

Ground-Water Quality in the Southeastern Sacramento Valley Aquifer, California, 1996

By Barbara J. Milby Dawson

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. (<http://www.usgs.gov/>). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

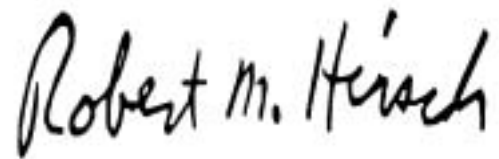
Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (<http://water.usgs.gov/nawqa/nawqamap.html>). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The

assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings. (<http://water.usgs.gov/nawqa/natsyn.html>).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

CONTENTS

Abstract	1
Introduction	1
Purpose and Scope	3
Study Area Description	3
Climate and Population	3
Water Use and Land Use	3
Hydrogeology	3
Study Design and Methods	5
Study Area and Well Selection	5
Water Sample Collection and Analysis	5
Data Reporting and Analysis	5
Acknowledgments	7
Well Descriptions	7
Quality-Control Data Analyses	8
Ground-Water Quality	9
General Water Chemistry	9
Inorganic Constituents	10
Nutrient Constituents	10
Dissolved Organic Carbon	11
Stable Isotopes	11
Tritium	11
Radon	13
Pesticides	13
Volatile Organic Compounds	15
Factors Affecting Ground-Water Quality	17
Ground-Water Redox Condition	17
Depth to Water Table and Well Opening	17
Land Use, Pesticide Use, and Fertilizer Use	21
Summary and Conclusions	21
References Cited	22

FIGURES

1. Location of Sacramento Valley aquifer, Sacramento subunit study area, Sacramento River Basin, and physiographic provinces	2
2. Locations of wells sampled in the southeastern Sacramento Valley aquifer, California	4
3. Well locations and surficial geology in the southeastern Sacramento Valley aquifer, California	6
4. Major-ion composition of ground-water samples from the southeastern Sacramento Valley aquifer, California	12
5. Relation between delta (δ) deuterium and δ oxygen-18 in ground water, surface water, and rain water in parts of the Sacramento Valley, California	14
6. Number of pesticides detected in wells sampled in the southeastern Sacramento Valley aquifer, California	16

7. Number of volatile organic compounds detected in wells sampled in the southeastern Sacramento Valley aquifer, California	18
8. Ground-water redox condition in wells sampled in the southeastern Sacramento Valley aquifer, California	20

TABLES

1. Laboratory analyses methods for measured water-quality constituents	7
2. Well construction information for wells sampled in rice areas in the Sacramento Valley, California, 1996	8
3. Summary of mean relative standard deviations for replicate samples of inorganic constituents, nutrient constituents, and dissolved organic carbon for ground-water studies in the Sacramento River Basin, California	9
4. Summary of general water chemistry in ground water in the southeastern Sacramento Valley aquifer, California, 1996	10
5. Comparison of selected ground-water-quality constituents measured in the southeastern Sacramento Valley aquifer, California, 1996, with those measured in other National Water-Quality Assessment Program studies in drinking water aquifers, 1992–1995	11
6. Summary of inorganic constituents detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	12
7. Summary of nutrient constituents and dissolved organic carbon detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	13
8. Summary of isotopes detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	13
9. Summary of pesticides in ground water in the southeastern Sacramento Valley aquifer, California, 1996	14
10. Pesticides and degradation products not detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	15
11. Summary of volatile organic compounds detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	17
12. Volatile organic compounds not detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996	19
13. Amount of nitrogen applied as fertilizer in the Sacramento Subunit study area	21

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
centimeter per year (cm/y)	.3937	inch per year
cubic meter per day (m ³ /d)	.000811	cubic foot per day
meter (m)	3.281	foot
meter per day (m/d)	3.281	foot per day
square kilometer (km ²)	.3861	square mile

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

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

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.

Abbreviations and Acronyms

µg/L	microgram per liter
µS/cm	microsiemen per centimeter
mg/L	milligram per liter
pCi/L	picocurie per liter
CADHS	California Department of Health Services
DOC	dissolved organic carbon
DWR	California Department of Water Resources
DWS	drinking-water standard
EPA	U.S. Environmental Protection Agency
HAL	lifetime health advisory level
MCL	maximum contaminant level
NAWQA	National Water-Quality Assessment (Program)
NWQL	National Water Quality Laboratory
QC	quality control
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey
VOC	volatile organic compound

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ABSTRACT

In 1996, the U.S. Geological Survey sampled 29 domestic wells and 2 monitoring wells in the southeastern Sacramento Valley as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program. This area, designated as the NAWQA Sacramento subunit study area, was chosen because it had the largest amount of ground-water use in the Sacramento River Basin. The Sacramento subunit study area is about 4,400 square kilometers and includes intense agricultural and urban development. The wells sampled ranged from 14.9 to 79.2 meters deep. Ground-water samples from 31 wells were analyzed for 6 field measurements, 14 inorganic constituents, 6 nutrient constituents, organic carbon, 86 pesticides, 87 volatile organic compounds, tritium (hydrogen-3), radon-222, deuterium (hydrogen-2), and oxygen-18.

Nitrate levels were lower than the 2000 drinking-water standards in all but one well, but many detections were in the range that indicated an effect by human activities on ground-water quality. Radon was detected in all wells, and was measured at levels above the proposed Federal 2000 maximum contaminant level in 90 percent of the wells. Five pesticides and one pesticide degradation product were detected in ground-water samples and concentrations were below 2000 drinking-water standards. All pesticides detected during this study have been used in the Sacramento Valley. Thirteen volatile organic compounds were detected in ground water. One detection of trichloroethene was above Federal 2000 drinking-water standards, and another, tetrachloromethane, was above California 1997 drinking-water standards; both occurred in a well that had eight volatile organic compound detections and is near a known source of ground-water contamination. Pesticides and volatile organic compounds were detected in agricultural and urban

areas; both pesticides and volatile organic compounds were detected at a higher frequency in urban wells.

Ground-water chemistry indicates that natural processes and human activities are affecting ground-water quality in the upper part of the southeastern Sacramento Valley aquifer. The factors identified as having an influence on ground-water quality were redox condition in the aquifer, depth within the aquifer, and land use overlying the aquifer. Nitrate concentrations showed a statistical correlation with each of these factors. Detections of pesticides and volatile organic compounds were too few to compare concentrations with the various factors, but the types of synthetic compounds detected were consistent with the surrounding land use. Sixty-one percent of the wells sampled in this study showed the effect of human activities on ground-water quality in the form of a nitrate concentration over 3 milligrams per liter or a detection of a pesticide or volatile organic compound. In general, the water quality in the southeastern Sacramento Valley aquifer was found suitable for most uses.

INTRODUCTION

In 1996, the U.S. Geological Survey (USGS) conducted a ground-water-quality study on the southeastern side of the Sacramento Valley in northern California (fig. 1). This study is one component of the USGS National Water-Quality Assessment (NAWQA) Program, which began in 1991. The NAWQA Program is described in Hirsch and others (1988). NAWQA studies began in the Sacramento River Basin in 1994; data from these studies will be compared to similar studies throughout the United States to assess the quality of the Nation's water resources, to assess long-term changes in the Nation's water quality, and to identify natural and human factors that govern the Nation's water quality.

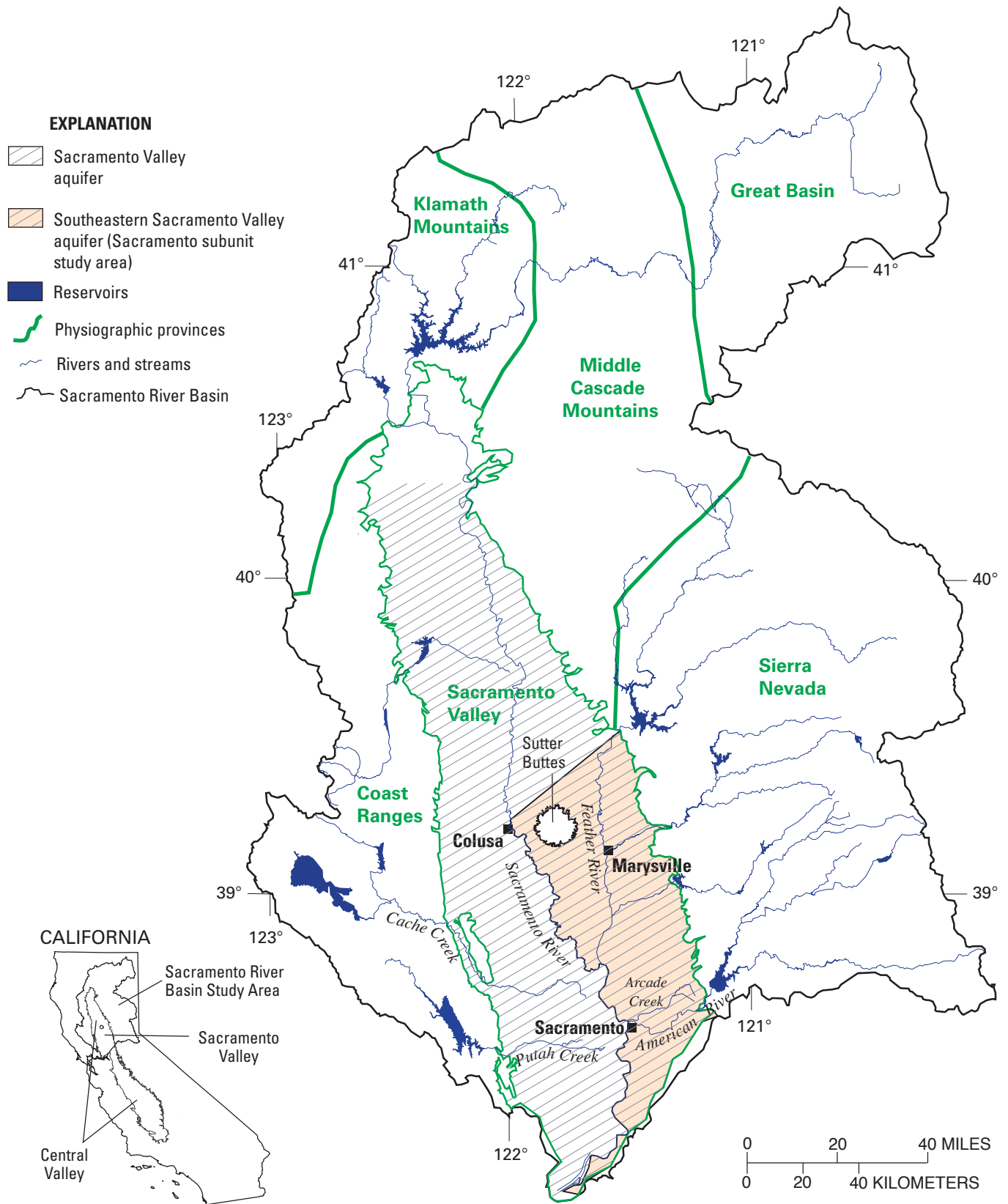


Figure 1. Location of Sacramento Valley aquifer, Sacramento subunit study area, Sacramento River Basin, and physiographic provinces.

