

Tracing Reclaimed Water in the Menifee, Winchester, and Perris-South Ground-Water Subbasins, Riverside County, California

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

CONVERSION FACTORS

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
square foot (ft ²)	0.09290	square meter
foot squared per minute(ft ² /min)	0.00155	meter squared per second
cubic foot (ft ³)	0.02832	cubic meter
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile(mi ²)	2.590	square kilometer

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

$$^{\circ}\text{F}=1.8\text{ }^{\circ}\text{C}+32.$$

Specific conductance is given microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

VERTICAL DATUM

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

Altitude, as used in this report, refers to distance above or below sea level.

ABBREVIATIONS

D or ² H	deuterium
DOC	dissolved organic carbon
¹⁸ O	oxygen-18
EDTA	ethylenediaminetetraacetic acid
LAS	linear alkylbenzene sulfonate
MBAS	methylene blue activated substances

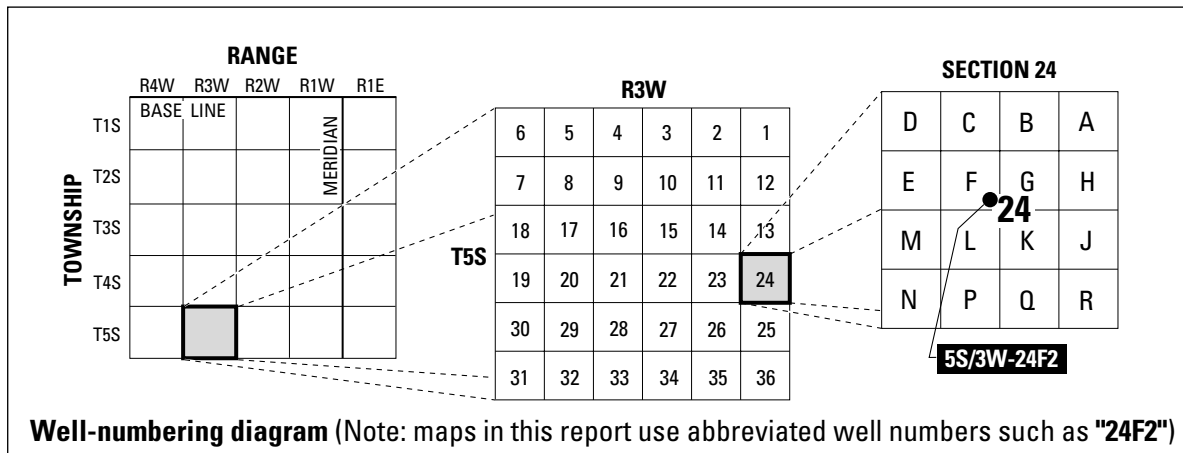
MCL	maximum contaminant level (U.S. Environmental Protection Agency, 1990, Drinking water regulations and health advisories)
µg/L	microgram per liter
µS/cm	microsiemen per centimeter at 25 °Celsius
MEQ/L	milliequivalents per liter
mg/L	milligram per liter
nm	nanometer
RWRF	regional water-reclamation facility
TOC	total organic carbon
TOX	total organic halide
UV-A	ultraviolet absorbance

Organizations

EMWD	Eastern Municipal Water District
USGS	U.S. Geological Survey

WELL-NUMBERING SYSTEM

Wells are identified and numbered according to their location in the rectangular system for the subdivision of public lands. Identification consists of the township number, north or south; the range number, east or west; and the section number. Each section is divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with "A" in the northeast corner of the section and progressing in a sinusoidal manner to "R" in the southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. In California, there are three base lines and meridians; Humboldt (H), Mount Diablo (M), and San Bernardino (S). All wells in the study area are referenced to the San Bernardino base line and meridian (S) Well numbers consist of 15 characters and follow the format 005S003W024F02S. In this report, well numbers are abbreviated and written 5S/3W-24F2. Wells in the same township and range are referred to only by their section designation (for example, 24F2). The following diagram shows how the number for well 05S/3W-24F2 is derived.



Tracing Reclaimed Water in the Menifee, Winchester, and Perris-South Ground-Water Subbasins, Riverside County, California

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ABSTRACT

As a component in the management of water resources in the Menifee, Winchester, and Perris-South subbasins in Riverside County, California, ponds are operated by the Eastern Municipal Water District for the temporary storage of reclaimed water that is produced by several regional water-reclamation facilities. A primary goal of this study was to evaluate the potential for using various ground-water constituents or characteristics as tracers of reclaimed water that has infiltrated from the storage ponds into the ground water in the three subbasins. A secondary goal was to estimate the degree to which the infiltrated reclaimed water has mixed with the native ground water. The evaluation of potential tracers and the estimation of mixing focused on data from wells located relatively close to the ponds.

The most useful constituents and characteristics for evaluation of the fate and mixing of reclaimed water in the Menifee, Winchester, and Perris-South subbasins are major-ion composition, stable isotopes of hydrogen and oxygen, ultraviolet absorbance (UV-A), chloride concentration, and boron/chloride ratio plotted against chloride concentration. Emphasis in this study was placed on evaluating the utility of UV-A as a tracer and boron/chloride ratios in estimating the fraction of reclaimed water in ground water.

In the Menifee subbasin, major-ion data, stable isotopes, chloride, UV-A, and boron/chloride ratio are all useful in identifying reclaimed water, and the results based on these indicators are consistent with each other. The results suggest that values of UV-A greater than or equal to 0.007 indicate the presence of reclaimed water in the Menifee subbasin. Ground-water samples with UV-A greater than 0.007 are estimated to consist of about 75 to 100 percent reclaimed water, on the basis of chloride-mixing calculations and boron/chloride-versus-chloride mixing calculations.

In the Winchester subbasin, results based on the same factors used in the Menifee subbasin are less conclusive; nevertheless, UV-A can be used as a tracer. The results suggest that values of UV-A greater than 0.01 indicate the presence of reclaimed water. Values from 0.006 to 0.01 may indicate the presence of reclaimed water; however, water from wells not likely to have reclaimed water may also have UV-A values in this range. Ground-water samples with UV-A greater than 0.01 seem to contain about 25 percent reclaimed water (range 6 to 32 percent), on the basis of the consistency of the results of three types of mixing calculations—chloride alone, boron/chloride versus chloride, and UV-A.

In the Perris-South subbasin, the potential tracers are not as conclusive in identifying reclaimed water in the subsurface as in the Menifee and Winchester subbasins. The less-conclusive results are a consequence of the multiple, spatially distributed sources of reclaimed water; the relative absence of wells close to the reclaimed-water pond; and the short period of operation (about 1 year) of the pond at the time of sampling. Mixing calculations suggest that ground-water samples with elevated UV-A values (greater than 0.01) in the Perris-South subbasin could contain as much as 40 to 65 percent reclaimed water.

INTRODUCTION

Artificial recharge of ground water using treated reclaimed water has been an increasingly important aspect of water management in recent years, as the need for reuse of water has grown. Common mechanisms that result in recharge of ground water include injection of water into recharge wells, percolation of reclaimed water from infiltration ponds, and percolation of reclaimed water applied as irrigation. In many situations where reclaimed water recharges ground water, information regarding the quantity, fate, or impact of the reclaimed water is needed by water managers.

Previous studies of percolated reclaimed water indicate that the percolated water may have a beneficial or an adverse effect on ground-water quality. For example, results of a study at East Meadow, Long Island, New York, suggest that concentrations of nitrate-nitrogen and several low-molecular-weight hydrocarbons decreased at a location recharged with reclaimed water; however, concentrations of sodium and chloride in the reclaimed water increased somewhat relative to the unaffected ground water, but remained within drinking-water standards (Schneider and others, 1987). In a study near Tallahassee, Florida, increases in nitrate and chloride concentrations in ground water were attributed to irrigation using reclaimed water (Pruitt and others, 1988). In a third

study, ground-water quality was generally degraded by reclaimed water used for irrigation in Alameda County, California (Sylvester, 1983).

In a study of ground-water quality near artificial-recharge basins that receive reclaimed water and (or) stormwater and imported water in Los Angeles County, California (Schroeder and others, 1997), which was done after the present study's data-collection and analysis phases, it was concluded that (1) significant correlations exist between elevated (above natural background levels) concentrations of chloride, boron, and nitrogen back-calculated to the time of recharge, and that these constituents were indicators for the presence of reclaimed water in the sampled wells; and (2) bacterial numbers in wells near the recharge ponds were generally less than in wastewater-impacted aquifers elsewhere, and were strongly correlated with aqueous organic carbon concentration and weakly correlated with distance from the recharge ponds. Analysis of organic data from the same study area (Barber and others, 1997) indicated that: (1) concentrations of dissolved organic carbon (DOC) were greater in production wells near the recharge ponds than in an upgradient background well; (2) total organic halide (TOX), not detected in the background well, was present at concentrations as great as 14.6 mg/L in the production wells; (3) concentrations of ethylenediaminetetraacetic acid (EDTA), if assumed to be a conservative tracer, can be used to estimate the percentage of reclaimed water in the sampled wells; and (4) fluorescent whitening agents were highly correlated with DOC and EDTA.

The results of these, and other, studies indicate that the movement and effect of percolated reclaimed water can vary from site to site. The variability from site to site may be dependent on the chemical characteristics of the reclaimed water relative to those of the pre-existing ground water; the chemical and physical characteristics of the soil and aquifer matrix through which the ground water travels; or the amount and distribution of reclaimed water. In the study reported herein, selected constituents were evaluated as indicators of the presence of reclaimed water in ground water.

Background

The Eastern Municipal Water District (EMWD), located in the San Jacinto and Santa Margarita Basins in southwestern Riverside County, California, serves a population of nearly 500,000 in a service area that exceeds 550 mi² (fig. 1). The EMWD provides water, obtained from local wells and imported from non-local surface-water sources, for domestic and irrigation uses. In addition, EMWD operates five regional water-reclamation facilities (RWRFs) that treat wastewater. In 1995, the five RWRFs had a combined reclaimed-water production of 31,900 acre-ft/yr, all of which (except evaporated or percolated storage-pond water) was used within the EMWD service area--mostly for agricultural irrigation or irrigation of golf courses. Because demand for the reclaimed water is seasonal, storage ponds have been constructed at three areas: near the town of Winchester (Winchester subbasin); at the Sun City RWF (Menifee subbasin); and at the Perris Valley RWF (including the Trumble Road pond) (Perris-South subbasin) (figs. 1, 2). Approximately 13,000 acre-ft of reclaimed water is estimated by the EMWD to be lost annually to evaporation and to percolation to the ground-water system through operation of the storage ponds (Behrooz Mortazavi, EMWD, oral commun., 1995).

Although some of the ponds have been in operation for more than 25 years, little is known about the amount of water percolating and its effect on ground-water quality. The ponds and RWRFs are located in subbasins in which the ground water is characterized by relatively high dissolved-solids concentrations. Although the quality of reclaimed water percolating from those ponds is generally better than that of the ground water near the percolation site, the reclaimed water may have higher concentrations of some individual constituents.

Mechanisms used by the EMWD in managing the quantity and chemical quality of water resources in the Menifee, Winchester, and Perris-South subbasins (and surrounding areas) include pumping of ground water, importation of surface water from distant

sources, treatment of wastewater, storage of reclaimed water in unlined ponds, delivery of reclaimed water for irrigation, and extraction and desalting of poor-quality ground water. Owing to the role of reclaimed water in a number of these mechanisms, the EMWD needs information regarding the quantity of reclaimed water that recharges the ground-water system, and regarding the subsurface mixing of percolated reclaimed water and ground water. These issues continue to be important as regulations evolve and as conjunctive-use and desalting projects are planned and implemented. Specifically, there is a need to develop methods of tracing reclaimed water in the subsurface to determine the percent of mixing with ground water at various locations. Development of methods for quantifying the amount of reclaimed water percolating from ponds would be potentially useful to water managers for estimating possible recharge credits.

Previously, the U.S. Geological Survey (USGS), in cooperation with the EMWD, conducted the first phase of this study to investigate the quantity and fate of water percolation from selected reclaimed-water storage ponds to the ground-water system. As a product of the first phase, Burton and others (1996) presented (1) data on historical water quality, historical and then-current (1995) water levels, and construction specifications of existing wells; (2) borehole-lithologic descriptions and depth-to-bedrock data; (3) maps showing general directions of ground-water flow determined on the basis of water-level data collected during the study; and (4) pond water-level data and infiltration estimates, using water budgets, for one storage pond at each site. These data were used, in part, to quantify the rates of percolation from the storage ponds. The study revealed that the rates were variable, and in particular, dependent on the management actions that affect water levels in the ponds. In the present phase of the study, chemical tracers were used to evaluate percolation from the ponds in an effort to provide results that integrate percolation rates over a longer period of time than that of the estimates made in the first phase.

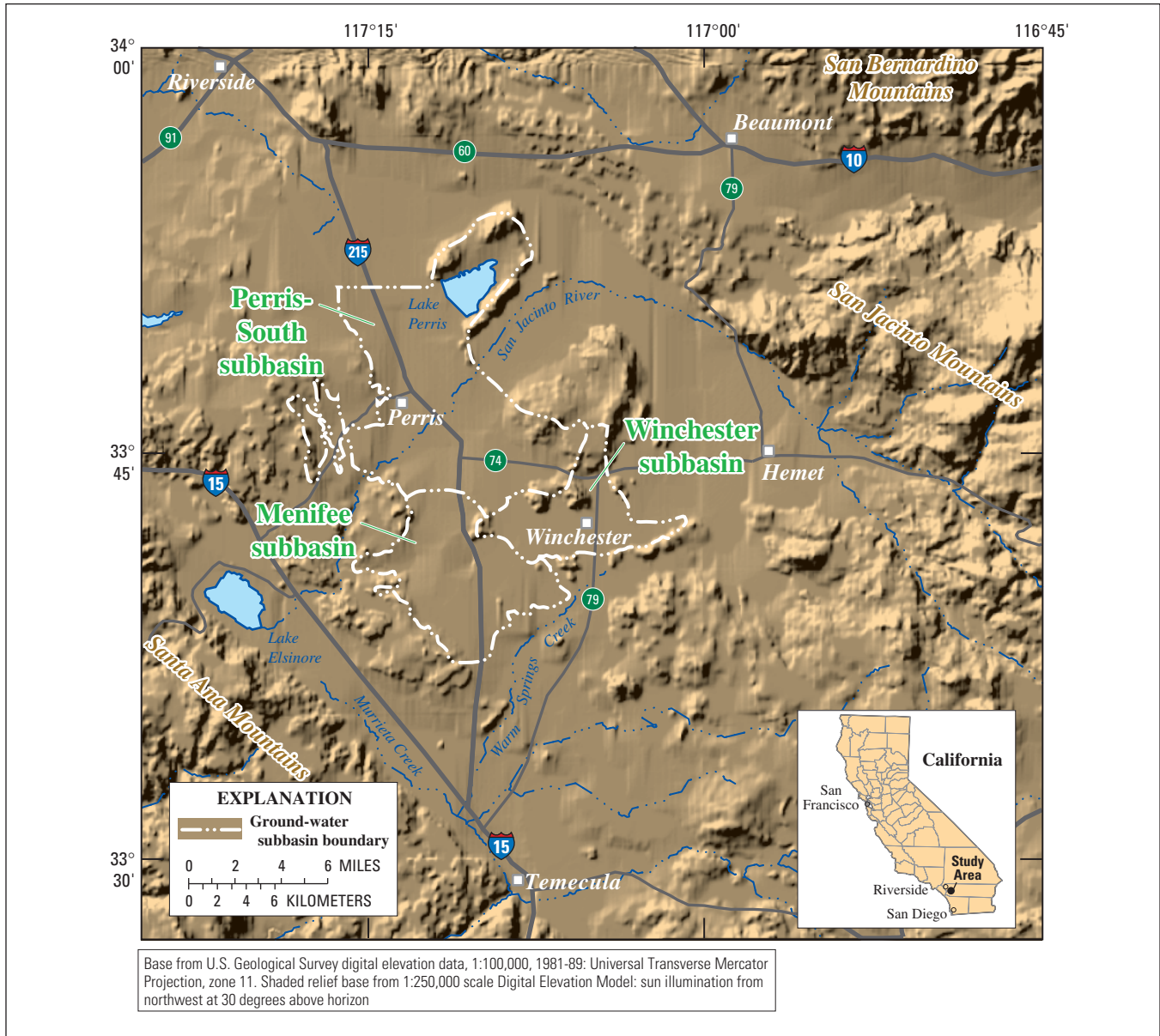


Figure 1. Location of the Menifee, Winchester, and Perris-South ground-water subbasin study area, Riverside County, California.

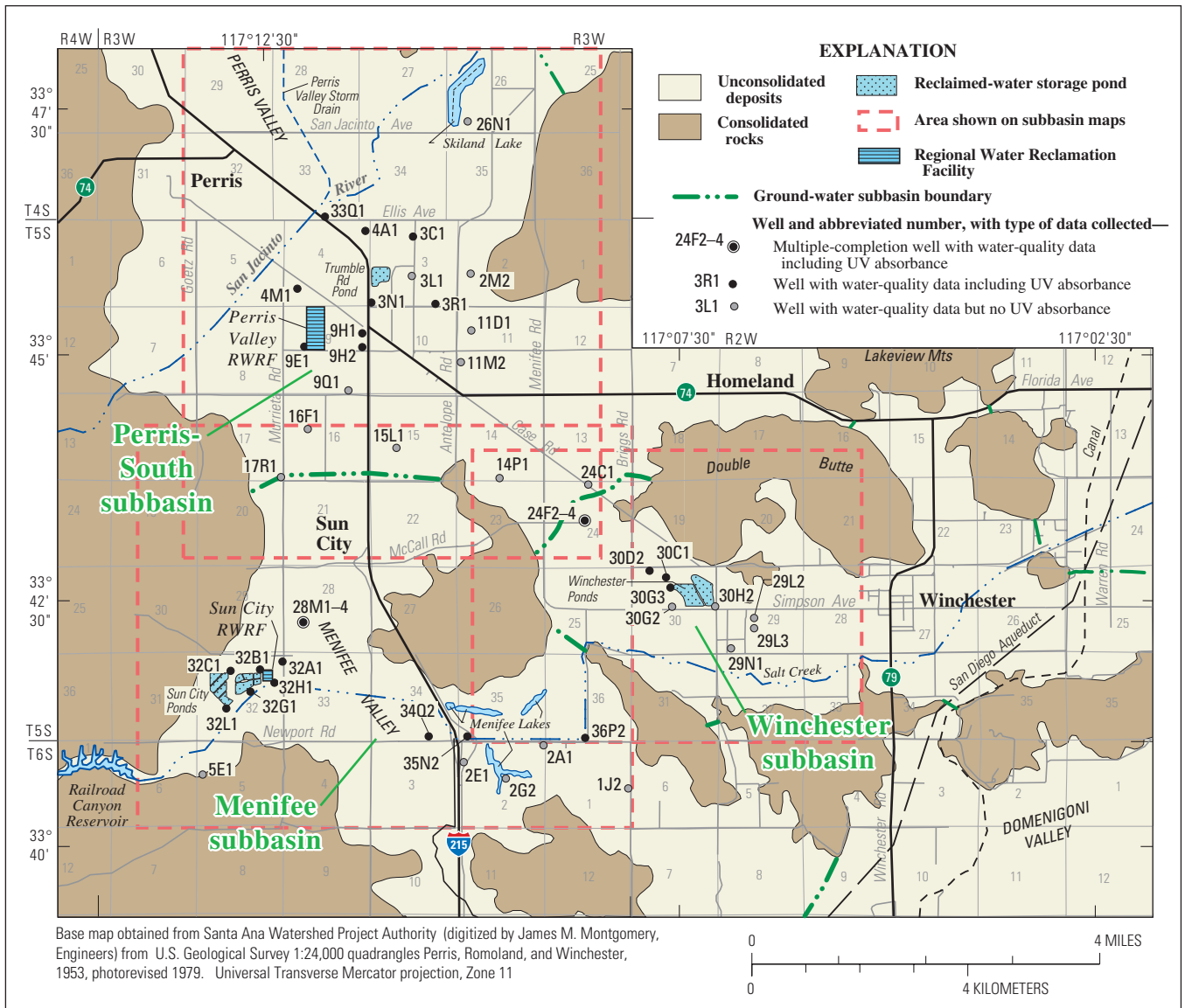


Figure 2. Selected wells and reclaimed-water storage ponds, and regional water-reclamation facilities, in the Menfee, Winchester, and Perris-South groundwater subbasins, Riverside County, California.

Purpose and Scope

The primary goal of the second phase of the reclaimed-water study done by the USGS in cooperation with the EMWD was to trace the fate and mixing of reclaimed water from selected storage ponds in the Menifee, Winchester, and Perris-South subbasins by identifying constituents or characteristics of the reclaimed water that may be useful as tracers. The purpose of this report is to present (1) the inorganic, organic, and isotopic water-quality data collected in 1995 from treatment plants, reclaimed-water storage ponds, and wells; (2) an assessment of the suitability of analyzed constituents and characteristics for use as a tracer of infiltrated reclaimed water in vicinity of the storage ponds; and (3) an estimate of the degree to which the infiltrated reclaimed water has mixed with the pre-existing ground water.

Approach

After historical water-quality, water-level, and well-construction information were compiled in the first phase of the study (Burton and others, 1996), a network of 47 wells was established for water-quality sampling. The wells were selected on the basis of (1) broad areal distribution (varying distances, from immediately adjacent to a pond site to about 4 mi distant); (2) depth of the perforated interval; and (3) accessibility for sampling. The location of the network wells is shown in [figure 2](#).

Water samples collected from the network wells, the three RWRFs, and the three pond sites in July and August 1995 were analyzed for major ions, trace metals, pH, alkalinity, and stable isotopes of hydrogen and oxygen. To determine if organic compounds might be useful as tracers of reclaimed water that has infiltrated from the storage ponds, samples from each of the RWRFs, the three selected ponds, and a subset of the network wells were analyzed for a suite of organic compounds: samples from the RWRFs, the ponds, and 37 wells were analyzed for total organic carbon (TOC) and dissolved organic carbon (DOC); samples from 27 wells were analyzed for methylene blue activated substances (MBAS); samples from the RWRFs, the ponds, and 9 wells were analyzed for caffeine and linear alkylbenzene sulfonate (LAS); samples from the RWRFs, the ponds, and 28 wells were analyzed for

ultraviolet absorbance (UV-A) at 254 nm (nanometers); and samples from the RWRFs and the ponds were analyzed for ethylenediaminetetraacetic acid (EDTA).

The results of the analyses were evaluated to determine which of the compounds best serves as a tracer for infiltrated reclaimed water in the study area. The water-quality results, including the tracer data, were used to infer the degree to which infiltrated reclaimed water has mixed with pre-existing ground water, taking into consideration factors such as local and regional flow directions, location and depth of the sampled wells, and location of areas where ground water has been recharged by percolation of reclaimed water from storage ponds or from lands irrigated with reclaimed water. In each of the subbasins, emphasis was placed on interpretation of the data collected from wells near the storage ponds.

Methods of Sample Collection and Analysis

Ground-water samples were collected from wells using protocols modified from the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997). To ensure that each well had been completely purged, approximately three casing volumes of water were removed prior to sample collection. Water samples from each treatment plant were collected into a 4-liter amber glass bottle using automated compositors over a 6- to 8-hour period. The samples were chilled at 4°C during the collection process. Water samples from reclaimed-water storage ponds were collected by dipping a polyethylene bottle attached to a handle into the pond at four to six points within a 600-ft reach. The subsamples obtained by each dipping were composited in a churn splitter.

Samples collected for determination of major ions, nutrients, and trace elements were filtered using a 0.45- μm capsule filter. The cations and trace-element samples were adjusted to a pH of 2 using nitric acid. The samples were shipped on ice to the USGS National Water-Quality Laboratory (NWQL) for analysis by various methods (Fishman and Friedman, 1989; Fishman, 1993). DOC and UV-A samples were filtered through a 0.45- μm silver filter. MBAS, LAS, and caffeine samples were filtered through a 1- μm glass-fiber filter and preserved with 2-percent formalin. These samples were shipped on ice to a USGS organics research laboratory in Boulder, Colorado.

DOC was determined using ultraviolet-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993). UV-A was determined using a spectrophotometer. MBAS concentrations were determined using a miniaturized version of a method described by Wershaw and others (1983). LAS and caffeine were analyzed by solid-phase extraction and gas chromatography/mass spectrometry (Trehly and others, 1990; Barber and others, 1995). Unfiltered samples were shipped to the USGS Isotope Laboratory in Reston, Virginia, for analysis of stable isotopes (deuterium and oxygen-18) using methods described by Epstein and Mayeda (1953) and Coplen and others (1991).

