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Prepared in cooperation with the California State Water Resources Control Board

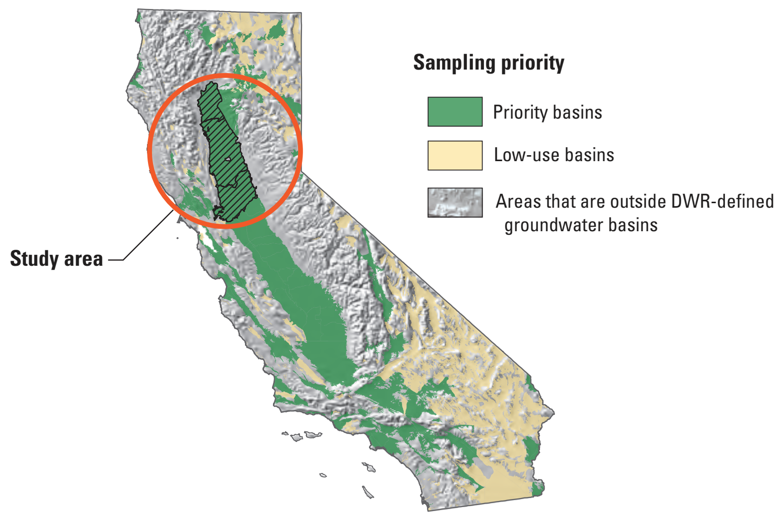
A product of the California Groundwater Ambient Monitoring and Assessment (GAMA) Program

Status of Groundwater Quality in the Southern, Middle, and Northern Sacramento Valley Study Units, 2005–08: California GAMA Priority Basin Project

Scientific Investigations Report 2011–5002

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

Front Cover Map: Groundwater basins categorized by sampling priority. Location of groundwater basin boundaries from California Department of Water Resources (DWR, 2003).



Cover photographs:

Front cover: Fields of rice near Williams, California. (Photograph taken by Cathy Munday, U.S. Geological Survey)

Back cover: Looking east across the northern Sacramento Valley towards Mt. Lassen. (Photograph taken by George Bennett, U.S. Geological Survey)

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Tables—Continued

Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

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

$$°F=(1.8×°C)+32.$$

Datums

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

Horizontal coordinate information is referenced to the North American Datum of 183 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Abbreviations and Acronyms

AL-US	U.S. Environmental Protection Agency action level
DG	Grid cell with USGS sampled grid well that has been supplemented by CDPH data
DPH	Grid cell without USGS sampled grid well that has been supplemented by CDPH data
ESAC	Eastern Sacramento study area (part of MSACV)
ESAC-FP	Eastern Sacramento flowpath (part of MSACV)
FP	flow path
GAMA	Groundwater Ambient Monitoring and Assessment program
HAL-US	U.S. Environmental Protection Agency lifetime health advisory level
HBB	health-based benchmark
HBSL	health-based screening level
LSD	land-surface datum
LT-MDL	long-term method detection level
MCL-CA	California Department of Public Health maximum contaminant level
MCL-US	U.S. Environmental Protection Agency maximum contaminant level
MDL	method detection level
NAVD88	North American Vertical Datum 1988
MSACV	Middle Sacramento Valley study unit
NL-CA	California Department of Public Health notification level
NAM	North American study area (part of SSACV)
MW	monitoring well
NAMFP	North American flowpath (part of SSACV)
NSAC	Northern Sacramento study area (part of NSACV)
NSAC-MW	North Sacramento monitoring well (part of NSACV)
NSAC-U	North Sacramento understanding (part of NSACV)
NSACV	Northern Sacramento Valley study unit
pmc	percent modern carbon
RC	relative-concentration
RED	Redding study area (part of NSACV)
RED-MW	Redding monitoring well (part of NSACV)
RED-U	Redding understanding (part of NSACV)
RSD	relative standard deviation
RSD5-US	U.S. Environmental Protection Agency risk-specific dose at a risk factor of 10^{-5}
SAM	South American study area (part of SSACV)
SC	specific conductance
SMCL-CA	California Department of Public Health secondary maximum contaminant level
SMCL-US	U.S. Environmental Protection Agency secondary maximum contaminant level
SOL	Solano study area (part of SSACV)
SSACV	Southern Sacramento Valley study unit
SSV-QPC	Southern Sacramento Uplands study area (part of SSACV)
SSV-QPCFP	Southern Sacramento Upland flowpath (part of SSACV)
SUI	Suisun-Fairfield study area (part of SSACV)
TDS	total dissolved solids
TEAP	terminal electron acceptor process
U	understanding
WSAC	Western Sacramento study area (part of MSACV)
WSAC-FP	Western Sacramento flowpath (part of MSACV)
YOL	Yolo study area (part of SSACV)
YOLFP	Yolo flowpath (part of SSACV)