This study is one of three ground-water studies conducted by the Sacramento River Basin NAWQA Program during 1996–1998, and is part of the NAWQA ground-water study component called a study-unit survey. The objective of a study-unit survey is to assess the overall water quality in the aquifers that supply the highest amount of drinking water within the study basin. In the Sacramento River Basin, the study-unit survey will consist of at least three subunit surveys within the Sacramento Valley aquifer, which is the largest aquifer within the basin and supplies the most drinking water from ground water. This report describes the first subunit survey to be conducted, designated the Sacramento subunit, which assessed the general water chemistry and quality of the ground water in the upper part of the southeastern Sacramento Valley aquifer, including the occurrence and distribution of arsenic, nitrate, radon, pesticides, and volatile organic compounds (VOC).

Purpose and Scope

This report describes the ground-water quality in the upper part of the southeastern Sacramento Valley aquifer, California, and factors that may be affecting that water quality, such as human activities (land use, pesticide use, and fertilizer use) and natural conditions (depth to water level in relation to top of well opening and redox condition). Ground-water samples from 31 wells (fig. 2) were analyzed for 6 field measurements, 14 inorganic constituents, 6 nutrient constituents, organic carbon, 86 pesticides, 87 VOCs, tritium (hydrogen-3), radon-222, deuterium (hydrogen-2) and oxygen-18. Measured concentrations were compared to data on ground-water redox conditions, depth to water table and well opening, land use, and pesticide and fertilizer use.

Study Area Description

Climate and Population

The Sacramento subunit is in the southeastern part of the Sacramento Valley (fig. 1). The Sacramento Valley occupies the northern one-third of California's Central Valley. The Sacramento subunit is about 4,400 km² (square kilometer) and includes intense agricultural and urban development. Land-surface elevations range from sea level to about 150 m (meter) above sea level along the eastern edge of the valley. The southeastern Sacramento Valley has a Mediterranean climate (Blair and Fite, 1957, p. 323) with hot, dry summers and wet, mild winters. Rainfall in the study area ranges from about 43 to 53 cm/y (centimeter per year) (Daly and Taylor, 1998), almost all of which

occurs between late autumn and early spring. The total population of the study area in 1990 was about 1,276,000, which was mostly in the Sacramento metropolitan area; the population density ranges from less than 100 per square kilometer in agricultural areas to greater than 4,800 per square kilometer in parts of the Sacramento metropolitan area (Hitt, 1994).

Water Use and Land Use

Ground water and surface water in the study area are used for drinking water and irrigation. Drinking-water supply in the Sacramento metropolitan area is a mix of surface water and ground water; drinking water in rural areas and small towns is supplied mostly from ground water. About one-half of the drinking water in this study area is supplied from ground water. Total ground-water use in 1995 was about 2 million cubic meters per day. About one-third of the study area is irrigated by a combination of ground water and surface water. [All water-use data are from Perlman (1999).] The principle land uses in the study area are agriculture and urban; the main agricultural land uses are rice crops and fruit and nut orchards. Other land uses include grain, field crops, tomatoes, and pasture (Domagalski and others, 1998).

Hydrogeology

The wells sampled for the Sacramento subunit study tap the upper 80 m of the Sacramento Valley aquifer, a single heterogeneous aquifer with no continuous confining layers or other distinct internal boundaries that occupies the northern one-third of California's Central Valley (fig. 1). The aquifer occupies a structural trough between the Sierra Nevada and Coast Ranges (fig. 1) and consists of thousands of meters of sediment eroded from the surrounding mountains (Page, 1986). In most areas, fine-grained sediments make up more than 50 percent of the aquifer system (Page, 1986). Intensive development of surface- and ground-water resources for water supply and flood control during the last 100 years has greatly altered the hydrologic system in the Sacramento Valley; discharge and recharge have increased from natural conditions due to ground-water pumping and irrigation return (Bertoldi and others, 1991). Regional ground-water flow extends from the sides of the valley toward the center and southward. Ground-water conditions grade downward from unconfined to semiconfined to confined below the upper hundred meters. Pumping depressions have developed in some areas from pumping for irrigation and drinking-water supply (Williamson and others, 1989).

The alluvial deposits that compose the upper part of the southeastern Sacramento Valley aquifer range in

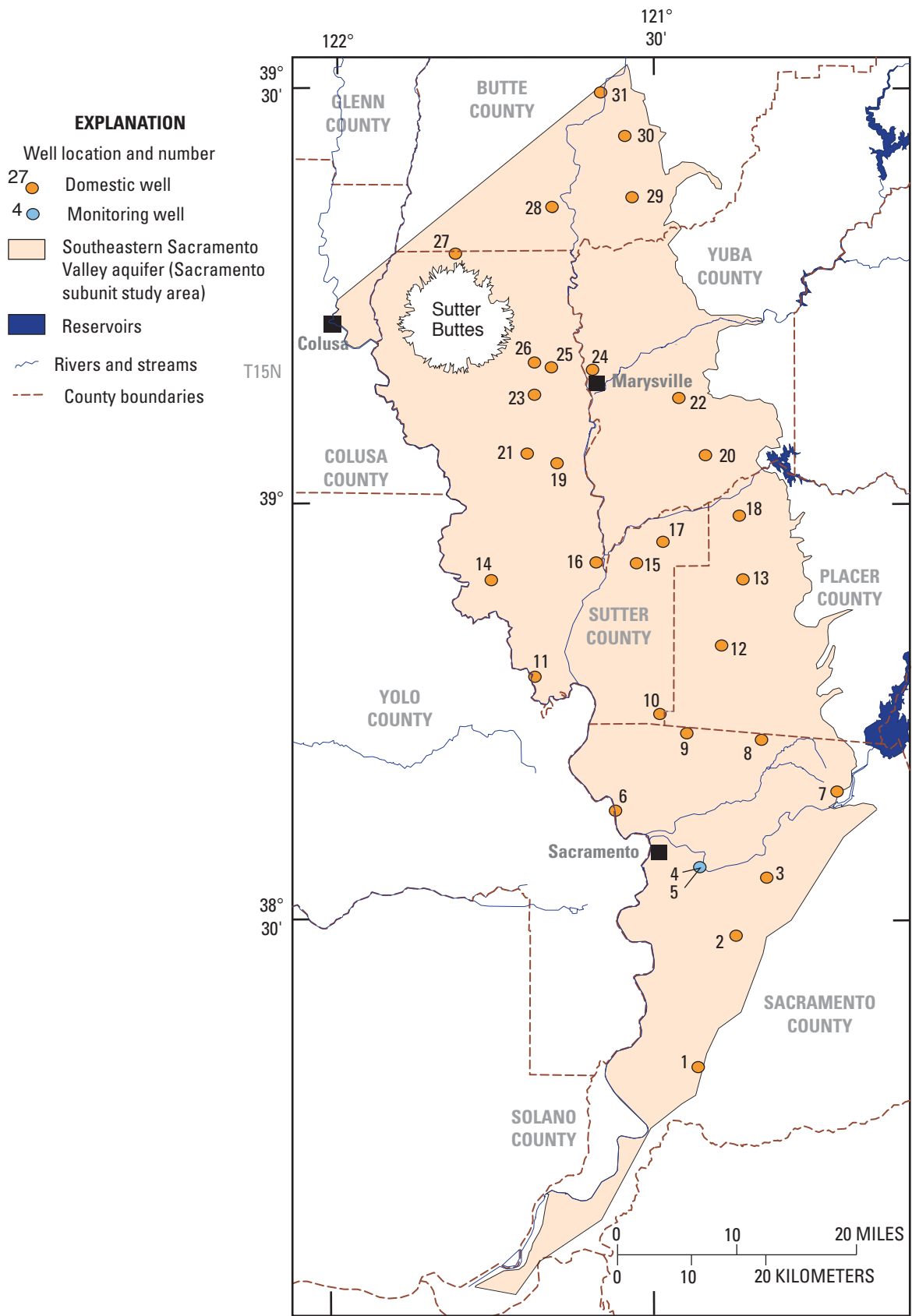


Figure 2. Locations of wells sampled in the southeastern Sacramento Valley aquifer, California.

age from Eocene to Holocene (fig. 3). These deposits, eroded from the Sierra Nevada, Sutter Buttes, and other areas of the basin, consist of clay, silt, sand, and gravels that have been transported and deposited by the Sacramento River and its east-side tributaries (Helley and Harwood, 1985). The sediment source areas consist mainly of metamorphic, granitic, and volcanic rock types. Recharge is thought to occur mainly along the river channels, in irrigated areas, and, to some extent, from precipitation. Estimated soil permeabilities throughout most of the study area generally are less than 3 m/d (meters per day) and can range up to 6 m/d (Bertoldi, 1974).

Study Design and Methods

Study Area and Well Selection

For this study, the Sacramento Valley Aquifer was divided into subunits that could be characterized by sampling 30 wells; divisions were based on the source of sediment that composes the aquifer. The Sacramento subunit study area, which mostly consists of sediment derived from the Sierra Nevada to the east, has the highest ground-water use in the Sacramento River Basin and was selected by the Sacramento River Basin NAWQA Program to be sampled in 1996.

The criteria used for well selection in this study follow those published in Lapham and others (1997). After selecting the study boundaries, a computer geographic information system was used to divide the Sacramento subunit into 30 equal-area cells. A computer program (Scott, 1990) was used to randomly select and prioritize the wells from the USGS well database that met the well-selection criteria and were located in one of the 30 cells. The same program also was used to randomly prioritize grid points in each cell; township/range/section of the selected grid points was determined, and records of wells in these township/range/sections were obtained from the California Department of Water Resources (DWR). The selected wells then were field inventoried and a final evaluation of each well was made and permission to sample the well was obtained from the property owner. If a well did not meet the selection criteria or the owner would not give permission to sample, the search was expanded to the other wells within that cell, and, in some cases, a suitable well in an adjacent cell was selected. Thirty-one wells were selected for sampling, 29 domestic wells and a pair (shallow and deep) of monitoring wells.

Water Sample Collection and Analysis

The wells selected for this study were sampled between May and August 1996. Sampling equipment

consisted of Teflon tubing with stainless steel fittings attached to a faucet on the well head or discharge line at a point before pressure tanks or treatment. Samples were collected and processed following the protocols in Koterba and others (1995) with the exception of dissolved organic carbon (DOC) samples, which were filtered using a Teflon filter holder and an electric, oil-free vacuum pump.

Before pumping, the water level in the well was measured and used to calculate the volume of standing water in the well casing. The well then was purged by pumping at least three full casing-volumes of water. While the well was being purged, water temperature, pH, specific conductance, and dissolved oxygen were monitored. Ground-water samples were collected after three full casing-volumes were pumped or when the field measurements were stable. After all the samples were collected at each site, the sampling equipment was cleaned and stored in plastic bags. Periodically, quality-control (QC) samples were collected to document sample bias and variability.

All ground-water samples were shipped to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado, for analysis, except tritium samples, which were analyzed at the USGS Tritium Laboratory in Menlo Park, California, and stable isotope samples, which were analyzed at the USGS Isotope Laboratory in Reston, Virginia. Analytical methods used in this study are listed in table 1. Semiquantitative (presence/absence) measurements for ferrous iron and hydrogen sulfide also were made in the field using colorimetric methods.