Quality Control

Replicate samples were collected at five wells to assess variability of the analyses for nutrients, major ions, and trace elements. For this assessment, the mean relative standard deviation (MRSD), which is defined as 100 times the standard deviation divided by the mean concentration for each replicate pair of samples, was used. The MRSDs were less than 5 percent for 22 of 32 constituents. Values of MRSD less than 20 percent are considered acceptable in this study. MRSDs were greater than 20 percent for three constituents--lithium (21 percent), lead (28 percent), and zinc (39 percent). MRSDs that exceeded 20 percent generally were for low measured concentrations at or near the laboratory reporting levels. This may indicate analytical uncertainty at low measured concentrations.

Description of the Study Area

The study area includes parts of the ground-water subbasins in which the three EMWD storage-pond sites are located: the Menifee subbasin, the Winchester subbasin, and the Perris-South subbasin (figs. 1, 2). The ground-water subbasins, located 20–25 mi southeast of Riverside, California, are part of the San Jacinto ground-water basin and are in the upper Santa Ana River drainage basin. The boundaries of the basins and subbasins were previously outlined by the California Department of Water Resources (1979). Well-defined surface-water drainages in the study area consist solely of the San Jacinto River and Salt Creek.

The downstream part of the ephemeral San Jacinto River flows southwestward across the Perris-South subbasin and into the northern end of Railroad Canyon Reservoir. The ephemeral Salt Creek flows westward through the Winchester subbasin, through the Menifee subbasin, and into the eastern end of the Railroad Canyon Reservoir (fig. 2).

The 40-mi² Menifee subbasin, which contains the Sun City RWRf, is bounded by metamorphic rocks on the west and by igneous rocks on the south and east (NBS/Lowry, 1987). Alluvium in the Menifee subbasin is about 600 ft thick in the Sun City area and more than 800 ft thick in the vicinity of Menifee Lakes (Biehler and Lee, 1995; NBS/Lowry, 1987). The boundary with the Perris-South subbasin to the north is in an area of a bedrock constriction about 1 mi north of Sun City (California Department of Water Resources, 1979). The Sun City RWRf and ponds are located in the southwest part of the subbasin, and are bordered on the north and northeast by suburban development (including a golf course), to the south and east by the Salt Creek flood plain and suburban development, and to the west by bedrock hills.

The 20-mi² Winchester subbasin includes about 12 mi² of relatively level alluvial valley floor and is bounded by granitic and undifferentiated metamorphic rocks (California Department of Water Resources, 1959, plate B–1B). The project study area includes the western half of the subbasin. The boundaries of the Winchester subbasin coincide with surface-water drainage divides, except in areas where valley-floor alluvium is contiguous with neighboring basins. Alluvium-filled constrictions were selected as boundaries between the Winchester subbasin and the Perris-South subbasin to the northwest, the Menifee subbasin to the southwest, and the Hemet subbasin to the east (fig. 1) (California Department of Water Resources, 1964). Saturated alluvium that fills the constrictions connects the subbasins hydrologically in the subsurface. Alluvium in the Winchester subbasin is estimated to be as much as 500 to 900 ft thick (Biehler and Lee, 1994). Depth to water generally ranged from 6 to 75 ft in 1994–95 (Kaehler and others, 1998). The Winchester reclaimed-water storage ponds are located in the northwestern part of the subbasin, and are bordered to the north by the Lakeview Mountains (fig. 2) and to the east, south, west and northwest by

agricultural and livestock land uses. The storage ponds, which receive water from the Temecula RWRf (located about 15 mi to the south in the Santa Margarita Basin), had been in operation for 2 to 3 years at the time data were collected for the study.

The 50-mi² Perris-South subbasin is bounded on the west and east primarily by granitic mountains (Lang, 1979). The study area includes the southern two-thirds of the subbasin, the northern boundary of which is an arbitrary line extending westward from the northern end of Lake Perris (fig. 1). Boundaries with the Winchester subbasin to the southeast and the Menifee subbasin to the south have been defined in alluvium-filled constrictions (California Department of Water Resources, 1979). Alluvium in the Perris-South subbasin is more than 800 ft thick in places (Biehler and Lee, University of California, Riverside, written commun., 1996). The Trumble Road pond is located about 2 mi southeast of the town of Perris, and about 1 mi northeast of the Perris Valley RWRf (fig. 2). Additional ponds are present at the Perris Valley RWRf site, which had been in operation about 30 years at the time data were collected for this study. The area surrounding the Trumble Road pond, which had been in operation for only 1 year, is used primarily for agriculture and contains some rural residences.

Acknowledgments

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INORGANIC AND ORGANIC TRACERS

One of the principal objectives of the study was to assess the suitability of selected constituents and characteristics, determined from ground-water- and reclaimed-water samples, for use as a tracer of reclaimed water that has percolated from storage ponds in the three subbasins. These chemical constituents can

be either naturally occurring or the result of human activity. The use of tracers that may be added to surface water (such as dye) or that may be injected into ground water (such as bromide, sulfur hexafluorine, or noble gases), specifically to trace movement or mixing, was not within the scope of this study.

In any given hydrologic setting, a useful chemical tracer, if present, has one or more of the following characteristics: (1) it is present and detectable in at least one of the waters being compared, prior to mixing; (2) the concentration or amount is measurable; (3) a contrast, or recognizable difference, in concentration exists between the subject waters; (4) it is conservative (the concentration or amount does not change owing to chemical reaction or other processes, either with time or distance of travel); or (5) the concentration or amount changes at a known rate. An example of a commonly used tracer is dissolved chloride; chloride is particularly useful because it is conservative over a wide range of conditions. Other examples of conservative tracers include the stable isotopes of water: deuterium and oxygen-18. Generally, conservative tracers are easier to use and model, but the use of non-conservative tracers may also be beneficial. Examples of tracers that may be non-conservative under some conditions include easily exchanged or reactive ions such as calcium, magnesium, boron, dissolved oxygen, or nitrogen. Commonly, several tracers or indicators are used in combination in an investigation to provide supporting or independent lines of evidence for mixing. Some tracers might be useful as qualitative indicators of the presence or absence of a water source; others might be useful for quantitatively estimating the percentage mixing of a water source.

In addition to categorizing tracers as conservative or non-conservative, potential tracers can be divided into two types: inorganic and organic. Organic tracers are generally distinguished from inorganic tracers by the presence of carbon compounds. Organic compounds generally are non-conservative.

Reclaimed water may contain different inorganic and organic constituents than does native ground water. In the San Jacinto Basin, reclaimed water generally differs from native ground water in ionic and isotopic (deuterium and oxygen-18) composition because reclaimed water includes water imported from the

Colorado River or from northern California. In addition, organic compounds in reclaimed water are different than organic compounds present in native ground water because the compounds in reclaimed water are added to water by humans, and may not be completely removed during treatment. Examples of added organic compounds include caffeine and components of detergents. Organic compounds also may be present in surface-water sources, both local and imported, that are not present in native ground water. The differences in composition, whether inorganic or organic, between reclaimed water and native ground water may be useful for tracing reclaimed water in the subsurface.

Inorganic Tracers

Potential inorganic tracers that were measured in ground-water- and reclaimed-water samples include major ions, nutrients, stable isotopes of hydrogen and oxygen, and trace elements. Other properties measured were temperature, specific conductance, dissolved-solids concentration, alkalinity, and pH.

The major ions included in the analyses were calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, bromide, and silica. As mentioned previously, conservative ions have the best potential as tracers. However, the use of major ions as tracers may be constrained if the concentrations of the major ions vary significantly either areally or vertically. Another difficulty is that the amounts introduced into the ground-water system may vary with time; under these circumstances, historical and (or) time-series water-quality data would be needed if mixing is to be assessed.

The analyzed nutrients included nitrate, nitrite, ammonia, and phosphorus. Dissolved nutrients commonly are non-conservative because they tend to be transformed during reduction and oxidation processes. The concentrations of dissolved nutrients may also vary over a wide range in a subbasin owing to the influence of past and present land use, where activities such as feed-lot operations, agriculture, or use of reclaimed water for irrigation may have contributed nutrients to the ground water.

Oxygen-18 (^{18}O) and deuterium (^2H or D), naturally occurring stable isotopes of oxygen and hydrogen, can be used in studies to determine the source of ground water or to trace its movement. Some examples of southern California ground-water studies that utilized isotope data include Izbicki and others (1995, 1998), and Izbicki and Martin (1997). The abundances of oxygen-18 and deuterium are expressed as ratios of per mil (parts per thousand) differences relative to an internationally agreed standard, the Vienna Standard Mean Ocean Water (VSMOW) (Gonfiantini, 1978), using delta notation (δ). The $\delta^{18}\text{O}$ and δD abundances in precipitation are linearly correlated around the world because almost all precipitation originates as evaporation from the ocean. The linear correlation can be graphed, and is known as the meteoric water line (Craig, 1961a,b). Oxygen-18 and deuterium have a greater atomic mass than that of the more common respective isotopes, oxygen-16 and hydrogen. As a result, their abundances in precipitation, relative to the average over time present in water vapor originating from seawater, are influenced by local differences in the temperature of condensation, which is in turn influenced by factors such as altitude, latitude, and climatic regime. The isotopic composition of surface water also can be affected by partial evaporation of the lighter isotopes, leaving the water enriched in the heavier isotopes through the process of fractionation. In these ways, isotopic composition reflecting source and evaporative history of the water is imprinted up until the time of recharge. Following recharge, the isotopic composition may reflect the mixing of the recharged water with the native ground water. Consequently, isotopic-abundance data from ground-water samples may be useful for tracing movement of recharged water in the subsurface.

A trace element is an element, associated with minerals, that may be found at low concentration—typically parts per billion—in water. The dissolved trace elements included in the analyses were arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, silver, strontium, vanadium, and zinc. As with major ions, the natural variability of dissolved trace-element concentrations tends to be large within a ground-water basin. An additional complication in the use of trace elements to investigate subsurface mixing

or movement of reclaimed water is that the trace-element characterization, or “signal,” of reclaimed water commonly is not distinct. However, a trace element that may be distinctive in reclaimed water is boron, especially in settings where boron concentrations are higher in reclaimed water than in the native ground water. In addition, boron is likely to be a conservative tracer: it is not removed during (septic system) treatment (Flynn and Barber, 2000) or likely sorbed during ground-water transport (Barber and others, 1988). However, the utility of boron as a tracer may be limited if there is significant spatial variability in the concentration of boron in the native ground water.

Inorganic-Constituent Mixing Models

Inorganic constituents may be useful indicators of mixing between two types of water. If the concentration of a single constituent in one water (end member) is sufficiently different than the concentration in the other water (second end-member), then that constituent may be suitable as a quantitative indicator of mixing. For example, chloride, a conservative tracer, is commonly used as a single constituent in two-end-member mixing models.

If the concentration of a constituent in a ground-water sample is the result of mixing between two distinct end-members, then the concentration in the sample is a linear function of the concentration in the two end-members. If the two end-members are reclaimed water and native ground water, then the concentration of a mixture is:

$$C_{\text{mix}} = F_{\text{reclaimed}} C_{\text{reclaimed}} + (1 - F_{\text{reclaimed}}) C_{\text{native}} \quad (1)$$

where

C_{mix} is concentration of the constituent in the mixture,

$F_{\text{reclaimed}}$ is fraction of reclaimed water in the mixture,

$C_{\text{reclaimed}}$ is concentration of the constituent in the reclaimed water,

$(1 - F_{\text{reclaimed}})$ is fraction of native ground water in the mixture, and

C_{native} is concentration of the constituent in the native ground water.

Equation 1 can be rearranged so that the fraction of reclaimed water in the ground-water sample is a function of the concentration observed in the ground-water sample and the concentrations observed in the two end-members (reclaimed water and native ground water):

$$F_{\text{reclaimed}} = (C_{\text{mix}} - C_{\text{native}}) / (C_{\text{reclaimed}} - C_{\text{native}}) \quad (2)$$

If the concentration of a single constituent varies significantly in one of the end-member water types, it may be possible to use two constituents simultaneously in a two-end-member mixing model. A two-constituent, two-end-member mixing model is most appropriate when the ratio between constituents within each of the water types is relatively constant and when each constituent behaves conservatively. For example, in some basins, the concentrations of boron and chloride in native ground water may vary over a wide range, and yet the boron/chloride ratio may remain relatively constant. However, when two end-members, each with constant boron/chloride ratios, are mixed, the ratio of the mix will not be a linear function of the boron/chloride ratios of the two end-members. Instead, the boron/chloride ratio of the mix must be calculated from the boron and chloride concentrations of the mix:

$$B_{\text{mix}} = F_{\text{reclaimed}} B_{\text{reclaimed}} + (1 - F_{\text{reclaimed}}) B_{\text{native}} \quad (3a)$$

$$Cl_{\text{mix}} = F_{\text{reclaimed}} Cl_{\text{reclaimed}} + (1 - F_{\text{reclaimed}}) Cl_{\text{native}} \quad (3b)$$

$$R_{\text{mix}} = B_{\text{mix}} / Cl_{\text{mix}} \quad (3c)$$

where

B_{mix} , $B_{\text{reclaimed}}$, and B_{native} are boron concentration in the mix, reclaimed water, and native ground water, respectively,

Cl_{mix} , $Cl_{\text{reclaimed}}$, and Cl_{native} are chloride concentration in the mix, reclaimed water, and native ground water, respectively, and

R_{mix} is ratio of boron to chloride.

Given equations 3a to 3c, a family of mixing curves can be calculated (fig. 3A). Each of the example curves originates at a reclaimed-water end-member assumed to have a single value of boron concentration and a single value of chloride concentration, but terminating at different points. The terminal point for each mixing curve has a different chloride concentration, but the same boron/chloride ratio. The different terminal points can be conceptualized as either representing different ground-water end-members, or as representing a ground water with spatially variable boron and chloride concentrations.

If a set of field samples plot along a single mixing curve (fig. 3A), then the samples may represent a native ground water—with an initial chloride concentration indicated by the terminal point of the curve—that has been mixed with differing proportions of the reclaimed water. The fraction of reclaimed water present in each of the samples can then be estimated using an accompanying plot (fig. 3B). The accompanying plot shows the boron/chloride ratio of the mix as a function of the fraction of reclaimed water, and is based on equations 3a to 3c. For a native ground water with a specified initial chloride value, there is a unique relation between the fraction of reclaimed water and the boron/chloride ratio (fig. 3B).

A set of field data may not plot on a single mixing curve owing to a number of factors, including natural variability in the ratio of boron to chloride, or non-conservative behavior of boron. In these cases, a range for the fraction of reclaimed water can be established. For example, if a data point plots beneath a mixing curve (fig. 4A), then one can shift the point to the right or upward. These two shifts provide two projected points that plot on the mixing curve (fig. 4A). The values of boron/chloride ratio from the projected points provide bounds for the fraction of reclaimed water (fig. 4B). Alternatively, if a point plots above a mixing curve, then one can shift the point to the left or downward; in this manner, two projected points are identified, which, in turn, provide the range for the fraction of reclaimed water.

If a shifted data point has a relatively high boron/chloride ratio, then the estimated fraction of reclaimed water is relatively insensitive to the initial chloride concentration of the native ground water (fig. 3B). For example 1 in figure 3B, the fraction of

reclaimed water ranges from about 92 percent to about 99 percent for a corresponding range in initial chloride concentration of 500 mg/L to 4,000 mg/L. In contrast, if a shifted data point has a relatively low boron/chloride ratio, then the estimated fraction of reclaimed water is relatively sensitive to the initial chloride concentration of the native ground water (fig. 3B). For example 2 in figure 3B, the fraction of reclaimed water ranges from about 25 percent to about 75 percent for a corresponding range in initial chloride concentration of 500 mg/L to 4,000 mg/L.

Organic Tracers

The potential exists for reclaimed water to contain any number of the hundreds of the organic compounds that are used in urban, agricultural, and industrial environments. These compounds commonly include pesticides, herbicides, solvents, detergents, pharmaceuticals, and hydrocarbons. Analysis for large numbers of organic compounds can become cost prohibitive, even if the number of samples is small. To determine if an organic compound might be used as a tracer for movement of reclaimed water that has infiltrated from the storage ponds, a suite of organic compounds were analyzed for samples from each of the RWRFs, the three selected ponds, and subsets of the network wells. The analyses included total organic carbon (TOC), dissolved organic carbon (DOC), methylene blue activated substances (MBAS), linear alkylbenzene sulfonate (LAS), ethylenediaminetetraacetic acid (EDTA), caffeine, and ultraviolet absorbance (UV-A) at 254 nm.

The various forms of dissolved carbon may serve as tracers if there are contrasts in concentrations in reclaimed water in comparison with native ground water. TOC, a measure of the concentration of all forms of organic carbon present in a sample, generally is less in ground water than in reclaimed water owing to the many sources of both biogenic and synthetic organic compounds contributed to reclaimed water, and to the incomplete removal of organic carbon during treatment. In addition, ground water generally is expected to have lower TOC values than those of reclaimed water owing to adsorption and biodegradation processes during ground-water recharge and movement (Flynn and Barber, 2000).

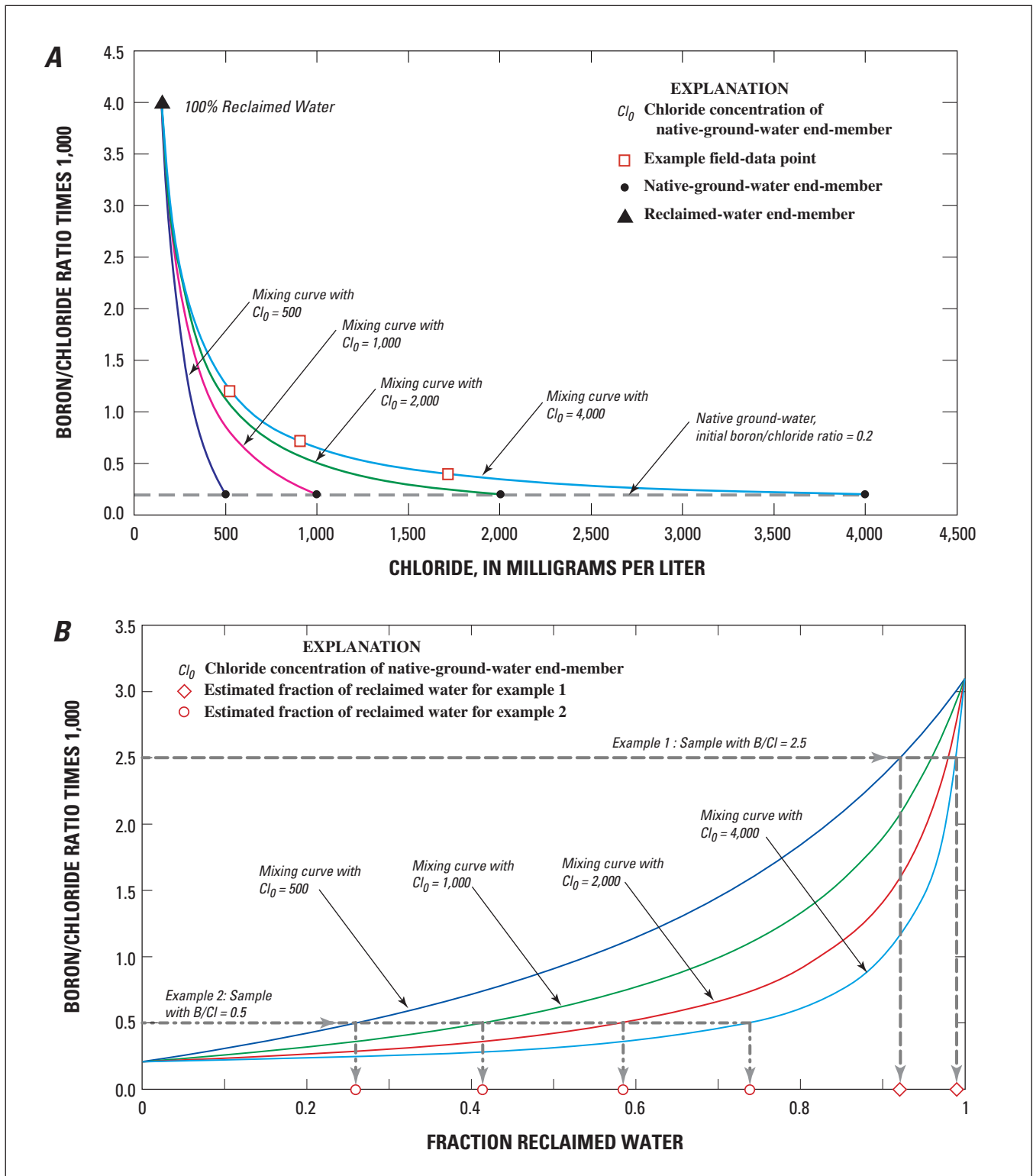


Figure 3. Example boron/chloride-ratio mixing curves. (A) Calculated family of mixing curves based on boron/chloride ratio plotted against chloride. One end-member is defined by boron and chloride values for reclaimed water, and the other end-member is defined by values for native ground water with chloride concentrations of 500, 1,000, 2,000, and 4,000 mg/L, respectively; all native ground waters have a $B/Cl = 0.2$. (B) Calculated family of mixing curves based on boron/chloride ratio plotted against fraction reclaimed water. The two diamonds represent the fraction of reclaimed water for a ground-water sample with a $B/Cl = 2.5$ mixed with two different native ground waters. The four circles represent the fraction of reclaimed water for a ground-water sample with a $B/Cl = 0.5$ and four different native ground waters.

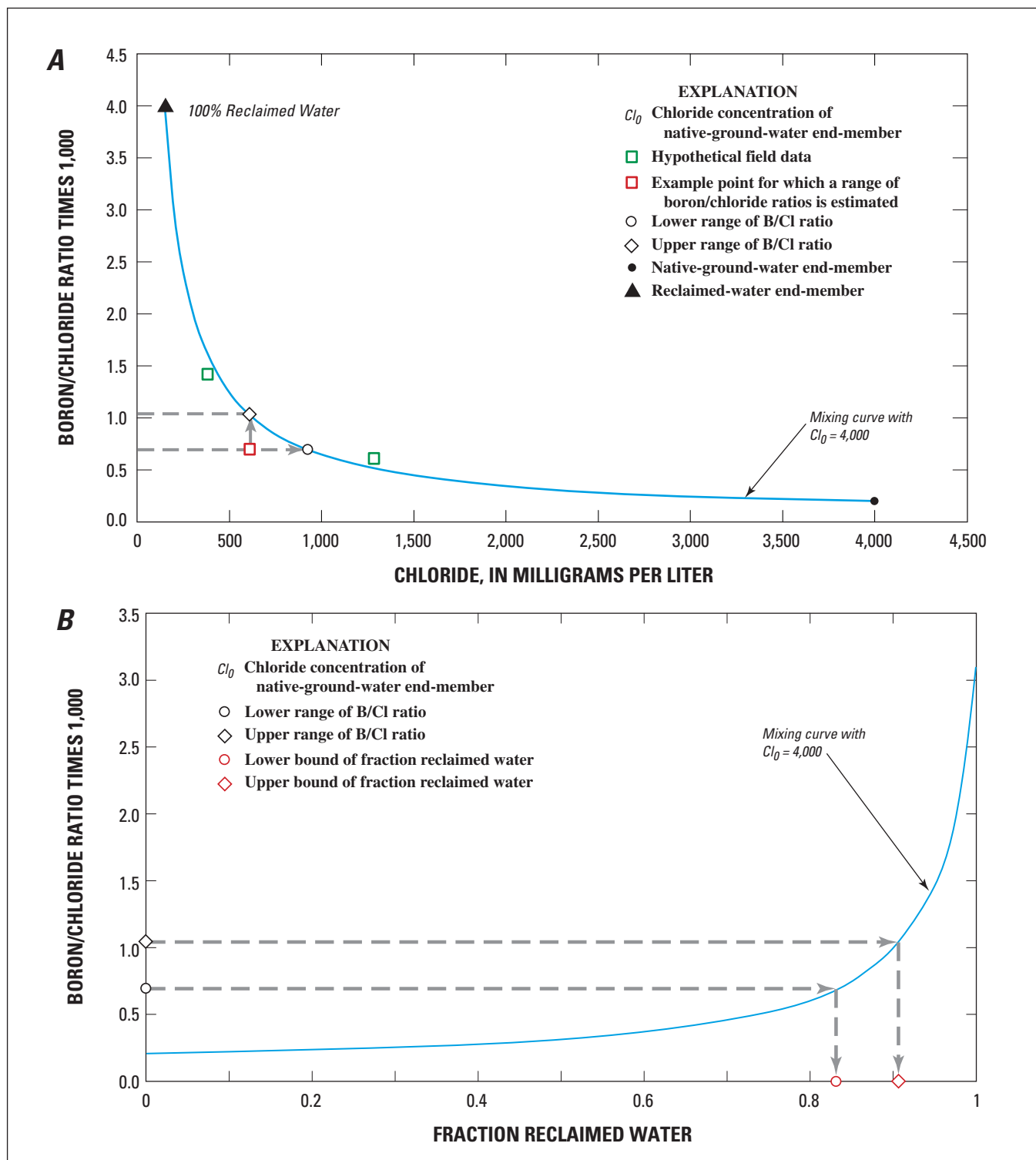


Figure 4. Example mixing curves and hypothetical field data. (A) Calculated mixing curve based on boron/chloride ratio plotted against chloride. Example of projecting a field-sample data point onto the mixing curve. (B) Calculated mixing curve based on boron/chloride ratio plotted against fraction reclaimed water. Example of use of the curve to estimate the fraction of reclaimed water.

