rate of about 0.08 ft/d between June 2006 and January 2009.

Almost immediately after the recharge of SWP water started in June 2006, the ratios of the stable isotopes of oxygen and hydrogen from the lysimeters at YVUZ-1 showed relatively rapid changes. The shift in isotopic ratios sampled from the lysimeters indicated that the SWP water infiltrated the unsaturated zone at a rate between 3.7 and 10.3 ft/d. The isotopic ratios showed the predominance of SWP water in the monitoring well by March 2008; therefore, the arrival of the SWP water to the water table was estimated to have been between 432 to 636 days after the start of artificial recharge, with an average rate between 0.6 and 0.9 ft/d.

There were notable variations in the stable-isotopic ratios collected at the YVUZ-2 lysimeters and the monitoring well, indicating differences in water sources with depth. All the isotopic ratios from the two shallowest lysimeters at 68 ft and 92 ft bls plotted below the meteoric water line (MWL), indicating evaporation of the source water. Because the isotopic ratios from the shallow lysimeters plotted below the MWL prior to and after the application of SWP water at site 3, the infiltration of SWP water from site 3 was not a possible source. The isotopic ratios showed that SWP water was not present in samples from the lysimeters or the monitoring well at YVUZ-2. The isotopic ratios from the lysimeters showed that septic effluent likely had mixed with the native pore water in the unsaturated zone to at least 154 ft bls. Assuming vertical infiltration, the minimal rate of infiltration of septic effluent at this site was about 3 feet per year (ft/yr) since 1960. The two deepest lysimeters and the monitoring well have isotopic ratios that plotted close to or above the MWL, indicating that native soil water or groundwater was present below 273 ft bls.

The isotopic ratios from the two lysimeters at YVUZ-3 indicated two different sources of water—irrigation-return flow and precipitation. This site was adjacent to a golf course that was irrigated between 1956 and 2007. Samples collected from the shallow lysimeter, at 13 ft bls in 2005, while the golf course was being irrigated, and all the samples from the lower lysimeter, at 42 ft bls, from 2007 to 2009 had similar isotopic ratios. These isotopic ratios lay along an evaporative trend line of the native groundwater and were consistent with partial evaporation prior to infiltration. The isotopic ratios from the shallow lysimeter showed a change in source beginning in 2007; deuterium values of the pore water showed a mixture of evaporated groundwater from when the golf course was irrigated and evaporated winter precipitation.

About 2 years after artificial recharge started at site 3, the isotopic ratios of samples from HDWD production well 2W began to reflect the same isotopic ratios as the SWP water; by September 2008, well 2W was producing almost 100 percent SWP water. The isotopic ratios from three of the HDWD production wells sampled (2W, 6W, and 9W) showed that the SWP water had reached all of them by September 2009.

With the exception of the lysimeter at 205.5 ft bls, the $NO_3$-N concentration of the initial samples of the pore water from the YVUZ-1 lysimeters were below the USEPA MCL for drinking water of 10 mg/L. The SWP water was sampled for nitrate 12 times during the study, and the nitrate concentrations ($NO_3$-N) did not exceed 1.0 mg/L. After the arrival of SWP water to each lysimeter, the nitrate concentrations decreased to less than 1.0 mg/L, with the exception of samples collected at 205.5 ft bls, which ranged from 2.11 to 4.12 mg/L. Between October 2006 and September 2008, $NO_3$-N concentrations from the well at YVUZ-1 decreased from 4.15 to less than 1.0 mg/L and, eventually, were similar to the $NO_3$-N concentrations measured in the SWP water. The low-nitrate concentrations in samples from the soil extracts, lysimeters, and monitoring well at YVUZ-1 indicated that the rising water table did not result in the mobilization of nitrate stored in the unsaturated zone near YVUZ-1. Possible explanations for the low-nitrate concentrations in the unsaturated zone near YVUZ-1 include the lack of septic tanks in the immediate area and that the accumulation of natural soil nitrates had not been leached by natural recharge from Water Canyon.

Samples from the YVUZ-2 lysimeters at 68 ft, 92 ft, and 154 ft bls had $NO_3$-N concentrations in excess of the USEPA MCL of 10 mg/L during the entire sampling period and ranged between 12 to 479 mg/L. The $NO_3$-N concentrations in samples from the lysimeter at 68 ft bls ranged from 49.2 to 86.5 mg/L, which was similar to the range of total nitrogen concentrations in two samples from a nearby septic tank that had $NO_3$-N concentrations between 50 and 60 mg/L. The highest $NO_3$-N concentrations were collected from the lysimeter at 92 ft bls and ranged between 359 and 479 mg/L, which were almost seven times the total nitrogen concentration of the two samples from a nearby septic tank. The high nitrate concentrations in the pore water at 92 ft bls could be from other nearby septic sources that have mobilized the natural soil nitrate. With the exception of the initial sample, $NO_3$-N concentrations in samples from the lysimeter at 154 ft bls ranged from 12 to 24.9 mg/L. These $NO_3$-N concentrations were significantly lower than the concentrations in samples from the overlying lysimeters, indicating that the nitrate sampled from this lysimeter originated from a different septic source, or denitrification in the unsaturated zone may have reduced the $NO_3$-N concentration in samples. After the lysimeter at 273 ft bls was saturated by the rising water table in December 2007, the $NO_3$-N concentrations increased to a high of 58 mg/L. These increases could be caused by the mobilization of nitrates from septic effluent after saturation or by high-nitrate water present at the top of the water table, but which may be diluted deeper in the aquifer.

At YVUZ-3, $NO_3$-N concentrations of the pore water at 13 ft bls ranged from about 6 to 11 mg/L. The $NO_3$-N concentrations in the pore water from the deeper lysimeter at 42 ft bls ranged from 424 to 512 mg/L. Because YVUZ-3 is located near a golf course green that was irrigated between 1956 and 2007, the likely source of the nitrate in the samples is fertilizer.

The $NO_3$-N concentrations in samples from five HDWD production wells (2W, 6W, 8W, 9W, and 10W) near site 3 remained below the USEPA MCL of 10 mg/L throughout the sampling period. After the application of SWP water at site 3, the $NO_3$-N concentrations in samples from the wells closest to the recharge ponds (wells 2W, 6W, and 9W) showed a decreasing trend, whereas the nitrate concentrations in wells further away from the ponds (wells 8W and 10W) remained relatively unchanged. The nitrate data supported the conclusions from the stable-isotope data—that is, the SWP water had reached production wells 2W, 6W, the upper parts of 9W, and YVUZ-1, but had not reached wells 8W, 10W, or YVUZ-2 by September 2009. In addition, increases in nitrate concentrations in the unsaturated zone in septic areas, potentially caused by the mobilization of high-nitrate septic effluent from the rising water table, were not observed in the HDWD production wells. It is possible that the heterogeneities in the aquifer have limited the vertical mixing of the nitrates through the unsaturated zone.

The dissolved organic carbon (DOC) concentrations were measured in the SWP water and groundwater because of the potential of DOC to react with chlorine to form trihalomethanes during the treatment process. The DOC concentrations of the SWP water ranged from 1.8 to 3.1 mg/L. The initial DOC concentrations in the groundwater samples were less than 0.5 mg/L, and they did not increase through September 2009, even though the isotopic ratios and nitrate data indicated that SWP water was present in samples from some wells by September 2008. The trihalomethane formation potential of the of the SWP water was more than double that found in the groundwater and ranged from 178.2 to 292.6 mg/L. These differences indicated that the DOC present in the SWP water did not reach the water table even though the SWP water infiltrated the unsaturated zone to the water table. These data indicated that the DOC in the SWP water was altered or consumed in the unsaturated zone, either by absorption to the grain particles in the soil or by microbiological processes. To more definitively address the fate of the DOC, further sampling and identification of the microbiological organisms is needed.