Data Reporting and Analysis

Water temperature is reported in degrees Celsius. Specific conductance values are reported in microsiemens per centimeter. Alkalinity and hardness are reported in milligrams per liter as calcium carbonate. Dissolved concentrations of oxygen, solids (residue-on-evaporation at 180°C), organic carbon and inorganic and nutrient compounds are reported in milligrams per liter (mg/L). Nitrate, nitrite, and ammonia are reported in milligrams per liter as nitrogen. Nitrate values in this report are equivalent to nitrate plus nitrite as no detections of nitrite were greater than 0.01 mg/L. Phosphorus and orthophosphorus are reported in milligrams per liter as phosphorus. Pesticide and VOC concentrations are reported in micrograms per liter. Radon and tritium concentrations are reported in picocuries per liter (pCi/L). Deuterium and oxygen-18 data are reported as ratios per mill or parts per thousand of deuterium to hydrogen and oxygen-18 to oxygen-16, respectively. All data used in this report are available on the Web at <http://infotrek.er.usgs.gov/wdbctx/nawqa/nawqa.home>.

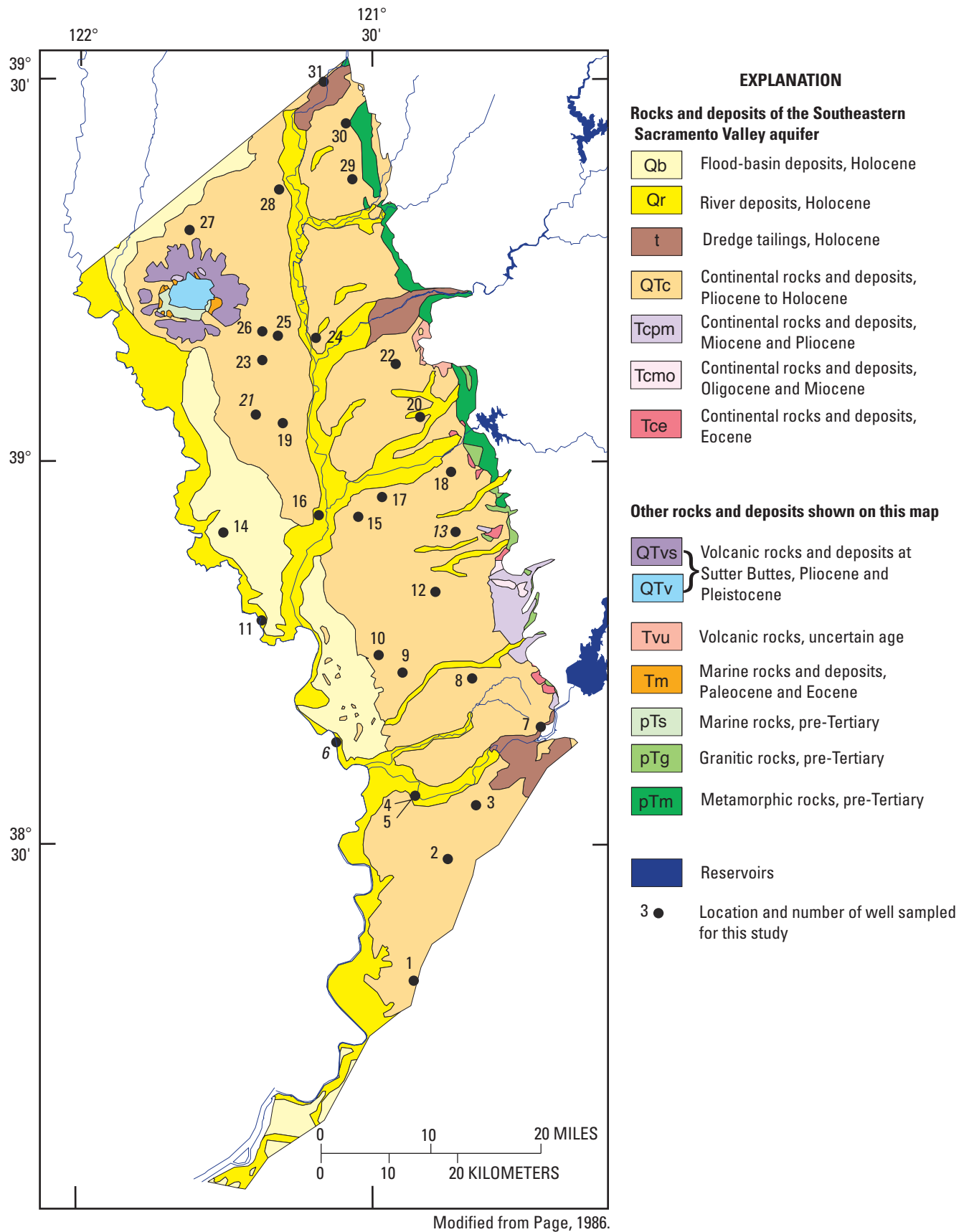


Figure 3. Well locations and surficial geology in the southeastern Sacramento Valley aquifer, California.

Table 1. Laboratory analyses methods for measured water-quality constituents

Constituent group	Analysis method	Reference
Deuterium/hydrogen	Hydrogen equilibrium and mass spectrometry	Coplen and others (1991)
Dissolved organic carbon	Ultraviolet-promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett (1993)
Inorganic constituents	Atomic absorption spectrometry, colorimetry, ion-exchange chromatography, or inductively coupled plasma atomic emission spectrometry or mass spectrometry	Fishman and Friedman (1989) Fishman (1993) Struzeski and others (1996)
Nutrient constituents	Colorimetry	Patton and Truitt (1992) Fishman (1993)
Oxygen-18/oxygen-16	Carbon dioxide equilibrium	Epstein and Mayeda (1953)
Pesticides	Solid-phase extraction on a carbon-18 cartridge and gas chromatography/mass spectrometry	Zaugg and others (1995) Lindley and others (1996)
Pesticide	Solid-phase extraction on a Carbowpak-B cartridge and high performance liquid chromatography with ultraviolet detection	Werner and others (1996)
Radon-222	Liquid scintillation counting	American Society for Testing and Materials (1992)
Tritium	Electrolytic enrichment with gas counting	Ostlund and Dorsey (1975)
Volatile organic compounds	Purge and trap capillary gas chromatography/mass spectrometry	Rose and Schroeder (1995)

In this report, water-quality constituents are compared to the year 2000 drinking-water standards (DWS) set by the U.S. Environmental Protection Agency (EPA) and to 1997 DWS set by the California Department of Health Services (CADHS); CADHS standards are used for constituents not currently regulated by the EPA or for those constituents with a CADHS standard lower than the EPA standard. Drinking-water standards used for comparison are the maximum contaminant level (MCL), which is the maximum concentration of a contaminant permissible in a public water system; the secondary maximum contaminant level (SMCL), which is a guideline for taste, odor, and appearance of drinking water (EPA SMCLs are unenforceable, while CADHS SMCLs are enforceable) and the lifetime health advisory level (HAL), which is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects during a lifetime of exposure (California Department of Water Resources, 1997; U.S. Environmental Protection Agency, 2000).

Summary statistics include median values because most ground-water chemistry data have non-normal distributions and many outliers. The Spearman rank correlation test was used to determine the degree of correlation between two different variables. The data for each variable were ranked, and the ranks of each pair of data were compared to see if the higher- and lower-ranking data of one variable corresponded to the higher- and lower-ranking data of the other variable. The linear correlation coefficient, rho, (Spearman's rho) is computed on the ranks of the data; rho varies between -1 and 1, with values closer to -1 indicating an inverse correlation, values closer to 1 indicating a

positive correlation, and values closer to 0 indicating no correlation (Helsel and Hirsch, 1995). A significance level of 95 percent confidence was used for all statistical tests in this report. The words "significant" and "correlation" always are used in the statistical sense.

Acknowledgments

The author thanks the homeowners and businesses in the Sacramento Valley and the Geology Department at California State University, Sacramento, for allowing the USGS to sample their wells during this study. Their cooperation has added much to the understanding of ground-water quality in the Sacramento Valley.

WELL DESCRIPTIONS

Well construction data for the wells sampled during this study are listed in table 2. These wells included twenty-nine 10- to 25-cm (centimeter)-diameter wells used for domestic or irrigation supply and two 5- and 10-cm-diameter wells used for monitoring. Well depths ranged from 14.9 to 79.2 m below land surface, with the depth to the top of the opening in the well casings ranging from 8.5 to 65.5 m below land surface. Well casings are steel or polyvinyl chloride. Land-use information was obtained from the DWR. Land use around the wells sampled in 1996 was verified in the field by the USGS. Water levels were measured during field inventory and again during sampling. Water levels ranged from 0.7 to 48.8 m below land surface, with a median value of 7.5 m below land surface.

Table 2. Well construction information for wells sampled in rice areas in the Sacramento Valley, California, 1996

[USGS, U.S. Geological Survey; masl, meter above sea level; mbls, meter below land surface; ND, no data]

Well number	USGS Site ID	State well number	Land surface elevation (masl)	Well depth (mbls)	Open interval (mbls)	Depth to ground water (mbls)	Water level elevation (masl)	Date water-level measured
1	381923121255001	006N005E33Q001M	5.5	48.2	42.1–48.2	17.4	-11.9	5/23/96
2	382855121221601	007N005E01R001M	14.0	79.2	59.4–79.2	28.5	-14.5	6/26/96
3	383304121192501	008N006E16B002M	22.9	45.7	30.5–45.7	25.2	-2.4	5/2/96
4	383350121254301	008N005E09H001M	9.9	14.9	8.2–14.3	7.3	2.6	5/13/96
5	383352121254002	008N005E09H003M	9.7	63.4	58.8–63.4	11.2	-1.4	5/13/96
6	383801121333801	009N004E17J002M	8.5	45.7	42.4–45.7	4.3	4.2	5/20/96
7	383914121124901	009N007E09B001M	82.6	76.2	38.1–76.2	17.6	65.0	5/30/96
8	384301121195101	010N006E16P001M	42.4	70.1	64.0–70.1	48.8	-6.4	4/16/96
9	384330121265601	010N005E17H001M	17.4	73.2	64.6–73.2	29.9	-12.5	8/6/96
10	384455121292101	010N004E01K001M	12.2	49.4	42.7–48.8	16.9	-4.7	7/12/96
11	384736121411501	011N003E18N001M	8.8	68.0	60.7–65.5	5.8	3.0	¹ 4/2/85
12	384949121233501	011N005E02M001M	25.9	54.9	36.6–54.9	27.7	-1.8	5/30/96
13	385432121213001	012N005E12A001M	33.8	33.5	21.3–30.5	15.6	18.2	6/3/96
14	385432121451401	012N002E09A001M	6.7	47.2	42.7–47.2	0.9	5.8	6/6/96
15	385546121312801	013N004E33J001M	14.6	47.2	30.5–47.2	5.1	9.5	6/4/96
16	385550121352201	013N003E36L001M	10.7	16.8	13.4–16.8	2.6	8.0	8/8/96
17	385718121290401	013N004E24N001M	19.2	64.9	24.4–64.9	3.4	15.8	3/21/96
18	385914121215801	013N005E12Q002M	38.1	32.6	29.3–32.6	14.5	23.6	5/21/96
19	390301121391001	014N003E20H003M	13.4	38.1	20.7–38.1	4.4	9.0	5/22/96
20	390333121250701	014N005E16Q001M	30.5	71.6	62.2–71.6	28.4	2.1	6/3/96
21	390342121415501	014N002E13L002M	11.3	27.4	18.0–27.4	0.7	10.6	5/22/96
22	390743121273601	015N005E30C001M	26.2	61.0	48.8–61.0	18.3	7.9	7/3/96
23	390756121411901	015N002E24J001M	14.6	25.9	11.0–25.9	2.3	12.3	6/26/96
24	390945121354601	015N003E12M001M	18.3	21.3	12.2–21.3	5.8	12.5	8/5/96
25	390954121394302	015N003E08F002M	17.4	35.1	21.3–35.1	6.8	10.6	6/13/96
26	391016121411701	015N002E01R001M	17.4	16.2	8.5–16.2	2.2	15.2	6/12/96
27	391806121484501	017N001E25D001M	23.2	27.4	18.3–27.4	10.0	13.2	6/12/96
28	392121121393401	017N003E05L001M	28.7	29.0	18.3–29.0	2.2	26.4	6/10/96
29	392209121320301	018N004E33L001M	33.8	42.7	ND	5.3	28.5	6/10/96
30	392636121324501	018N004E05M001M	54.9	34.7	28.7–34.7	16.0	38.8	6/11/96
31	392945121350001	019N003E13P001M	45.7	52.4	48.5–52.4	7.5	38.2	6/11/96

¹Most recent water level available for this well.