MBAS, LAS, and EDTA (organic components of detergents) and caffeine, might be expected to be present in reclaimed water, and therefore are potential tracers. However, these compounds also have limitations. MBAS may not be a reliable tracer of reclaimed water owing to chloride interference (Burkhardt and others, 1995). LAS, degradable under aerobic conditions, is non-conservative. EDTA was found to be a useful indicator of infiltrated municipal wastewater in Los Angeles County, California (Barber and others, 1997); Barber and others (1997) assumed that EDTA was a conservative tracer because it is not believed to undergo significant biodegradation or to sorb strongly to sediments. A potential drawback to the use of caffeine as tracer is that it can be removed from water biologically, and therefore is non-conservative.

Measurement of the absorption of light, such as ultraviolet-light absorbance at selected wavelengths, can show qualitative differences in the composition of DOC from different sources. For example, the absorption properties of synthetic detergent organic compounds are different than those of natural organic material. The absorbance is related to the molecular structure of specific functional groups within complex carbon molecules, and to the concentration of those molecules. Maximum absorbance generally occurs at a wavelength of about 254 nm and is indicative of aromatic rings that form the building blocks of many organic compounds (Izbicki and others, 2000). Elevated DOC concentrations can be associated with reclaimed water in some situations (Barber and others, 1997; Leenheer and others, 2001). In some previous studies, UV-A measurements have been used as a surrogate for DOC concentrations (California Department of Water Resources, 1994), with variable results. In another study (Izbicki and others, 2000), UV-A was compared with DOC concentrations to examine qualitative differences in DOC composition between early-season and late-season stormflows. In the present study, an objective was to determine if UV-A can be used as an indicator of infiltrated reclaimed water in the three subbasins, either with or without elevated values of DOC. Because DOC can include a wide range of different compounds, each of which may absorb UV energy differently, the UV-A measured in ground-water samples may not be a simple function of DOC concentration.

TRACING RECLAIMED WATER IN THE THREE SUBBASINS

Reclaimed water is introduced to the ground-water flow systems in the Menifee, Winchester, and Perris-South subbasins by two principal mechanisms: percolation from storage ponds and from irrigation of fields. Preliminary analysis of the water-quality data collected for this study indicates that reclaimed water originating as percolation from ponds is more easily traced than is reclaimed water applied as irrigation. Percolation from ponds is a more localized source, and the local history of irrigation using reclaimed water is not as well documented. Therefore, our analysis focuses primarily on water samples collected from the ponds and from wells located near the ponds.

When interpreting water-quality data, both the proximity of the sampled wells to the reclaimed-water storage ponds and the depth of the perforated intervals of the sampled wells should be considered. A generalized conceptual-model diagram ([fig. 5](#)) shows a hypothetical plume of reclaimed water infiltrating from a pond, and examples of some possible well-location/depth combinations representing a variety of theoretical sampling situations relative to the plume. For example, in the conceptual model, well 3 would be the well with the highest proportion of reclaimed water, and therefore highest concentration of reclaimed water indicators. Other wells with a deep perforated interval, such as wells 5 and 6, also can show relatively elevated proportions of reclaimed water even though they are located relatively far from the ponds. In the conceptual model, wells with perforated intervals located above the plume, such as wells 2 and 7, will contain little to no reclaimed water (and reclaimed water indicators), even if these wells are located close to the ponds. In contrast, well 8, located away from the plume associated with the pond, can contain some reclaimed water due to infiltration from the overlying field irrigated using reclaimed water. This conceptual model illustrates the importance of considering the hydrologic position of wells relative to sources of reclaimed water.

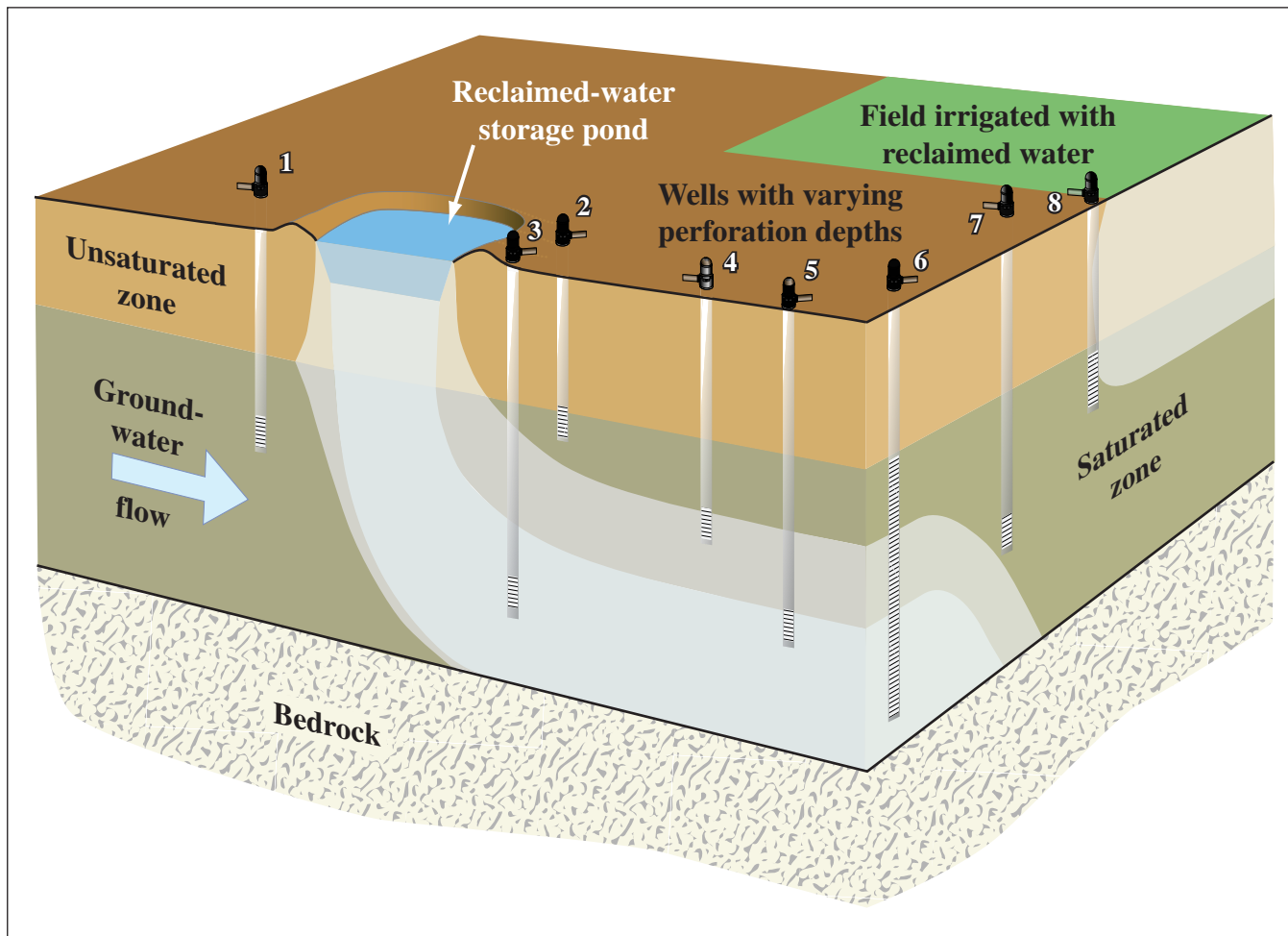


Figure 5. Conceptual model of reclaimed-water infiltration, ground-water flow, and well positions.

Water samples were collected from three Regional Water Reclamation Facilities (RWRFs), from three sets of storage ponds that receive water from the treatment facilities, and from selected ground-water wells in the Menifee, Winchester, and Perris-South subbasins (fig. 2). These samples were analyzed for major ions, nutrients, selected trace elements, stable isotopes of hydrogen and oxygen, and organic carbon. Also, some of the samples were analyzed for ultraviolet absorbance (UV-A) at a wavelength of 254 nm, methylene blue active substances (MBAS), linear alkylbenzene sulfonate (LAS), and caffeine, each of which might be useful as an organic tracer of infiltrated reclaimed water. The results of the water-quality analyses are given in table 1 (at back of report).

Several of the organic compounds analyzed were not used in this study for evaluating the presence of reclaimed water in the subsurface. MBAS analysis

was run for 27 ground-water samples, but MBAS was not analyzed for the samples from the RWRFs or storage ponds; MBAS was detected at similar concentrations in all 27 ground-water samples. Therefore, MBAS was not suitable as a tracer for reclaimed water in this study. LAS was detected in three ponds and one of the RWRFs, but not in any of the nine well samples for which this analysis was run. Therefore, LAS was not suitable as a tracer. Owing to logistical problems, EDTA analysis in the present study was done only for the RWRFs and the three pond sites. Analysis for caffeine was done for samples from the RWRFs, the three ponds, and nine wells. Caffeine was found at, or slightly above, the detection limit in samples from 1 RWRF and 2 ponds, and in none of the 11 wells for which this analysis was run. Therefore, caffeine was not suitable as a tracer of reclaimed water in this study.

Menifee Subbasin

Ground-water quality in the Menifee subbasin is generally poor. The concentration of dissolved solids (residue on evaporation) exceeded 500 mg/L in 17 of the 18 wells sampled, and exceeded 1,000 mg/L in 16 of the wells. The median concentration was about 2,400 mg/L. In contrast, the dissolved-solids concentration in the reclaimed-water samples obtained from the Sun City RWRf and Sun City Pond no.7 was 763 (computed) and 864 mg/L, respectively.

A trilinear diagram (Piper, 1944) of water analyses from the Menifee subbasin ([fig. 6](#)) shows that the chemical composition is variable. No predominant water type exists for the subbasin. Two groups can be identified on the basis of anions: a low-sulfate group and a low-bicarbonate group. Within the low-sulfate group, chloride and bicarbonate each range from about 10 to about 90 percent. Within the low-bicarbonate group, chloride ranges from about 20 to about 80 percent, and sulfate ranges from about 10 to about 60 percent. Unlike the anions, there is some tendency toward one predominant cation: sodium accounts for more than 50 percent of the cations in about half of the samples. Water samples from the RWRf and the pond show the presence of all three major anions in about equal proportions ([fig. 6](#)), and show sodium as the predominant cation. Consequently, major-ion composition alone is not sufficient as an indicator of the presence of reclaimed water in the subsurface of the Menifee subbasin.

Stiff diagrams for water samples from the Menifee subbasin, like the Piper trilinear diagram, show that the chemical composition in the Menifee subbasin is variable. The Stiff diagrams plotted on a map ([fig. 7](#)), unlike the trilinear diagram, are able to show the spatial and vertical (where multiple-completion wells were sampled) variability of chemical composition. In general, both ground water close to the

ponds and reclaimed water tend to have lower concentrations of dissolved ions than does ground water farther from the ponds ([fig. 7](#)). These patterns suggest that selected constituents may be useful as indicators in the Menifee subbasin.

Selected chemical constituents may be useful as tracers of reclaimed water if the hydrology of the flow system is understood. Reclaimed water in the Menifee subbasin enters the ground-water flow system primarily as infiltration from the Sun City storage ponds, which are located in the southwestern part of the subbasin. Ground-water flow ([fig. 8](#)) based on 1995 data from Burton and others (1996, [figs. 10, 11, and table 3](#)) is away from the storage ponds, both toward the northeast and the southwest. Given the opposite directions of flow in the vicinity of the ponds, a ground-water divide likely is located in that area. The precise location of the ground-water divide is not known, but the 1995 ground-water-level data indicate that it was near the southwest edge of the ponds. It is likely that the location of the divide shifts in response to management of water levels in the ponds.

Major-ion data from wells located near the ponds indicate mixing of reclaimed water and downgradient native ground water. Ground water downgradient and near the ponds (wells 32B1, 32C1, 32G1, and 32H1) is lower in dissolved-solids concentration than is water in the well that is located upgradient and near the ponds (32L1) ([fig. 7](#), and [table 2](#)). Also, there is a shift in chemical composition: the dominant anion is chloride in the upgradient well, and sulfate in the downgradient wells. The lowering of dissolved-solids concentrations and shift in chemical composition along the flow path indicate mixing of relatively saline, sodium/calcium-chloride native ground water, and relatively fresh sodium-sulfate reclaimed water. The high concentration of dissolved solids at well 32A1 suggests that the dissolved-solids concentration of native ground water can vary widely.

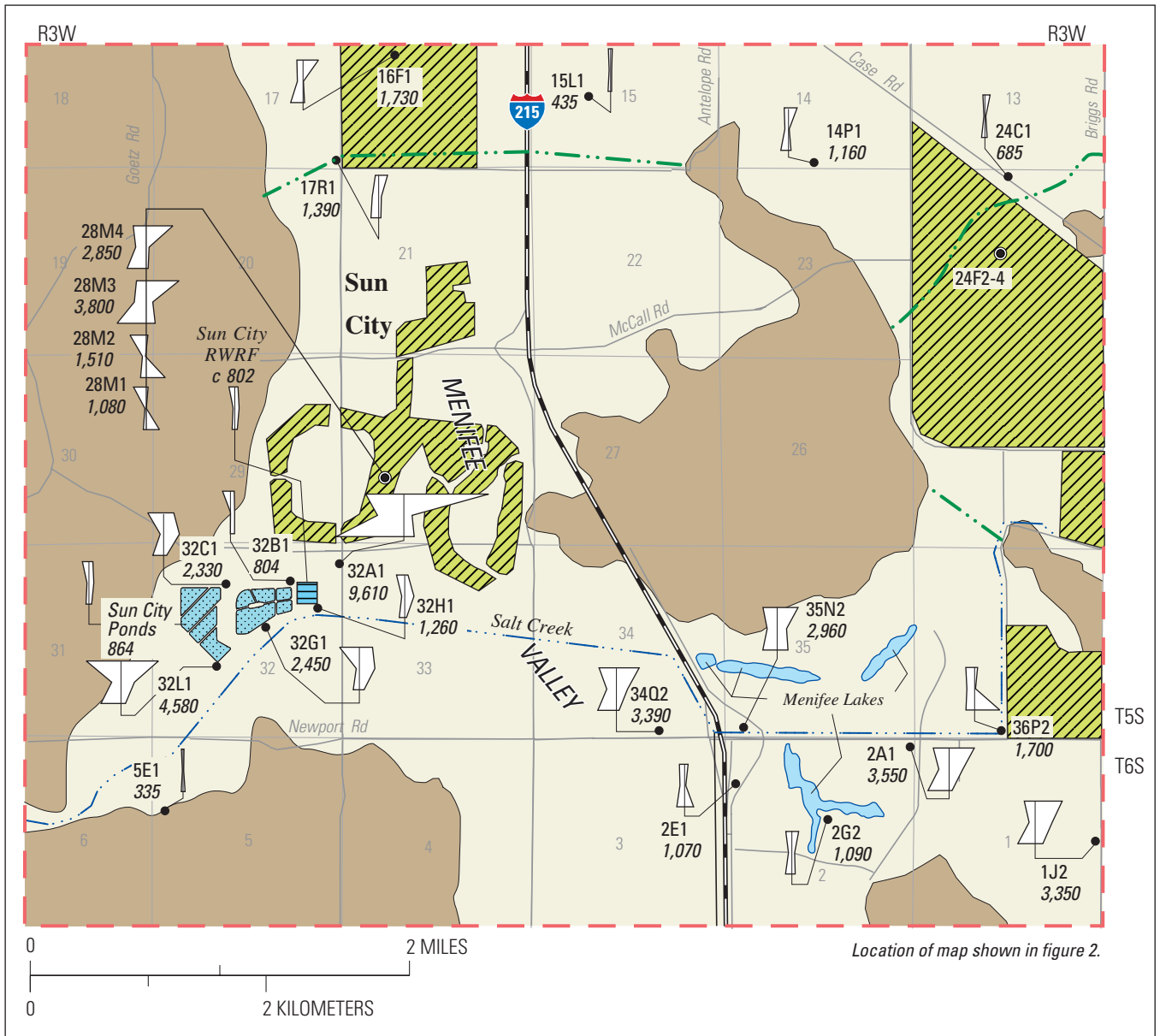


Figure 7. Stiff diagrams for selected wells and reclaimed-water storage ponds, and the Sun City reclamation facility, Menifee subbasin, Riverside County, California.

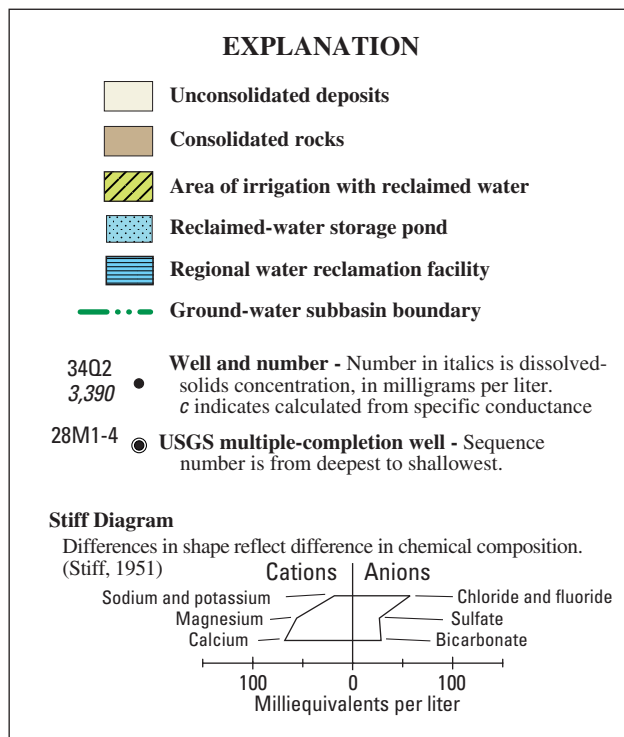


Figure 7.—Continued.

In the Menifee subbasin, stable isotopes of hydrogen and oxygen (fig. 9) are useful for distinguishing between ground water and reclaimed water. Eighteen wells in the subbasin were sampled for analysis of stable isotopes; 15 of the analyses plot along or near the global meteoric water line, indicating recharge from local precipitation. In contrast, analyses of reclaimed-water samples from the Sun City RWRf and storage ponds plot to the right and below the global meteoric water line, reflecting both the isotopically lighter original source of the reclaimed water (water imported from the Colorado River) and its evaporative history. Water from the remaining three wells (32B1, 32C1, and 32H1) has an isotopic composition similar to that of the water from the RWRf and storage pond (fig. 9), suggesting the presence of reclaimed water in the subsurface at these well locations. These are three of the four wells that are physically close to and downgradient from the storage ponds, and that show a decrease in dissolved-solids and chloride concentrations from 1993 (Burton and others, 1996, table 2) to 1995 (table 1). Water from the fourth well (32G1) is shifted away from the meteoric water line, but not as much as water from the other three wells.

Ultraviolet absorbance (UV-A) also is useful for identifying the presence of reclaimed water in the subsurface. The UV-A values for reclaimed water from the Sun City RWRf and storage pond are 0.17 and 0.15, respectively (rounded, table 1). The three ground-water samples that are isotopically similar to the reclaimed-water samples (wells 32B1, 32C1, and 32H1) have UV-A values ranging from 0.02 to 0.06. A fourth well, 32G1, has a UV-A value of 0.007, and also has stable isotope values that are shifted away from the meteoric water line toward the values of reclaimed water (fig. 9). In contrast, water from well 32L1, located near and upgradient from the ponds, has an isotopic composition and a UV-A value (0.003) that are similar to those of ground water from wells located relatively far from the storage ponds, thus suggesting the absence of reclaimed water at that location. All four of the downgradient wells located near the ponds have chemical compositions indicative of the presence of reclaimed water. These results suggest that the threshold value for UV-A as an indicator of the presence of reclaimed water in ground water in the Menifee subbasin is approximately 0.007.

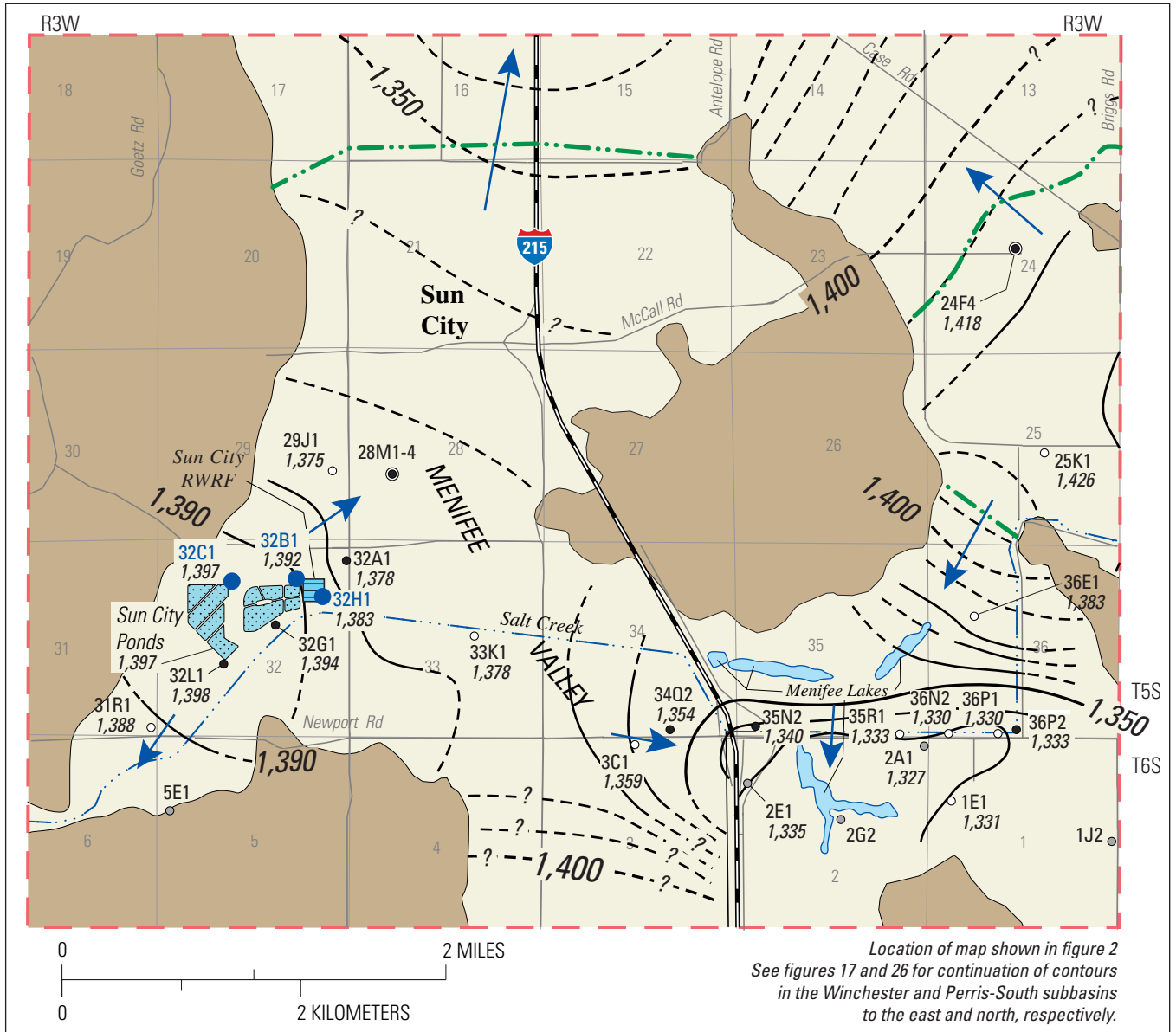


Figure 8. Water-level contours, directions of ground-water flow, and wells with ultraviolet-absorbance data in the Menifee subbasin, Riverside County, California.