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# Appendixes

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 6 | 9 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 9 | 10 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 10 | 11 | Gravelly sand (gS); medium to very coarse sand with granule- to cobble-size gravel; moderately sorted; subangular to subrounded; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 11 | 12 | Gravelly sand (gS); medium to very coarse sand with granule- to cobble-size gravel; moderately sorted; subangular to subrounded; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 12 | 13 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 13 | 14 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 16 | 18 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 18 | 19 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 19 | 20 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 20 | 21 | Sandy gravel (sG); granule- to pebble-size gravel with very coarse sand; moderately sorted; subangular to subrounded; pebbles are <12 mm in diameter; <5% mafics; pale yellow (2.5Y 7/3). |
| 21 | 22 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 22 | 23 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 23 | 24 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 24 | 25 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 25 | 26 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 26 | 27 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 27 | 28 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to cobble-size gravel; poorly sorted; subangular; pebbles are <10 mm in diameter; <15% mafics; pale yellow (2.5Y 7/3). |
| 28 | 29 | Gravelly sand (gS); fine to very coarse sand with granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 29 | 30 | Sand (S); fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 30 | 31 | Sand (S); fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 31 | 32 | Slightly gravelly sand (gS); medium to very coarse sand with minor granule-size gravel; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 32 | 33 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule- to pebble-size gravel; poorly sorted; subangular; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 33 | 34 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 34 | 35 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 35 | 36 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 36 | 37 | Gravelly sand (gS); coarse to very coarse sand with granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 37 | 38 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 38 | 39 | Slightly gravelly sand (gS); medium to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 39 | 40 | Slightly gravelly sand (gS); medium to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 40 | 41 | Slightly gravelly sand (gS); medium to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 41 | 42 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 42 | 43 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 43 | 44 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 44 | 45 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 45 | 46 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 46 | 47 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 47 | 48 | Sand (S); fine to very coarse sand; very poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 48 | 49 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 49 | 50 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 50 | 51 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and occasional pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 51 | 52 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and occasional pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 52 | 53 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and occasional pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <12 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 53 | 54 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 54 | 55 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 55 | 56 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 56 | 57 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 57 | 58 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 58 | 59 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 59 | 60 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 60 | 61 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 61 | 62 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 62 | 63 | Gravelly sand (gS); coarse to very coarse sand with granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 63 | 64 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 64 | 65 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 65 | 66 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 66 | 67 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 67 | 68 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 68 | 69 | Silty sand (zS); very fine to medium sand with minor coarse sand and silt; well sorted; subangular to subrounded; approximately 30% mafics; pale yellow (2.5Y 7/4). |
| 69 | 70 | Silty sand (zS); very fine to medium sand with minor coarse sand and silt; well sorted; subangular to subrounded; approximately 30% mafics; pale yellow (2.5Y 7/4). |
| 70 | 71 | Silty sand (zS); very fine to medium sand with minor coarse sand and silt; well sorted; subangular to subrounded; approximately 30% mafics; pale yellow (2.5Y 7/4). |
| 71 | 72 | Slightly gravelly silty sand (gmS); very fine to medium sand with minor coarse sand, minor granule-size gravel and silt; moderately sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 30% mafics; pale yellow (2.5Y 7/4). |
| 72 | 73 | Gravelly silty sand (gmS); very fine to very coarse sand with silt and granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 30% mafics; pale yellow (2.5Y 7/3). |
| 73 | 74 | Silty sand (zS); very fine to coarse sand with minor silt; moderately sorted; subangular to subrounded; approximately 30% mafics; pale yellow (2.5Y 7/3). |
| 74 | 75 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 75 | 76 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 76 | 77 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 77 | 78 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 78 | 79 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 79 | 80 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 80 | 81 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 81 | 82 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 82 | 83 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 83 | 84 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 84 | 85 | Gravelly silty sand (gmS); very fine to very coarse sand with granule-size gravel and minor silt; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 20% mafics; pale yellow (2.5Y 7/3). |
| 85 | 86 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 86 | 87 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 87 | 88 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 88 | 89 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 89 | 90 | Slightly gravelly silty sand (gmS); very fine to very coarse sand with minor silt and minor granule-size gravel; well sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 90 | 91 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 91 | 92 | Gravelly sand (gS); medium to coarse sand with granule-size gravel; moderately sorted; subangular; pebbles are <4 mm in diameter; <5% mafics; pale yellow (2.5Y 7/3). |
| 92 | 93 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; <10% mafics; pale yellow (2.5Y 7/3). |
| 93 | 94 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 94 | 95 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 95 | 96 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 96 | 97 | Silty sand (zS); very fine to very coarse sand with minor silt; poorly sorted; subangular; 20% mafics; pale yellow (2.5Y 7/3). |
| 97 | 98 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 98 | 99 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 99 | 100 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 100 | 101 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 101 | 102 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 102 | 103 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 103 | 104 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 104 | 105 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 105 | 106 | Slightly gravelly sand (gS); coarse sand with minor fine to medium sand and minor granule-size gravel; moderately sorted; subangular to subrounded; pebbles are <3 mm in diameter; 15% mafics; pale yellow (2.5Y 7/3). |
| 106 | 107 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 107 | 108 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 108 | 109 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; 15% mafics; pale yellow (2.5Y 7/3). |
| 109 | 110 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 110 | 111 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 111 | 112 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 112 | 113 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 113 | 114 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 114 | 115 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 115 | 116.5 | No sample collected. |
| 116.5 | 118.5 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 118.5 | 119 | No sample collected. |
| 119 | 120 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 120 | 121 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 121 | 122 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 122 | 123 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 123 | 124 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 124 | 125 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 125 | 126 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 126 | 127 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 127 | 128 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 128 | 129 | Sand (S); medium to very coarse sand with minor fine sand; moderately sorted; subangular; <10% mafics; pale yellow (2.5Y 7/3). |
| 129 | 130 | Sand (S); medium to very coarse sand with minor fine sand; moderately sorted; subangular; <10% mafics; pale yellow (2.5Y 7/3). |
| 130 | 131 | Sand (S); very fine to very coarse sand; poorly sorted; subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 131 | 132 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 132 | 133 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 133 | 134 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 134 | 135 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 135 | 136 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 136 | 137 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 137 | 138 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 138 | 139 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 139 | 140 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 140 | 141 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 141 | 142 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/4). |
| 142 | 143 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 143 | 144 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 144 | 145 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 145 | 146 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 146 | 147 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 147 | 148 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 148 | 149 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 149 | 150 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 150 | 151 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 151 | 152 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 152 | 153 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 153 | 154 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 154 | 155 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 155 | 156 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 156 | 157 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 157 | 158 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 158 | 159 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 159 | 160 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 160 | 161 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 161 | 162 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 162 | 163 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 163 | 164 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 164 | 165 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 165 | 166 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 166 | 167 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 167 | 168 | Slightly gravelly sand (gS); fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 168 | 169 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 169 | 170 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 170 | 171 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 171 | 172 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; pale yellow (2.5Y 7/3). |