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Organizations

CDPH	California Department of Public Health (Department of Health Services prior to July 1, 2007)
CDPR	California Department of Pesticide Regulation
CDWR	California Department of Water Resources
LLNL	Lawrence Livermore National Laboratory
SWRCB	State Water Resources Control Board (California)
USEPA	U.S. Environmental Protection Agency
USGS	U. S. Geological Survey

Selected Chemical Names

EDB	1,2-dibromoethane
MTBE	methyl *tert*-butyl ether
NDMA	*N*-nitrosodimethylamine
PCE	tetrachloroethene
TBA	*tert*-butyl alcohol
TCE	trichloroethylene
TU	tritium unit
1,2,3-TCP	1,2,3-trichloropropane
TDS	total dissolved solids
THM	trihalomethane
VOC	volatile organic compound

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Status of Groundwater Quality in the Southern, Middle, and Northern Sacramento Valley Study Units, 2005–08: California GAMA Priority Basin Project

By George L. Bennett, V, Miranda S. Fram, and Kenneth Belitz

Abstract

Groundwater quality in the Southern, Middle, and Northern Sacramento Valley study units was investigated as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The study units are located in California's Central Valley and include parts of Butte, Colusa, Glenn, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo, and Yuba Counties. The GAMA Priority Basin Project is being conducted by the California State Water Resources Control Board in collaboration with the U.S. Geological Survey and the Lawrence Livermore National Laboratory.

The three study units were designated to provide spatially-unbiased assessments of the quality of untreated groundwater in three parts of the Central Valley hydrogeologic province, as well as to provide a statistically consistent basis for comparing water quality regionally and statewide. Samples were collected in 2005 (Southern Sacramento Valley), 2006 (Middle Sacramento Valley), and 2007–08 (Northern Sacramento Valley).

The GAMA studies in the Southern, Middle, and Northern Sacramento Valley were designed to provide statistically robust assessments of the quality of untreated groundwater in the primary aquifer systems that are used for drinking-water supply. The assessments are based on water-quality data collected by the USGS from 235 wells in the three study units in 2005–08, and water-quality data from the California Department of Public Health (CDPH) database. The primary aquifer systems (hereinafter, referred to as primary aquifers) assessed in this study are defined by the depth intervals of the wells in the CDPH database for each study unit. The quality of groundwater in shallow or deep water-bearing zones may differ from quality of groundwater in the primary aquifers; shallow groundwater may be more vulnerable to contamination from the surface.

The status of the current quality of the groundwater resource was assessed by using data from samples analyzed for volatile organic compounds (VOC), pesticides, and naturally occurring inorganic constituents, such as major ions and trace elements. This *status assessment* is intended to characterize the quality of groundwater resources within the primary aquifers of the three Sacramento Valley study units, not the treated drinking water delivered to consumers by water purveyors.

Relative-concentrations (sample concentrations divided by benchmark concentrations) were used for evaluating groundwater quality for those constituents that have Federal or California regulatory or non-regulatory benchmarks for drinking-water quality. A relative-concentration greater than 1.0 indicates a concentration greater than a benchmark. For organic (volatile organic compounds and pesticides) and special-interest (perchlorate) constituents, relative-concentrations were classified as high (greater than 1.0); moderate (equal to or less than 1.0 and greater than 0.1); or low (equal to or less than 0.1). For inorganic (major ion, trace element, nutrient, and radioactive) constituents, the boundary between low and moderate relative-concentrations was set at 0.5.

Aquifer-scale proportions were used in the *status assessment* for evaluating regional-scale groundwater quality. High aquifer-scale proportion is defined as the percentage of the area of the primary aquifers that have a relative-concentration greater than 1.0 for a particular constituent or class of constituents; percentage is based on an areal rather than a volumetric basis. Moderate and low aquifer-scale proportions were defined as the percentage of the primary aquifers that have moderate and low relative-concentrations, respectively. Two statistical approaches—grid-based, which used one value per grid cell, and spatially-weighted, which used the full dataset—were used to calculate aquifer-scale proportions for individual constituents and classes of constituents.