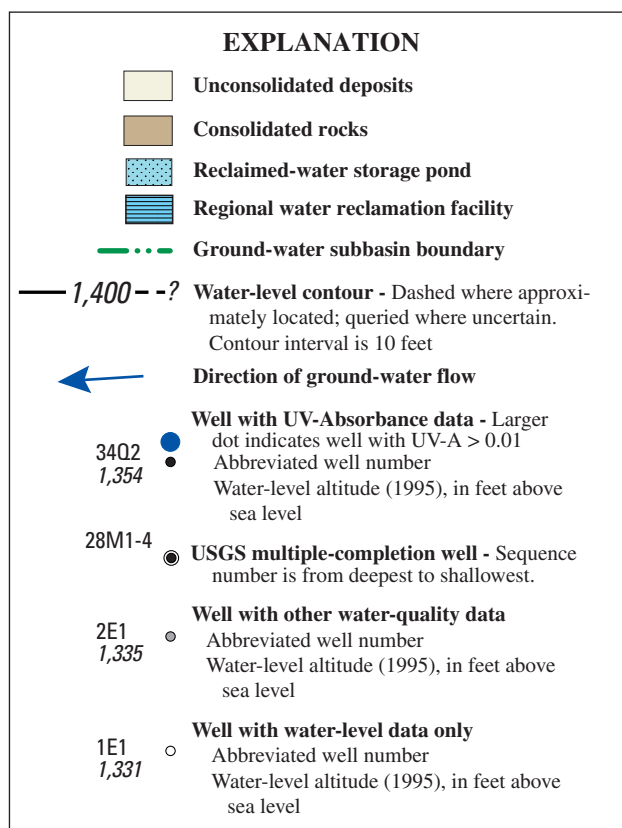


Figure 8.—Continued.

Table 2. Dissolved-solids (residue on evaporation) and chloride concentrations for selected wells located adjacent to the Sun City Ponds, Menifee subbasin, Riverside County, California

[Site name: RWRF, Sun City Regional Water Reclamation Facility; POND, Sun City Reclaimed Water Storage Pond no.7; abbreviated State well numbers, all are 5S/3W-___(see “Well-Numbering System” at front of report); perforated interval in feet below land surface, from Burton and others (1996); water-quality data collected in summer 1995; mg/L, milligrams per liter; —, no data]

Site name or State well No.	Perforated interval	Dissolved solids (mg/L)	Chloride (mg/L)	Location of well relative to ponds
RWRF	—	763 ¹	130	—
POND	—	864	160	—
32L1	200–220	4,580	1,600	Upgradient (near)
32B1	200–220	804	130	Downgradient
32C1	200–220	2,330	430	Downgradient
32G1	200–220	2,450	520	Downgradient
32H1	200–220	1,260	150	Downgradient

¹Dissolved-solids value computed using method described by Fishman and Friedman (1989).

As shown in [figure 10](#), ground-water samples can have elevated values of UV-A (indicating the presence of reclaimed water) without having elevated values of dissolved organic carbon (DOC). The four wells with elevated UV-A values have DOC values within the range of DOC observed in wells not having elevated UV-A. The lack of correspondence between UV-A and DOC may occur for two reasons: (1) UV-A at 254 nm is sensitive only to certain types of organic matter; and (2) other dissolved compounds also may absorb ultraviolet light (Izbicki and others, 2000; California Department of water Resources, 1994; Krazner and others, 1996). Therefore, in some cases, UV-A is a better indicator than is DOC for tracing reclaimed water. Also, in those cases, the common practice of dividing UV-A values by DOC concentrations (Leenheer and others, 2001) may lessen the usefulness of UV-A as a tracer.

As noted previously, reclaimed water in the Menifee subbasin is characterized by relatively low concentrations of chloride and elevated values of UV-A. Wells with high UV-A (and water that is isotopically similar to reclaimed water) also have low chloride concentrations (wells 32B1, 32H1, 32C1, and 32G1) ([fig. 11](#)). However, wells with low chloride concentrations do not necessarily contain reclaimed water. For example, wells 36P2, 28M1, and 28M2 have intermediate values of UV-A (0.003 to 0.007) and values of chloride that are even less than those for the RWRF and pond. These wells, which are located in areas of irrigation with reclaimed water, but not near the ponds, are perforated at depths starting at 365 ft or more below land surface; therefore, they may not contain a large percentage of reclaimed water, and the low chloride values may simply represent those of native ground water in that part of the subbasin.

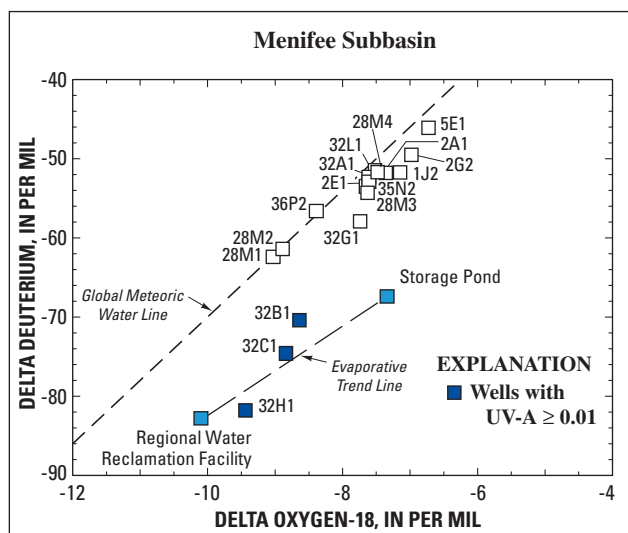


Figure 9. Delta deuterium plotted against delta oxygen-18 for selected wells in the Menifee subbasin, Riverside County, California.

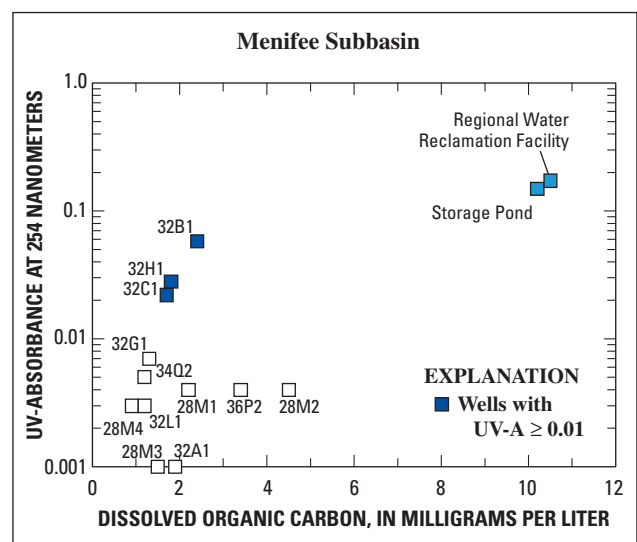


Figure 10. Ultraviolet-absorbance at 254 nanometers plotted against dissolved organic carbon for selected wells in the Menifee subbasin, Riverside County, California.

The UV-A values for samples from the four wells with water that is isotopically similar to that of reclaimed water help to distinguish, and suggest mixing, between native ground water and reclaimed water. One way to estimate the extent of mixing, and to evaluate UV-A as a tracer, is to compare two sets of mixing calculations: one using chloride, a known conservative constituent, and the other using UV-A. The estimated percent reclaimed water, calculated on the basis of chloride concentrations, at the four downgradient wells ranges from 75 to 102 percent (table 3). When calculated using UV-A instead of chloride, the estimated percent reclaimed water in ground water at the same well sites ranges from 3 to 38 percent. Comparison of these two sets of calculations shows that UV-A is a non-conservative tracer. In addition, the mixing calculations based on chloride (a conservative tracer) suggest that a minimum mixture of about 75-percent reclaimed water might be needed for a recognizable UV-A signal to be seen in ground water in the Menifee subbasin. (A minimum of 75 percent reclaimed water might be needed because the UV-A based percent reclaimed water for that same sample is only 3 percent (table 3); water that contains less than 75 percent reclaimed water may not necessarily have an elevated UV-A value.)

Boron, a trace element, also is useful for identifying the presence of reclaimed water in the subsurface in the Menifee subbasin. Wells with elevated UV-A also have relatively high concentrations of boron, as shown in figure 12: the same four wells for which the presence of reclaimed water is indicated by isotope and UV-A data (wells 32B1, 32C1, 32H1, and 32G1) have higher concentrations of dissolved boron than do all but one of the wells (35N2) tested for boron in the Menifee subbasin, and the boron concentrations from these four wells are similar to those from the RWRWF and pond. However, elevated values of boron do not necessarily indicate reclaimed water, as shown by the UV-A and boron data for well 35N2 (high boron, low UV-A) and wells 32L1, 32A1, and 36P2 (high boron and intermediate-to-low UV-A) (fig. 12).

The ratio of boron to chloride can be used to trace reclaimed water in the Menifee subbasin, and to estimate the extent of mixing at specific locations. A plot of boron/chloride versus chloride concentrations (fig. 13A) suggests threshold values for indicating the presence of reclaimed water: all of the wells with elevated UV-A plot within a region approximately defined by boron/chloride ratios above 1.0 and chloride concentrations ranging from 130 mg/L (the value for the RWRWF reclaimed water) to 520 mg/L.

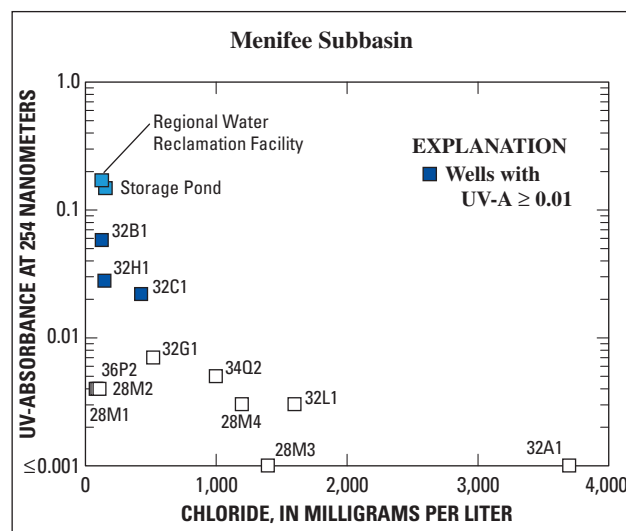


Figure 11. Ultraviolet-absorbance at 254 nanometers plotted against dissolved chloride for selected wells in the Menifee subbasin, Riverside County, California.

The proportion of reclaimed water in a ground-water sample can be estimated from the observed boron/chloride ratios and chloride values of the sample and hypothetical boron/chloride mixing curves. For example, the mixing curve in [figure 13B](#) shows the result of mixing native ground water, assumed to be represented by the boron and chloride concentrations measured at well 32L1, and reclaimed water, represented by the concentrations measured in the Sun City storage-pond sample. The wells with elevated UV-A (32C1, 32G1, 32H1, and 32B1) plot relatively close to the calculated mixing curve, suggesting that

these ground-water samples are mixes of the two proposed end-members. Given the proposed mixing model, water from wells 32C1 and 32G1, with boron/chloride ratios of about 1, consists of nearly 80 percent reclaimed water ([fig. 14](#) and [table 3](#)). Water from wells 32H1 and 32B1, with boron/chloride ratios greater than 2.5, consists of about 98 percent reclaimed water. The percentages based on boron/chloride ratios are similar to the percentages based on chloride alone ([table 3](#)). This correspondence is expected for data points that plot relatively close to a single mixing curve.

Table 3. Calculated percentage of reclaimed water in ground water at selected wells located adjacent to the Sun City Ponds, Menifee subbasin, Riverside County, California

[Percentages based on a two-end-member mixing model; chloride and UV-A values for reclaimed-water end-member based on data collected at Sun City pond no.7; values of chloride, UV-A, and boron/chloride ratio for native-ground-water end member based on data collected at well 32L1, located upgradient from the Winchester ponds; well No, abbreviated State well number: all are 5S/3W-____(see “Well-Numbering System” at front of report); UV-A, ultraviolet absorbance at 254 nanometers; —, no data]

State well No.	Percent reclaimed water based on chloride	Percent reclaimed water based on UV-A	Percent reclaimed water based on boron/chloride ratio
32L1	0	0	—
32B1	102	38	98
32C1	81	13	80
32G1	75	3	80
32H1	101	17	98

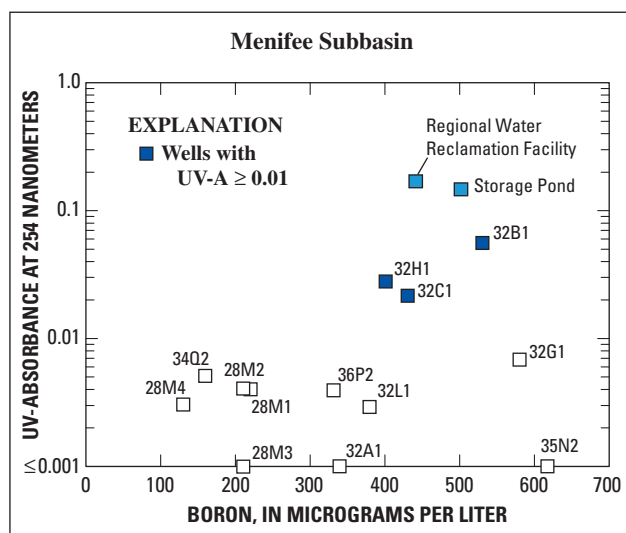


Figure 12. Ultraviolet-absorbance at 254 nanometers plotted against dissolved boron for selected wells in the Menifee subbasin, Riverside County, California.

Winchester Subbasin

Ground-water quality in the Winchester subbasin is generally poor. The concentration of dissolved solids (residue on evaporation) exceeds 1,000 mg/L in 10 of the 11 wells sampled in the central and western parts of the subbasin ([table 1](#)), with a median concentration of about 3,300 mg/L. In contrast, the dissolved-solids concentration in the samples obtained from the Temecula RWRf and Winchester Storage Pond B are 686 and 772 mg/L, respectively. A Piper trilinear plot for samples from the Winchester subbasin ([fig. 15](#))

indicates that the ground water ranges from calcium-chloride to sodium-chloride composition; there is no predominant anion in the reclaimed water, but sodium is the predominant cation. As in the Menifee subbasin, major-ion composition alone is not sufficient for identifying the presence of reclaimed water in the subsurface. However, Stiff diagrams ([fig. 16](#)) do indicate that concentrations and chemical composition vary spatially, both areally and vertically. Therefore, selected constituents may be useful as indicators of reclaimed water in the subsurface if the ground-water hydrology is understood.

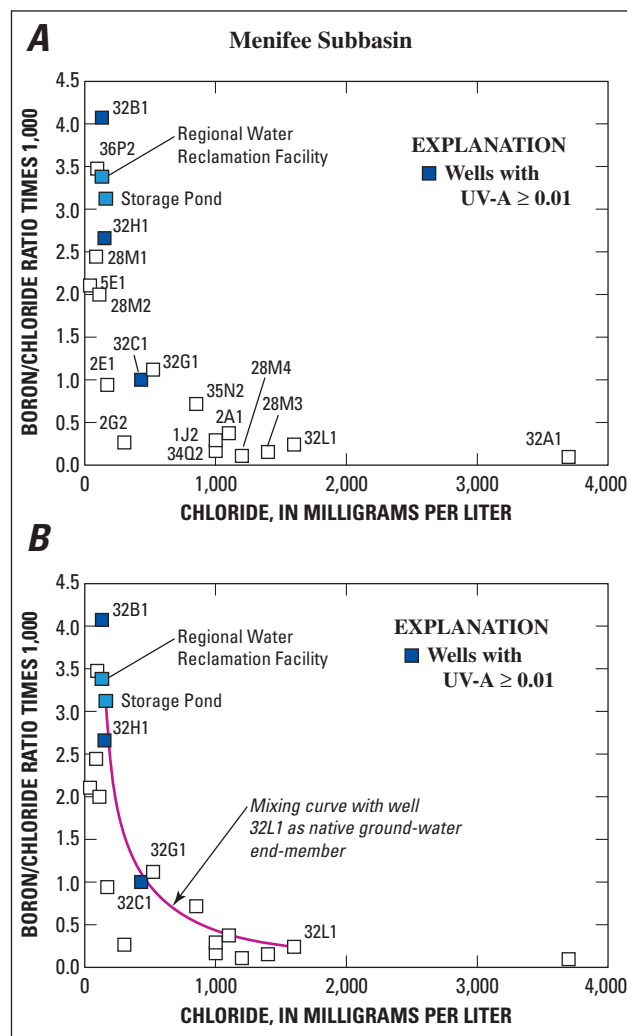


Figure 13. Boron/chloride ratio plotted against dissolved chloride for selected wells in the Menifee subbasin, California, without and with a superimposed mixing curve. (A) Boron/chloride ratio plotted against dissolved chloride. (B) Boron/chloride ratio plotted against dissolved chloride with a superimposed mixing curve. Mixing curve is based on well 32L1 as representative of native ground water and the RWRf as representative of reclaimed water.

Ground-water flow in the Winchester subbasin is generally from east to west (fig. 17, 1995 data). In the immediate vicinity of the Winchester Storage Ponds there is a southwesterly component of flow away from the ponds, indicating recharge to the ground water from the ponds. The influence of this recharge can be seen in the general differences in water quality between wells located downgradient and upgradient from the ponds. Ground-water levels in the vicinity of the ponds vary with time (Burton and others, 1996, figs. 10, 11, and table 3), and therefore flow directions also vary with time. Indeed, the Winchester Storage Ponds sometimes receive ground-water inflow (Burton and others, 1996). Water quality, however, tends to reflect long-term trends. Ground water from wells located downgradient

and relatively near the ponds (wells 30C1, 30G3, 30D2, and 30G2) is lower in dissolved-solids concentration, particularly sodium and chloride, than is water from the well located upgradient and near the ponds (30H2) (table 4; figs. 16, 17). The lowering of dissolved-solids concentrations along the flow path indicates dilution of relatively saline ground water with relatively fresh reclaimed water. Also shown in table 4 are concentrations of dissolved solids and chloride in samples from two wells (29L2 and 29L3) that are farther upgradient from the ponds than 30H2; the lower concentrations at 29L3 might reflect natural variability or the influence of reclaimed water from a source other than the storage ponds, such as irrigation using reclaimed water.

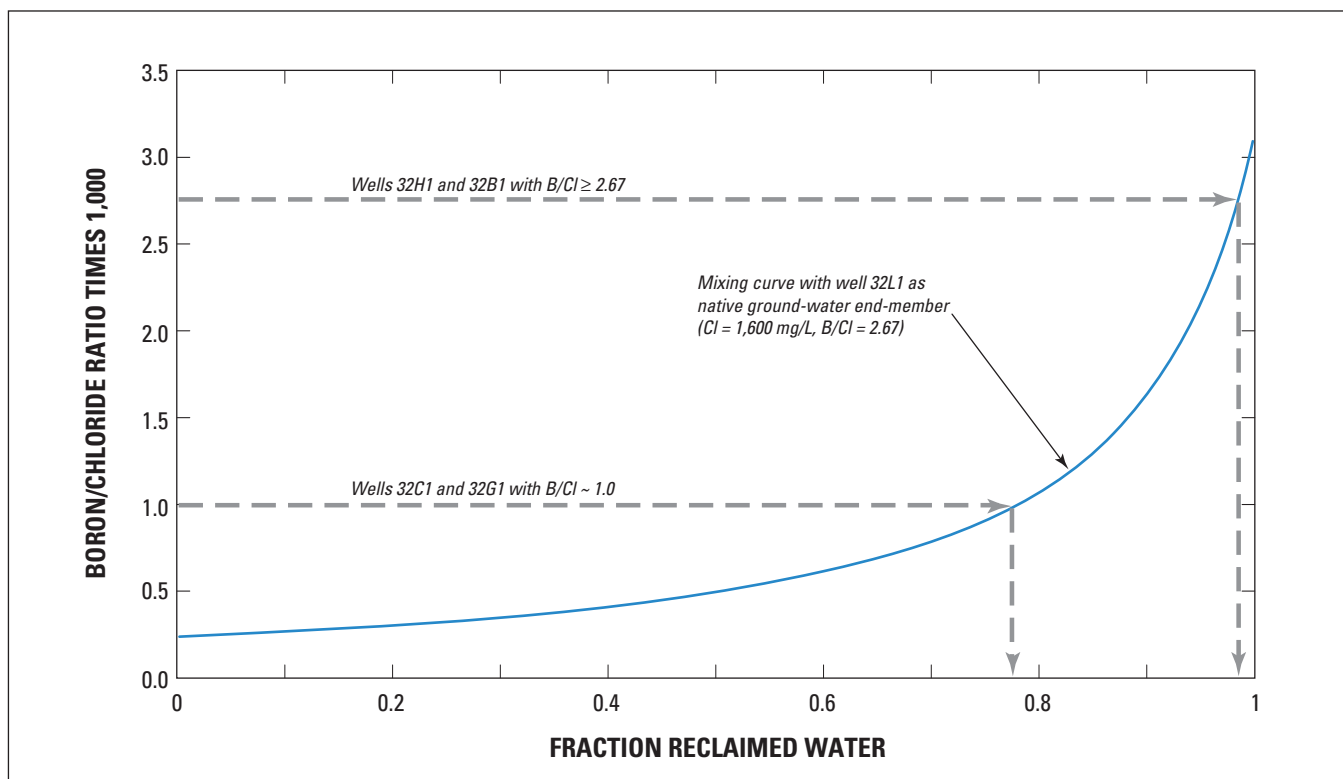


Figure 14. Estimation of fraction reclaimed water, plotted against boron/chloride ratio, generated using a two-end-member mixing model for water in the vicinity of the Sun City storage ponds, Menifee subbasin, Riverside County, California.

Winchester Subbasin,
including USGS Multiple-completion Well 24F2-4

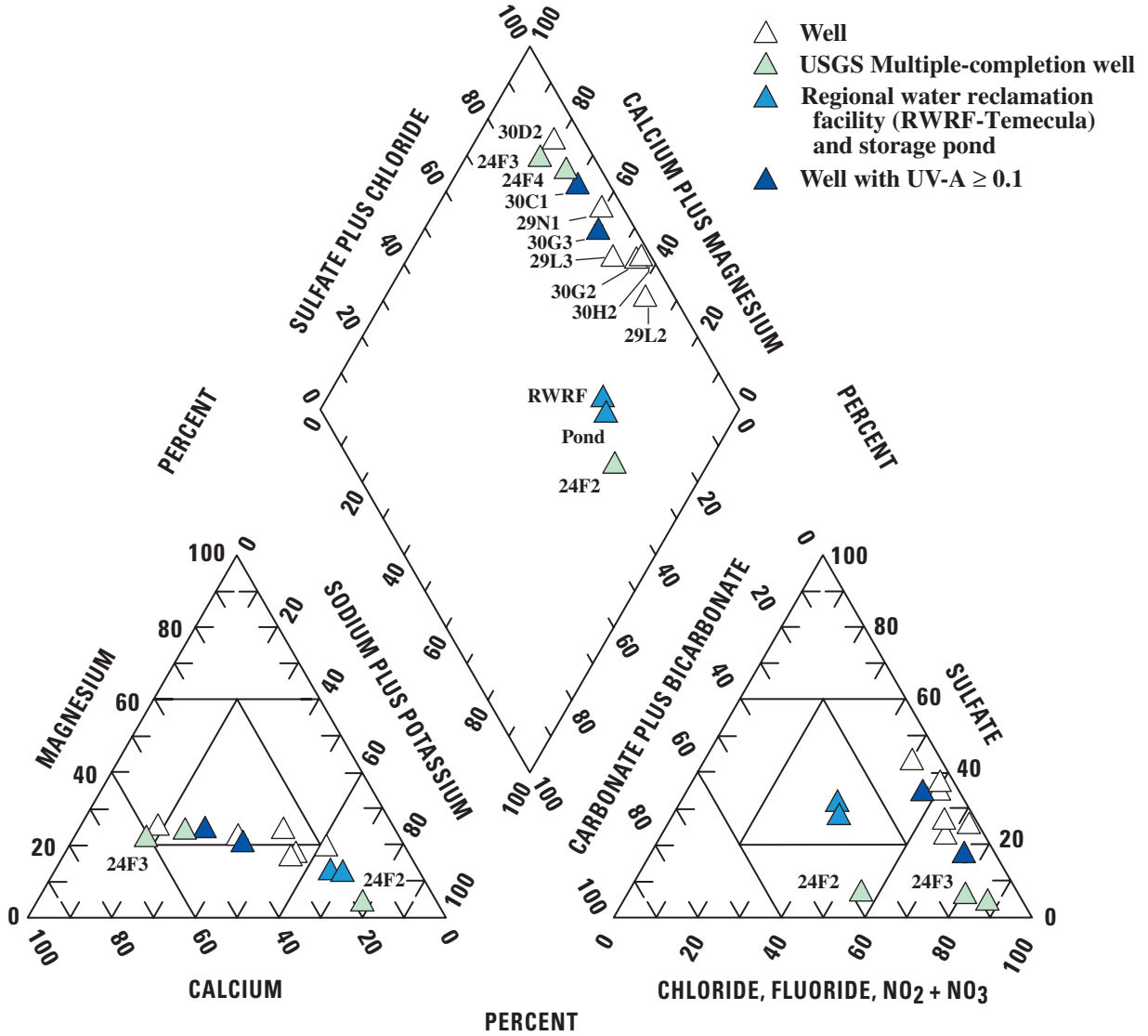


Figure 15. Piper trilinear plot of major-ion concentrations for selected wells in the Winchester subbasin, Riverside County, California.