| 172 | 173 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 173 | 174 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 174 | 175 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 175 | 176 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 176 | 177 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 177 | 178 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 178 | 179 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <20 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 179 | 180 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 180 | 181 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 181 | 182 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 182 | 183 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 183 | 184 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 184 | 185 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 185 | 186 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 186 | 187 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 187 | 188 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 188 | 189 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 189 | 190 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 190 | 191 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 191 | 192 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 192 | 193 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; poorly sorted; subangular to subrounded; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 193 | 194 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 194 | 195 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 195 | 196.8 | No sample collected. |
| 196.8 | 198.5 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 198.5 | 199 | No sample collected. |
| 199 | 200 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 200 | 201 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 201 | 202 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 202 | 203 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 203 | 204 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 204 | 205 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 205 | 206 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 206 | 207 | Sand (S); very fine to very coarse sand; poorly sorted; subangular to subrounded; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 207 | 208 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 208 | 209 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 209 | 210 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 210 | 211 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 211 | 212 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 212 | 213 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 213 | 214 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 214 | 215 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 215 | 216 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 216 | 217 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 217 | 218 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 218 | 219 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 219 | 220 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 220 | 221 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 221 | 222 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 222 | 223 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <6 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 223 | 224 | Slightly gravelly sand (gS); very fine to coarse sand with very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 224 | 225 | Slightly gravelly sand (gS); very fine to coarse sand with very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 225 | 226 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 226 | 227 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 227 | 228 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 228 | 229 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 229 | 230 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 230 | 231 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 231 | 232 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 232 | 233 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 233 | 234 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 234 | 235 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 235 | 236 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 236 | 237 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 237 | 238 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 238 | 239 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 239 | 240 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 240 | 241 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 241 | 242 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 242 | 243 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 243 | 244 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 244 | 245 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 245 | 246 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 246 | 247 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 247 | 248 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 248 | 249 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 249 | 250 | Slightly gravelly sand (gS); fine to medium sand with coarse to very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 250 | 251 | Sand (S); fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 251 | 252 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 252 | 253 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 253 | 254 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 254 | 255 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 255 | 256 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 256 | 257 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 257 | 258 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 258 | 259 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 259 | 260 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 260 | 261 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 261 | 262 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 262 | 263 | Sand (S); very fine to medium sand; moderately sorted; subrounded to subangular; approximately 30% mafics; gray (2.5Y 6/1). |
| 263 | 264 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 264 | 265 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 265 | 268 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 268 | 269 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 269 | 270 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 270 | 271 | Slightly gravelly sand (gS); very fine to medium sand with coarse to very coarse sand and minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 271 | 272 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; 40% mafics; light olive brown (2.5Y 5/3). |
| 272 | 273 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; 40% mafics; light olive brown (2.5Y 5/3). |
| 273 | 274 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 274 | 275 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 275 | 276 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 276 | 277 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 277 | 278 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 278 | 279 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 279 | 280 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 280 | 281 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 281 | 282 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 282 | 283 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 283 | 284 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 284 | 285 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 285 | 286 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 286 | 287 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 287 | 288 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 288 | 289 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 289 | 290 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 290 | 291 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 291 | 292 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 292 | 293 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 293 | 294 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 294 | 295 | Slightly gravelly sand (gS); very fine to coarse sand with minor very coarse sand and granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 295 | 296 | Slightly gravelly sand (gS); very fine to coarse sand with minor very coarse sand and granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 296 | 297 | Slightly gravelly sand (gS); very fine to coarse sand with minor very coarse sand and granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 297 | 298 | Slightly gravelly sand (gS); very fine to coarse sand with minor very coarse sand and granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 298 | 299 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 299 | 300 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 300 | 301 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 301 | 302 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 302 | 303 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 303 | 304 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 304 | 305 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 305 | 306 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 306 | 307 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 307 | 308 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 308 | 309 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 309 | 310 | No sample collected. |
| 310 | 311 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; light yellowish brown (2.5Y 6/4). |
| 311 | 312 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; light yellowish brown (2.5Y 6/4). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 312 | 313 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; light yellowish brown (2.5Y 6/4). |
| 313 | 314 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 314 | 315 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 315 | 316 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 316 | 317 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 317 | 318 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 318 | 319 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 319 | 320 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 320 | 321 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 321 | 322 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 322 | 323 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 323 | 324 | Sand (S); very fine to coarse sand with minor very coarse sand; moderately sorted; subrounded to subangular; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 324 | 325 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 325 | 326 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; light yellowish brown (2.5Y 6/3). |
| 326 | 327 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 327 | 328 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 328 | 329 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 329 | 330 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 330 | 331 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 331 | 332 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 332 | 333 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 333 | 334 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 334 | 335 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 335 | 336 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 336 | 337 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 337 | 338 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor pebble-size gravel; moderately sorted; subrounded to subangular; pebbles are <18 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 338 | 339 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 339 | 340 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 340 | 341 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 341 | 342 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 342 | 343 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 343 | 344 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 344 | 345 | No sample collected. |
| 345 | 348 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 348 | 349 | No sample collected. |
| 349 | 350 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 350 | 351 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 351 | 352 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 352 | 353 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 353 | 354 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 354 | 355 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 355 | 356 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 356 | 357 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 357 | 358 | No sample collected. |