High and moderate aquifer-scale proportions were significantly greater for inorganic constituents than organic constituents in all three study units. In the Southern Sacramento Valley study unit, relative-concentrations for one or more inorganic constituents with health-based benchmarks (HBBs) were high in 30 percent (%), moderate in 30%, and low in 40% of the primary aquifer. In the Middle Sacramento Valley study unit, aquifer-scale proportions for inorganic constituents with HBBs were high in 24%, moderate in 38%, and low in 38% of the primary aquifer. Arsenic, boron, and nitrate were detected at high relative-concentrations in the Southern and Middle Sacramento Valley study units. In the Northern Sacramento Valley study unit, high, moderate, and low relative-concentrations of inorganic constituents relative to HBBs were 2.1, 12, and 86% of the primary aquifer, respectively. Arsenic was the only constituent detected at high relative-concentrations. The high aquifer-scale proportions for inorganic constituents with non-health-based benchmarks were 32, 27, and 4.6% of the primary aquifer for the Southern, Middle, and Northern Sacramento Valley study units, respectively.

The high aquifer-scale proportions for organic constituents with HBBs were less than 1% in the Southern, Middle, and Northern Sacramento Valley study units. Organic constituents were detected at moderate relative-concentrations in about 3% of the Southern and Middle Sacramento Valley study units and in 1% of the Northern Sacramento Valley study unit. Of the 227 organic constituents analyzed for, 86 were detected, and of those detected, 56 have HBBs. Six organic constituents (atrazine, bentazon, chloroform, simazine, tetrachloroethene, and trichloroethene) were detected in 10% or more of the sampled wells in one or more of the three Sacramento Valley study units.

Introduction

Groundwater comprises nearly one-half of the water used for drinking-water supply in California (Hutson and others, 2004). To assess the quality of ambient groundwater in aquifers used for drinking-water supply and to establish a baseline groundwater quality monitoring program, the State Water Resources Control Board (SWRCB), in collaboration with the U.S. Geological Survey (USGS) and Lawrence Livermore National Laboratory (LLNL), implemented the Groundwater Ambient Monitoring and Assessment (GAMA) Program (California Environmental Protection Agency, 2010, website at http://www.swrcb.ca.gov/gama). The GAMA Program currently consists of three projects: (1) the GAMA Priority Basin Project, conducted by the USGS (U.S. Geological Survey, 2010, website at http://ca.water.usgs.gov/gama); (2) the GAMA Domestic Well Project, conducted by the SWRCB; and (3) GAMA Special Studies, conducted by LLNL. On a statewide basis, the Priority Basin Project focused primarily on the deep portion of the groundwater resource (primary aquifer), and the SWRCB Domestic Well Project generally focused on the shallow aquifer systems.

The SWRCB initiated the GAMA Program in response to Legislative mandates (State of California, 1999, 2001a, Supplemental Report of the 1999 Budget Act 1999-00 Fiscal Year). The GAMA Priority Basin Project was initiated in response to the Groundwater Quality Monitoring Act of 2001 (State of California, 2001b) {Sections 10780-10782.3 of the California Water Code, Assembly Bill 599} to assess and monitor the quality of groundwater in California. The GAMA Priority Basin Project is a comprehensive assessment of statewide groundwater quality designed to help better understand and identify risks to groundwater resources and to increase the availability of information about groundwater quality to the public. For the Priority Basin Project, the USGS, in collaboration with the SWRCB, developed the monitoring plan to assess groundwater basins by using statistically reliable sampling approaches (Belitz and others, 2003; State Water Resources Control Board, 2003). Additional partners in the GAMA Priority Basin Project include the California Department of Public Health (CDPH), the California Department of Pesticide Regulation (CDPR), the California Department of Water Resources (CDWR), and local water agencies and well owners.

The range of hydrologic, geologic, and climatic conditions that exist in California must be considered in an assessment of groundwater quality. Belitz and others (2003) partitioned the State into 10 hydrogeologic provinces, each with distinctive hydrologic, geologic, and climatic characteristics (fig. 1). All these hydrogeologic provinces include groundwater basins and subbasins designated by the CDWR (California Department of Water Resources, 2003). Groundwater basins generally are filled with relatively permeable, unconsolidated deposits of alluvial or volcanic origin. Eighty percent of California's approximately 16,000 active and standby drinking-water wells listed in the statewide database maintained by the CDPH (hereinafter referred to as CDPH wells) are located in designated groundwater basins within these hydrogeologic provinces. Groundwater basins and subbasins were prioritized for sampling on the basis of the number of CDPH wells, with secondary consideration given to municipal groundwater use, agricultural pumping, registered pesticide applications, and the number of historical leaking underground fuel tanks (Belitz and others, 2003). Of the 472 basins and subbasins designated by the CDWR, 116 priority basins, which include approximately 95 percent (%) of the CDPH wells located in basins, were selected for the project. The Southern, Middle, and Northern Sacramento Valley GAMA study units are located in the Central Valley hydrogeologic province (fig. 1) (Belitz and others, 2003).