QUALITY-CONTROL DATA ANALYSES

Quality-control samples, in addition to the ground-water samples, were collected to evaluate the bias and variability of the ground-water chemistry data measured in this study. QC sample types included field-blank samples, replicate ground-water samples, and field-spiked ground-water samples. Blank and replicate sample data from all three ground-water studies in the Sacramento River Basin from 1996 to 1998 were used for this analysis.

Blank samples were collected to evaluate bias in ground-water chemical data from contamination introduced during the sample collection and analysis of inorganic constituents, nutrient constituents, DOC, pesticides, and VOCs. On the basis of contamination in blank samples, environmental data were affected for ammonia and DOC. The concentrations of these two compounds measured in the ground water were all within three standard deviations of the mean of the concentrations measured in the field blanks. This indicates that measured concentrations of these

constituents may be partly or entirely due to contamination that was introduced during sampling or analysis; these data were not used for data analyses in this report. DOC contamination in field blanks may have come from the cleaning methods used to prevent contamination of other organic constituents during sampling; this contamination may not be present in the ground-water samples. Sources of ammonia contamination are not known.

Replicate samples were collected to determine variability of the ground-water chemical data for inorganic constituents and for DOC. A total of 11 replicate sample pairs were used for this evaluation. The mean relative standard deviations for all constituents were less than 15 percent and for most constituents were less than 5 percent (table 3).

Surrogates (compounds that behave similarly to pesticide or VOC analytes) were added to all pesticide and VOC samples to evaluate the ability of the sampling and analysis methods to detect the target analytes in each ground-water sample. The mean recoveries of the surrogates in all ground-water samples for pesticides and VOCs were within the control limits determined by the NWQL for 1996 (R.W. Brenton, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1997; M.P. Schroeder, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1997; B. Connor, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1998).

Spike solutions containing known amounts of some target analytes were added to some replicate ground-water samples to evaluate bias of those pesticide and VOC analyses. Seventy-nine of 86 pesticides were evaluated with field-spiked samples; 77 of these had mean recoveries within NWQL's 1996 control

limits (R.W. Brenton, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1997; M.P. Schroeder, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1997). Thirteen VOCs were evaluated with field-spiked samples; 12 had mean recoveries within NWQL's 1996–1998 control limits (B. Connor, U.S. Geological Survey National Water Quality Laboratory, unpub. data, 1998). The mean recoveries of two compounds, atrazine (a pesticide) and tetrachloromethane (a VOC), detected in ground-water samples were slightly higher (1 percent and 4 percent, respectively) than the upper control limits, indicating that detected values of those compounds may be biased slightly high in some ground-water samples. The mean recovery of the pesticide chloramben was lower than the lower control limit, indicating that chloramben may not have been detected if present in low concentrations in some ground-water samples. Replicates of VOC field-spiked samples also were collected; the relative standard deviation of all VOC-spike compounds was less than 20 percent.

GROUND-WATER QUALITY

General Water Chemistry

Summary statistics for general water chemistry measurements are listed in table 4. The pH in one well was below the secondary DWS (measured at 6.4; SMCL is 6.5–8.5; U.S. Environmental Protection Agency, 2000). Secondary DWSs for specific conductance, measured at 1,402 and 2,270 $\mu\text{S}/\text{cm}$ (microsiemen per centimeter) (SMCL=900 $\mu\text{S}/\text{cm}$; California Department of Water Resources, 1997), and

Table 3. Summary of mean relative standard deviations for replicate samples of inorganic constituents, nutrient constituents, and dissolved organic carbon for ground-water studies in the Sacramento River Basin, California

Mean relative standard deviation of less than 5 percent	Mean relative standard deviation of less than 10 percent	Mean relative standard deviation of less than 15 percent
Arsenic	Ammonia ¹	Boron ¹
Calcium	Dissolved organic carbon ¹	Bromide ¹
Chloride ¹	Fluoride ¹	Orthophosphorus ¹
Iron	Nitrate ¹	
Hardness as calcium carbonate (CaCO ₃)	Phosphorus ¹	
Magnesium		
Nitrite		
Potassium		
Silica		
Sodium		
Sulfate		
Total dissolved solids		

¹One to two individual replicate pairs had a relative standard deviation of greater than 20 percent.

Table 4. Summary of general water chemistry in ground water in the southeastern Sacramento Valley aquifer, California, 1996

[°C, degrees Celsius; CaCO₃, calcium carbonate; SMCL, secondary maximum contaminant level; µS/cm, microsiemen per centimeter; mg/L, milligram per liter]; —, no value available]

General water chemistry	Minimum measurement	Median measurement	Maximum measurement	Drinking-water standard	Drinking-water standard type	Number of wells exceeding a drinking-water standard
Alkalinity, mg/L as CaCO ₃	53	136	345	—	—	—
Dissolved solids, mg/L, residue on evaporation at 180°C	134	258	1,750	500	SMCL ¹	3
Dissolved oxygen, mg/L	0	4.2	7.6	—	—	—
Hardness, total, mg/L as CaCO ₃	48 (soft)	135 (hard)	940 (very hard)	—	—	—
pH, standard units	6.4	7.4	8	6.5–8.5	SMCL ¹	1
Specific conductance, µS/cm at 25°C	159	390	2,270	900	SMCL ²	2
Water temperature, °C	16.8	19.6	21	—	—	—

¹U.S. Environmental Protection Agency, 2000.

²California Department of Water Resources, 1997.

dissolved solids, measured at 912 and 1,750 mg/L (SMCL=500 mg/L; U.S. Environmental Protection Agency, 2000) were exceeded in two wells. The SMCL for dissolved solids also was exceeded in a third well (measured at 569 mg/L). The median concentration of dissolved solids measured in this study (258 mg/L) was slightly lower than the national median for drinking-water aquifers (298 mg/L) measured in other NAWQA studies from 1992–1995 (table 5) (Gilliom and others, 1998, p. 18).

Inorganic Constituents

The major inorganic constituents (those with median concentrations greater than 1 mg/L) detected in ground water in this study were bicarbonate, silica, calcium, sodium, chloride, magnesium, sulfate, and potassium; summary statistics for these inorganic constituents are listed in table 6. The major water types found in this study were magnesium-calcium-bicarbonate waters (fig. 4), with some wells having sodium-bicarbonate water types and others having a more mixed water type (magnesium-calcium-sodium-bicarbonate-chloride). The higher concentrations of sodium and chloride in some wells may be due to natural or man-made causes. The minor inorganic constituents (those with median concentrations less than 1 mg/L) that were detected in ground water in this study were boron, fluoride, manganese, bromide, iron, and arsenic (table 6).

Drinking-water standards were exceeded for five inorganic constituents. The SMCL for chloride (250 mg/L; U.S. Environmental Protection Agency, 2000) was exceeded in 1 of 31 wells (3 percent). The HAL for boron (0.6 mg/L; U.S. Environmental Protection Agency, 2000) was exceeded in 2 of 31 wells (6 percent); these wells also exceeded the water-quality

criterion for boron in irrigation water (0.75 mg/L; National Academy of Sciences and National Academy of Engineering, 1972). The SMCL for iron (300 µg/L; U.S. Environmental Protection Agency, 2000) was exceeded in 3 of 31 wells (10 percent). The SMCL for manganese (50 µg/L; U.S. Environmental Protection Agency, 2000) was exceeded in 5 of 31 wells (16 percent) sampled during this study. Arsenic was detected in 28 of 31 wells (90 percent); all concentrations were below the current 1996 EPA MCL (50 µg/L; U.S. Environmental Protection Agency, 1996). Lower MCLs for arsenic have been proposed [0.005 mg/L (U.S. Environmental Protection Agency, 2000); 0.010 mg/L (U.S. Environmental Protection Agency (2001a))]; however, those MCLs are being withdrawn and a new MCL is under review (U.S. Environmental Protection Agency, 2001b). The EPA also has an HAL for arsenic of 0.002 mg/L (U.S. Environmental Protection Agency, 2000); 20 out of 31 wells (64 percent) have an arsenic concentration over the HAL.

Nutrient Constituents

The nutrient inorganic constituents detected in ground water during this study were nitrate, nitrite, ammonia, phosphorus, and orthophosphorus (table 7). However, detections of ammonia in field blanks indicate that the concentrations of ammonia in ground water may be partly or entirely due to contamination introduced during sample collection or analysis. The MCL for nitrate (10 mg/L as nitrogen; U.S. Environmental Protection Agency, 2000) was exceeded in 1 of 31 wells (3 percent). Nitrate was detected in 29 of 31 wells sampled (94 percent). Eight of the wells (26 percent) had nitrate values greater than 3 mg/L. Ground water containing 3 mg/L or more nitrate is considered to be affected by human activity (Madison and Brunett, 1984).

Table 5. Comparison of selected ground-water-quality constituents measured in the southeastern Sacramento Valley aquifer, California, 1996, with those measured in other National Water-Quality Assessment Program studies in drinking water aquifers, 1992–1995

[mg/L, milligram per liter; pCi/L, picocurie per liter. —, no value available]

Compound	Median concentration in southeastern Sacramento Valley aquifer, 1996	National median concentration in drinking water aquifers, 1992–1995
Dissolved solids (mg/L)	258	298
Nitrate + nitrite (mg/L)	1.4	1.0
Radon (pCi/L)	495	450
Compound	Detection frequency in southeastern Sacramento Valley aquifer, 1996 (percent)	National detection frequency in drinking water aquifers, 1992–1995 (percent)
Pesticides, total	35.5	39.6
Atrazine	6.4	19.1
Bentazon	16.7	1.3
Bromacil	3.2	0.6
Desethyl atrazine	12.9	17.5
Simazine	9.7	6.3
Tebuthiuron	3.2	0.9
Volatile organic compounds, total	38.7	10
1,1-Dichloroethane	6.4	—
1,2,4-Trimethylbenzene	9.7	0.0
1,2-Dichloroethane	3.2	0.0
Bromodichloromethane	3.2	1.2
<i>cis</i> -1,2-Dichloroethene (1,2-DCE)	3.2	0.2
Dichlorodifluoromethane (Freon 12)	9.7	1.2
Methyl <i>tert</i> -butyl ether (MTBE)	3.2	2.8
Styrene	3.2	0.0
Tetrachloroethene (PCE)	6.4	2.0
Tetrachloromethane	3.2	0.2
Trichloroethene (TCE)	12.9	0.9
Trichlorofluoromethane (Freon 11)	3.2	1.4
Trichloromethane (Chloroform)	6.4	6.8

Nitrite was detected in 3 of 31 wells (10 percent) at 0.01 mg/L. The median concentration for nitrate + nitrite in this study was 1.4 mg/L, which is higher than the national NAWQA median concentration of 1.0 mg/L in drinking-water aquifers (table 5) (Gilliom and others, 1998, p. 17).