| 358 | 359 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 359 | 360 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 360 | 361 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 361 | 362 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 362 | 363 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 363 | 364 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 364 | 365 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 365 | 366 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 366 | 367 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 367 | 368 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 368 | 369 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 369 | 370 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 370 | 371 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 371 | 372 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 372 | 373 | Sand (S); very fine to very coarse sand; moderately sorted; subrounded to subangular; 40% mafics; light yellowish brown (2.5Y 6/3). |
| 373 | 374 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 374 | 375 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 375 | 376 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 376 | 377 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 377 | 378 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 378 | 379 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 379 | 380 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 380 | 381 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 381 | 382 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 382 | 383 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 383 | 384 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 384 | 385 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 385 | 388 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 388 | 389 | Gravelly sand (gS); fine to coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 389 | 390 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 390 | 391 | Slightly gravelly sand (gS); very fine to coarse sand with very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 391 | 392 | Slightly gravelly sand (gS); very fine to coarse sand with very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 392 | 393 | Slightly gravelly sand (gS); very fine to coarse sand with very coarse sand and minor granule-size gravel; moderately sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 393 | 394 | Slightly gravelly sand (gS); very fine to coarse sand with minor granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 394 | 395 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 395 | 396 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 396 | 397 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 397 | 398 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 1.** Lithologic log for monitoring site YVUZ-1 (1N/5E-34K3) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 398 | 399 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; poorly sorted; subrounded to subangular; pebbles are <8 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 399 | 400 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 400 | 401 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 401 | 402 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 402 | 403 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 403 | 404 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; poorly sorted; subrounded to subangular; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 404 | 405 | Sand (S); very fine to very coarse sand; poorly sorted; subrounded to subangular; <10% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 5 | 6 | Sandy gravel (sG); granule- to pebble-size gravel with very fine to coarse sand; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 6 | 7 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 7 | 8 | Slightly silty gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and very minor silt; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 8 | 9 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 9 | 10 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 10 | 11 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 11 | 12 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 12 | 13 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 13 | 14 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 14 | 15 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 15 | 16 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 16 | 17 | Sandy gravel (sG); granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 17 | 18 | Sandy gravel (sG); granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 18 | 19 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 19 | 20 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 20 | 21 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 21 | 22 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 22 | 23 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel and minor pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 23 | 24 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 24 | 25 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 25 | 26 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 26 | 27 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 27 | 28 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light yellowish brown (2.5Y 6/3). |
| 28 | 29 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light yellowish brown (2.5Y 6/3). |
| 29 | 30 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light yellowish brown (2.5Y 6/3). |
| 30 | 31 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 31 | 32 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 32 | 33 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 33 | 34 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 34 | 35 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 35 | 36 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 36 | 37 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 37 | 38 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 38 | 39 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 39 | 40 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 40 | 41 | Sandy gravel (sG); granule-to pebble-size gravel with coarse sand; subangular to subrounded; poorly sorted; pebbles are <20 mm in diameter; <1% mafics; pale yellow (2.5Y 7/3). |
| 41 | 42 | Sand (S); fine to medium sand with minor coarse to very coarse sand; subangular to subrounded; moderately sorted; approximately 15% mafics; olive brown (2.5Y 4/4). |
| 42 | 43 | Sand (S); fine to medium sand with minor coarse to very coarse sand; subangular to subrounded; moderately sorted; approximately 15% mafics; olive brown (2.5Y 4/4). |
| 43 | 44 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 44 | 45 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 45 | 46 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 46 | 47 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 47 | 48 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 48 | 49 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 49 | 50 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 50 | 51 | Sandy gravel (sG); granule- to pebble-size gravel with medium to very coarse sand and minor fine sand; subrounded to subangular; poorly sorted; pebbles are <20 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 51 | 52 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 52 | 53 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 53 | 54 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 54 | 55 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 55 | 56 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 56 | 57 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 57 | 58 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 58 | 59 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 59 | 60 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 60 | 61 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 61 | 62 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 62 | 63 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 63 | 64 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 64 | 65 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 65 | 66 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 66 | 67 | Gravelly sand (gS); medium to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 67 | 68 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 68 | 69 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 69 | 70 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 70 | 71 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 71 | 72 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 72 | 73 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 73 | 74 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 74 | 75 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 75 | 76 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 76 | 77 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 77 | 78 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 78 | 79 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 79 | 80 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <6 mm in diameter; <10% mafics; light olive brown (2.5Y 5/4). |
| 80 | 81 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <6 mm in diameter; <10% mafics; light olive brown (2.5Y 5/4). |
| 81 | 82 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 82 | 83 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 83 | 84 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 84 | 85 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 85 | 86 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 86 | 87 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 87 | 88 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 88 | 89 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <6 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 89 | 90 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <6 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 90 | 91 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 91 | 92 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 92 | 93 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 93 | 94 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 94 | 95 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 95 | 96 | Sand (S); very fine to medium sand with minor coarse to very coarse sand and very minor granule-size gravel; subangular to subrounded; well sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light olive brown (2.5Y 5/3). |
| 96 | 97 | Sand (S); very fine to medium sand with minor coarse to very coarse sand and very minor granule-size gravel; subangular to subrounded; well sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light olive brown (2.5Y 5/3). |
| 97 | 98 | Sand (S); very fine to medium sand with minor coarse to very coarse sand and very minor granule-size gravel; subangular to subrounded; well sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light olive brown (2.5Y 5/3). |
| 98 | 99 | Slightly gravelly sand (gS); very fine to medium sand with coarse to very coarse sand and minor granule-size gravel; subangular to subrounded; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light olive brown (2.5Y 5/3). |
| 99 | 100 | Slightly gravelly sand (gS); very fine to medium sand with coarse to very coarse sand and minor granule-size gravel; subangular to subrounded; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; light olive brown (2.5Y 5/3). |
| 100 | 101 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 101 | 102 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 102 | 103 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 103 | 104 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 104 | 105 | Gravelly sand (gS); coarse to very coarse sand with fine to medium sand and granule-size gravel; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/4). |
| 105 | 106 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/4). |
| 106 | 107 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/4). |
| 107 | 108 | Sand (S); very fine to medium sand; subangular to subrounded; moderately sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 108 | 109 | Sand (S); very fine to medium sand; subangular to subrounded; moderately sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 109 | 110 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 10% mafics; pale yellow (2.5Y 7/3). |
| 110 | 111 | Sand (S); very coarse sand with fine to coarse sand; subrounded to subangular; moderately sorted; <10% mafics; pale yellow (2.5Y 7/3). |
| 111 | 112 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 112 | 113 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 113 | 114 | Sand (S); coarse to very coarse sand with very fine to medium sand; subangular to subrounded; poorly sorted; <10% mafics; pale yellow (2.5Y 7/3). |
| 114 | 115 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 115 | 116 | Slightly gravelly silty sand (gmS); very fine to medium sand with coarse to very coarse sand, minor granule-size gravel and very minor silt; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; brown (10YR 4/3). |