Figure 1. Location of the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units and California hydrogeologic provinces (modified from Belitz and others, 2003).

The GAMA Priority Basin Project comprises three types of water-quality assessments in each study unit:

1. *Status:* assessment of the current quality of the groundwater resource,
2. *Understanding:* identification of the natural and human factors affecting groundwater quality, and
3. *Trends:* detection of changes in groundwater quality (Kulongoski and Belitz, 2004).

The assessments are intended to characterize the quality of groundwater in the primary aquifer systems of the study unit. The primary aquifer systems (hereinafter referred to as primary aquifers) are defined by the depth intervals of the wells listed in the CDPH database for the study units. The CDPH database lists wells used for municipal and community drinking-water supplies, and includes wells from systems classified as non-transient (such as cities, towns, and mobile-home parks) and transient (such as schools, campgrounds, and restaurants). Groundwater quality in the primary aquifers may differ from water in shallow or deep parts of the aquifer systems. In particular, shallow groundwater may be more vulnerable to surface contamination. As a result, concentrations of constituents from anthropogenic sources (such as volatile organic compounds) can be higher in samples from shallow wells (such as many private domestic wells and environmental monitoring wells) than in samples from wells screened in the primary aquifer (Landon and others, 2010).

Purpose and Scope

The purposes of this report are to provide:

1. *Study unit description:* description of the hydrogeologic setting of the Southern, Middle, and Northern Sacramento Valley study units,
2. *Status assessment:* assessment of the current status of the quality of groundwater in the primary aquifers, and
3. *Compilation of ancillary data:* compilation of data for selected factors that may be useful for explaining water quality.

Water-quality data for all constituents analyzed in samples collected by the USGS for the GAMA program in the three study units, and details of sample collection, analysis, and quality-assurance procedures, are described by Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009). Untreated groundwater samples were collected from the three study units between April 2005 and January 2008. Utilizing those same data, this report describes methods used in designing the sampling network, identifying CDPH data for use in the *status assessment*, estimating aquifer-scale proportions of relative-concentrations, analyzing ancillary data sets, classifying groundwater age, and assessing the status of groundwater quality by statistical and graphical approaches.

The *status assessment* includes analyses of water-quality data for 181 wells selected by the USGS for spatial coverage of one well per grid cell across the three study units (hereinafter referred to as USGS grid wells). Samples were collected by the USGS for analysis of anthropogenic organic constituents, such as volatile organic compounds (VOCs) and pesticides, naturally occurring inorganic constituents, such as major ions, trace elements, nutrients, and radioactive constituents, and geochemical and age-dating tracers. (Dawson and others, 2008; Schmitt and others, 2008; Bennett and others, 2009). Water-quality data from the California Department of Public Health (CDPH) database also were used to supplement data collected by USGS for the GAMA program. The resulting set of water-quality data from USGS grid wells and selected CDPH wells was considered to be representative of the primary aquifer systems in the three study units; the primary aquifer systems (hereinafter referred to as primary aquifers) are defined by the depth intervals of the wells listed in the CDPH database for the MS study unit. GAMA status assessments are designed to provide a statistically robust characterization of groundwater quality in the primary aquifers at the basin-scale (Belitz and others, 2003). The statistically robust design also allows basins to be compared and results to be synthesized at regional and statewide scales.

To provide context, the water-quality data discussed in this report are compared to California and Federal drinking-water regulatory and non-regulatory benchmarks for treated drinking water. The assessments in this report characterize the quality of untreated groundwater resources in the primary aquifer in the study unit, not the treated drinking water delivered to consumers by water purveyors. After withdrawal from the ground, water typically is treated, disinfected, and (or) blended with other waters to maintain acceptable water quality. Regulatory benchmarks apply to treated water that is delivered to the consumer, not to untreated groundwater.

Definition and Location of Study Units

The Southern Sacramento Valley study unit (SSACV) covers an area of approximately 2,100 mi^2 and includes parts of Placer, Sacramento, Solano, Sutter, and Yolo Counties, California (figs. 1 and 2). SSACV was divided into six study areas, five of which are subbasins in the Sacramento Valley groundwater basin as defined by the California Department of Water Resources (2003): the North American, South American, Solano, Suisun-Fairfield, and Yolo subbasins.