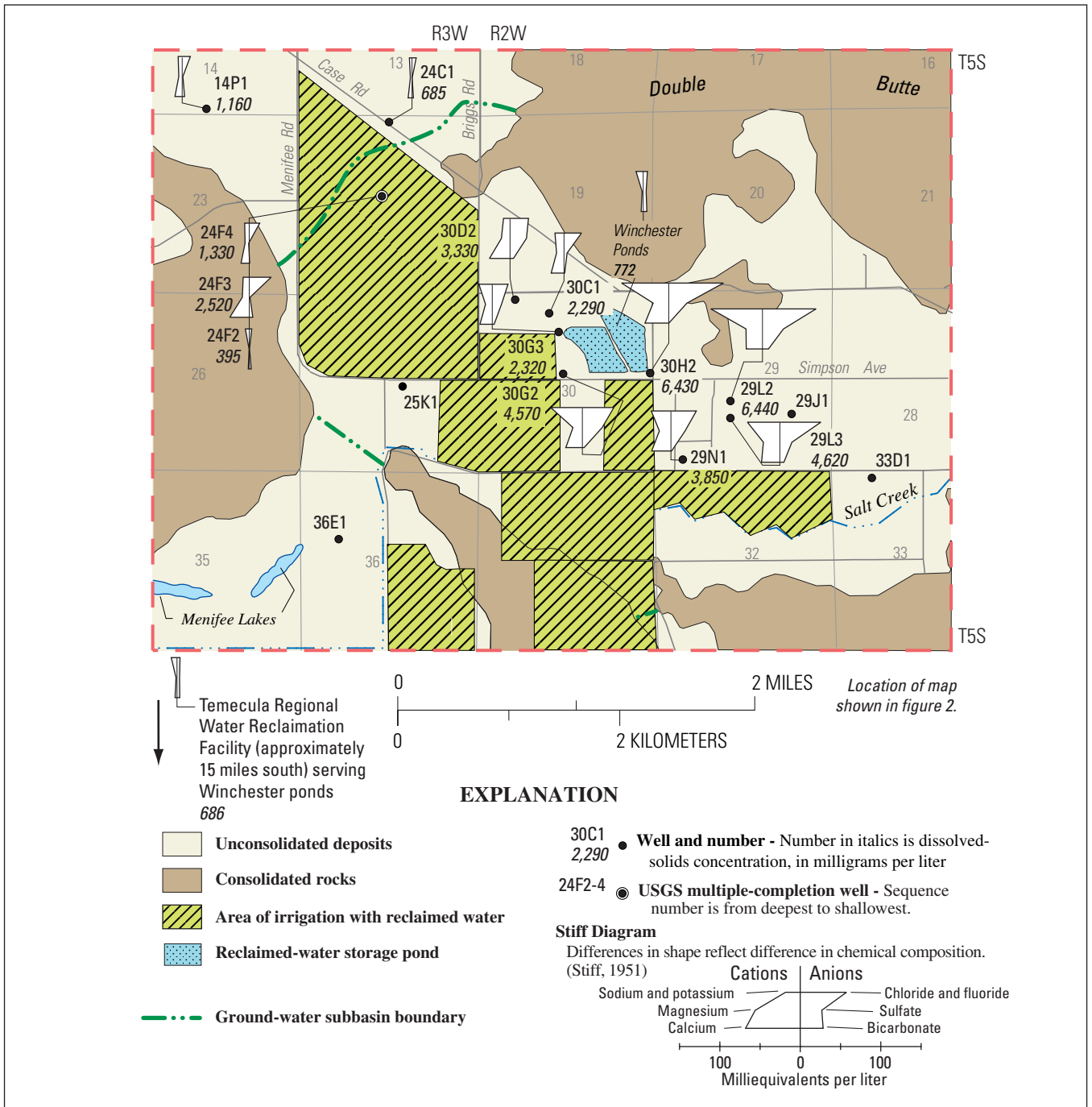


Figure 16. Stiff diagrams for selected wells and reclaimed-water storage ponds, and the Temecula reclamation facility, Winchester subbasin, Riverside County, California.

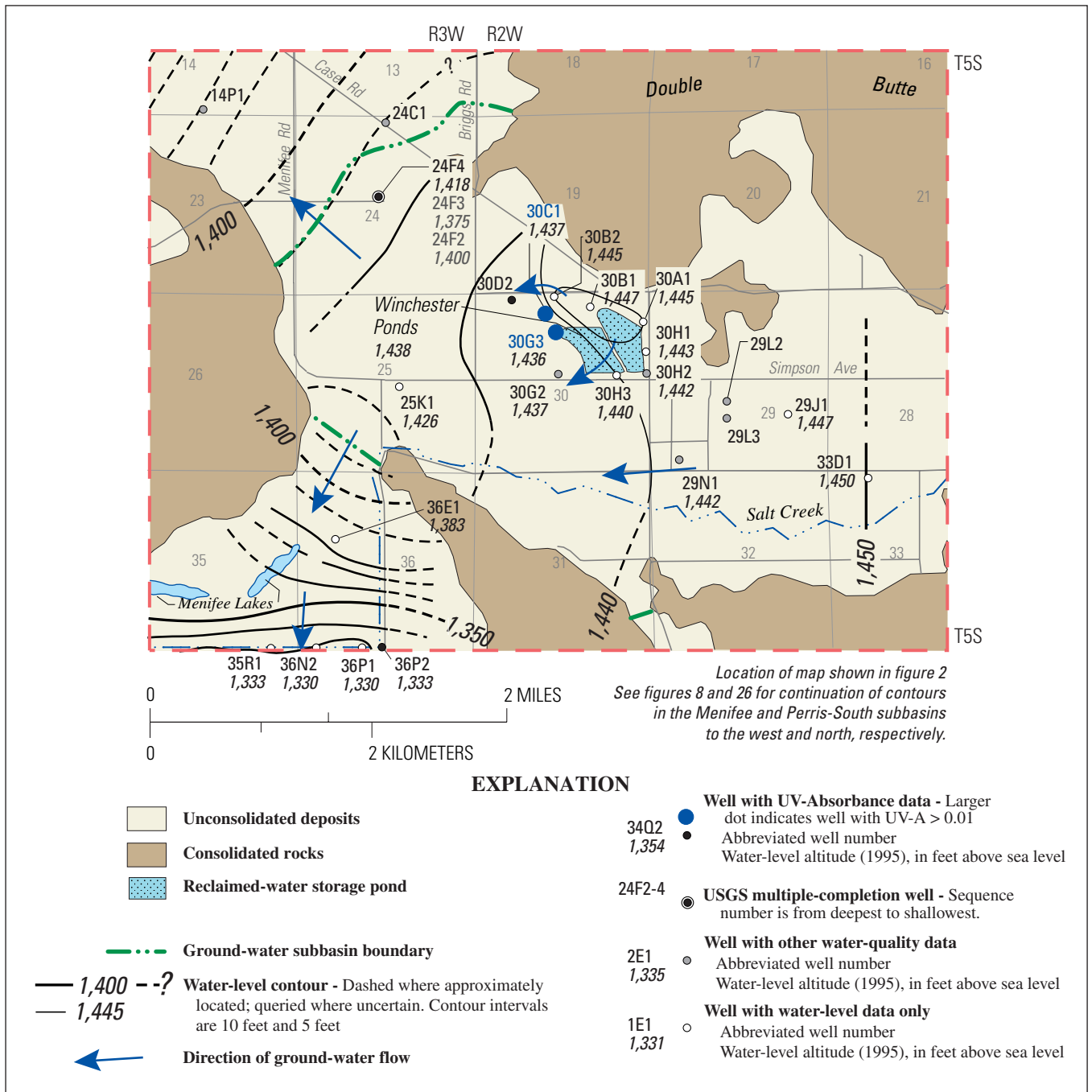


Figure 17. Water-level contours, directions of ground-water flow, and wells with ultraviolet-absorbance data in the Winchester subbasin, Riverside County, California.

In the Winchester subbasin, the stable isotopes of hydrogen and oxygen are not as useful for distinguishing between ground water and reclaimed water as in the Menifee subbasin. For example, ground-water samples from wells 30C1 and 30H2 have nearly identical isotopic values even though the two wells are located downgradient and upgradient from the ponds, respectively (fig. 18). In general, no clear distinction in isotopic composition is evident between wells located upgradient or downgradient, or near or far from the ponds. The relative lack of utility in using hydrogen and oxygen isotopes as indicators of mixing primarily is a consequence of the relative similarity in isotopic composition of the reclaimed water and native ground water in this subbasin. This similarity may be attributed to a relatively high proportion of local ground water used for water supply in the service area of the Temecula RWRf.

In the Winchester subbasin, the difference in isotopic composition between water from the Temecula RWRf and the Winchester storage ponds is larger than the range observed in the ground water. This relatively large difference is another factor limiting the usefulness of hydrogen and oxygen isotopes as tracers in the Winchester subbasin. The relatively large difference in isotopic composition between water from the RWRf and the storage ponds may be a function of the effects of evaporation on the isotopic composition

of the pond water and the 21-day difference in sampling dates for the pond and the RWRf. In the absence of a distinguishing isotopic characteristic for the reclaimed water in the Winchester subbasin, it is difficult to use stable isotopes to identify the presence of reclaimed water in the subsurface.

In the Winchester subbasin, as in the Menifee subbasin, the presence of reclaimed water in the subsurface is suggested by elevated values of UV-A. Six ground-water samples were analyzed for UV-A (fig. 19). Two of the samples (30C1 and 30G3) are from wells that are near and downgradient from the ponds, and have relatively high values of UV-A (greater than or equal to 0.02). Three samples are from the USGS multiple-depth cluster-well site (24F2-4) located relatively far from the ponds, and have relatively low UV-A values ranging from 0.003 to 0.008. The sixth well, 30D2, is downgradient from the ponds, but farther than are 30C1 and 30G3, and the well is perforated over a relatively large depth interval. The UV-A value for this well is relatively low (0.004). Although the distance of 30D2 from the ponds is less than 0.5 mi, this distance is relatively large because the ponds had only been in use for 2 to 3 years at the time of sampling. In this subbasin, UV-A values greater than 0.01 are likely indicators of the presence of reclaimed water.

Table 4. Dissolved-solids (residue on evaporation) and chloride concentrations for selected wells located adjacent to the Winchester Ponds, Winchester subbasin, Riverside County, California

[Site name: RWRf, Temecula Regional Water Reclamation Facility; Pond, Winchester Storage Pond B; well number, abbreviated State well number: all are 5S/2W-____ (see "Well-Numbering System" at front of report); perforated interval in feet below land surface, from Burton and others, 1996; mg/L, milligrams per liter; —, no data]

Site name or State well No.	Perforated interval	Dissolved solids (mg/L)	Chloride (mg/L)	Location of well relative to pond
RWRf	—	686	130	—
POND	—	772	180	—
29L2	—	6,440	2,400	Upgradient
29L3	50–180 ¹	4,620	1,900	Upgradient
30H2	50–70	6,430	2,500	Upgradient (near)
30C1	130–370 ²	2,290	830	Downgradient
30G3	52–72	2,320	730	Downgradient
30D2	40–355	3,330	790	Downgradient (far)
30G2	50–70	4,570	1,400	Downgradient (far)

¹ Several perforated intervals: 50–70, 100–120, 160–180 feet.

² Several perforated intervals: 130–190, 210–230, 270–370 feet.

In the Winchester subbasin, as in the Menifee subbasin, the presence of reclaimed water in the subsurface is not indicated by elevated values of DOC. The two wells with UV-A values greater than 0.01 and the four wells with UV-A less than 0.01 all have DOC values of 1.2 mg/L or less (fig. 19). The ponds and RWRf have DOC values greater than 7 mg/L.

Ground-water chloride concentrations in the Winchester subbasin are spatially variable, which may be due to natural variability or to the mixing of reclaimed water with native ground water. The two ground-water samples with elevated values of UV-A (wells 30C1 and 30G3), which suggest the presence of reclaimed water, have chloride concentrations (fig. 20) that are dissimilar to those for reclaimed water (pond and RWRf). In addition, these same two wells have chloride values that are bracketed by, and similar to, three other wells that do not have elevated values of UV-A. A fourth sample (well 24F2) with non-elevated UV-A has a chloride concentration even lower than that of the reclaimed water. This well, which is perforated near the alluvium/weathered-bedrock contact, may include ground water from the underlying fractured-bedrock flow system.

In the Winchester subbasin, as in the Menifee subbasin, we used chloride concentrations and UV-A values to estimate the percentage of reclaimed water in the subsurface. Using the chloride value at well 30H2 (located upgradient from the ponds) as an end-member,

the calculated percentage of reclaimed water in the three wells located downgradient and near the ponds ranges from 72 to 76 per cent (table 5, column 1). If the lowest value of UV-A obtained in the Winchester Basin (0.003 at well 24F4) is used as an end-member (in place of chloride at well 30H2), then the fraction of reclaimed water ranges from 2 to 29 percent (table 5, column 2). If the chloride value at well 24F4 is used as representative of native ground water, then the calculated percentages all are negative (table 5, column 3). These discrepancies could be due to variability in chloride concentrations and UV-A values in the native ground water or to the use of different wells as representative of the native ground water—the discrepancies may indicate that UV-A is a non-conservative tracer.

Boron concentrations in the Winchester subbasin, like chloride concentrations, are not generally indicative of the presence of reclaimed water in the subsurface. Ground-water samples with UV-A values similar to those measured in reclaimed water have boron concentrations that are dissimilar to that of the reclaimed water (fig. 21). In addition, the boron concentrations for reclaimed water from the RWRf and storage ponds (540 and 590 mg/L, respectively) are in the middle of the range of concentrations in native ground water in the Winchester subbasin (40 to 1,300 mg/L) (table 1).

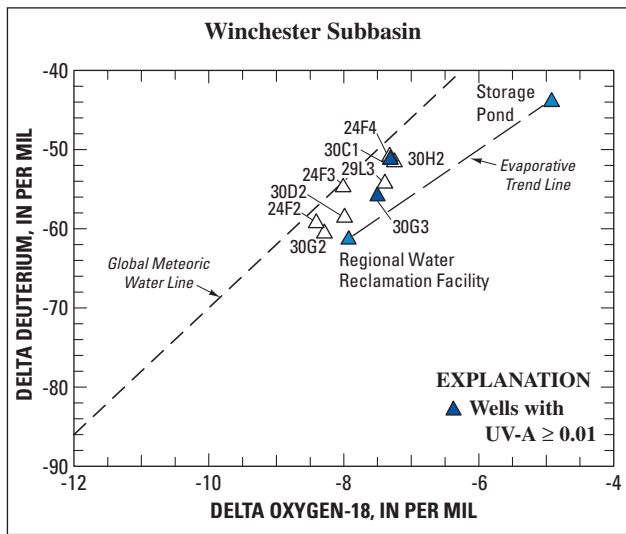


Figure 18. Delta deuterium plotted against delta oxygen-18 for selected wells in the Winchester subbasin, Riverside County, California.

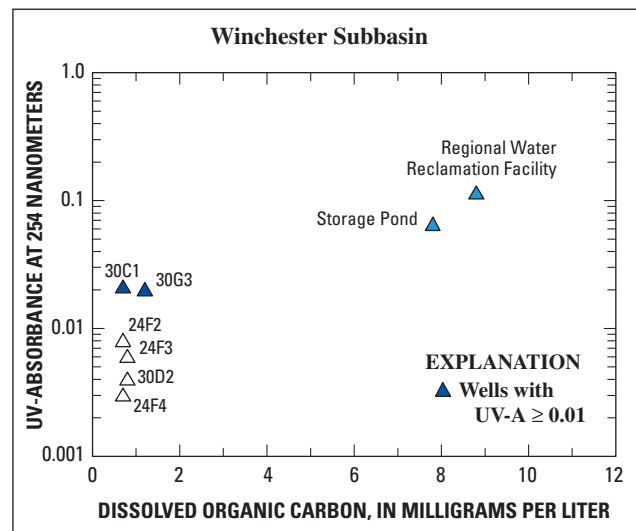


Figure 19. Ultraviolet-absorbance at 254 nanometers plotted against dissolved organic carbon for selected wells in the Winchester subbasin, Riverside County, California.

Interpretation of a plot of boron/chloride ratio versus chloride (fig. 22A) also is inconclusive with regard to tracing reclaimed water. The two wells with elevated UV-A (30C1 and 30G3) have boron/chloride ratios that are dissimilar to that of the reclaimed water and, in fact, the ratios are equal to or less than those of samples from wells not thought to contain reclaimed water (wells 29N1, 29L3, 28L2, and 24F2). These low values may indicate that boron is not conservative in this subbasin. However, it is nevertheless still illustrative to calculate mixing curves for the Winchester subbasin.

The upper curve in figure 22B shows the result of mixing native ground water, assumed to be represented by the boron and chloride concentrations measured in the sample from well 30H2, with reclaimed water, represented by the concentrations measured in the Winchester storage-pond sample. None of the ground-water data points, with the exception of well 30G2, plot near the mixing curve. Most significantly, the data for the two wells that have elevated UV-A (30C1 and 30G3) plot far below this mixing curve, suggesting that there is a negligible percentage of reclaimed water present. This is in contradiction with the results based on using chloride alone (table 5, column 1).

This contradiction indicates that the mixing model using well 30H2 as an end member may be inappropriate.

An alternative mixing curve, using well 24F3 as representative of the native ground water, also is shown in figure 22B. Well 24F3 is downgradient of the wells that have elevated UV-A (30C1 and 30G3), and may be representative of the native ground-water present prior to mixing with reclaimed water. This hypothesis is supported by the lower boron/chloride ratio and higher chloride concentration at well 24F3 than at the two wells with elevated UV-A. The two wells with elevated UV-A (30C1 and 30G3) plot near, but below, the alternative mixing curve. If the two points are shifted to the right onto the curve (thus holding the boron/chloride ratio constant), then the estimated percentage of reclaimed water present is less than 10 percent (figs. 22B, 23). If the two points are shifted upward onto the curve (thus holding chloride constant), then the estimated percentage of reclaimed water is about 30 percent. These values are consistent with the percentages based on using chloride alone (table 5, column 4—well 24F3 end-member) and are consistent with the percentages based on using UV-A (table 5, column 5). This consistency suggests that ground water sampled from well 24F3 is an appropriate end-member.

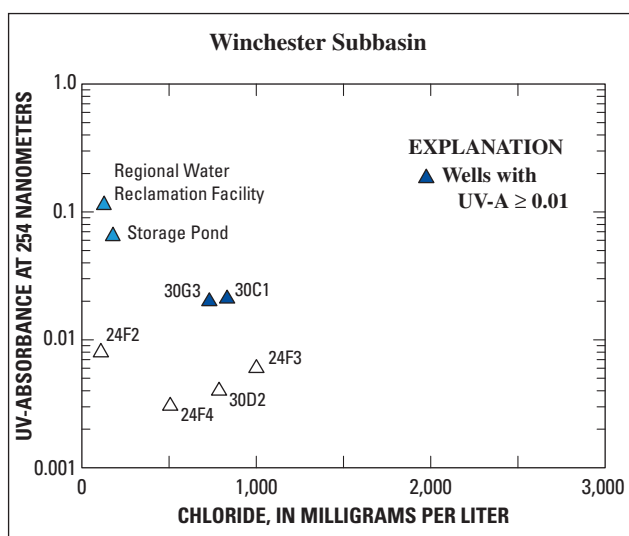


Figure 20. Ultraviolet-absorbance at 254 nanometers plotted against dissolved chloride for selected wells in the Winchester subbasin, Riverside County, California.

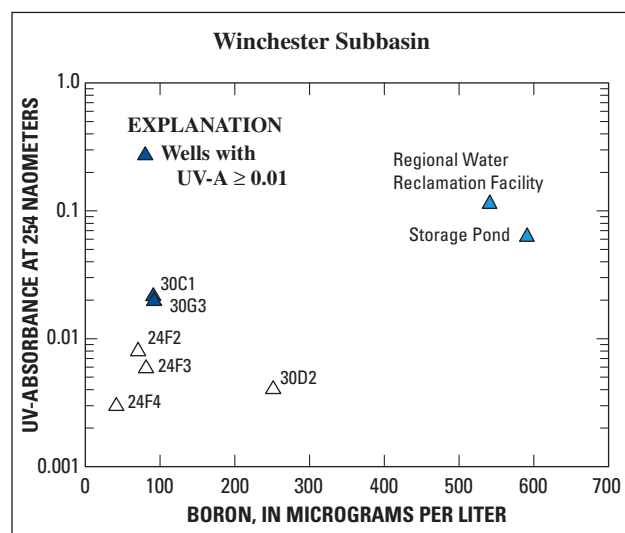


Figure 21. Ultraviolet-absorbance at 254 nanometers plotted against dissolved boron for selected wells in the Winchester subbasin, Riverside County, California.

The results using 24F3 as an end-member (fig. 22B and table 5, column 6), suggest that UV-A can be elevated in samples that have relatively low percentages of reclaimed water. Well 30D2, located downgradient and near the pond, but lacking an elevated UV-A value, plots on the 24F3 mixing curve; the estimated percentage of reclaimed water is about 30 percent (fig. 22B; and table 5, column 6). This value is consistent with the percentage calculated using chloride alone (table 5, column 4).

The data point for the RWRP plots along an upward extension of the two mixing curves (fig. 22B), suggesting that the water in the storage pond at the time of sampling (1995) may have been a mixture of reclaimed water and some fraction of native ground water. This result is consistent with a previous finding of upward movement of ground water into the Winchester pond in the same general time frame as the sampling (Burton and others, 1996). If the RWRP is used as the reclaimed-water end-member, then the resulting mixing curves are quite similar to those shown in figure 22B; the only significant difference is that the curves extend beyond the point representing the storage pond and terminate at the point representing the RWRP. If the RWRP had been used as the

reclaimed-water end-member, then the fraction of reclaimed water in the storage pond would be about 97 percent; the fraction of ground water would be about 3 percent. The computation of fractions at the wells, reported previously, remain virtually the same.

Perris-South Subbasin

Ground-water quality in the Perris-South subbasin is generally poor. The concentration of dissolved solids (residue on evaporation) exceeds 500 mg/L in 18 of the 19 wells sampled, and exceeds 1,000 mg/L in 16 of the wells. The median concentration is about 1,700 mg/L. In contrast, the dissolved-solids concentration in the sample obtained from the Trumble Road Storage Pond is 599 mg/L. A Piper trilinear plot (fig. 24) for samples from the Perris-South subbasin indicates that the native ground-water type ranges from calcium-chloride to sodium-chloride; there is no predominant anion in the reclaimed water, but sodium is the predominant cation. As in the Menifee and Winchester subbasins, major-ion composition alone is not sufficient as an indicator of the presence of reclaimed water in the subsurface.

Table 5. Calculated percentage of reclaimed water in ground water at selected wells located adjacent to the Winchester ponds, Winchester subbasin, Riverside County, California

[Percentages based on a two-end-member mixing model; chloride and UV-A values for reclaimed-water end-member based on data collected at Winchester Pond B (table 1); values of chloride and UV-A for native-ground-water end-member based on data collected at well 30H2, located upgradient of the Winchester ponds, and at wells 24F4 and 24F3, located far downgradient of the ponds; value of boron/chloride ratio for native-ground-water end-member based on data collected at well 24F3; State well number: abbreviated State well number; all are 5S/2W-____, except for 5S/3W-24F3 and -24F4 (see "Well-Numbering System" at front of report); UV-A, ultraviolet absorbance at 254 nanometers; B, boron; Cl, chloride; —, no data]

Calculated percent reclaimed water in ground water						
State well No.	Column 1: based on chloride at well 30H2 end-member	Column 2: based on UV-A at well 24F4 end-member	Column 3: based on chloride at well 24F4 end-member	Column 4: based on chloride at well 24F3 end-member	Column 5: based on UV-A at well 24F3 end-member	Column 6: based on B/Cl ratio at well 24F3 end-member
30H2	0	—	— ⁽¹⁾	— ⁽²⁾	—	—
30C1	72	29	— ⁽¹⁾	21	25	6 to 32
30G3	76	27	— ⁽¹⁾	33	24	6 to 32
30D2	74	2	— ⁽¹⁾	26	— ⁽³⁾	32

¹ Not reported because chloride concentration at well 30H2 is higher than at well 24F4, resulting in a negative percentage.

² Not reported because chloride concentration at well 30H2 is higher than at well 24F3, resulting in a negative percentage.

³ Not reported because UV-A value at well 30D2 is lower than at well 24F3, resulting in a negative percentage.