Dissolved Organic Carbon

Dissolved organic carbon was detected in 27 of 31 wells (87 percent) (table 7). The median concentration of DOC detected in ground water in this study was 0.3 mg/L, which is lower than the median DOC concentration detected in wells throughout the Nation (0.7 mg/L, Leenheer and others, 1974). Detections of DOC in field blanks indicate that all concentrations measured in ground water in this study may be partly or entirely due to contamination introduced during sample collection or analysis.

Stable Isotopes

The naturally occurring stable isotopes deuterium (hydrogen-2) and oxygen-18 were measured in 22 wells sampled for this study (table 8). Figure 5 shows a plot of these data along with values measured in surface water and rainfall for this and previous studies (Davisson and others, 1993). The large rivers of the Sacramento Valley that originate to the north and east carry large amounts of precipitation and snowmelt from higher elevations that is isotopically lighter (green triangles in fig. 5). Smaller creeks originating in the west and in the Sacramento Valley carry valley rainfall and irrigation drainage water that is isotopically heavier (blue triangles in fig. 5). Both groups of data plot along the line calculated for North American Meteoric Waters (Coplen, 1993, p. 235). Ground-water stable isotope data from the upper part of the southeastern Sacramento Valley aquifer (red circles in fig. 5) overlaps and spans the gap between the two groups of surface-water data along the North American Meteoric Water Line. This indicates that ground water in the study area is a combination of water from large rivers (high elevation precipitation) and from valley precipitation and surface water. No distinct areal or vertical pattern within the aquifer was found between wells with lighter or heavier stable isotopes.

Tritium

Tritium (hydrogen-3) was detected in 18 of 22 wells (82 percent) (table 8). Tritium concentrations were below the 1997 CADHS drinking-water standard (20,000 pCi/L; California Department of Water Resources, 1997) in all wells. Tritium, a naturally occurring and man-made radioactive isotope of hydrogen with a short half-life of 12.43 years, can be used to determine whether ground water has been recharged since the earlier 1950s [the beginning of nuclear bomb testing that produced tritium levels up to three orders of magnitude higher than natural concentrations (Michel, 1989, p. 2)]. Ground water that originated as

Table 6. Summary of inorganic constituents detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996 [mg/L, milligram per liter; µg/L, microgram per liter; SMCL, secondary maximum contaminant level; MCL, maximum contaminant level; HAL, health advisory level; —, no value available]

Compound	Number of detections/samples	Minimum detection	Median detection	Maximum detection	Drinking water standard	Drinking water standard type	Number of wells exceeding a drinking-water standard
Arsenic, µg/L as As	28/31	1	5	46	50	MCL ¹	0
Bicarbonate, mg/L as HCO ₃	31/31	67	160	413	—	—	—
Boron, µg/L as B	31/31	12	42	1100	600	HAL ¹	2
Bromide, mg/L as Br	30/31	0.02	0.06	1.2	—	—	—
Calcium, mg/L as Ca	31/31	10	24	210	—	—	—
Chloride, mg/L as Cl	31/31	2.0	17	620	250	SMCL ¹	1
Fluoride, µg/L as F	22/31	0.1	0.2	0.3	4	MCL ¹	0
Iron, µg/L as Fe	20/31	3	7	1600	300	SMCL ¹	3
Magnesium, mg/L as Mg	31/31	5.0	17	100	—	—	—
Manganese, µg/L as Mn	9/31	1	80	870	50	SMCL ¹	5
Potassium, mg/L as K	31/31	0.40	1.4	4.1	—	—	—
Silica, mg/L as SiO ₂	31/31	24	58	86	—	—	—
Sodium, mg/L as Na	31/31	5.7	20	120	—	—	—
Sulfate, mg/L as SO ₄	31/31	1.0	11	130	250	SMCL ¹	0

¹U.S. Environmental Protection Agency, 2000.

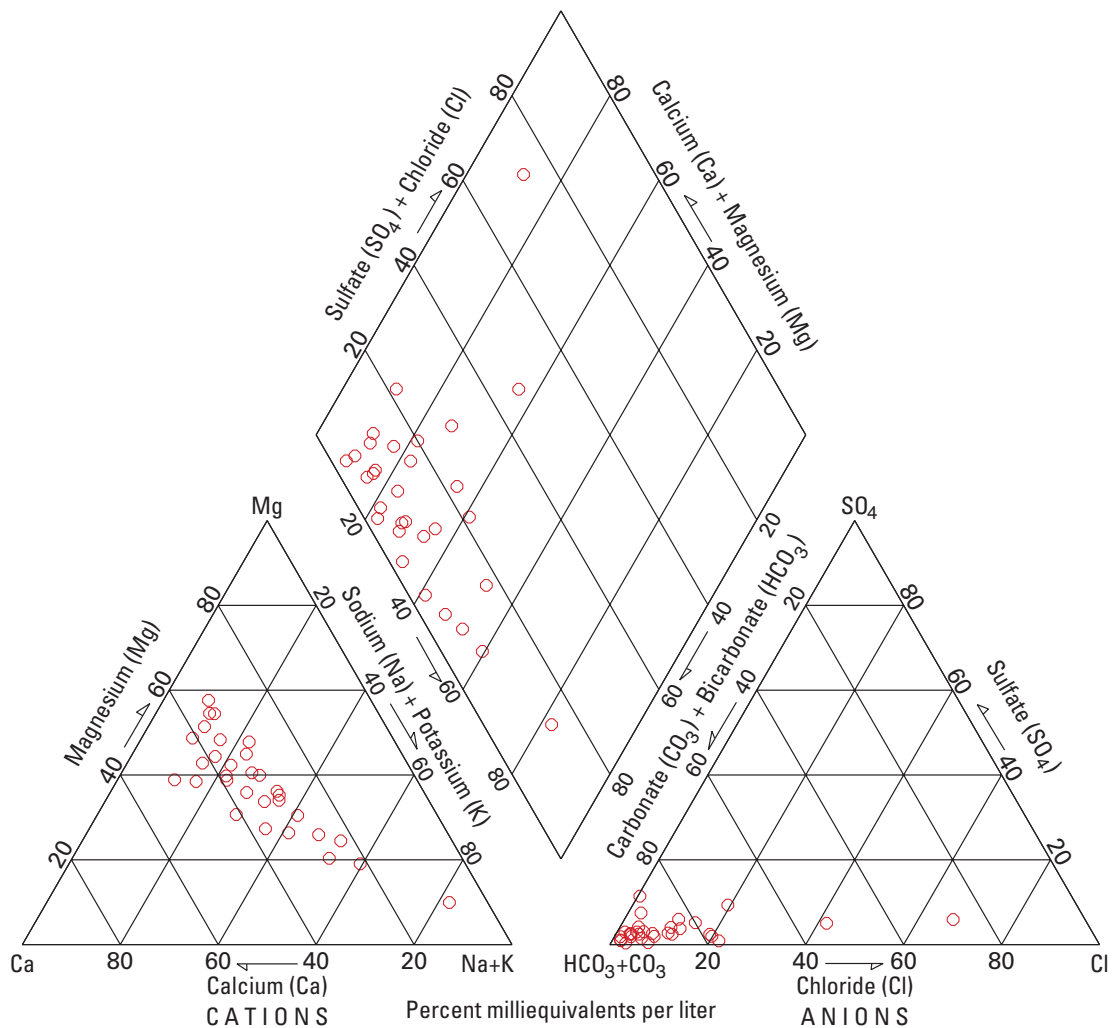


Figure 4. Major-ion composition of ground-water samples from the southeastern Sacramento Valley aquifer, California.

Table 7. Summary of nutrient constituents and dissolved organic carbon detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996

[All units shown in milligrams per liter; HAL, health advisory level; MCL, maximum contaminant level; C, carbon; N, nitrogen; P, phosphorous; —, no value available]

Compound	Number of detections/samples	Minimum detection	Median detection	Maximum detection	Drinking-water standard	Drinking-water standard type	Number of wells exceeding a drinking-water standard
Ammonia, as N	24/31	0.02	0.02	0.11	30	HAL ¹	0
Nitrate, as N	29/31	.06	1.4	12	10	MCL ¹	1
Nitrite, as N	3/31	.01	.01	.01	1	MCL ¹	0
Orthophosphorus, as P	31/31	.03	.1	.4	—	—	—
Phosphorus, as P	30/31	.03	.1	.45	—	—	—
Dissolved organic carbon, as C	27/31	.2	.3	.7	—	—	—

¹U.S. Environmental Protection Agency, 2000.

precipitation and recharged before the 1950s would now have a tritium concentration of about 1 pCi/L (Plummer and others, 1993). Current tritium concentrations in rainfall are about 44 pCi/L [1989–1993 average in rainfall at Menlo Park, California (International Atomic Energy Agency/World Meteorological Organization, 1998)]. The concentrations of tritium measured in ground water in the upper part of the southeastern Sacramento Valley aquifer ranged from 4 to 67 pCi/L; four wells contained no measurable tritium. This indicates that most of the ground water sampled was at least partly recharged in the last 45 years. It is possible that some wells yield a mixture of old and young ground water.

Radon

Radon-222 was detected in all the wells sampled, with a median concentration of 495 pCi/L in the study area (table 8). The proposed MCL for radon-222 (300 pCi/L; U.S. Environmental Protection Agency, 2000) was exceeded in 28 of 31 wells (90 percent). The median concentration of radon from this study slightly exceeded the NAWQA median concentration of

450 pCi/L in drinking-water aquifers (table 5) (Gilliom and others, 1998, p. 19).

Radon is a naturally produced radioactive isotope (radon-222) that occurs as a gas; it is a by-product of the natural decay of uranium that is present in small quantities in certain rock types, such as the granitic rocks found in the Sierra Nevada and sediment derived from those rocks in the Sacramento Valley. Radon gas is soluble in water and is transported in ground water. When water containing radon gas is exposed to air (as when pumped out of an aquifer and used as tap or shower water), the radon diffuses into the air where it can be inhaled.

Pesticides

Of the 86 pesticides and pesticide degradation products that were analyzed for in ground-water samples for this study, only 5 pesticides were detected in study wells (listed in order of decreasing frequency of detection): bentazon, simazine, atrazine, bromacil, and tebuthiuron (table 9). One degradation or breakdown product of atrazine, desethyl atrazine, also was detected. The pesticides and pesticide degradation

Table 8. Summary of isotopes detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996

—, no value available; pCi/L, picocurie per liter; MCL, maximum contaminant level]

Isotope	Units	Number of detections/samples	Minimum detection	Median detection	Maximum Detection	Drinking-water standard	Drinking-water standard type	Number of wells exceeding a drinking-water standard
Deuterium	Ratio per mill	22/22	-78.8	-59.3	-50.5	—	—	—
Oxygen-18	Ratio per mill	22/22	-10.9	-8.33	-6.82	—	—	—
Radon-222	pCi/L	30/30	230	495	940	300	MCL ¹	28
Tritium	pCi/L	18/22	4	19	67	20,000	MCL ²	0

¹Under review by the U.S. Environmental Protection Agency (2000).