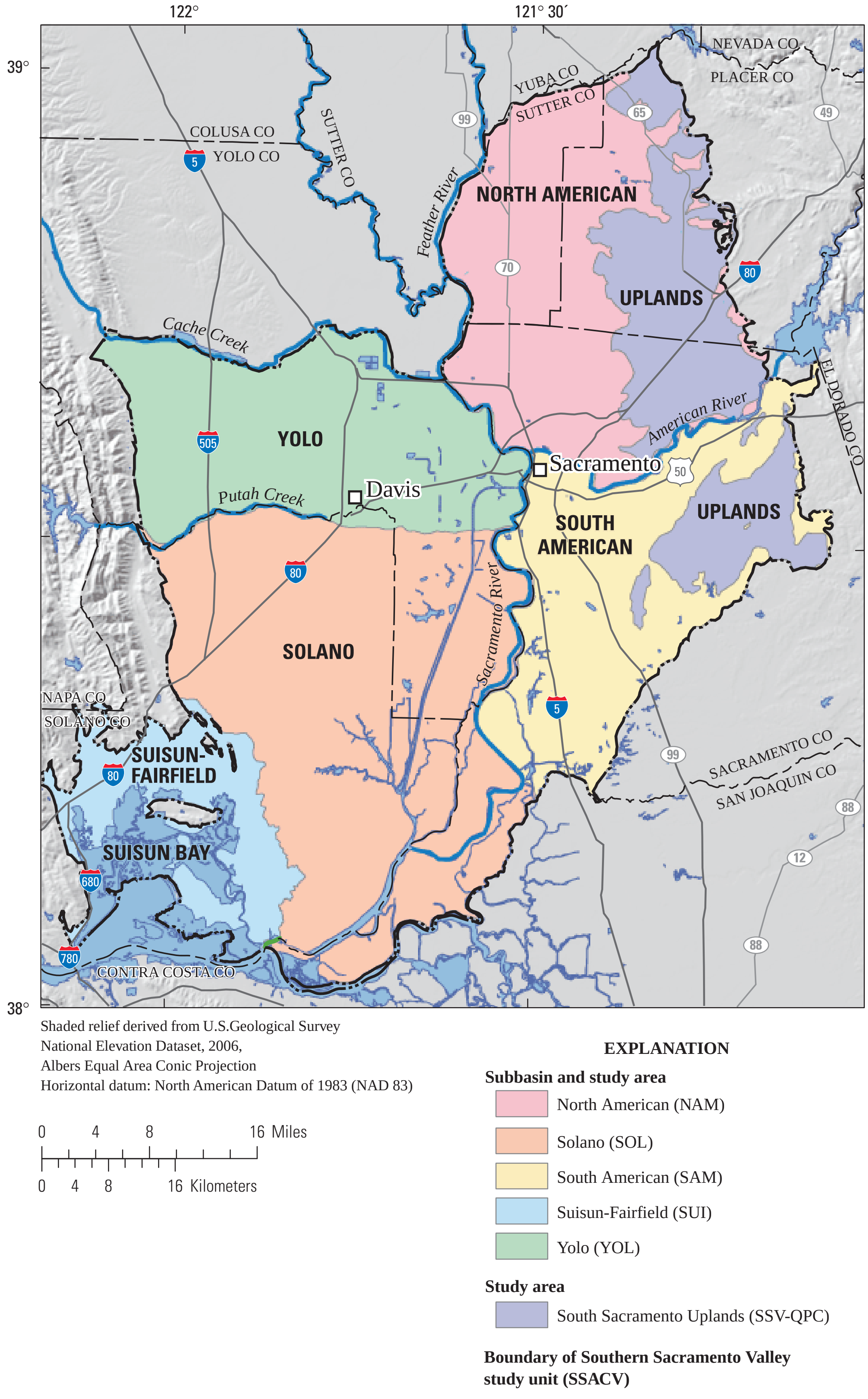


Figure 2. Study areas and geographic features of the Southern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

The sixth study area comprises the eastern portion of the North American and South American subbasins. Its extent is defined by Dawson and others (2008) as those portions of the CDWR-defined North and South American subbasins that include the surficial extent of the Quaternary/Plio-Pleistocene-age semiconsolidated deposits west of the bedrock of the Sierra Nevada. To differentiate the upland study area from similarly named study areas in other GAMA reports (Bennett and others, 2006; Landon and Belitz, 2008), the study area was given the acronym SSV-QPC. Unlike the other SSACV study areas, the Suisun-Fairfield groundwater subbasin has relatively few groundwater wells. Aquifers within the subbasin do not provide a significant source of drinking water due to low yields (Thomasson and others, 1960).