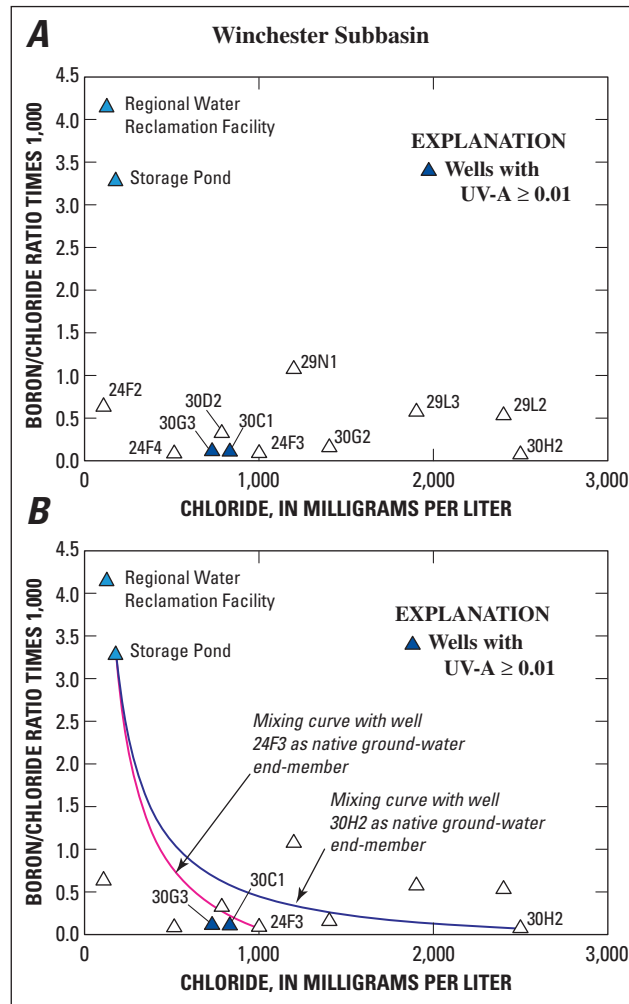


Figure 22. Boron/chloride ratio plotted against dissolved chloride for selected wells in the Winchester subbasin, Riverside County California, without and with superimposed mixing curves. (A) Boron/chloride ratio plotted against dissolved chloride. (B) Boron/chloride ratio plotted against dissolved chloride with a superimposed mixing curve. Mixing curves are based on wells 24F3 or 30H2 as representative of native ground water and the storage pond as representative of reclaimed water.

Although Stiff diagrams show spatial variability of dissolved-solids concentrations and composition in ground water sampled across the Perris-South subbasin (fig. 25), this variability likely is due to natural conditions as well as to the influence of infiltrated reclaimed water. In the vicinity of the Perris Valley RWRf and Trumble Road Pond, ground-water flow generally is from the southwest to the northeast (fig. 26). Ground water having relatively low dissolved-solids concentration is located in areas that may receive recharge from reclaimed-water sources (for example, wells 16F1, 9Q1, 9E1, and 9H1, located in or near fields irrigated with reclaimed water or near the Perris Valley RWRf ponds) as well as in areas unlikely to receive recharge from reclaimed-water sources (wells

15L1, 14P1 and 11D1, located relatively far from reclaimed-water sources) (fig. 25). These wells have similar concentrations of specific ions, particularly chloride, sodium, and calcium (tables 1 and 6). Similarly, ground water having relatively high dissolved-solids concentration also is located in areas both near to and far from reclaimed-water sources (wells 4M1 and 20N1). The absence of systematic spatial variation, either in concentration or composition, may be due to the complexities of spatially separated ponds; the short period of time (1 year) that the Trumble Road Pond was in operation prior to the sampling date; and the presence of a field irrigated with reclaimed water located upgradient from the RWRf.

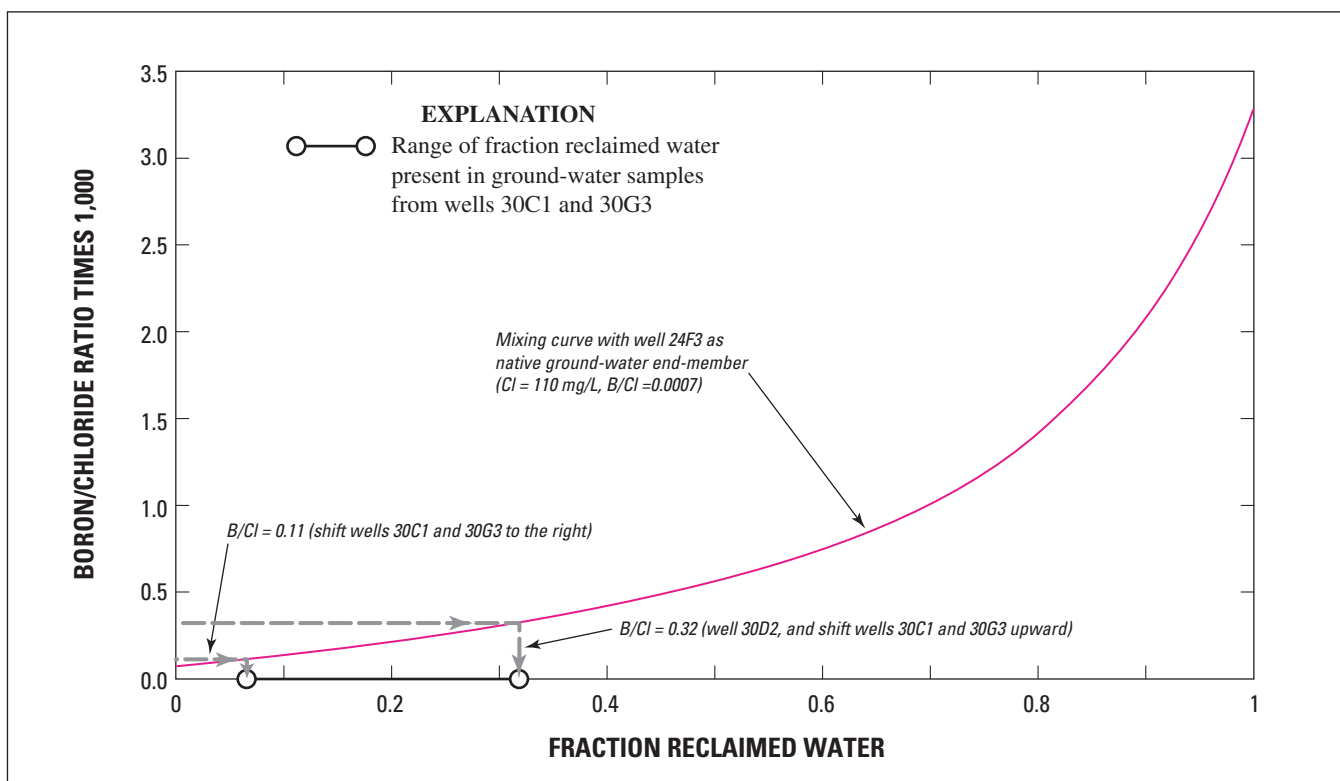


Figure 23. Estimation of fraction reclaimed water using a two-end-member mixing model in the vicinity of the Winchester storage ponds, Winchester subbasin, Riverside County, California.

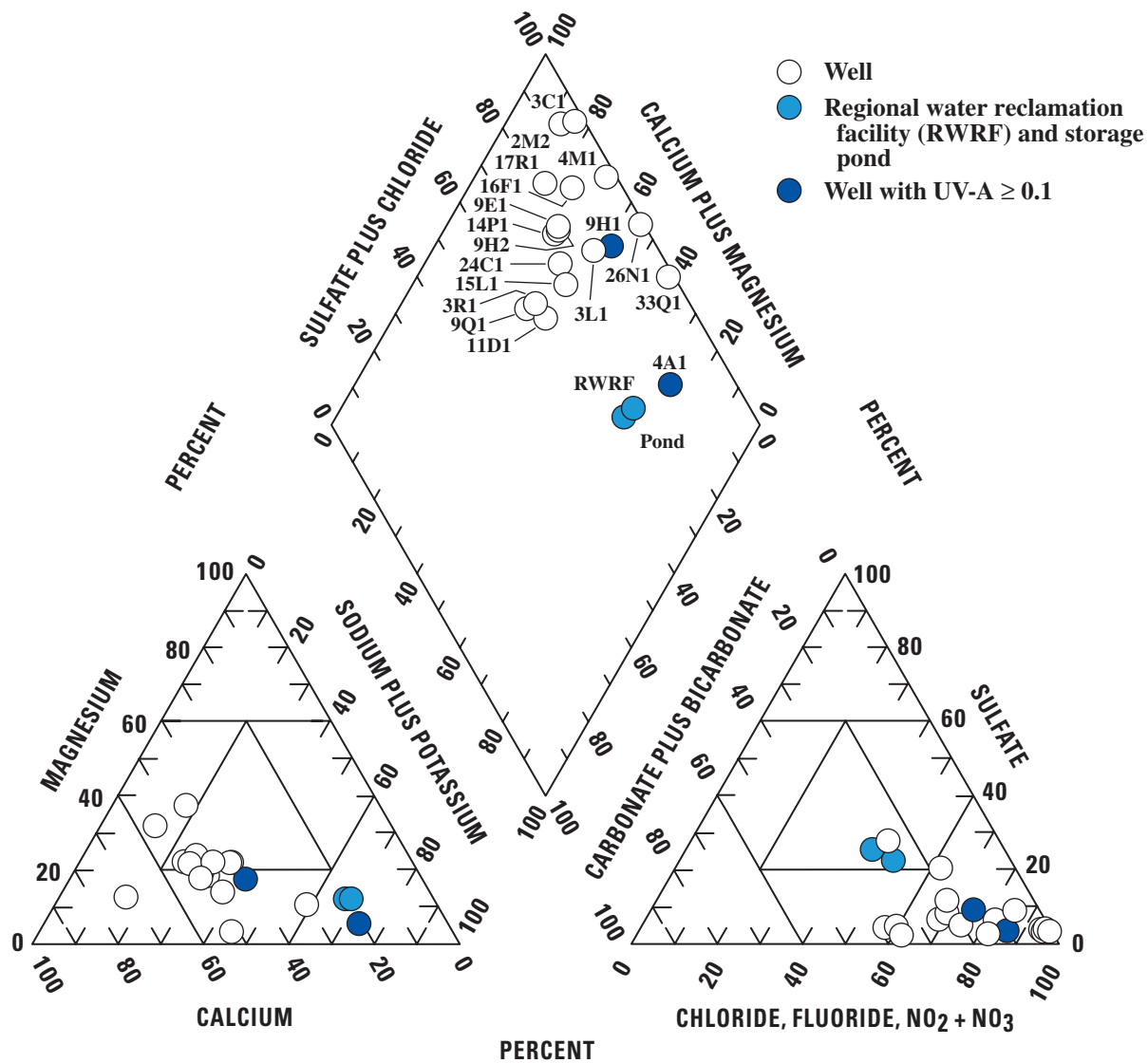


Figure 24. Piper trilinear plot of major-ion concentrations for selected wells in the Perris-South ground-water subbasin, Riverside County, California.

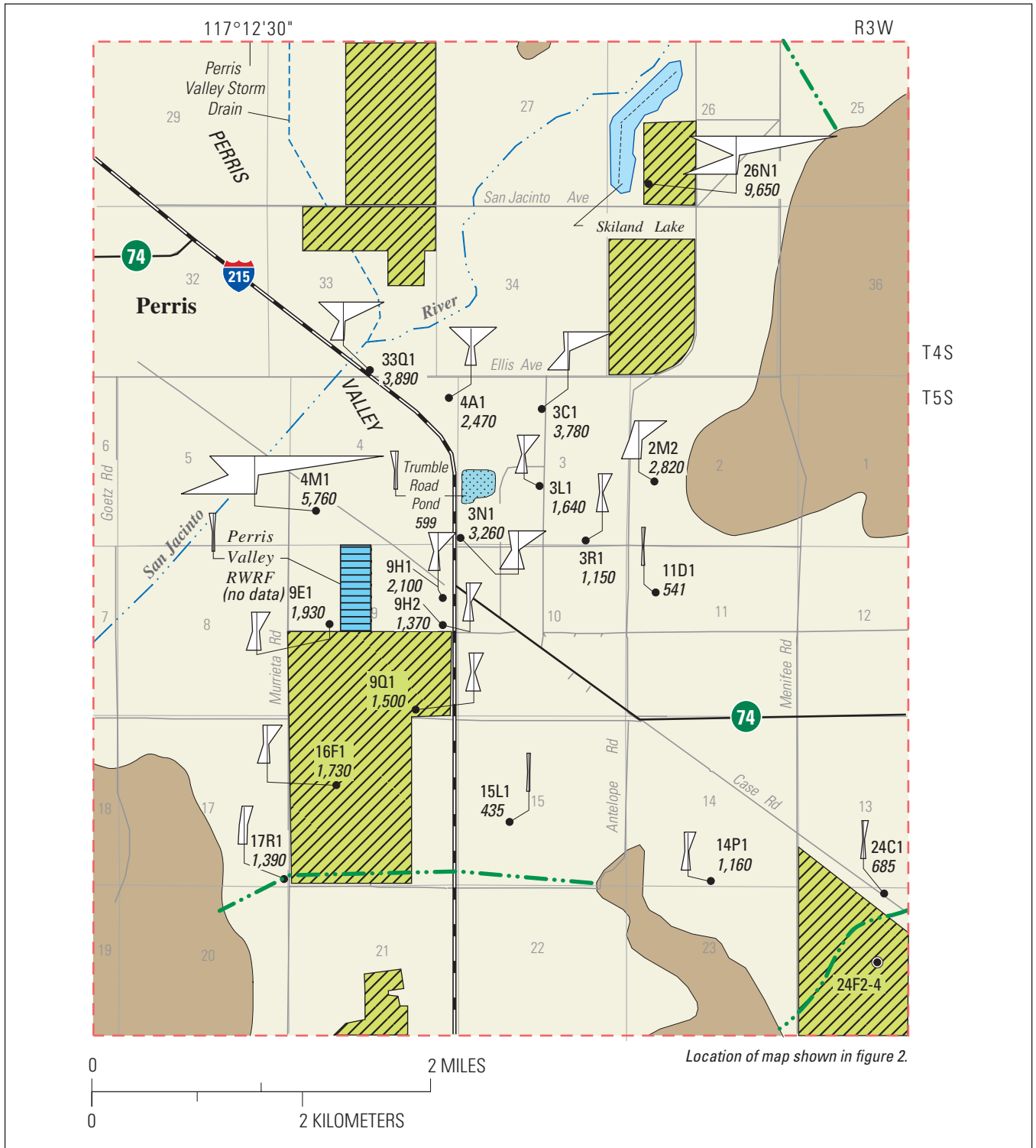


Figure 25. Stiff diagrams for selected wells and reclaimed-water storage ponds, and the Perris Valley reclamation facility, Perris-South subbasin, Riverside County, California.

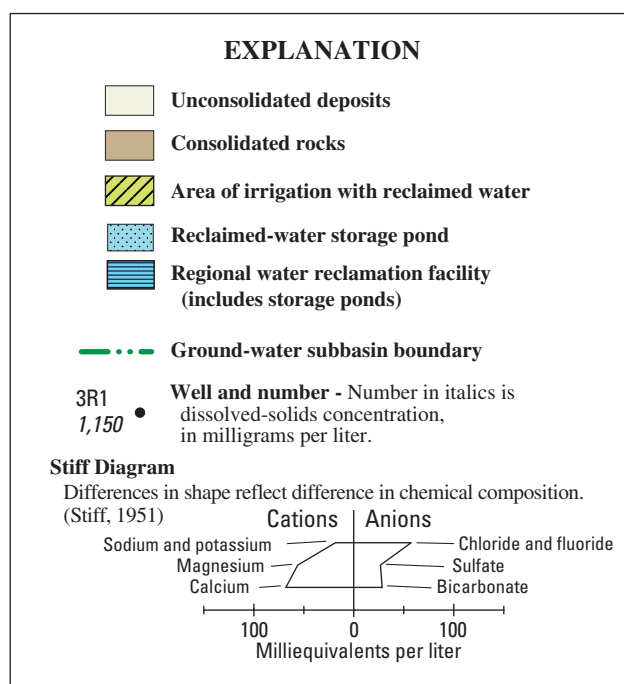


Figure 25.—Continued.

The stable isotopes of hydrogen and oxygen (fig. 27) are not useful for distinguishing between ground water and reclaimed water in the Perris-South subbasin. Ground water from all wells plot parallel to, and below, the global meteoric water line; none of the wells appear to have a greater proportion of reclaimed water than any of the others. The lack of differentiation may be due to the similarity in isotopic composition in the reclaimed water and native ground water. Of the three subbasins, reclaimed water from the Perris Valley RWRf and storage pond plot closest to the global meteoric water line. The lack of differentiation among ground-water samples may also arise because the difference in isotopic composition between water from the RWRf and the storage pond is larger than the range observed in the subbasin ground water. In the absence

of a distinguishing isotopic characteristic for a source of water, it is difficult to identify the presence of that source in the native ground water.

In the Perris-South subbasin, UV-A is less conclusive for identifying the presence of reclaimed water in the subsurface (fig. 28) than in the Menifee and Winchester subbasins. The UV-A values for reclaimed water from the Perris Valley RWRf and Trumble Road storage pond are 0.111 and 0.126, respectively. Two of the sampled wells (9H1 and 4A1) have UV-A values greater than 0.01; both are located in the general vicinity of the ponds (fig. 26). However, four wells (9E1, 9H2, 3N1, and 3C1), also located in the vicinity of the ponds, have UV-A values ranging from <0.001 to 0.009. Three wells (4M1, 3R1, and 33Q1), generally located away from the ponds, have UV-A values ranging from 0.005 to 0.009.

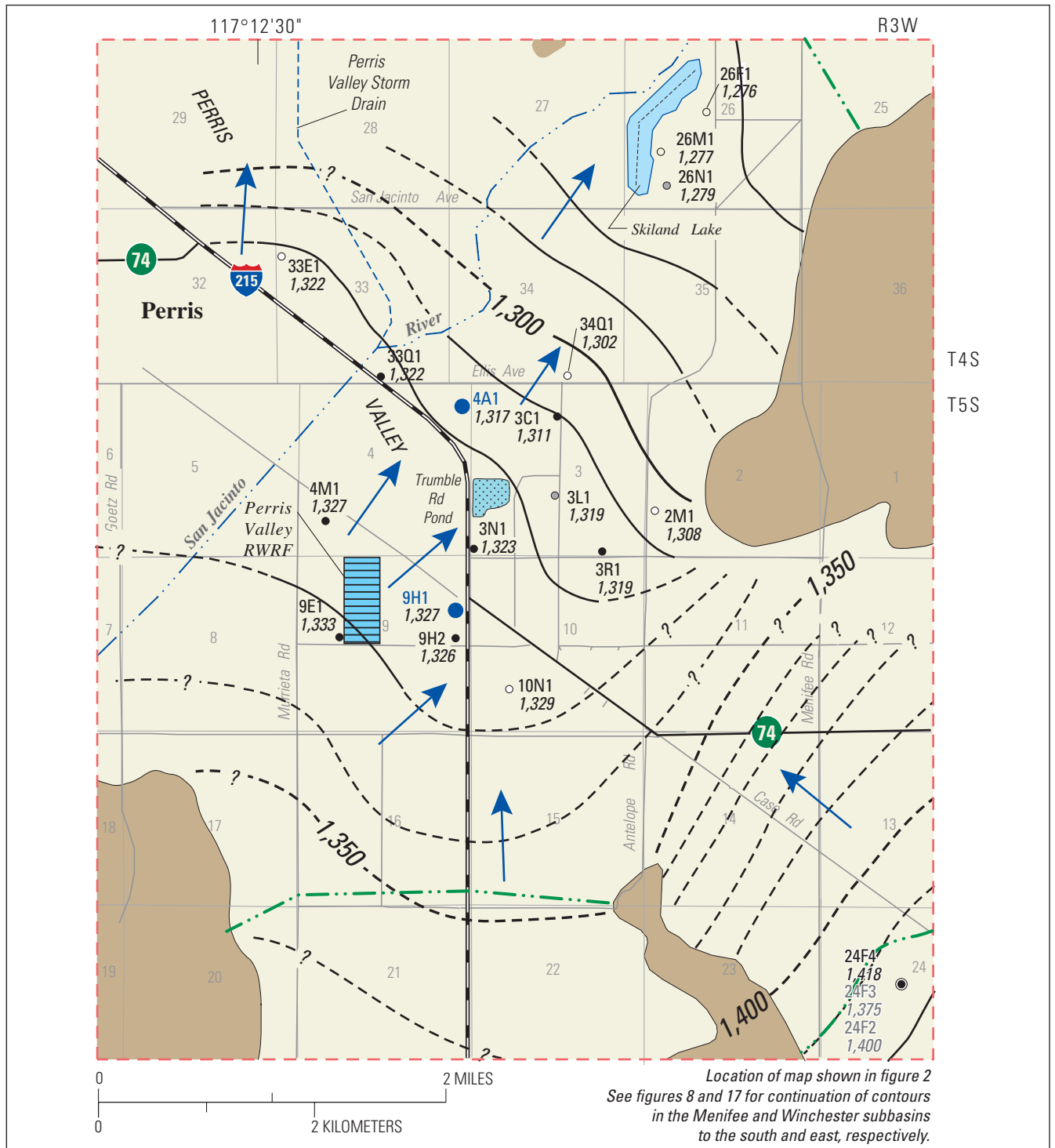


Figure 26. Water-level contours, directions of ground-water flow, and wells with ultraviolet-absorbance data in the Perris-South subbasin, Riverside County, California.

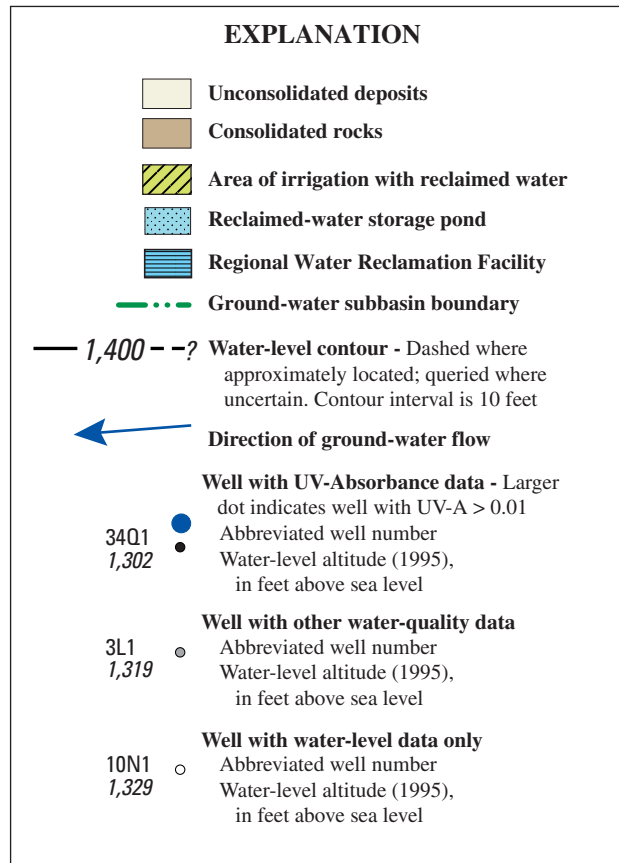


Figure 26.—Continued.

Table 6. Dissolved-solids (residue on evaporation) and chloride concentrations for selected wells in the vicinity of the reclaimed-water ponds, Perris-South subbasin, Riverside County, California

[Site name: RWRF, Perris Valley Regional Water Reclamation Facility; Pond, Trumble Road Pond; State well number (see “Well-Numbering System” at front of report); wells listed in general upgradient to downgradient order; perforated interval in feet below land surface, from Burton and others, 1996; mg/L, milligrams per liter; —, no data]

Site name or State well No.	Perforated interval	Dissolved solids (mg/L)	Chloride (mg/L)
RWRF	—	—	120
POND	—	599	130
5S/3W-17R1	?–370	1,390	390
5S/3W-16F1	—	1,730	680
5S/3W-9Q1	180–600	1,500	430
5S/3W-9E1	220–240	1,930	610
5S/3W-9H2	240–250	1,370	520
5S/3W-9H1	220–240	2,100	860
5S/3W-3N1	290–310, 555–575	3,260	1,300
5S/3W-3L1	230–250	1,640	710
5S/3W-4A1	190–210	2,470	1,200
5S/3W-3C1	230–250	3,780	2,100

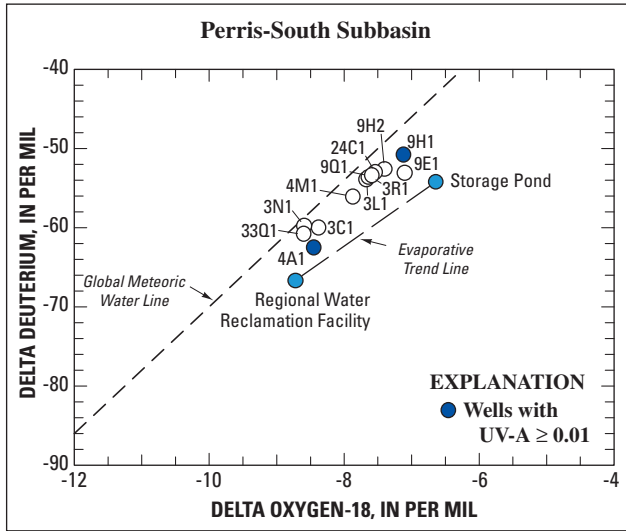


Figure 27. Delta deuterium plotted against delta oxygen-18 for selected wells in the Perris-South subbasin, Riverside County, California.