²California Department of Water Resources, 1997.

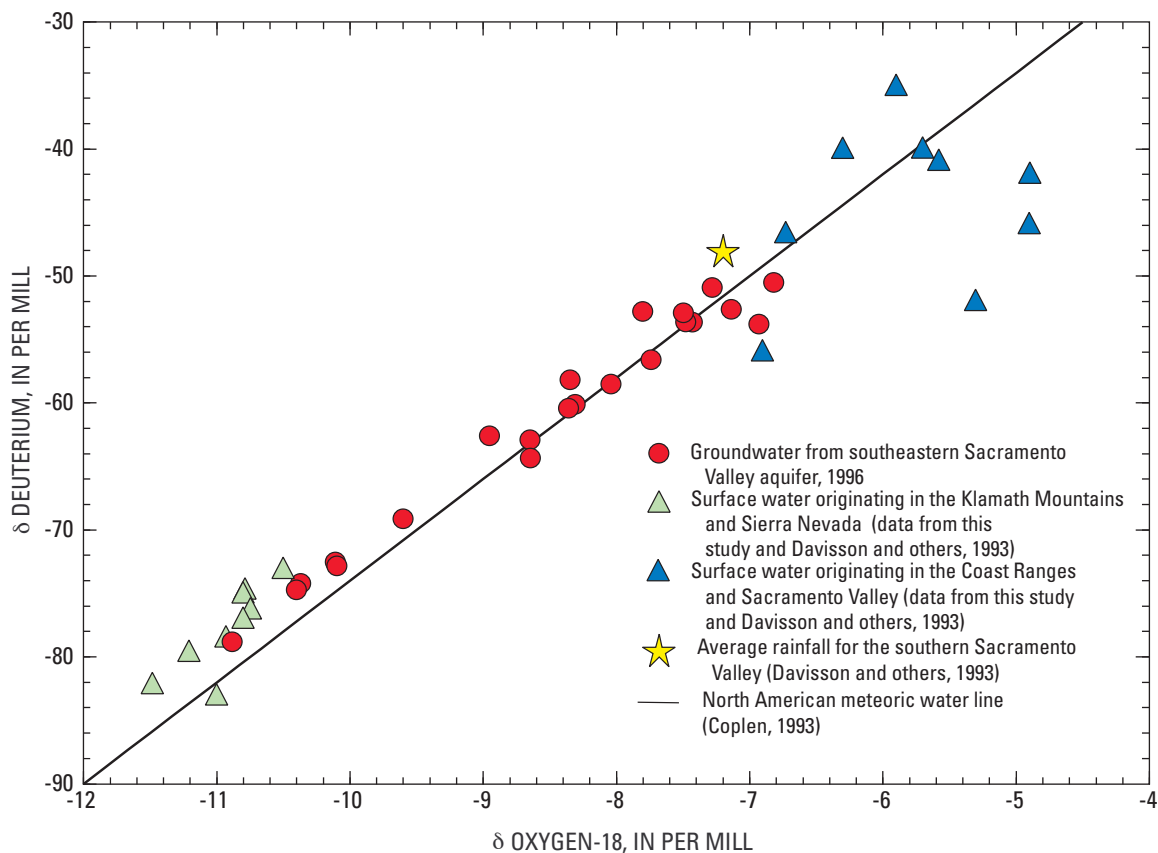


Figure 5. Relation between delta (δ) deuterium and δ oxygen-18 in ground water, surface water, and rain water in parts of the Sacramento Valley, California.

products not detected in ground-water samples in the southeastern Sacramento Valley aquifer are listed in table 10. A total of one, two, or three pesticides (table 9) were found in 9 of 31 wells (29 percent) that were sampled for this study. This frequency is less than the NAWQA median frequency of about 40 percent for pesticide detections in a drinking-water aquifer (table 5) (Gilliom and others, 1998, p. 17). The locations of wells in which one or more pesticides were

detected are shown in figure 6. Forty-six percent of the detections were estimated concentrations (the compound was present in the water sample, but the concentration was below the lowest calibration standard). All pesticides detected in this study were below the 2000 drinking-water standards (California Department of Water Resources, 1997; U.S. Environmental Protection Agency, 2000) (table 9). Atrazine and its breakdown product, desethyl atrazine,

Table 9. Summary of pesticides in ground water in the southeastern Sacramento Valley aquifer, California, 1996

[All units shown in micrograms per liter; E, estimated value, compound was detected at a concentration below the lowest calibration standard; MCL, maximum contaminant level; HAL, health advisory level; —, no value available]

Pesticide	Number of detections/samples	Minimum detection	Maximum detection	Drinking-water standard	Drinking-water standard type	Number of wells exceeding a drinking-water standard
Atrazine	2/31	0.001	0.001	3	MCL ¹	0
Bentazon	4/24	E .02	E 1.3	18	MCL ²	0
Bromacil	1/31	.34	—	90	HAL ¹	0
Desethyl atrazine	4/31	E .004	E .044	—	—	—
Simazine	3/31	.006	.077	4	MCL ¹	0
Tebuthiuron	1/31	.032	—	500	HAL ¹	0

¹U.S. Environmental Protection Agency, 2000.

²California Department of Water Resources, 1997.

Table 10. Pesticides and degradation products not detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996

Pesticides not detected	
2,4-D	Fonofos
2,4-DB	<i>gamma</i> -HCH
2,4,5-T	Linuron
2,4,5-TP	Malathion
Acetochlor	MCPA
Acifluorfen	MCPB
<i>alpha</i> -HCH	Methiocarb
Alachlor	Methomyl
Aldicarb	Methyl azinphos
Benfluralin	Methyl parathion
Bromoxynil	Metolachlor
Butylate	Metribuzin
Carbaryl	Molinate
Carbofuran	Napropamide
Chloramben	Neburon
Chlorothalonil	Norflurazon
Chlorpyrifos	Oryzalin
<i>cis</i> -Permethrin	Oxamyl
Clopyralid	Parathion
Cyanazine	Pebulate
Dacthal, mono-acid	Pendimethaline
DCPA	Phorate
Diazinon	Picloram
Dicamba	Prometon
Dichlobenil	Pronamide
Dichlorprop	Propachlor
Dieldrin	Propanil
Dinoseb	Propargite
Disulfoton	Propham
Diuron	Propoxur
DNOC	Terbacil
EPTC	Terbufos
Esfenvalerate	Thiobencarb
Ethalfuralin	Triallate
Ethoprop	Tricopyr
Fenuron	Trifluralin
Fluometuron	
Pesticide degradation products not detected	
Aldicarb sulfone	Carbofuran, -3-hydroxy
Aldicarb sulfoxide	

were detected less frequently than in other NAWQA drinking-water aquifer studies, whereas bentazon, simazine, bromacil, and tebuthiuron were detected more frequently (table 5) (U.S. Geological Survey Pesticide National Synthesis Project, 1998).

The five pesticides detected in ground-water samples collected during this study have been used in the study area, according to data from the California Department of Pesticide Regulation (1997). The most frequently detected pesticide, bentazon, was used on rice crops, but was banned in 1989 because of

detections in ground water (Miller-Maes and others, 1993) Bentazon continues to be detected in ground water in many parts of the Sacramento Valley, including this study area (Bartkowiak and others, 1998). The major uses for atrazine, bromacil, and tebuthiuron are for weed control in right-of-way areas and for landscape maintenance. Simazine is used for weed control in right-of-way areas and for landscape maintenance, and also on many crops grown in the study area, including nut and fruit orchards (California Department of Pesticide Regulation, 1997).

Volatile Organic Compounds

One, two, three, or eight VOCs were detected in 12 of 31 wells (39 percent) sampled for in this study (table 11, fig. 7). This is higher than the NAWQA median frequency of 10 percent for a VOC detection in drinking-water aquifers (table 5) (Gilliom and others, 1998, p. 18). Sixty-seven percent of these detections were estimated concentrations (the compound was present in the water sample, but the concentration was below the lowest calibration standard). Of the 87 VOCs analyzed for in this study, 13 VOCs were detected in ground-water samples (listed in order of decreasing frequency of detection) (table 11): trichloroethene, dichlorodifluoromethane, 1,2,4-trimethylbenzene, trichloromethane, tetrachloroethene, 1,1-dichloroethane, tetrachloromethane, 1,2-dichloroethane, trichlorofluoromethane, *cis*-1,2-dichloroethene, styrene, methyl *tert*-butyl ether, and bromodichloromethane. The VOCs not detected in ground-water samples from the southeastern Sacramento Valley aquifer are listed in table 12. In one of the wells sampled, eight VOCs were detected, two of which exceeded the MCLs—tetrachloromethane, measured at 1.2 µg/L [MCL=0.5 µg/L; California Department of Water Resources (1997)], and trichloroethene, measured at 5.5 µg/L [MCL=5 µg/L; U.S. Environmental Protection Agency (2000)] (table 11). This well is near a site of known contamination, and the compounds detected are consistent with contamination associated with that site. Of the VOCs detected, 12 were detected more frequently in this study than in NAWQA drinking-water aquifer studies nationwide between 1992–1995; only trichloromethane was detected less frequently (table 5) (U.S. Geological Survey Volatile Organic Compound National Synthesis Project, 1998). The 13 VOCs detected in ground-water samples in this study have many different uses, including gasoline components, pesticides, solvents, degreasers, and refrigerants, and can be by-products of drinking-water chlorination (Vershueren, 1983; U.S. Environmental Protection Agency, 1998). No information is available on the amount or uses for these VOCs in the Sacramento Valley.