The Middle Sacramento Valley study unit (MSACV) covers an area of approximately 3,340 mi^2 in Butte, Colusa, Glenn, Sutter, Tehama, Yolo, and Yuba Counties, California (figs. 1 and 3). MSACV includes eight subbasins of the Sacramento Valley groundwater basin as defined by the California Department of Water Resources (2003). These eight subbasins were consolidated into Eastern and Western study areas separated by the Sacramento River (fig. 3; Schmitt and others, 2008). The Eastern study area includes the Vina, West Butte, East Butte, North Yuba, South Yuba, and Sutter subbasins, and the Western study area includes the Colusa and Corning subbasins.

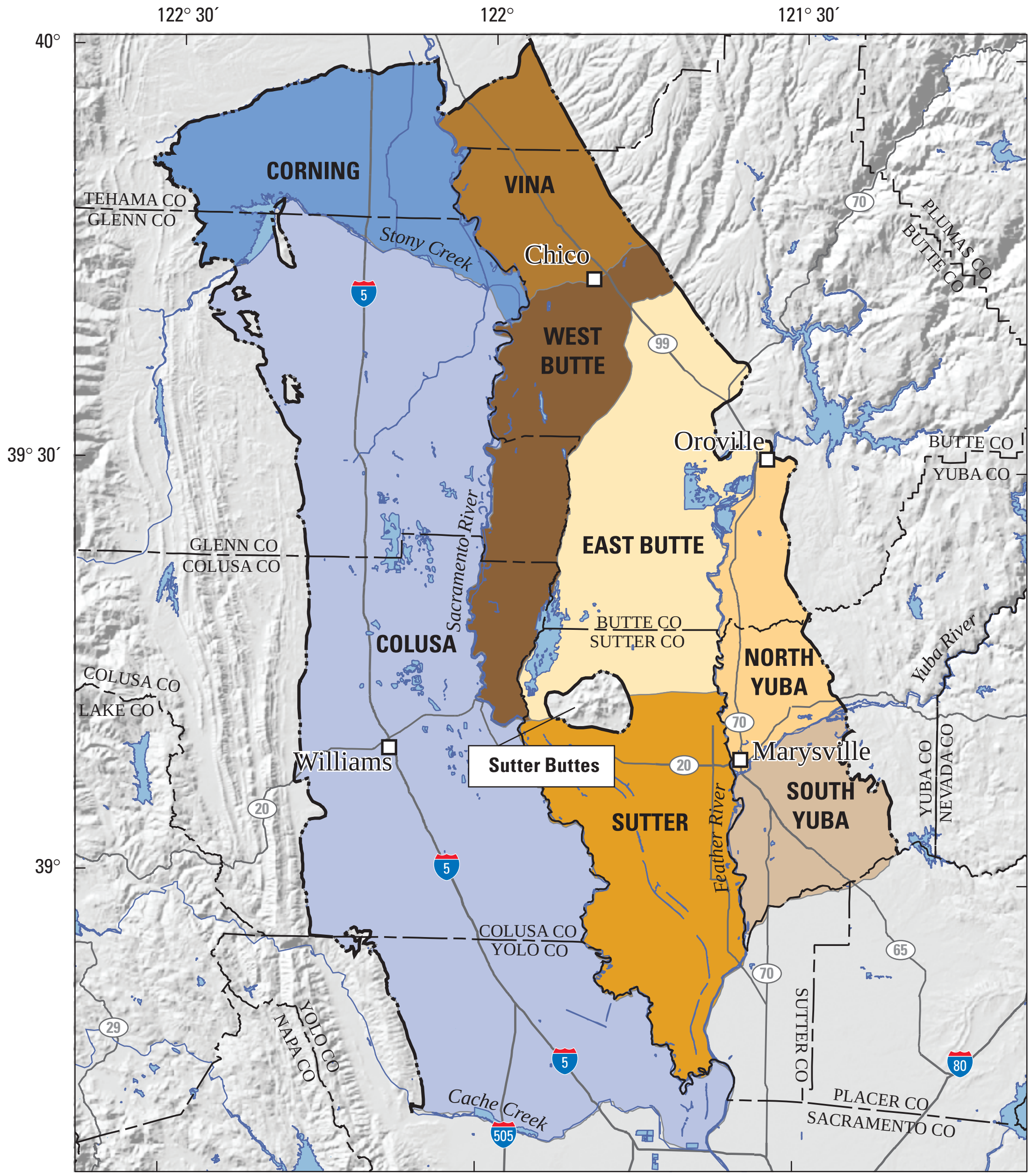
The Northern Sacramento Valley study unit (NSACV; also named REDSAC in Bennett and others, 2009) covers an area of approximately 1,200 mi^2 in Shasta and Tehama Counties, California, at the northern end of the Central Valley hydrogeologic province (figs. 1 and 4). NSACV includes 11 groundwater subbasins: 6 subbasins of the Redding Area groundwater basin and 5 subbasins of the Sacramento Valley groundwater basin as defined by the California Department of Water Resources (2003). The Redding study area includes the Enterprise, Millville, Anderson, South Battle Creek, Rosewood, and Bowman subbasins. The Northern Sacramento study area includes the Bend, Red Bluff, Antelope, Dye Creek, and Los Molinos subbasins. In NSACV, study area boundaries were defined by identifying the total area within the 3-kilometer (radius) circular buffer areas surrounding all CDPH wells in the study unit and are therefore not directly related to the subbasin boundaries.