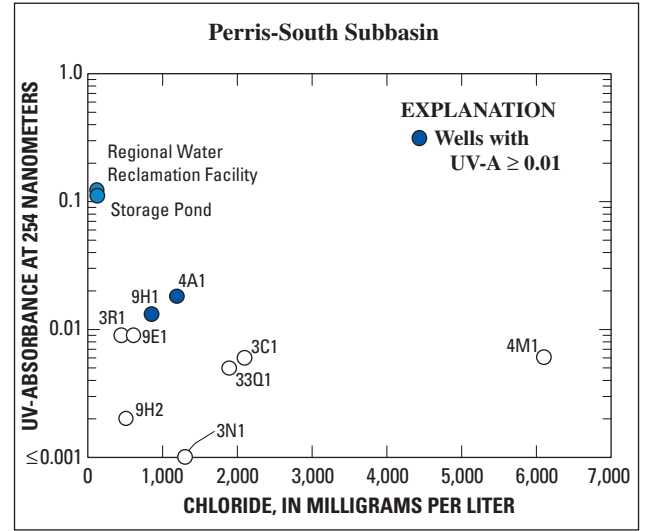


Figure 29. Ultraviolet-absorbance at 254 nanometers plotted against dissolved chloride for selected wells in the Perris-South subbasin, Riverside County, California.

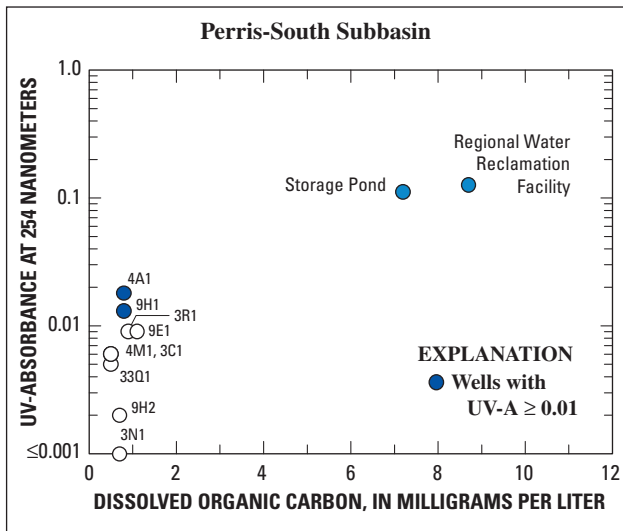


Figure 28. Ultraviolet-absorbance at 254 nanometers plotted against dissolved organic carbon for selected wells in the Perris-South subbasin, Riverside County, California.

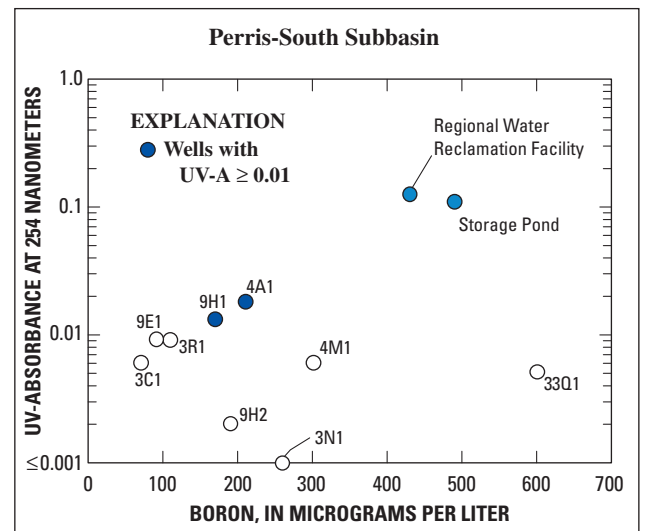


Figure 30. Ultraviolet-absorbance at 254 nanometers plotted against dissolved boron for selected wells in the Perris-South subbasin, Riverside County, California.

Plots of UV-A versus chloride, and UV-A versus boron, are insufficient for identifying the presence of reclaimed water in the subsurface in the Perris-South subbasin (figs. 29, 30). The chloride concentrations at the two wells that have elevated UV-A (9H1 and 4A1) are relatively low; however, other wells also have relatively low chloride concentrations. Consequently, we do not calculate the fraction reclaimed water using chloride (or UV-A) in the Perris-South subbasin, as was

done in the Menifee and Winchester subbasins. The boron concentrations at the two wells with elevated UV-A have boron concentrations dissimilar to that of the reclaimed water. Of greater significance, the boron concentration of the reclaimed water (430 to 490 mg/L) is not an end-member; ground water in the Perris-South subbasin can have boron concentrations lower or higher than that of the reclaimed water (30 to 820 mg/L, table 1).

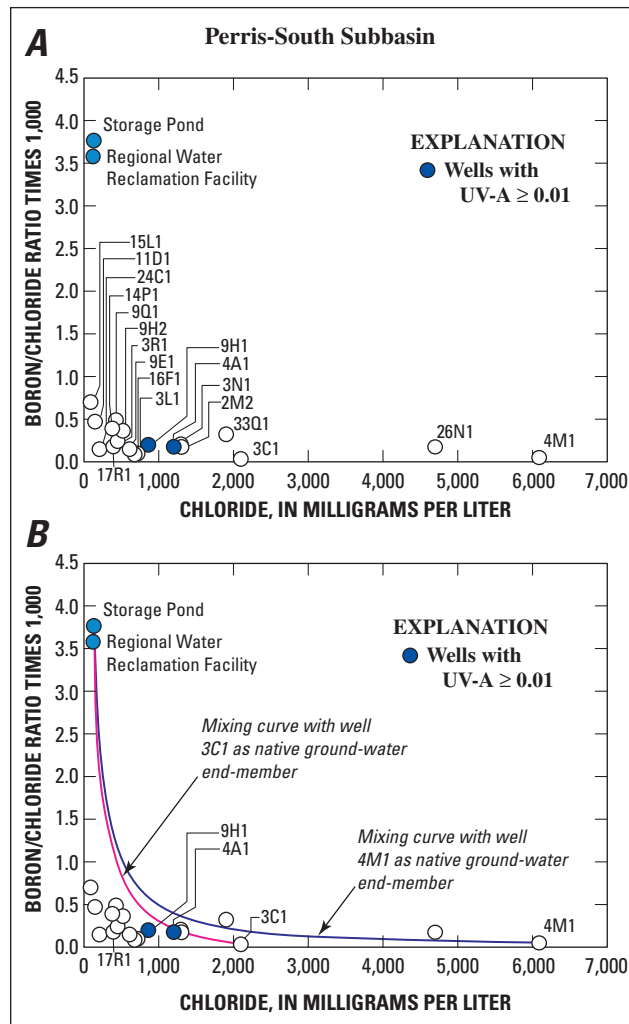


Figure 31. Boron/chloride ratio plotted against dissolved chloride for selected wells in the Perris-South subbasin, Riverside County California, without and with superimposed mixing curves. (A) Boron/chloride ratio plotted against dissolved chloride. (B) Boron/chloride ratio plotted against dissolved chloride with superimposed mixing curves. Mixing curves are based on wells 3C1 and 4M1 as representative of native ground water and the storage pond as representative of reclaimed water.

In the Perris-South subbasin, as in the Winchester and Menifee subbasins, the presence of reclaimed water in the subsurface is not indicated by elevated values of DOC. Both of the wells with UV-A values greater than 0.01 (9H1 and 4A1) have DOC values less than 1 mg/L (fig. 28). The ponds and RWRF have DOC values greater than 7 mg/L.

In the Perris-South subbasin, as in the Winchester subbasin, a plot of boron/chloride ratio versus chloride (fig. 31A) is not conclusive for

identifying the presence of reclaimed water in the subsurface. The two wells that have elevated UV-A (9H1 and 4A1) have boron/chloride ratios that are dissimilar to that of the reclaimed water. Instead, the data for wells 9H1 and 4A1 plot close to the wells thought not to contain reclaimed water. Nevertheless, evaluation of the data using mixing curves may still be useful.

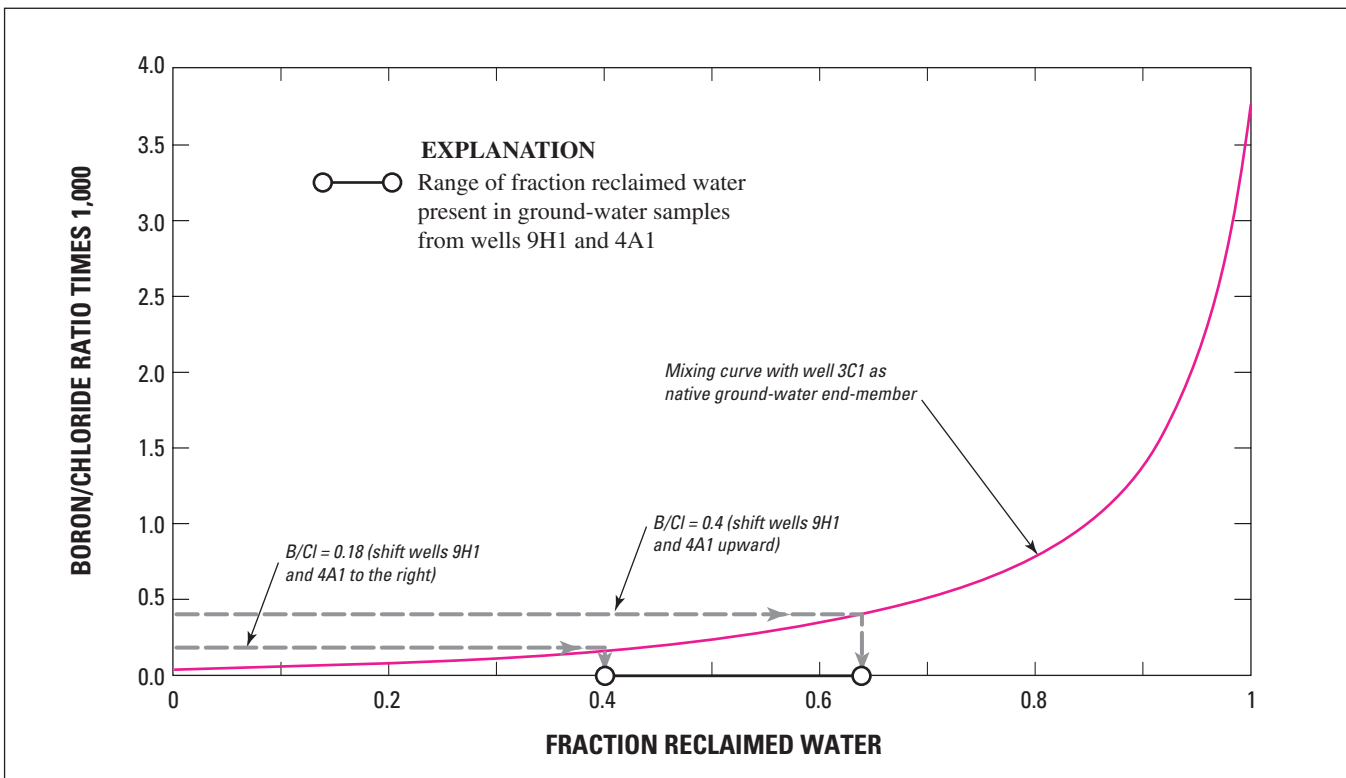


Figure 32. Estimation of the fraction reclaimed water using a two-end member mixing model in the vicinity of the Trumble Road storage pond, Perris-South subbasin, California.

Two wells were chosen as possibly representative of the native ground-water component present at the locations that have elevated UV-A. These wells, 4M1 and 3C1, were chosen because they have chloride concentrations greater, and boron/chloride ratios lower, than those of the wells with elevated UV-A. Consequently, mixing curves using one of these wells as an end-member and reclaimed water as the other, have the possibility of passing through or close to the wells with elevated UV-A (fig. 31B). The two wells with elevated UV-A (4A1 and 9H1) plot relatively far below the mixing curve that is based on end-member-well 4M1, and relatively close to the mixing curve based on well 3C1. These results suggest that water from well 3C1 is the more likely representative of the native ground-water component at wells 4A1 and 9H1. Well 4A1 is virtually on the mixing curve, and the fraction of reclaimed water is about 40 percent (fig. 32). If well 9H1 is shifted to the right onto the 3C1-mixing-curve, the fraction of reclaimed water is about 40 percent (fig. 32); if the point is shifted upward, then the fraction is about 65 percent. These results suggest that the ground water with elevated UV-A in the Perris-South subbasin could consist of 40 to 65 percent reclaimed water. However, the two-end-member model might not be valid in this subbasin, as indicated by the relatively large amount of variation in chloride concentrations and boron/chloride ratios observed at other wells nearby. Also, boron may not be conservative in this subbasin.

SUMMARY AND CONCLUSIONS

As a component in the management of water resources in the Menifee, Winchester, and Perris-South subbasins, ponds are operated by the Eastern Municipal Water District for the temporary storage of reclaimed water that is produced by several regional water-reclamation facilities (RWRFs). Although some of the ponds have been in operation for more than 25 years, the amount of water percolating and its effect on ground-water quality are not well understood. Therefore, there is a need to develop methods of tracing reclaimed water in the subsurface that can be used in the study area.

A primary goal of the study was to evaluate the potential for using various constituents or characteristics, measured in ground-water samples, as tracers of reclaimed water that has infiltrated from the storage ponds into the ground water in the three subbasins. A secondary goal was to estimate the degree to which the infiltrated reclaimed water has mixed with the native ground water. The evaluation of potential tracers and the estimation of mixing focused on data from wells located relatively close to the ponds.

The water samples collected from the three RWRFs, three sets of storage ponds, and selected ground-water wells were analyzed for major ions, nutrients, selected trace elements, stable isotopes of hydrogen and oxygen, and organic carbon. Also, some of the samples were analyzed for ultraviolet absorbance (UV-A) at a wavelength of 254 nm, methylene blue active substances (MBAS), linear alkylbenzene sulfonate (LAS), and caffeine.

The most useful constituents and characteristics for evaluation of the fate and mixing of reclaimed water in the Menifee, Winchester, and Perris-South subbasins are major-ion composition (as expressed in Stiff diagrams), stable isotopes of hydrogen and oxygen, UV-A, chloride concentration, and plots of boron/chloride ratios versus chloride concentrations. Emphasis was placed on evaluating the utility of UV-A as a tracer and the utility of boron/chloride ratios for estimating the percentage of reclaimed water in ground water. The use of UV-A is convenient because analysis of samples for UV-A is relatively easy and inexpensive.

In the Menifee subbasin, major-ion data, stable isotopes, chloride, UV-A, and boron/chloride ratio are all useful in identifying reclaimed water, and the results based on these indicators are consistent with each other. In water from wells near, and downgradient from, the ponds, stable-isotope values and ionic composition are shifted relative to native ground water; have lower chloride concentration; have elevated UV-A; and plot on a single boron/chloride mixing curve. The results suggest that values of UV-A greater than or equal to 0.007 indicate the presence of reclaimed water in the Menifee subbasin. Ground-water samples with UV-A greater than 0.007 consist of about 75 to 100 percent reclaimed water, on the basis of chloride-mixing calculations and boron/chloride-versus-chloride mixing calculations.

In the Winchester subbasin, results based on the same factors used in the Menifee subbasin are less conclusive; nevertheless, UV-A can be used as a tracer. Values of UV-A greater than 0.01 indicate the presence of reclaimed water. Values from 0.006 to 0.01 may indicate the presence of reclaimed water; however, water from wells not likely to have reclaimed water may also have UV-A values in this range. Groundwater samples with UV-A greater than 0.01 appear to contain about 25 percent reclaimed water (range 6 to 32 percent), on the basis of the consistency of the results of three types of mixing calculations—chloride alone, boron/chloride versus chloride, and UV-A.

In the Perris-South subbasin, the potential tracers are not as conclusive in identifying reclaimed water as in the Menifee and Winchester subbasins. The inability to identify tracers may be a consequence of the multiple, spatially distributed sources of reclaimed water; the relative absence of wells close to the reclaimed-water pond; and the short period of operation (about 1 year) of the pond at the time of sampling. Mixing calculations suggest that groundwater samples with elevated UV-A values (greater than 0.01) in the Perris-South subbasin could contain as much as 40 to 65 percent reclaimed water. However, the assumptions on which these numbers are based are not as appropriate as in the other two subbasins.

The results of this study indicate that UV-A can be used as a qualitative indicator of the presence of reclaimed water. Mixing calculations based on chloride and on boron/chloride ratios indicate that UV-A is not conservative, and therefore UV-A is not suitable for estimating the fraction of reclaimed water in the subsurface. The results also suggest that boron/chloride ratios are useful for estimating the fraction of reclaimed water. The accuracy of the estimates depends primarily on correctly identifying the boron/chloride ratio—and secondarily the chloride concentration—of the native ground water present prior to mixing. Resampling of selected wells located close to the reclaimed-water ponds, and sampling of additional wells, would provide updated estimates of the fraction of reclaimed water and confirm the usefulness of UV-A and boron/chloride ratios as tracers of reclaimed water.

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TABLE 1

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California

[State well number: See “Well-Numbering System” in “Contents” section; RWRF, regional water-reclamation facility; for well-construction information and water-level data, see Burton and others, 1996, tables 1 and 3; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; per mil, parts per thousand; TOC, total organic carbon; DOC, dissolved organic carbon; nm, nanometer; MBAS, methylene blue activated substances; LAS, linear alkylbenzene sulfonate; <, actual value less than value shown; e, estimated; c, calculated from specific conductance; —, no data]

Site name or State well No.	Date	Specific conductance, field ($\mu\text{S}/\text{cm}$)	pH, field (standard units)	Water temperature (°C)	Hardness (mg/L as CaCO_3)	Calcium, dissolved (mg/L)
Menifee subbasin						
Sun City RWRF	07/03/95	1,230	7.0	11.1	260	64
Sun City Storage Pond	07/03/95	1,380	7.1	24.5	300	70
5S/3W-28M1S	07/20/95	1,750	7.2	23.1	230	64
5S/3W-28M2S	07/20/95	2,370	6.9	22.5	440	110
5S/3W-28M3S	07/20/95	5,540	6.3	22.5	2,300	670
5S/3W-28M4S	07/20/95	4,160	6.4	21.6	1,500	400
5S/3W-32A1S	08/01/95	12,400	5.9	24.3	5,100	1,500
5S/3W-32B1S	08/03/95	1,280	7.2	21.6	77	17.0
5S/3W-32C1S	08/02/95	3,230	6.8	24.4	820	250
5S/3W-32G1S	07/19/95	3,590	6.6	21.7	620	160
5S/3W-32H1S	08/02/95	1,770	6.5	21.7	460	120
5S/3W-32L1S	07/28/95	6,910	6.4	22.7	1,600	450
5S/3W-34Q2S	07/28/95	4,230	6.6	23.5	1,500	410
5S/3W-35N2S	08/01/95	4,310	5.9	25.5	1,500	350
5S/3W-36P2S	08/01/95	2,610	6.3	26.0	1,000	220
6S/3W-01J2S	08/15/95	4,670	6.5	21.5	1,700	480
6S/3W-02A1S	07/26/95	4,910	6.3	23.3	1,700	470
6S/3W-02E1S	07/27/95	1,730	6.1	28.9	660	170
6S/3W-02G2S	07/26/95	1,750	6.9	23.1	530	140
6S/3W-05E1S	08/15/95	517	7.4	24.0	150	43.0
Winchester subbasin						
Temecula RWRF	07/20/95	1,120	7.5	13.1	190	50
Winchester Storage Pond	06/29/95	1,240	9.3	26.0	210	53
5S/2W-29L2S	08/11/95	9,550	6.6	21.0	2,000	390
5S/2W-29L3S	08/14/95	7,270	6.2	21.5	1,900	410
5S/2W-29N1S	07/12/95	5,320	6.0	22.7	1,700	440
5S/2W-30C1S	07/28/95	3,370	7.1	22.8	1,100	290
5S/2W-30D2S	07/19/95	4,440	6.3	22.6	1,900	530
5S/2W-30G2S	07/07/95	6,550	6.6	21.2	1,600	410
5S/2W-30G3S	08/02/95	3,660	6.7	20.5	1,100	290
5S/2W-30H2S	07/06/95	9,430	6.3	22.0	2,200	550
5S/3W-24F2S	07/21/95	690	8.0	24.6	70	24.0
5S/3W-24F3S	08/03/95	3,780	6.3	23.9	1,600	470
5S/3W-24F4S	07/21/95	1,970	6.8	35.0	650	180

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and South Perris subbasins, Riverside County, California—Continued

Site name or State well No.	Date	Specific conductance, field ($\mu\text{S}/\text{cm}$)	pH, field (standard units)	Water temperature ($^{\circ}\text{C}$)	Hardness (mg/L as CaCO_3)	Calcium, dissolved (mg/L)
Perris-South subbasin						
Perris Valley RWRf	07/03/95	804	7.6	13.1	120	29
Trumble Road Storage Pond	06/30/95	990	7.9	26.5	160	39
4S/3W-26N1S	08/24/95	13,900	7.4	27.1	3,700	1,400
4S/3W-33Q1S	07/25/95	6,060	7.5	21.7	1,100	340
5S/3W-02M2S	08/17/95	4,470	7.0	23.0	1,800	460
5S/3W-03C1S	07/17/95	6,450	7.6	24.2	1,600	540
5S/3W-03L1S	07/17/95	2,770	7.2	23.6	770	240
5S/3W-03N1S	07/24/95	4,800	6.4	25.6	1,700	490
5S/3W-03R1S	07/18/95	1,900	7.3	23.5	590	160
5S/3W-04A1S	07/18/95	4,260	7.5	22.8	500	160
5S/3W-04M1S	07/26/95	17,500	6.4	21.5	6,400	1,900
5S/3W-09E1S	07/26/95	2,780	6.9	23.1	990	280
5S/3W-09H1S	07/25/95	3,190	6.5	24.1	860	240
5S/3W-09H2S	07/27/95	2,180	6.4	24.1	740	200
5S/3W-09Q1S	08/22/95	2,270	6.3	25.6	760	220
5S/3W-11D1S	08/09/95	859	7.5	23.3	260	68.0
5S/3W-11M2S	08/30/95	1,390	6.8	23.0	—	—
5S/3W-14P1S	08/10/95	1,750	6.1	22.3	610	170
5S/3W-15L1S	08/11/95	663	6.7	22.5	190	51.0
5S/3W-16F1S	08/09/95	2,570	7.1	22.3	960	270
5S/3W-17R1S	07/24/95	1,920	7.2	25.1	780	170
5S/3W-24C1S	08/04/95	963	6.8	24.9	310	89.0

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L),	Potassium, dissolved (mg/L)	Alkalinity, (mg/L as CaCO3)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)
Menifee subbasin								
Sun City RWRf	25	150	16.0	e140	240	130	0.4	0.04
Sun City Storage Pond	29	170	16.0	150	270	160	.3	.14
5S/3W-28M1S	17.0	330	13.0	780	14.0	86.0	.3	.31
5S/3W-28M2S	40.0	400	19.0	1,200	13.0	110	.3	.27
5S/3W-28M3S	160	230	23.0	570	410	1,400	.1	2.30
5S/3W-28M4S	120	290	7.50	240	280	1,200	.2	1.80
5S/3W-32A1S	320	900	38.0	840	690	3,700	<.1	12.0
5S/3W-32B1S	8.30	230	1.00	200	200	130	.3	.20
5S/3W-32C1S	47.0	420	6.30	190	900	430	.2	.68
5S/3W-32G1S	54.0	550	5.10	240	840	520	.4	1.00
5S/3W-32H1S	38.0	210	5.40	130	540	150	.3	.22
5S/3W-32L1S	120	910	8.80	320	810	1,600	.3	.03
5S/3W-34Q2S	120	430	11.0	230	700	1,000	.3	.31
5S/3W-35N2S	150	390	13.0	610	500	850	.2	1.70
5S/3W-36P2S	120	250	10.0	1,440	13.0	95.0	.3	.08
6S/3W-01J2S	130	370	11.0	280	790	1,000	.3	2.00
6S/3W-02A1S	130	390	11.0	240	840	1,100	.3	1.90
6S/3W-02E1S	58.0	120	8.20	560	100	170	.3	.50
6S/3W-02G2S	43.0	150	5.50	220	180	300	.4	.71
6S/3W-05E1S	10.0	44.0	1.80	120	36.0	38.0	.5	.18
Winchester subbasin								
Temecula RWRf	16	160	14.0	170	150	130	.5	.12
Winchester Storage Pond	18	200	14.0	220	170	180	.5	.28
5S/2W-29L2S	240	1,460	5.60	410	1,300	2,400	.2	4.50
5S/2W-29L3S	220	870	9.30	370	840	1,900	.2	3.60
5S/2W-29N1S	150	510	9.70	150	950	1,200	.1	2.60
5S/2W-30C1S	94.0	220	5.80	120	260	830	.3	1.60
5S/2W-30D2S	140	200	7.70	170	950	790	.1	1.60
5S/2W-30G2S	140	900	6.50	120	1,200	1,400	.2	2.70
5S/2W-30G3S	91.0	360	4.50	160	600	730	.3	1.30
5S/2W-30H2S	210	1,300	7.90	120	1,200	2,500	.2	4.60
5S/3W-24F2S	2.40	110	3.60	120	17.0	110	.4	.42
5S/3W-24F3S	95.0	150	10.00	260	86.0	1,000	<.1	1.60
5S/3W-24F4S	48.0	98.0	6.40	88	28.0	510	.1	1.20