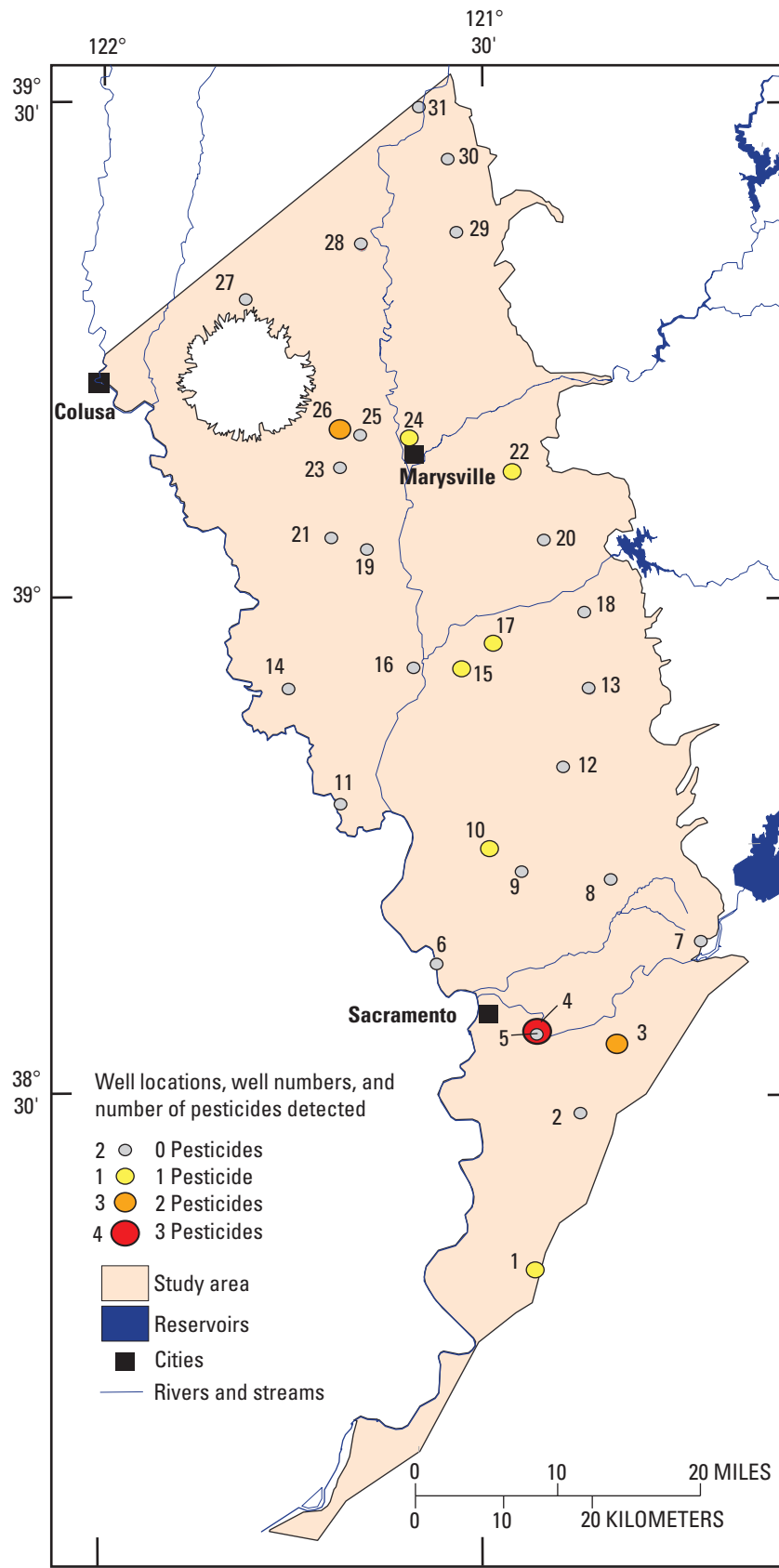


Figure 6. Number of pesticides detected in wells sampled in the southeastern Sacramento Valley aquifer, California.

Table 11. Summary of volatile organic compounds detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996

[All units shown in micrograms per liter; E, estimated value, compound was detected at a concentration below the lowest calibration standard; —, no value available; MCL, maximum contaminant level; HAL, health advisory level]

Volatile organic compound	Number of detections/samples	Minimum detection	Maximum detection	Drinking-water standard	Drinking-water standard type	Number of wells exceeding a drinking-water standard
1,1-Dichloroethane	2/31	E 0.02	E 0.04	—	—	—
1,2,4-Trimethylbenzene	3/31	E .01	E .02	—	—	—
1,2-Dichloroethane	1/31	.19	—	0.5	MCL ¹	0
Bromodichloromethane	1/31	E .03	—	100	MCL ¹	0
<i>cis</i> -1,2-Dichloroethene	1/31	.43	—	6	MCL ²	0
Dichlorodifluoromethane	3/31	E .04	E .29	1,000	HAL ¹	0
Methyl <i>tert</i> -butyl ether	1/31	E .06	—	20	HAL ¹	0
Styrene	1/31	E .06	—	100	MCL ¹	0
Tetrachloroethene	2/31	.58	.97	5	MCL ¹	0
Tetrachloromethane	1/31	1.2	—	.5	MCL ²	1
Trichloroethene	4/31	E .01	5.5	5	MCL ¹	1
Trichlorofluoromethane	1/31	E .04	—	150	MCL ²	0
Trichloromethane	3/31	E .03	1.1	100	MCL ¹	0

¹U.S. Environmental Protection Agency, 2000.

²California Department of Water Resources, 1997.

FACTORS AFFECTING GROUND-WATER QUALITY

Ground-Water Redox Condition

The oxidation-reduction (redox) state of water can affect which compounds are present in that water. Water with chemistry indicating oxidizing chemical reactions is referred to as oxic; water with chemistry indicating reducing chemical reactions is referred to as anoxic. As it is easy to introduce oxygen into ground water during the sampling process, the classification of ground water as oxic or anoxic is based on the concentrations of several compounds that are sensitive to dissolved oxygen concentration (such as nitrate, iron, manganese, and sulfate), rather than dissolved oxygen concentrations (Saad and Thorstenson, 1998).

Hull (1984) proposed that reducing conditions in the fine-grained sediments in flood-basin areas are a major factor influencing the ground-water chemistry of the Sacramento Valley. Concentrations of dissolved oxygen, nitrate, nitrite, iron, manganese, sulfate, and sulfide in this study indicate that anoxic conditions exist in parts of the southeastern Sacramento Valley aquifer. Wells having dissolved oxygen concentrations of at least 1 mg/L, nitrogen present as principally nitrate, sulfur present as sulfate (no sulfides), and very low concentrations of manganese and iron were classified as oxic. Wells having low concentrations of dissolved oxygen, nitrate, and sulfate, and relatively high concentrations of dissolved iron and manganese, and the presence of sulfide were classified as anoxic. Ten of 31 wells (32 percent) in this study have

chemistry indicating anoxic conditions; these wells are near the center of the Sacramento Valley, and correspond to the areas with finer-grained flood basin or alluvial deposits (fig. 8).

A significant correlation was found between nitrate concentrations and dissolved oxygen concentrations ($p=0.006$, $\rho=0.49$; Spearman's rank correlation), indicating that reducing chemical reactions that decrease the dissolved oxygen concentrations may be decreasing the nitrate concentrations and preventing them from exceeding the MCL in some areas. A significant inverse correlation also was found between arsenic and dissolved oxygen concentrations ($p=0.001$, $\rho=-0.56$; Spearman's rank correlation), suggesting that the presence and concentration of arsenic is related to the redox condition of the ground water.

No significant correlations were found between the number of pesticides or VOCs detected in a well and the dissolved oxygen concentration ($p=0.77$, $\rho=0.05$ for pesticides and $p=0.54$, $\rho=0.12$ for VOCs; Spearman's rank correlation). The number of pesticides or VOCs detected in this study were too few to compare their concentrations with dissolved oxygen concentrations, but an inverse correlation has been found in other studies (Barbash and Resek, 1996).

Depth to Water Table and Well Opening

Depth from land surface to the water table or to the top of the well opening can influence the presence and amount of a compound in ground water. In this study, pesticides were detected in wells as deep as 49 m

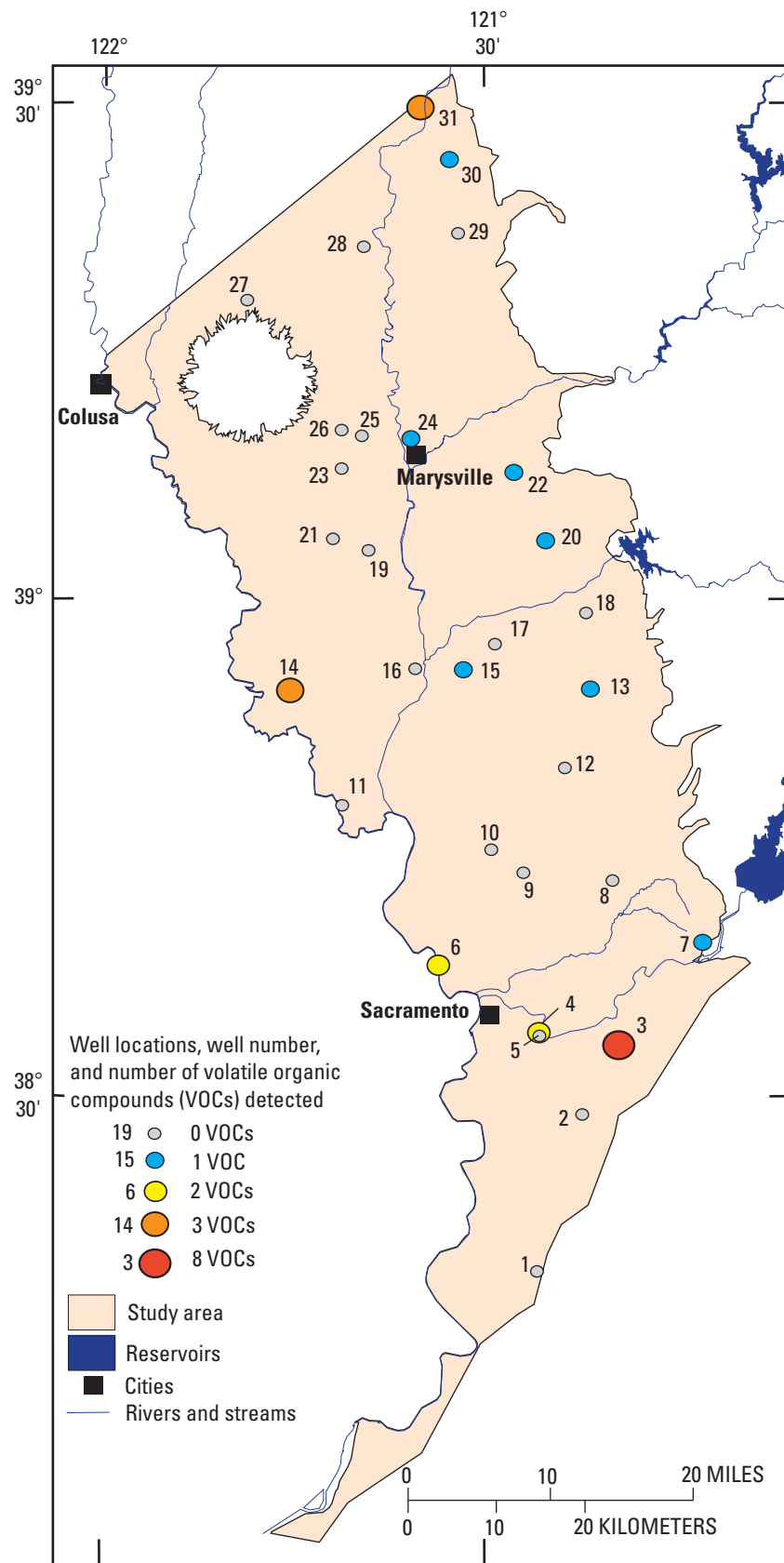


Figure 7. Number of volatile organic compounds detected in wells sampled in the southeastern Sacramento Valley aquifer, California.