Hydrogeologic Setting

The SSACV, MSACV, and NSACV study units, combined, cover an area of approximately 6,500 mi^2 of the Sacramento Valley, the northern one-third of the Central Valley hydrogeologic province defined by Belitz and others (2003). The Sacramento Valley is approximately 150-mi long and ranges in width from 20 mi in the north to 45 mi in the central and southern portions. An uplifted area north of Red Bluff known as the Red Bluff Arch separates the Redding groundwater basin from the Sacramento Valley groundwater basin (fig. 5). The Sutter Buttes near the center of the Sacramento Valley rise more than 2,000 ft above the valley floor and consists of the remnants of an extinct volcano nearly 10 mi in diameter. Two mountain ranges border the eastern part of the Sacramento Valley study units—the southernmost extension of the Cascade Range along the eastern edge of the Redding groundwater basin and the northeastern portion of the Sacramento Valley, and the Sierra Nevada along the central and southeastern portions of the Sacramento Valley and extending south along the remaining length of the Central Valley (fig. 5). The western margin of the Sacramento Valley and Redding groundwater basins is bounded by the northern Coast Ranges, a series of folded and faulted parallel ridges and valleys trending to the northwest (fig. 5) The Klamath Mountains border the Redding groundwater basin to the north (fig. 5).

Sediments containing fresh groundwater in the Sacramento Valley are derived from the surrounding mountain ranges and constitute a mix of marine, continental, and volcanic sediments. Marine sediments are derived from the Coast Ranges, whereas the continental and volcanic sediments are derived from the Sierra Nevada and Cascade Ranges. The Cascade Range primarily is composed of extrusive volcanic rocks and pyroclastic deposits, whereas the Sierra Nevada primarily is composed of intrusive granitic rocks. Sediments that have filled the Sacramento Valley may be as much as 10-mi thick (Page, 1986). Fresh groundwater typically occurs in Pliocene- to Holocene-age sediments that overlie saline-water-saturated sediments at depth (Olmstead and Davis, 1961). The base of freshwater [water with a specific conductance less than 3,000 µS/cm, or about 2,000 mg/L, total dissolved solids] in the Sacramento Valley generally occurs at less than 2,500ft below land surface (Berkstresser, 1973).

The Sacramento River, California's largest river, begins its course in northern California, and meanders through and drains the Sacramento Valley and Redding groundwater basins, flowing south until it joins the San Joaquin River in the Sacramento-San Joaquin Delta at the southern end of the Sacramento Valley (fig. 5). Major rivers flowing into the Sacramento River from the eastern Sacramento Valley include the Feather, American, and Yuba Rivers. Reservoirs have been constructed on all these major rivers just above the Sacramento Valley margin to provide flood protection, irrigation water, municipal water, and a source of fresh water used to control salinity in the Sacramento-San Joaquin Delta (Domagalski and others, 1998). Streams of much smaller size than those draining the Sierra Nevada flow into the Sacramento River from the Coast Ranges and western Sacramento Valley and include Stony, Cache, and Putah Creeks.