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L),	Potassium, dissolved (mg/L)	Alkalinity, (mg/L as CaCO ₃)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Bromide, dissolved (mg/L)
Perris-South subbasin								
Perris Valley RWRf	11	110	12.0	e102	81	120	0.2	0.07
Trumble Road Storage Pond	14	140	13.0	138	110	130	.3	.18
4S/3W-26N1S	50.0	1,400	17.0	56	200	4,700	.9	7.60
4S/3W-33Q1S	71.0	750	10.0	36	100	1,900	.2	4.30
5S/3W-02M2S	160	120	16.0	120	190	1,300	.4	2.30
5S/3W-03C1S	57.0	130	14.0	71	100	2,100	<.1	4.10
5S/3W-03L1S	42.0	210	9.20	190	31.0	710	.1	1.60
5S/3W-03N1S	110	280	16.0	—	37.0	1,300	.2	2.80
5S/3W-03R1S	46.0	120	7.10	390	22.0	450	.4	1.30
5S/3W-04A1S	25.0	650	7.70	350	200	1,200	.1	2.70
5S/3W-04M1S	400	1,300	21.0	220	340	6,100	<.1	2.10
5S/3W-09E1S	71.0	160	4.50	270	150	610	.2	1.20
5S/3W-09H1S	62.0	270	7.40	150	48.0	860	.1	1.90
5S/3W-09H2S	57.0	120	6.60	210	50.0	520	.1	1.20
5S/3W-09Q1S	50.0	150	7.50	420	44.0	430	.2	.98
5S/3W-11D1S	21.0	62.0	6.10	140	17.0	150	.4	.53
5S/3W-11M2S	—	—	—	180	—	—	—	—
5S/3W-14P1S	45.0	100	4.10	180	68.0	380	.2	.89
5S/3W-15L1S	16.0	49.0	2.40	81	82.0	85.0	.3	.32
5S/3W-16F1S	68.0	140	3.50	140	73.0	680	.2	1.40
5S/3W-17R1S	85.0	74.0	4.00	160	180	390	.2	.81
5S/3W-24C1S	20.0	63.0	4.50	110	28.0	200	.2	.47

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Silica, dissolved (mg/L)	Dissolved Solids, residue (mg/L)	Nitrate, NO ₂ + NO ₃ dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)
Menifee subbasin								
Sun City RWRf	12.0	c802	8.28	0.72	3.90	2.40	2	59
Sun City Storage Pond	13.0	864	2.70	.70	3.00	2.10	2	62
5S/3W-28M1S	37.0	1,080	<.05	<.010	.03	.29	2	430
5S/3W-28M2S	51.0	1,510	<.05	<.010	.02	1.00	12	590
5S/3W-28M3S	59.0	3,800	1.50	<.010	.34	1.80	1	120
5S/3W-28M4S	69.0	2,850	4.80	<.010	.16	.46	1	75.0
5S/3W-32A1S	43.0	9,610	.77	.020	.40	<.01	<1	400
5S/3W-32B1S	45.0	804	1.90	<.010	<.01	.09	2	25.0
5S/3W-32C1S	48.0	2,330	1.10	.020	<.01	.03	1	38.0
5S/3W-32G1S	51.0	2,450	2.20	<.010	.02	.04	8	25.0
5S/3W-32H1S	54.0	1,260	1.70	<.010	<.01	.08	2	18.0
5S/3W-32L1S	54.0	4,580	2.30	<.010	.11	.02	<1	<100
5S/3W-34Q2S	51.0	3,390	7.40	.010	.12	<.01	<1	39.0
5S/3W-35N2S	73.0	2,960	1.90	<.010	.08	.08	3	200
5S/3W-36P2S	89.0	1,700	3.40	.020	.05	.10	2	630
6S/3W-01J2S	52.0	3,350	6.30	<.010	.10	.05	1	70.0
6S/3W-02A1S	57.0	3,550	5.30	<.010	.12	.06	<1	44.0
6S/3W-02E1S	65.0	1,070	2.60	<.010	.03	.06	2	180
6S/3W-02G2S	56.0	1,090	5.20	<.010	.03	.06	1	74.0
6S/3W-05E1S	38.0	335	10.0	<.010	.04	.08	6	190
Winchester subbasin								
Temecula RWRf	20.0	686	2.90	<.010	.04	4.20	4	45.0
Winchester Storage Pond	14.0	772	1.34	.060	<.01	.56	6	23.0
5S/2W-29L2S	64.0	6,440	1.80	<.004	.06	.04	<1	<100
5S/2W-29L3S	56.0	4,620	1.25	.050	.12	<.01	<1	<100
5S/2W-29N1S	60.0	3,850	16.0	<.010	.12	.06	1	20.0
5S/2W-30C1S	48.0	2,290	6.60	<.010	.03	.06	3	180
5S/2W-30D2S	63.0	3,330	13.0	<.010	.08	.07	1	36.0
5S/2W-30G2S	60.0	4,570	13.0	<.010	.08	.09	1	26.0
5S/2W-30G3S	56.0	2,320	3.30	<.010	.02	.13	3	25.0
5S/2W-30H2S	60.0	6,430	13.0	<.010	.11	.48	3	33.0
5S/3W-24F2S	30.0	395	5.70	<.010	<.01	.16	1	36.0
5S/3W-24F3S	69.0	2,520	13.0	<.010	.09	.87	1	510
5S/3W-24F4S	49.0	1,330	14.0	<.010	.02	1.00	1	570

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Silica, dissolved (mg/L)	Dissolved Solids, residue (mg/L)	Nitrate, NO ₂ + NO ₃ dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)	Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L)	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)
Perris-South subbasin								
Perris Valley RWRf	19	—	4.42	0.080	0.61	2.50	1	14
Trumble Road Storage Pond	19	599	3.28	.120	.23	1.40	1	34
4S/3W-26N1S	17.0	9,650	0.59	<.010	.54	<.01	2	300
4S/3W-33Q1S	13.0	3,890	2.50	<.010	.02	<.01	<1	300
5S/3W-02M2S	37.0	2,820	21.0	<.010	.07	.03	1	380
5S/3W-03C1S	11.0	3,780	3.00	<.010	.20	<.01	<1	200
5S/3W-03L1S	35.0	1,640	5.50	<.010	.03	<.01	<1	710
5S/3W-03N1S	43.0	3,260	1.08	.020	.08	<.01	<1	1,100
5S/3W-03R1S	44.0	1,150	9.90	<.010	.02	<.01	3	450
5S/3W-04A1S	17.0	2,470	3.60	<.010	.05	<.01	<1	100
5S/3W-04M1S	46.0	5,760	1.90	<.010	.72	.02	<1	200
5S/3W-09E1S	58.0	1,930	7.50	<.010	.05	.02	<1	120
5S/3W-09H1S	63.0	2,100	7.80	<.010	.05	.02	<1	150
5S/3W-09H2S	68.0	1,370	8.00	<.010	.04	.04	<1	130
5S/3W-09Q1S	55.0	1,500	6.80	<.010	.05	<.01	<1	360
5S/3W-11D1S	52.0	541	7.60	<.010	<.01	.03	2	390
5S/3W-11M2S	—	—	—	—	—	—	—	—
5S/3W-14P1S	62.0	1,160	8.50	<.010	<.01	.05	1	210
5S/3W-15L1S	61.0	435	6.40	<.010	.03	.05	2	44.0
5S/3W-16F1S	46.0	1,730	11.0	<.010	<.01	.02	<1	300
5S/3W-17R1S	60.0	1,390	5.70	<.010	<.01	<.01	<1	81.0
5S/3W-24C1S	54.0	685	4.90	<.010	<.01	.04	2	200

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Beryllium, dissolved (µg/L)	Boron, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Cobalt, dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)
Menifee subbasin								
Sun City RWRf	<0.5	440	<1	<5	<3	<10	13	<10
Sun City Storage Pond	<.5	500	2	<5	3	<10	<3	10
5S/3W-28M1S	<.5	210	<1	<5	<3	<10	48	10
5S/3W-28M2S	<1.0	220	<2	<10	<6	<20	160	<20
5S/3W-28M3S	<1.5	210	<3	<15	<9	<30	<9	<30
5S/3W-28M4S	<1.5	130	<3	<15	<9	<30	36	100
5S/3W-32A1S	<10	340	<4	1.4	13	<1	590	<4
5S/3W-32B1S	<.5	530	<1	<5	4	<10	<3	30
5S/3W-32C1S	<1.0	430	<2	<10	<6	<20	<6	<20
5S/3W-32G1S	<1.0	580	<2	<10	<6	<20	14	30
5S/3W-32H1S	<.5	400	<1	<5	<3	<10	<3	<10
5S/3W-32L1S	<10	380	<1	2.0	<1	2.0	30	2
5S/3W-34Q2S	<1.5	160	<3	<15	16	<30	2,800	<30
5S/3W-35N2S	<1.5	610	<3	<15	<9	<30	130	70
5S/3W-36P2S	<1.0	330	<2	<10	8	<20	180	40
6S/3W-01J2S	<1.5	290	<3	<15	<9	<30	<9	<30
6S/3W-02A1S	<2.0	410	<4	<20	<12	<40	45	<40
6S/3W-02E1S	<.5	160	<1	<5	<3	<10	62	<10
6S/3W-02G2S	<.5	80	<1	<5	<3	<10	37	<10
6S/3W-05E1S	<.5	80	<1	<5	<3	<10	6	<10
Winchester subbasin								
Temecula RWRf	<.5	540	2	<5	<3	<10	9	20
Winchester Storage Pond	<.5	590	3	<5	5	<10	<3	10
5S/2W-29L2S	<10	1,300	<.01	1.6	<1	<1	10	<2
5S/2W-29L3S	<10	1,100	<1	1.7	6	<1	21,000	<2
5S/2W-29N1S	<1.5	1,300	<3	<15	<9	<30	<9	<30
5S/2W-30C1S	<1.0	90	<2	<10	<6	<20	87	30
5S/2W-30D2S	<1.5	250	<3	<15	<9	<30	10	70
5S/2W-30G2S	<2.0	230	<4	<20	<12	<40	<12	<40
5S/2W-30G3S	<1.0	90	<2	<10	<6	<20	<6	<20
5S/2W-30H2S	<5.0	170	20	<50	<30	<100	<30	<100
5S/3W-24F2S	<.5	70	<1	<5	<3	<10	9	<10
5S/3W-24F3S	<1.0	80	<2	<10	<6	<20	<6	20
5S/3W-24F4S	<.5	40	<1	<5	<3	<10	<3	<10

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Beryllium, dissolved (µg/L)	Boron, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Cobalt, dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)
Perris-South subbasin								
Perris Valley RWRf	<0.5	430	2	<5	<3	<10	18	<10
Trumble Road Storage Pond	<.5	490	2	<5	<3	<10	5	<10
4S/3W-26N1S	<10	820	<1	<5	<1	<1	310	<2
4S/3W-33Q1S	<10	600	<2	1	<1	<1	10	<2
5S/3W-02M2S	<1.5	250	<3	<15	<9	<30	21	<30
5S/3W-03C1S	<10	70	<1	<1	<1	<1	<10	5
5S/3W-03L1S	<1.0	70	<2	<10	<6	<20	<6	<20
5S/3W-03N1S	<1.5	260	<3	<15	20	<30	9,100	<30
5S/3W-03R1S	<.5	110	1	<5	<3	<10	6	20
5S/3W-04A1S	<1.5	210	3	<15	12	<30	<9	60
5S/3W-04M1S	<10	300	<4	3.7	<1	1.0	30	<4
5S/3W-09E1S	<1.0	90	<2	<10	<6	<20	8	<20
5S/3W-09H1S	<1.0	170	<2	<10	<6	<20	<6	60
5S/3W-09H2S	<1.0	190	<2	<10	<6	<20	9	30
5S/3W-09Q1S	<.5	210	<1	<5	<3	10.0	84	<10
5S/3W-11D1S	<.5	70	3	<5	<3	<10	13	20
5S/3W-11M2S	—	—	—	—	—	—	—	—
5S/3W-14P1S	<.5	150	1	<5	<3	<10	9	30
5S/3W-15L1S	<.5	60	3	<5	<3	<10	<3	<10
5S/3W-16F1S	<.5	60	1	<5	<3	<10	<3	10
5S/3W-17R1S	.5	70	<1	<5	<3	<10	<3	<10
5S/3W-24C1S	<.5	30	<1	<5	<3	<10	13	20

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Lithium, dissolved (µg/L)	Manganese, dissolved (µg/L)	Molybdenum, dissolved (µg/L)	Nickel, dissolved (µg/L)	Silver, dissolved (µg/L)	Strontium, dissolved (µg/L)	Vanadium, dissolved (µg/L)	Zinc, dissolved (µg/L)
Menifee subbasin								
Sun City RWRf	43	5.0	20	<10	1	790	<6	59
Sun City Storage Pond	42	5.0	30	<10	<1	830	<6	11
5S/3W-28M1S	26	160	20	<10	<1	1,700	<6	<3
5S/3W-28M2S	39	280	30	<20	<2	3,100	<12	<6
5S/3W-28M3S	48	640	60	<30	<3	8,500	20	<9
5S/3W-28M4S	27	370	<30	<30	<3	2,300	<18	<9
5S/3W-32A1S	150	4,600	<2.0	3.0	<1	17,000	100	200
5S/3W-32B1S	7	35.0	20	<10	1	130	43	6
5S/3W-32C1S	8	65.0	<20	<20	<2	1,700	24	13
5S/3W-32G1S	48	180	30	<20	<2	1,200	<12	19
5S/3W-32H1S	43	41.0	<10	<10	<1	780	25	110
5S/3W-32L1S	40	80.0	1.2	24	<1	3,100	39	180
5S/3W-34Q2S	34	53.0	<30	<30	<3	2,100	<18	14
5S/3W-35N2S	140	530	40	50	<3	1,600	<18	3,600
5S/3W-36P2S	200	1,200	<20	<20	<2	1,100	28	3,900
6S/3W-01J2S	37	<3.0	40	<30	4	2,300	<18	38
6S/3W-02A1S	49	4.0	<40	110	<4	2,300	<24	<12
6S/3W-02E1S	80	520	10	30	<1	1,000	10	6
6S/3W-02G2S	24	19.0	20	<10	<1	740	11	15
6S/3W-05E1S	30	2.0	30	<10	4	160	12	17
Winchester subbasin								
Temecula RWRf	23	4	10	<10	<1	490	22	38
Winchester Storage Pond	22	1	20	<10	<1	470	<3	<3
5S/2W-29L2S	30	10	9.0	1.0	<1	2,700	64	<10
5S/2W-29L3S	60	3,100	15	6.0	<1	2,800	40	10
5S/2W-29N1S	66	1,200	<30	<30	<3	2,900	<18	10
5S/2W-30C1S	17	8.0	30	<20	<2	1,400	<12	<6
5S/2W-30D2S	36	5.0	<30	<30	<3	3,400	<18	<9
5S/2W-30G2S	44	4.0	<40	<40	<4	2,200	<24	13
5S/2W-30G3S	<8	<2.0	<20	<20	<2	1,400	<12	11
5S/2W-30H2S	53	14.0	<100	<100	<10	3,100	<60	<30
5S/3W-24F2S	6	52.0	30	10	<1	200	<6	<3
5S/3W-24F3S	38	14.0	<20	<20	<2	2,000	16	13
5S/3W-24F4S	8	<1.0	20	<10	<1	1,100	16	<3

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	Lithium, dissolved (µg/L)	Manganese, dissolved (µg/L)	Molybdenum, dissolved (µg/L)	Nickel, dissolved (µg/L)	Silver, dissolved (µg/L)	Strontium, dissolved (µg/L)	Vanadium, dissolved (µg/L)	Zinc, dissolved (µg/L)
Perris-South subbasin								
Perris Valley RWRf	13	8.0	20	<10	<1	220	<6	35
Trumble Road Storage Pond	13	7.0	<10	<10	<1	290	<6	29
4S/3W-26N1S	50	50.0	20	2.0	<2	14,000	150	210
4S/3W-33Q1S	30	<10.0	<1.0	<1.0	<1	2,800	46	<10
5S/3W-02M2S	50	<3.0	<30	<30	<3	1,900	31	82
5S/3W-03C1S	20	<10.0	<1.0	<1.0	<1	4,800	47	<10
5S/3W-03L1S	29	<2.0	<20	<20	<2	1,700	16	<6
5S/3W-03N1S	32	2,400	<30	<30	<3	3,300	<18	<9
5S/3W-03R1S	7	<1.0	<10	<10	<1	950	64	5
5S/3W-04A1S	29	<3.0	<30	<30	8	1,300	<18	<9
5S/3W-04M1S	60	<10	4.0	1.0	7	12,000	160	<10
5S/3W-09E1S	<8	<2.0	<20	<20	<2	1,600	26	6
5S/3W-09H1S	18	<2.0	<20	<20	<2	1,400	19	10
5S/3W-09H2S	16	15.0	20	<20	<2	1,200	15	<6
5S/3W-09Q1S	25	67.0	<10	<10	1	1,600	14	350
5S/3W-11D1S	6	<1.0	30	<10	<1	370	48	410
5S/3W-11M2S	—	—	—	—	—	—	—	—
5S/3W-14P1S	20	1.0	20	<10	<1	960	20	10
5S/3W-15L1S	14	<1.0	<10	<10	3	290	21	<3
5S/3W-16F1S	7	<1.0	20	20	<1	1,600	20	210
5S/3W-17R1S	10	<1.0	20	<10	2	890	47	95
5S/3W-24C1S	17	2.0	<10	<10	<1	410	16	11

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	$^2\text{H}/^1\text{H}$, ratio (per mil)	$^{18}\text{O}/^{16}\text{O}$ ratio (per mil)	TOC, (in mg/L)	DOC, (in mg/L)	Ultraviolet absorbance, (at 254 nm)	MBAS, (in $\mu\text{g/L}$)	LAS, (in $\mu\text{g/L}$)	Caffeine, (in $\mu\text{g/L}$)
Menifee subbasin								
Sun City RWRf	-82.80	-10.1	9.4	10.5	0.172	—	<0.1	0.09
Sun City Storage Pond	-67.40	-7.34	10.2	10.2	.149	—	.1	.09
5S/3W-28M1S	-62.40	-9.03	2.9	2.2	.004	0.079	—	—
5S/3W-28M2S	-61.40	-8.89	3.8	4.5	.004	.131	—	—
5S/3W-28M3S	-54.30	-7.63	1.4	1.5	.001	.464	—	—
5S/3W-28M4S	-51.70	-7.48	1.1	.9	.003	.339	—	—
5S/3W-32A1S	-52.30	-7.61	2.2	1.9	.001	—	<.1	<.05
5S/3W-32B1S	-70.40	-8.64	2.3	2.4	.058	.279	—	—
5S/3W-32C1S	-74.60	-8.84	1.8	1.7	.022	.432	—	—
5S/3W-32G1S	-57.90	-7.74	1.5	1.3	.007	—	<.1	<.05
5S/3W-32H1S	-81.80	-9.44	1.7	1.8	.028	.325	—	—
5S/3W-32L1S	-51.50	-7.52	1.2	1.2	.003	—	<.1	<.05
5S/3W-34Q2S	-49.80	-7.06	1.2	1.2	.005	—	<.1	<.05
5S/3W-35N2S	-52.90	-7.61	1.7	1.6	<.001	.396	—	—
5S/3W-36P2S	-58.00	-8.41	3.2	3.4	.004	.139	—	—
6S/3W-01J2S	-51.40	-7.18	—	—	—	—	—	—
6S/3W-02A1S	-51.80	-7.36	—	—	—	—	—	—
6S/3W-02E1S	-53.50	-7.65	0.9	.9	—	.205	—	—
6S/3W-02G2S	-49.70	-6.94	—	—	—	—	—	—
6S/3W-05E1S	-46.10	-6.74	—	—	—	—	—	—
Winchester subbasin								
Temecula RWRf	-61.20	-7.93	8.2	8.8	.114	—	<.1	<.05
Winchester Storage Pond	-43.80	-4.92	7.7	7.8	.065	—	.7	<.05
5S/2W-29L2S	-52.00	-7.15	1.3	1.3	—	.648	—	—
5S/2W-29L3S	-54.10	-7.39	1.6	1.3	—	.557	—	—
5S/2W-29N1S	-51.90	-7.42	—	—	—	—	—	—
5S/2W-30C1S	-51.10	-7.31	.7	.7	.021	.516	—	—
5S/2W-30D2S	-58.40	-7.99	.8	.8	.004	—	<.1	<.05
5S/2W-30G2S	-60.40	-8.29	—	—	—	—	—	—
5S/2W-30G3S	-55.70	-7.50	1.2	1.2	.020	.391	—	—
5S/2W-30H2S	-51.40	-7.25	—	—	—	—	—	—
5S/3W-24F2S	-59.10	-8.41	.7	.7	.008	.188	—	—
5S/3W-24F3S	-54.60	-8.01	.7	.8	.006	1.041	—	—
5S/3W-24F4S	-50.70	-7.32	.7	.7	.003	.478	—	—

Table 1. Water-quality data for selected wells in the Menifee, Winchester, and Perris-South subbasins, Riverside County, California—Continued

Site name or State well No.	² H/ ¹ H, ratio (per mil)	¹⁸ O/ ¹⁶ O ratio (per mil)	TOC, (in mg/L)	DOC, (in mg/L)	Ultraviolet absorbance, (at 254 nm)	MBAS, (in µg/L)	LAS, (in µg/L)	Caffeine, (in µg/L)
Perris-South subbasin								
Perris Valley RWRf	-66.7	-8.72	9.3	8.7	0.126	—	0.04	<0.05
Trumble Road Storage Pond	-54.2	-6.64	6.9	7.2	.111	—	1.1	.05
4S/3W-26N1S	-62.3	-8.56	—	—	—	—	—	—
4S/3W-33Q1S	-60.8	-8.60	.5	.5	.005	0.697	—	—
5S/3W-02M2S	-56.0	-7.41	—	—	—	—	—	—
5S/3W-03C1S	-60.0	-8.38	.5	.5	.006	.618	—	—
5S/3W-03L1S	-53.9	-7.67	.6	—	—	.410	—	—
5S/3W-03N1S	-59.8	-8.59	.7	.7	<.001	.421	—	—
5S/3W-03R1S	-53.4	-7.59	.9	.9	.009	—	<.1	<.05
5S/3W-04A1S	-62.5	-8.45	.8	.8	.018	—	—	—
5S/3W-04M1S	-56.1	-7.87	.7	.7	.006	1.208	—	—
5S/3W-09E1S	-53.1	-7.10	1.3	1.1	.009	—	<.1	<.05
5S/3W-09H1S	-50.80	-7.12	.8	.8	.013	—	<.1	<.05
5S/3W-09H2S	-52.60	-7.40	.7	.7	.002	—	<.1	<.05
5S/3W-09Q1S	-53.60	-7.64	1.4	1.2	—	.276	—	—
5S/3W-11D1S	-51.00	-7.25	.8	.7	—	.216	—	—
5S/3W-11M2S	-51.60	-7.21	—	—	—	—	—	—
5S/3W-14P1S	-51.60	-7.26	—	—	—	—	—	—
5S/3W-15L1S	-49.10	-6.62	.6	.6	—	.180	—	—
5S/3W-16F1S	-51.00	-6.92	—	—	—	—	—	—
5S/3W-17R1S	-51.00	-7.07	.6	.6	—	.249	—	—
5S/3W-24C1S	-53.00	-7.54	.5	—	—	.216	—	—