Table 12. Volatile organic compounds not detected in ground water in the southeastern Sacramento Valley aquifer, California, 1996

Volatile organic compounds not detected	
1,1,1,2-Tetrachloroethane	Bromoethene
1,1,1-Trichloroethane	Bromomethane
1,1,2,2-Tetrachloroethane	Carbon Disulfide
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	Chlorobenzene
1,1,2-Trichloroethane	Chlorodibromomethane
1,1-Dichloroethene	Chloroethane
1,1-Dichloropropene	Chloroethene (Vinyl chloride)
1,2,3,4-Tetramethylbenzene	Chloromethane
1,2,3,5-Tetramethylbenzene	<i>cis</i> -1,3-Dichloropropene
1,2,3-Trichlorobenzene	Dibromomethane
1,2,3-Trichloropropane	Dichloromethane
1,2,3-Trimethylbenzene	Diethyl ether
1,2,4-Trichlorobenzene	Diisopropyl ether
1,2-Dibromo-3-chloropropane (DBCP)	Ethyl methacrylate
1,2-Dibromoethane (EDB)	Ethyl <i>tert</i> -butyl ether (ETBE)
1,2-Dichlorobenzene	Ethylbenzene
1,2-Dichloropropane	Hexachlorobutadiene
1,2-Dimethylbenzene	Hexachloroethane
1,3,5-Trimethylbenzene	Iodomethane
1,3-Dichlorobenzene	Isopropylbenzene
1,3-Dichloropropene	Methyl acrylate
1,4-Dichlorobenzene	Methyl acrylonitrile
1,4-Dimethylbenzene	Methyl methacrylate
2,2-Dichloropropane	Methylbenzene (Toluene)
2-Butanone	<i>n</i> -Butylbenzene
2-Chlorotoluene	<i>n</i> -Propylbenzene
2-Ethyltoluene	Napthalene
2-Hexanone	<i>p</i> -Isopropyltoluene
2-Propenal	<i>sec</i> -Butylbenzene
2-Propenenitrile	<i>tert</i> -Amyl methyl ether (TAME)
3-Chloro-1-propene	<i>tert</i> -Butylbenzene
4-Chlorotoluene	Tetrahydrofuran
4-Methyl-2-pentanone	<i>trans</i> -1,2-Dichloroethene
Acetone	<i>trans</i> -1,3-Dichloropropene
Benzene	<i>trans</i> -1,4-Dichloro-2-butene
Bromobenzene	Tribromomethane
Bromochloromethane	Vinyl acetate

below land surface, and VOCs were detected in wells as deep as 62 m below land surface (depth to top of well opening). Three different depths (depth to water, depth from land surface to top of well opening, and depth from water level to well opening) have been found to influence the occurrence and concentrations of nitrate and pesticides (Barbash and Resek, 1996; Rupert, 1997).

An inverse correlation was found in this study between depth to well opening and nitrate concentration in oxygenated wells ($p=0.02$, $\rho=-0.52$; Spearman's rank correlation). No correlation was found between nitrate concentration and depth to water ($p=0.64$, $\rho=0.11$; Spearman's rank correlation); however, an inverse correlation was found between depth of well opening below water level and nitrate concentration ($p=0.01$, $\rho=-0.52$; Spearman's rank correlation). These two correlations suggest that well

construction (depth) may be a factor in the occurrence and concentration of nitrate detected in the wells sampled during this study.

No correlation was found between arsenic concentration and depth of water table or well opening ($p=0.10$, $\rho=-0.32$, and $p=0.94$, $\rho=-0.01$, respectively; Spearman's rank correlation). No correlation was found between the number of pesticides detected in a well and the depth of the well opening below the water table ($p=0.09$, $\rho=-0.38$; Spearman's rank correlation). No correlation was found between the number of pesticides detected in a well and the depth of the well opening below land surface or the depth of the water level below land surface (respectively: $p=0.16$, $\rho=-0.26$ and $p=0.85$, $\rho=-0.04$; Spearman's rank correlation). No correlation was found between depth to water table or well opening and the number of VOCs detected in a well.

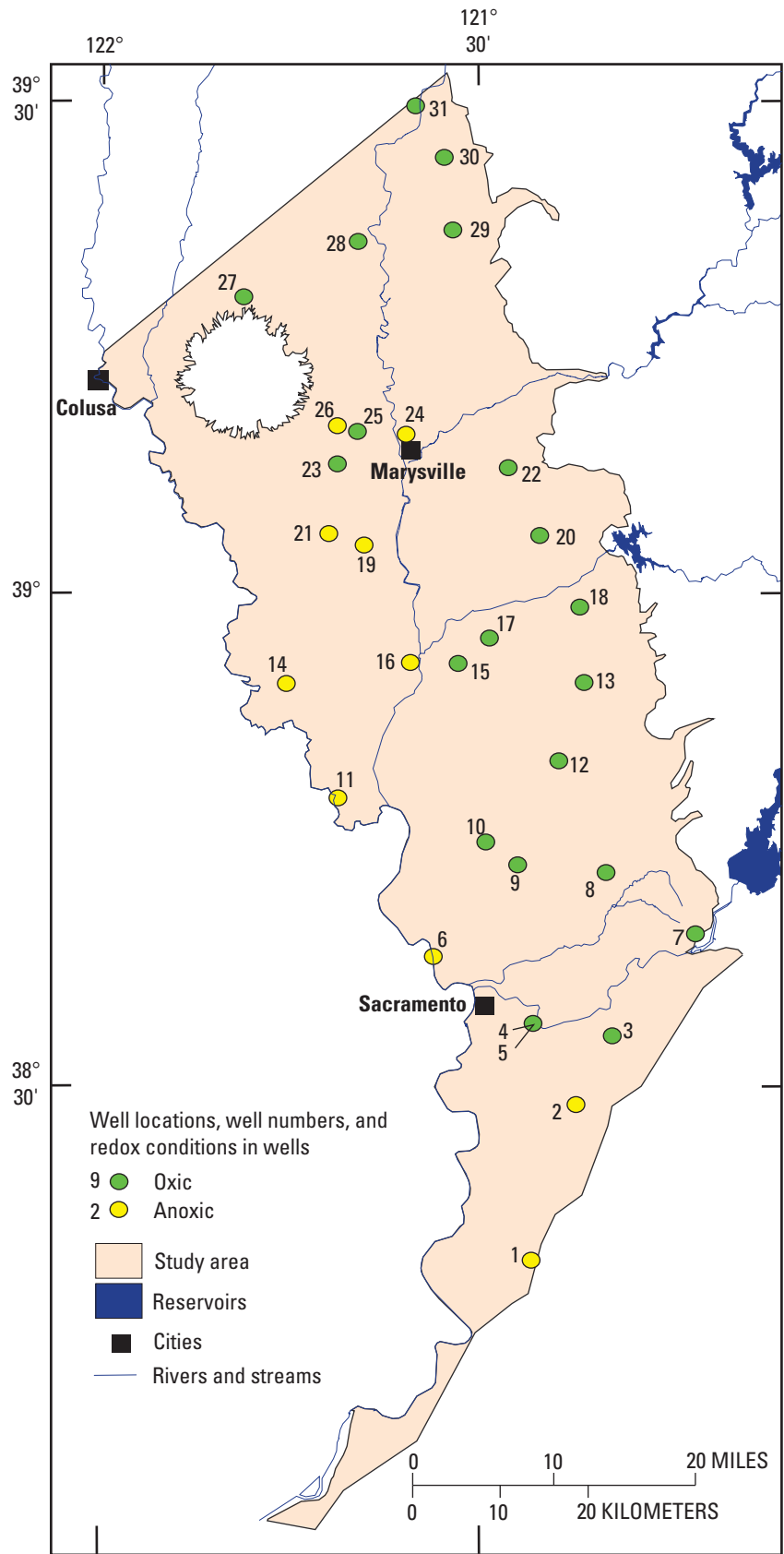


Figure 8. Ground-water redox condition in wells sampled in the southeastern Sacramento Valley aquifer, California.

Land Use, Pesticide Use, and Fertilizer Use

The amount and types of compounds that are used by humans can influence which compounds will be present in the ground water in that area. Tritium concentrations indicate that ground water in the study area has been exposed to surface conditions in the Sacramento Valley since the 1950s, and therefore, pesticides and nitrate in fertilizers at land surface could enter the ground water.

Pesticides and VOCs were detected in urban and agricultural areas; higher percentages of both chemicals were detected in wells surrounded by urban land use. No data were available on the amounts or types of VOCs used in the study area. The types of compounds detected in this study are consistent with the land use surrounding each well. The compounds detected in urban wells were consistent with urban activities (nonagricultural pesticide use, such as landscape maintenance, right-of-way weed control, pest control, and VOCs associated with gasoline, industrial uses, or chlorinated drinking water). Those detected in agricultural areas are consistent with agricultural activities (pesticides used on crops or rights-of-way and VOCs that may be present in pesticides or gasoline).

Data on fertilizer sales in 1987 are available for each county in the study area (Battaglin and Goolsby, 1995). For this study, the amount of nitrogen calculated from these data is used to estimate the amount of nitrogen from fertilizer applied to the land surface in each county (table 13). A correlation was found between the estimated amount of nitrogen applied in each county and the nitrate concentrations measured in oxygenated wells in that county ($p=0.02$, $\rho=0.50$; Spearman's rank correlation). Also, the nitrate concentration that exceeded the EPA MCL was in the county with the highest estimated amount of applied nitrogen. This correlation suggests that, in addition to depth from land surface to well opening and the redox condition, nitrate concentrations in ground water may be related to the amount of nitrogen applied to the land surface.

Table 13. Amount of nitrogen applied as fertilizer in the Sacramento subunit study area

[Calculated from fertilizer sales by county in 1987 (Battaglin and Goolsby, 1995)]

County	Nitrogen (pounds per acre)
Butte	20
Placer	2
Sacramento	20
Sutter	60
Yuba	20

SUMMARY AND CONCLUSIONS

In 1996, the U.S. Geological Survey sampled 29 domestic wells and 2 monitoring wells in the south-eastern Sacramento Valley Aquifer as part the National Water-Quality Assessment Program. Measurements of inorganic constituents, nitrate, tritium, and stable isotopes indicate that ground water in the study area originated as precipitation that fell over the Coast Ranges, the Sacramento Valley, and the Sierra Nevada, was at least partly recharged since the 1950s and shows the effect of human activities. In general, the water quality in the southeastern Sacramento Valley aquifer was found suitable for most uses. Four of 31 wells (13 percent) exceeded a maximum contaminant level (MCL) or health advisory level drinking-water standard (DWS) for any one compound. Nitrate was detected in 29 of 31 wells (94 percent) at levels below 2000 in all but one well. Radon-222 was detected in all wells sampled, and it was measured at levels above the proposed Federal MCL in 90 percent of the wells. Pesticides were detected in 29 percent of the wells sampled at levels below 2000 DWS. Volatile organic compounds (VOC) were detected in 39 percent of the wells sampled at levels below 2000 DWS in all but one well. That well is near a source of ground-water contamination, and water from that well contained eight VOCs, two of which (tetrachloromethane and trichlorethene) were above either California or Federal MCL DWS.

Some of the water-quality components identified in this study can be linked to natural processes. Evidence of the effects of natural activities on ground-water quality found in this study included a positive correlation between nitrate and dissolved oxygen concentrations, suggesting that nitrate concentrations are being lowered by reducing chemical reactions in the ground water; inverse correlation between arsenic and dissolved oxygen concentrations but no correlation between arsenic concentrations and depth to well opening or water level; and detections of radon-222, which are naturally occurring in all wells.

Evidence of the effect of human activities on ground-water quality was found in 61 percent of the wells sampled in this study in the form of a nitrate concentration of more than 3 milligrams per liter, or detections of pesticides or VOCs. Pesticides and VOCs were detected in urban and agricultural areas; both types of synthetic compounds were detected in a higher percentage of urban wells, although no statistical correlation was found between land-use type or population density and number of synthetic compounds detected in a well. The types of synthetic compounds detected were consistent with the land use in the area

(VOCs and pesticides related to urban activities were detected in urban wells; VOCs and pesticides related to agricultural activities were detected in wells located in agricultural areas).

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