| 116 | 117 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; <10% mafics; light yellowish brown (10YR 6/4). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 117 | 118 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (10YR 6/4). |
| 118 | 119 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (10YR 6/4). |
| 119 | 120 | Sand (S); very fine to medium sand with minor coarse to very coarse sand; subangular to subrounded; moderately sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 120 | 121 | No sample collected. |
| 121 | 122 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 122 | 123 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 123 | 124 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 124 | 125 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 15% mafics; light yellowish brown (2.5Y 6/4). |
| 125 | 126 | Slightly gravelly sand (gS); very fine to medium sand with coarse to very coarse sand and minor granule- to pebble-size gravel; subrounded to subangular; moderately sorted; pebbles are <10 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 126 | 127 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 127 | 128 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 128 | 129 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 129 | 130 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 130 | 131 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 131 | 132 | Slightly gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 132 | 133 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 133 | 134 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 134 | 135 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; pale yellow (2.5Y 7/4). |
| 135 | 136 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 136 | 137 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 137 | 138 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 138 | 139 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 139 | 140 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 140 | 141 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 141 | 142 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 142 | 143 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 143 | 144 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 144 | 145 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; pale yellow (2.5Y 7/4). |
| 145 | 146 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 146 | 147 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 147 | 148 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; <10% mafics; pale yellow (2.5Y 7/4). |
| 148 | 149 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 149 | 150 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 150 | 151 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 151 | 152 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light olive brown (2.5Y 5/3). |
| 152 | 153 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 153 | 154 | Gravelly sand (gS); very fine to very coarse sand with granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 154 | 155 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel and relatively abundant medium to coarse sand; subangular to subrounded; moderately sorted; pebbles are <3 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 155 | 156 | Sandy gravel (sG); granule-size gravel with very fine to very coarse sand; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 156 | 157 | Sandy gravel (sG); granule-size gravel with very fine to very coarse sand; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 157 | 158 | Sandy gravel (sG); granule-size gravel with very fine to very coarse sand; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 158 | 159 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/4). |
| 159 | 160 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light olive brown (2.5Y 5/4). |
| 160 | 161 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <3 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 161 | 162 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 162 | 163 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 163 | 164 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 164 | 165 | Gravelly sand (gS); fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <6 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 165 | 166 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to angular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 166 | 167 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to angular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 167 | 168 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to angular; poorly sorted; pebbles are <4 mm in diameter; <10% mafics; pale yellow (2.5Y 7/3). |
| 168 | 169 | Sand (S); very fine to very coarse sand, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; <10% mafics; pale yellow (2.5Y 7/3). |
| 169 | 170 | Sand (S); very fine to very coarse sand, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; <10% mafics; pale yellow (2.5Y 7/3). |
| 170 | 171 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 171 | 172 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 172 | 173 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 173 | 174 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 174 | 175 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 175 | 176 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 176 | 177 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 177 | 178 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 178 | 179 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 179 | 180 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 180 | 181 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 181 | 182 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; light yellowish brown (2.5Y 6/3). |
| 182 | 183 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (2.5Y 6/3). |
| 183 | 184 | Sand (S); very fine to very coarse sand, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 184 | 185 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; pale yellow (2.5Y 7/3). |
| 185 | 186 | Gravelly sand (gS); fine to very coarse sand with some gravel; subangular; poorly sorted; light tan. |
| 186 | 187 | Silty sand (zS); very fine to very coarse sand with rare silt; subangular; poorly sorted; light tan. |
| 187 | 188 | Silty sand (zS); very fine to very coarse sand with occasional silt; subangular; poorly sorted; light tan. |
| 188 | 189 | Silty sand (zS); very fine to very coarse sand with occasional silt; subangular; poorly sorted; light tan. |
| 189 | 190 | Silty sand (zS); very fine to very coarse sand with occasional silt; subangular; poorly sorted; light tan. |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 190 | 191 | Silty sand (zS); medium to very coarse sand with occasional silt; subangular; moderately sorted; light tan. |
| 191 | 192 | Silty sand (zS); fine to medium sand with occasional silt; subangular to subrounded; well sorted; light tan. |
| 192 | 193 | Silty sand (zS); fine sand to coarse sand with occasional silt; subangular; well sorted; mica rich; light tan. |
| 193 | 194 | Silty sand (zS); fine sand to coarse sand with occasional silt; subangular; well sorted; mica rich; light tan. |
| 194 | 195 | Gravelly silty sand (gmS); fine to very coarse sand with some silt and some gravel; subangular; moderately sorted; light tan. |
| 195 | 196 | Gravelly silty sand (gmS); fine to very coarse sand with some silt and some gravel; subangular; moderately sorted; pebbles are <9 mm in diameter; light tan. |
| 196 | 197 | Silty sand (zS); very fine to medium sand with silt; subrounded; well sorted; quartz and mica rich; light tan. |
| 197 | 198 | Silty sand (zS); fine to very coarse sand with some silt; subrounded; well sorted; light tan. |
| 198 | 199 | Gravelly silty sand (gmS); very fine to coarse sand with silt; subrounded; well sorted; reddish tan. |
| 199 | 200 | Gravelly silty sand (gmS); fine to very coarse sand with some silt and some gravel; subrounded; moderately sorted; light tan. |
| 200 | 201 | Silty sand (zS); fine to coarse sand with some silt; subangular to subrounded; well sorted; light tan. |
| 201 | 202 | Silty sand (zS); very fine to coarse sand with silt; subrounded; well sorted; mica rich; light tan. |
| 202 | 203 | Silty sand (zS); very fine to coarse sand with silt; subrounded; well sorted; mica rich; light tan. |
| 203 | 204 | Silty sand (zS); very fine to coarse sand with silt; subrounded; well sorted; mica rich; light tan. |
| 204 | 205 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 205 | 206 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 206 | 207 | Gravelly silty sand (gmS); fine to coarse sand with some silt and some granules; subrounded; well sorted; light tan. |
| 207 | 208 | Gravelly silty sand (gmS); fine to coarse sand with some silt and some granules; subrounded; well sorted; light tan. |
| 208 | 209 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 209 | 210 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 210 | 211 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 211 | 212 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 212 | 213 | Gravelly silty sand (gmS); fine to coarse sand with some silt and rare granules; subrounded; well sorted; light tan. |
| 213 | 214 | Gravelly silty sand (gmS); fine to very coarse sand, including granules with some silt; subangular; moderately sorted; light tan. |
| 214 | 215 | Gravelly silty sand (gmS); fine to very coarse sand, including granules with some silt; subangular; moderately sorted; light tan. |
| 215 | 216 | Gravelly sand (gS); fine to coarse sand with some granules; subrounded; moderately sorted; light tan. |
| 216 | 217 | Gravelly sand (gS); fine to coarse sand; subrounded; well sorted; light tan. |
| 217 | 218 | Gravelly sand (gS); fine to coarse sand; subrounded; well sorted; light tan. |
| 218 | 219 | Gravelly sand (gS); fine to coarse sand with occasional granules; subrounded; well sorted; light tan. |
| 219 | 220 | Gravelly sand (gS); fine to coarse sand with occasional granules; subrounded; well sorted; light tan. |
| 220 | 221 | Gravelly sand (gS); fine to very coarse sand with some granules; subangular to subrounded; moderately sorted; light tan. |
| 221 | 222 | Gravelly sand (gS); fine to very coarse sand with rare granules; subrounded; moderately sorted; light tan. |
| 222 | 223 | Gravelly sand (gS); medium to very coarse sand with occasional granules; subrounded; well sorted; light tan. |
| 223 | 224 | Gravelly silty sand (gmS); very fine to very coarse sand with some silt, occasional granules and rare pebbles; subangular to subrounded; poorly sorted; pebbles are <12 mm in diameter; light tan. |
| 224 | 225 | Gravelly sand (gS); very fine to very coarse sand with occasional granules; subangular; moderately sorted; light tan. |
| 225 | 226 | Gravelly sand (gS); fine to very coarse sand with rare granules and pebbles; subrounded; moderately sorted; pebbles are <8 mm in diameter; light tan. |
| 226 | 227 | Gravelly sand (gS); fine to very coarse sand with rare granules and rare pebbles; subangular to subrounded; poorly sorted; pebbles are <8 mm in diameter; light tan. |
| 227 | 228 | Gravelly sand (gS); fine to very coarse sand with rare granules; subangular; poorly sorted; light tan. |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 228 | 229 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular to subrounded; poorly sorted; light tan. |
| 229 | 230 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular to subrounded; poorly sorted; light tan. |
| 230 | 231 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular to subrounded; poorly sorted; light tan. |
| 231 | 232 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular to subrounded; poorly sorted; light tan. |
| 232 | 233 | Gravelly sand (gS); fine to coarse sand with rare granules; subangular; moderately sorted; light tan. |
| 233 | 234 | Gravelly sand (gS); fine to very coarse sand with some granules and rare pebbles; subangular to subrounded; moderately sorted; pebbles are <9 mm in diameter; whitish tan. |
| 234 | 235 | Gravelly sand (gS); very fine to coarse sand with some granules; subrounded; moderately sorted; whitish tan. |
| 235 | 236 | Gravelly sand (gS); very fine to very coarse sand, including pebbles with occasional granules; subangular to subrounded; poorly sorted; pebbles are <7 mm in diameter; light tan. |
| 236 | 237 | Gravelly sand (gS); very fine to very coarse sand with occasional granules; subangular; poorly sorted; tan. |
| 237 | 238 | Gravelly sand (gS); very fine to very coarse sand with occasional granules and pebbles; subangular; poorly sorted; pebbles are <10 mm in diameter; tan. |
| 238 | 239 | Sand (S); very fine to coarse sand; subrounded; moderately sorted; tan. |
| 239 | 240 | Sand (S); very fine to coarse sand; subrounded; moderately sorted; tan. |
| 240 | 241 | Sand (S); very fine to coarse sand; subrounded; moderately sorted; tan. |
| 241 | 242 | Sand (S); very fine to coarse sand; subrounded; moderately sorted; tan. |
| 242 | 243 | Sand (S); very fine to coarse sand; subrounded; moderately sorted; tan. |
| 243 | 244 | Sand (S); fine to very coarse sand; subangular; poorly sorted; tan. |
| 244 | 245 | Sand (S); very fine to very coarse sand; subangular; poorly sorted; tan. |
| 245 | 246 | Silty gravelly sand (gS); very fine to very coarse sand with occasional granules and rare silt; subangular to subrounded; poorly sorted; dark tan. |
| 246 | 247 | Silty gravelly sand (gS); very fine to coarse sand with occasional granules and rare silt; subangular; poorly sorted; brown (7.5YR 4/3). |
| 247 | 248 | Gravelly sand (gS); very fine to coarse sand with rare granules; subangular to subrounded; moderately sorted; tan. |
| 248 | 249 | Gravelly sand (gS); very fine to coarse sand with rare granules; subangular to subrounded; moderately sorted; tan. |
| 249 | 250 | Gravelly sand (gS); very fine to coarse sand with rare granules; subangular to subrounded; moderately sorted; tan. |
| 250 | 251 | Gravelly sand (gS); very fine to coarse sand with occasional granules and pebbles; subrounded; poorly sorted; pebbles are <15 mm in diameter; tan. |
| 251 | 252 | Gravelly sand (gS); fine to very coarse sand with rare granules; subangular; moderately sorted; tan. |
| 252 | 253 | Gravelly sand (gS); very fine to very coarse sand with occasional granules with rare pebbles; subangular; poorly sorted; pebbles are <8 mm in diameter; tan. |
| 253 | 254 | Gravelly silty sand (gmS); very fine to very coarse sand with some silt and rare granules; subangular; poorly sorted; tan. |
| 254 | 255 | Gravelly silty sand (gmS); very fine to very coarse sand with some silt and rare granules; subangular; poorly sorted; tan. |
| 255 | 256 | Clayey sand (cS); very fine to coarse sand, including granules and occasional clay; subrounded; moderately sorted; dark brown (10YR 3/3). |
| 256 | 257 | Clayey sand (cS); fine to coarse sand with some clay; subrounded; well sorted; dark brown (10YR 3/3). |
| 257 | 258 | Gravelly sand (gS); fine to coarse sand with occasional granules; subrounded; well sorted; light tan. |
| 258 | 259 | Gravelly sand (gS); very fine to very coarse sand with occasional granules and rare pebbles; subangular to subrounded; poorly sorted; pebbles are <15 mm in diameter; light tan. |
| 259 | 260 | Silty sand (zS); very fine to coarse sand with rare silt; subrounded; well sorted; light tan. |
| 260 | 261 | Sandy silt (sZ); silt with fine to medium sand; well sorted. |
| 261 | 262 | Gravelly silty sand (gmS); very fine to medium sand with some silt and rare granules; subrounded; well sorted. |
| 262 | 263 | Gravelly silty sand (gmS); very fine to medium sand with some silt and rare granules; subrounded; well sorted. |
| 263 | 264 | Gravelly sand (gS); very fine to medium sand with rare granules and rare pebbles; subangular; moderately sorted; pebbles are <7 mm in diameter; mica rich; dark tan. |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 264 | 265 | Gravelly sand (gS); very fine to medium sand with rare granules and rare pebbles; subangular; moderately sorted; pebbles are <7 mm in diameter; mica rich; dark tan. |
| 265 | 266 | Gravelly sand (gS); very fine to medium sand with rare granules and rare pebbles; subangular; moderately sorted; pebbles are <7 mm in diameter; mica rich; dark tan. |
| 266 | 267 | Gravelly sand (gS); very fine to coarse sand with occasional granules and rare pebbles; subangular; moderately sorted; pebbles are <10 mm in diameter; tan. |
| 267 | 268 | Gravelly sand (gS); very fine to coarse sand with occasional granules and rare pebbles; subangular; moderately sorted; pebbles are <10 mm in diameter; tan. |
| 268 | 269 | Gravelly sand (gS); fine to very coarse sand with rare granules; subangular; moderately sorted; light tan. |
| 269 | 270 | Gravelly sand (gS); fine to very coarse sand with rare granules; subangular; moderately sorted; light tan. |
| 270 | 271 | Sandy silt (sZ); silt with very fine to medium sand; well sorted. |
| 271 | 272 | Gravelly sandy silt ((g)sM); silt with very fine to medium sand and rare granules; moderately sorted. |
| 272 | 273 | Gravelly sandy silt ((g)sM); silt with very fine to medium sand and rare granules; moderately sorted. |
| 273 | 274 | Gravelly sandy silt ((g)sM); silt with very fine to medium sand and rare granules; moderately sorted. |
| 274 | 275 | Gravelly sand (gS); fine to very coarse sand with occasional granules and rare pebbles; subangular; poorly sorted; pebbles are <14 mm in diameter; light tan. |
| 275 | 276 | Gravelly sand (gS); fine to very coarse sand with occasional granules and rare pebbles; subangular; poorly sorted; light tan. |
| 276 | 277 | Gravelly sand (gS); fine to very coarse sand with occasional granules and rare pebbles; subangular; poorly sorted; light tan. |
| 277 | 278 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 278 | 279 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 279 | 280 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 280 | 281 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 281 | 282 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 282 | 283 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 283 | 284 | Sandy silt (sZ); silt with some very fine to fine sand; well sorted. |
| 284 | 285 | Gravelly silty sand (gmS); very fine to medium sand with some silt and rare granules; subangular; moderately sorted. |
| 285 | 286 | Gravelly silty sand (gmS); very fine to medium sand with some silt and rare granules; subangular; moderately sorted. |
| 286 | 287 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular; moderately sorted; light tan. |
| 287 | 288 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular; moderately sorted; light tan. |
| 288 | 289 | Gravelly sand (gS); fine to very coarse sand with some granules; subangular; moderately sorted; light tan. |
| 289 | 290 | Gravelly sand (gS); fine to very coarse sand with occasional granules; subangular; moderately sorted; light tan. |
| 290 | 291 | Gravelly silty sand (gmS); very fine to fine sand with some silt and rare granules; subrounded; well sorted. |
| 291 | 292 | Gravelly silty sand (gmS); very fine to fine sand with some silt and rare granules; subrounded; well sorted. |
| 292 | 293 | No sample collected. |
| 293 | 294 | Sand (S); very fine to very coarse sand, skewed to fine to medium sand; subangular to subrounded; moderately sorted; approximately 20% mafics; relative abundance of mica; light yellowish brown (2.5Y 6/3). |
| 294 | 295 | Sand (S); very fine to very coarse sand; subangular to subrounded; poorly sorted; approximately 20% mafics; light yellowish brown (2.5Y 6/3). |
| 295 | 296 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 296 | 297 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 297 | 298 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 298 | 299 | No sample collected. |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 299 | 300 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 300 | 301 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 301 | 302 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 20% mafics; brown (10YR 4/3). |
| 302 | 303 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subangular to subrounded; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 303 | 304 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 304 | 305 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 305 | 306 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 306 | 307 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 307 | 308 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 308 | 309 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 309 | 310 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 310 | 311 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 311 | 312 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subangular to subrounded; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 312 | 313 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <20 mm in diameter; approximately 15% mafics; dark yellowish brown (10YR 4/4). |
| 313 | 314 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 314 | 315 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 315 | 316 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 316 | 317 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 317 | 318 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 318 | 319 | No sample collected. |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 319 | 320 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 320 | 321 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 321 | 322 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 322 | 323 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; dark yellowish brown (10YR 4/4). |
| 323 | 324 | Slightly gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light yellowish brown (10YR 6/4). |
| 324 | 325 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15–20% mafics; relative abundance of mica and ferro-magnetic minerals; light olive brown (2.5Y 5/3). |
| 325 | 326 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15–20% mafics; relative abundance of mica and ferro-magnetic minerals; light olive brown (2.5Y 5/3). |
| 326 | 327 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15–20% mafics; relative abundance of mica and ferro-magnetic minerals; light olive brown (2.5Y 5/3). |
| 327 | 328 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 328 | 329 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 329 | 330 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 330 | 331 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 331 | 332 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 332 | 333 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 333 | 334 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel, slightly skewed to fine to medium sand; subrounded to subangular; moderately sorted; pebbles are <4 mm in diameter; approximately 20% mafics; relative abundance of micas and ferro-magnetic minerals; light olive brown (2.5Y 5/4). |
| 334 | 335 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; relatively abundant micas; dark yellowish brown (10YR 3/4). |
| 335 | 336 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 20% mafics; relatively abundant micas; olive brown (2.5Y 4/4). |
| 336 | 337 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 20% mafics; relatively abundant micas; olive brown (2.5Y 4/4). |
| 337 | 338 | Slightly silty sand (zS); very fine to very coarse sand with very minor silt, skewed to fine to medium sand; subrounded to subangular; moderately sorted; approximately 30% mafics; abundance of mica; dark yellowish brown (10YR 3/4). |
| 338 | 339 | Slightly silty sand (zS); very fine to very coarse sand with very minor silt, skewed to fine to medium sand; subrounded to subangular; moderately sorted; approximately 30% mafics; abundance of mica; dark yellowish brown (10YR 3/4). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| **From** | **To** | |
| 339 | 340 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 30% mafics; abundance of mica; dark yellowish brown (10YR 3/4). |
| 340 | 341 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; approximately 30% mafics; abundance of mica; dark yellowish brown (10YR 3/4). |
| 341 | 342 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 3/4). |
| 342 | 343 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <8 mm in diameter; approximately 20% mafics; dark yellowish brown (10YR 3/4). |
| 343 | 344 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 344 | 345 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 345 | 346 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 346 | 347 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 347 | 348 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 348 | 349 | Slightly silty slightly gravelly sand ((gm)S); very fine to very coarse sand with minor granule-size gravel and very minor silt; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 349 | 350 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 350 | 351 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 351 | 352 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 352 | 353 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 353 | 354 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 354 | 355 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 30% mafics; abundance of micas; dark yellowish brown (10YR 4/4). |
| 355 | 356 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 356 | 357 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 357 | 358 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 20% mafics; dark yellowish brown (10YR 4/4). |
| 358 | 359 | Slightly gravelly sand (gS); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; yellowish brown (10YR 5/4). |
| 359 | 360 | Slightly gravelly sand (gS); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; yellowish brown (10YR 5/4). |
| 360 | 361 | Slightly gravelly sand (gS); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; yellowish brown (10YR 5/4). |
| 361 | 362 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (10YR 6/4). |

**Appendix 2.** Lithologic log for monitoring site YVUZ-2 (1N/5E-34R2) in the Warren subbasin, San Bernardino County, California.—Continued

[Location shown in figure 1. Depth is in feet below land surface. Soil and rock color notation from Munsell Color (1994). **Abbreviations**: ft, foot; mm, millimeter; <, less than; %, percent]

| Depth (ft) | | Description |
|---|---|---|
| From | To | |
| 362 | 363 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (10YR 6/4). |
| 363 | 364 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (10YR 6/4). |
| 364 | 365 | Gravelly sand (gS); very fine to very coarse sand with granule- to pebble-size gravel; subrounded to subangular; poorly sorted; pebbles are <10 mm in diameter; <10% mafics; light yellowish brown (10YR 6/4). |
| 365 | 366 | No sample collected. |
| 366 | 367 | Sand (S); very fine to very coarse sand, subangular to subrounded; poorly sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 367 | 368 | Sand (S); coarse to very coarse sand; subangular to subrounded; well sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 368 | 369 | Sand (S); very fine to very coarse sand, skewed to coarse to very coarse sand; subrounded to subangular; moderately sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 369 | 370 | Sand (S); very fine to very coarse sand, skewed to coarse to very coarse sand; subrounded to subangular; moderately sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 370 | 371 | Sand (S); very fine to very coarse sand, skewed to coarse to very coarse sand; subrounded to subangular; moderately sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 371 | 372 | Sand (S); very fine to very coarse sand, skewed to coarse to very coarse sand; subrounded to subangular; moderately sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 372 | 373 | Sand (S); coarse to very coarse sand; subrounded to subangular; well sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 373 | 374 | Sand (S); medium to very coarse sand; subrounded to subangular; poorly sorted; <5% mafics; light reddish brown (2.5YR 6/4). |
| 374 | 375 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 375 | 376 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 376 | 377 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 377 | 378 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 378 | 379 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 379 | 380 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; <5% mafics; light yellowish brown (2.5Y 6/4). |
| 380 | 381 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; <10% mafics; light olive brown (2.5Y 5/3). |
| 381 | 382 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; olive brown (2.5Y 4/4). |
| 382 | 383 | Slightly gravelly sand (gS); very fine to very coarse sand with minor granule-size gravel; subrounded to subangular; poorly sorted; pebbles are <4 mm in diameter; approximately 15% mafics; olive brown (2.5Y 4/4). |
| 383 | 384 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; light olive brown (2.5Y 5/3). |
| 384 | 385 | Sand (S); very fine to very coarse sand; subrounded to subangular; poorly sorted; approximately 15% mafics; light olive brown (2.5Y 5/3). |

**Appendix 3.** Lithologic log for monitoring site YVUZ-3 (1N/5E-34N Test Hole) in the Warren subbasin, San Bernardino County, California.

[Location shown in figure 1.]

| Depth below land surface (feet) | | Description |
|---|---|---|
| From | To | |
| 1 | 6 | Gravelly sand, very fine to fine with some medium to very coarse sand, granule to medium pebble size gravel; poorly sorted; angular to sub-rounded; some organic material. |
| 6 | 11 | Slightly gravelly sand, very fine to fine with some medium to very coarse sand, granule to small pebble size gravel; moderately sorted, angular to subangular. |
| 11 | 22 | No sample. |
| 22 | 23 | Slightly gravelly sand, very fine to fine with some medium to very coarse sand, granule to small pebble size gravel, occasional medium to large pebbles; poorly sorted; angular to subangular. |
| 23 | 24 | Sand, very fine to fine, some medium to very coarse, occasional granule to small pebble size gravel; moderately sorted; angular to subrounded. |
| 24 | 25 | Slightly gravelly sand, very fine to medium with some coarse to very coarse sand, granule to medium pebble size gravel; poorly sorted; angular to subangular. |
| 25 | 26 | Slightly gravelly sand, very fine to fine with some medium to very coarse sand, minor granule to medium pebble size gravel; poorly sorted; angular to subangular. |
| 26 | 27 | Gravelly sand, very fine to fine with some medium to very coarse sand, granule to medium pebble size gravel; poorly sorted; angular to subangular. |
| 27 | 28 | Slightly gravelly sand, very fine to medium with some coarse to very coarse sand, minor granule to small pebble size gravel; poorly sorted; angular to subangular. |
| 28 | 29 | Gravelly sand, very fine to very coarse sand with some granule to small pebble size gravel; poorly sorted; angular to subangular. |
| 29 | 30 | Sandy gravel, granule to small pebble size gravel, very fine to very coarse sand; poorly sorted; angular to subangular. |
| 30 | 31 | Sandy gravel, granule to medium pebble size gravel, very fine to fine with some medium to very coarse sand; poorly sorted; angular to subangular. |
| 31 | 32 | Sand, very fine to fine with some medium, occasional granule to small pebble size gravel; moderately sorted; angular to subangular. |
| 32 | 33 | Sand, fine with some very fine to very coarse sand; moderately sorted; angular to subangular. |
| 33 | 34 | Sandy gravel, granule to medium pebble size gravel, very fine to fine with some medium to very coarse sand; poorly sorted; angular to subangular. |
| 34 | 35 | Clayey sand, very fine with some fine to medium sand, clay, occasional granule to small pebble size gravel; poorly sorted; angular to subangular. |
| 35 | 36 | Slightly gravelly sand, very fine to fine with some medium to very coarse sand, minor granule to small pebble with occasional medium to large pebble size gravel; poorly sorted; angular to subangular, some rounded. |
| 36 | 37 | Slightly gravelly sand, very fine to fine with some minor medium to very coarse sand, occasional granule to small pebble size gravel; moderately sorted; angular to subangular. |
| 37 | 38 | Sand, very fine to fine with some minor medium to coarse sand, occasional very coarse sand to small pebble size gravel; moderately sorted; angular to subangular. |
| 38 | 39 | Sandy gravel, granule to medium pebble size gravel, very fine to very coarse sand; poorly sorted; angular to subangular. |
| 39 | 40 | Sand, very fine to fine, some minor medium to coarse sand, occasional very coarse sand to small pebble size gravel; moderately sorted; angular to subangular. |
| 40 | 41 | Sand, very fine to fine with some minor medium to very coarse, occasional granule size gravel; moderately sorted; angular to subangular. |

# Appendix 4. Chemical composition of leachate for selected core material and cuttings from monitoring site YVUZ-1 (1N/5E-34K3), September 2004, Warren subbasin, San Bernardino County, California.

Appendix 4 provided separately as a Microsoft Excel® file at *http://pubs.usgs.gov/sir/2013/5088*.

## Appendix 5. Chemical composition of leachate for selected core material and cuttings from monitoring site YVUZ-2 (1N/5E-34R2), September 2004, Warren subbasin, San Bernardino County, California.

Appendix 5 provided separately as a Microsoft Excel® file at *http://pubs.usgs.gov/sir/2013/5088*.

**Appendix 6.** Chemical composition of leachate for selected core material and cuttings from monitoring site YVUZ-3 (1N/5E-34N Test Hole), October 2004, Warren subbasin, San Bernardino County, California.

[Site location is shown in figure 1. The five digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Abbreviations**: bls, below land surface; E, estimated; ft, feet; mg/L, milligrams per liter; <, less than value shown]

| Depth to top of sample interval, in ft bls (72015) | Depth to bottom of sample interval, in ft bls (72016) | Bromide, water, filtered, mg/L (71870) | Chloride, water, filtered, mg/L (00940) | Sulfate, water, filtered, mg/L (00945) | Nitrate, water, filtered, mg/L as Nitrogen (00618) | Nitrite, water, filtered, mg/L as Nitrogen (00613) | Phosphorus ortho, water, filtered, mg/L as Phosphorus (00671) |
|---|---|---|---|---|---|---|---|
| 1.00 | 6.00 | <0.3 | 160 | 320 | 1.57 | <0.030 | 0.500 |
| 6.00 | 11.00 | <0.3 | 100 | 220 | 1.40 | <0.030 | <0.500 |
| 11.50 | 13.50 | E0.1 | 73.0 | 96.0 | 1.19 | E0.020 | <0.500 |
| 23.00 | 24.00 | <0.3 | 65.0 | 83.0 | 3.20 | <0.030 | <0.500 |
| 24.00 | 25.00 | <0.3 | 96.0 | 78.0 | 4.40 | <0.030 | <0.500 |
| 25.00 | 26.00 | <0.3 | 40.0 | 36.0 | 0.94 | <0.030 | <0.500 |
| 26.00 | 27.00 | <0.3 | 29.0 | 32.0 | 0.49 | <0.030 | <0.500 |
| 27.00 | 28.00 | <0.3 | 17.0 | 24.0 | 0.07 | <0.030 | <0.500 |
| 28.00 | 29.00 | <0.3 | 12.0 | 19.0 | 0.30 | <0.030 | <0.500 |
| 30.00 | 31.00 | <0.3 | 6.5 | 20.0 | 0.12 | <0.030 | <0.500 |
| 31.00 | 32.00 | <0.3 | 8.1 | 22.0 | <0.06 | <0.030 | <0.500 |
| 32.00 | 33.00 | <0.3 | 17.0 | 43.0 | <0.06 | 0.080 | <0.500 |
| 33.00 | 34.00 | <0.3 | 6.9 | 23.0 | <0.06 | <0.030 | <0.500 |
| 34.00 | 35.00 | <0.3 | 5.8 | 30.0 | <0.06 | <0.030 | <0.500 |
| 35.00 | 36.00 | <0.3 | 5.7 | 27.0 | <0.06 | <0.030 | <0.500 |
| 36.00 | 37.00 | <0.3 | 3.9 | 21.0 | 0.12 | E0.020 | 0.600 |
| 37.00 | 38.00 | <0.3 | 2.6 | 14.0 | <0.06 | <0.030 | E0.400 |
| 38.00 | 39.00 | <0.3 | 3.7 | 20.0 | 0.41 | <0.030 | 0.700 |
| 39.00 | 40.00 | <0.3 | 4.1 | 18.0 | 3.18 | <0.030 | <0.500 |
| 40.00 | 41.00 | <0.3 | 4.8 | 20.0 | 5.14 | <0.030 | <0.500 |
| 41.00 | 42.00 | <0.3 | 5.6 | 26.0 | 5.85 | <0.030 | <0.500 |
| 41.00 | 43.00 | <0.3 | 4.4 | 12.0 | 5.42 | 0.200 | <0.500 |

# Appendix 7. Chemical and isotopic composition of water from suction-cup lysimeters, Warren subbasin, San Bernardino County, California.

Appendix 7 provided separately as a Microsoft Excel® file at *http://pubs.usgs.gov/sir/2013/5088*.

# Appendix 8. Chemical and isotopic composition of water from monitoring wells, selected Hi-Desert Water District production wells, and surface-water sources in the Warren subbasin, San Bernardino County, California.

Appendix 8 provided separately as a Microsoft Excel® file at *http://pubs.usgs.gov/sir/2013/5088*.

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For more information concerning this report, contact:

Director
U.S. Geological Survey
California Water Science Center
6000 J Street, Placer Hall
Sacramento, CA 95819
dc_ca@usgs.gov

or visit our Web site at:
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Stamos and others—**The Effects of Artificial Recharge on Groundwater Levels and Water Quality in the West Hydrogeologic Unit of the Warren Subbasin, San Bernardino County, California**—Scientific Investigations Report 2013–5088

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