Shaded relief derived from U.S.Geological Survey National Elevation Dataset, 2006, Albers Equal Area Conic Projection Horizontal datum: North American Datum of 1983 (NAD 83)

0 4 8 16 Miles

0 4 8 16 Kilometers

EXPLANATION

Western Sacramento study area subbasins (WSAC)

- Colusa
- Corning

Boundary of Middle Sacramento Valley study unit (MSACV)

Eastern Sacramento study area subbasins (ESAC)

- East Butte
- North Yuba
- South Yuba
- Sutter
- Vina
- West Butte

Figure 3. Study areas and geographic features of the Middle Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

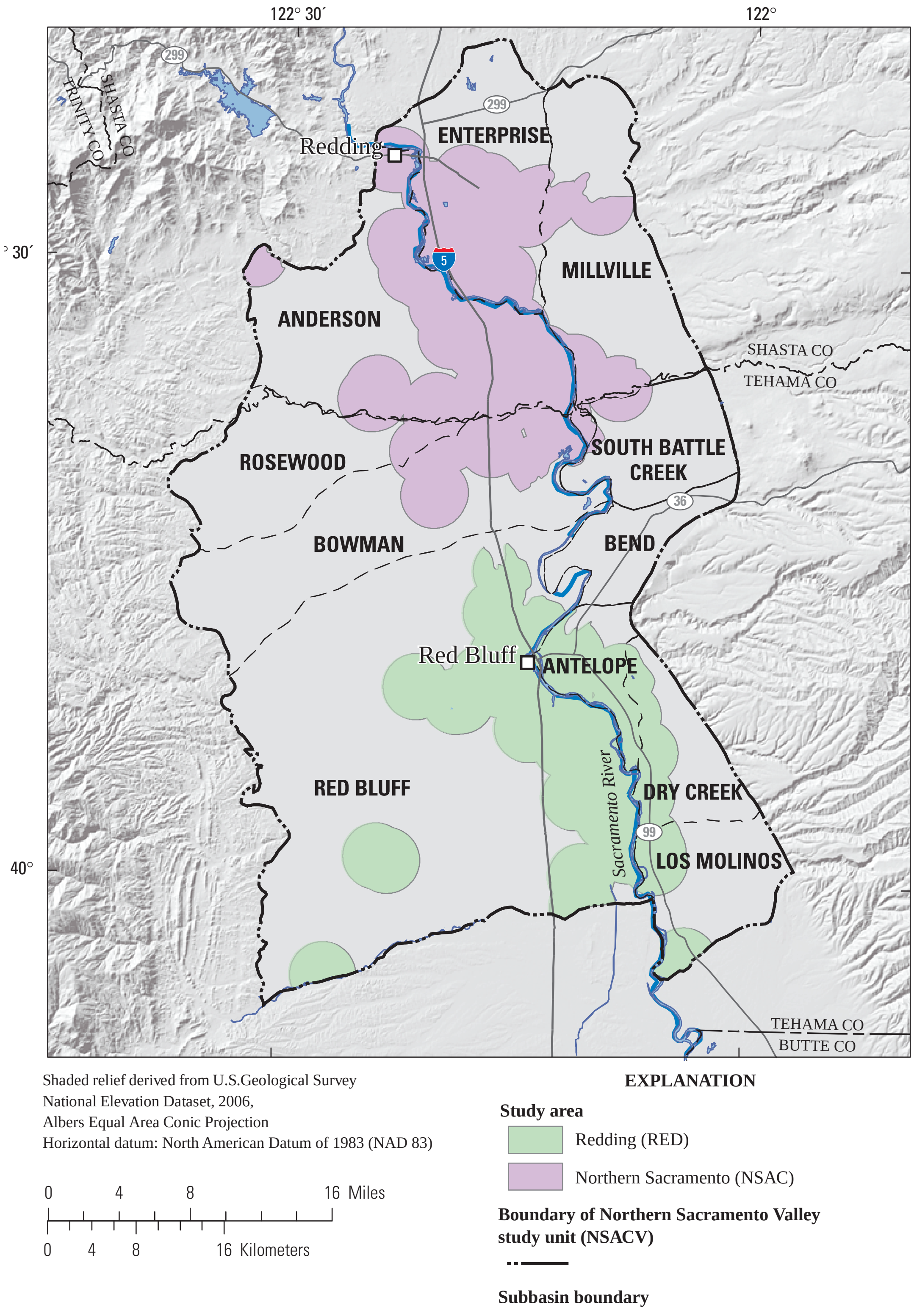


Figure 4. Study areas and geographic features of the Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

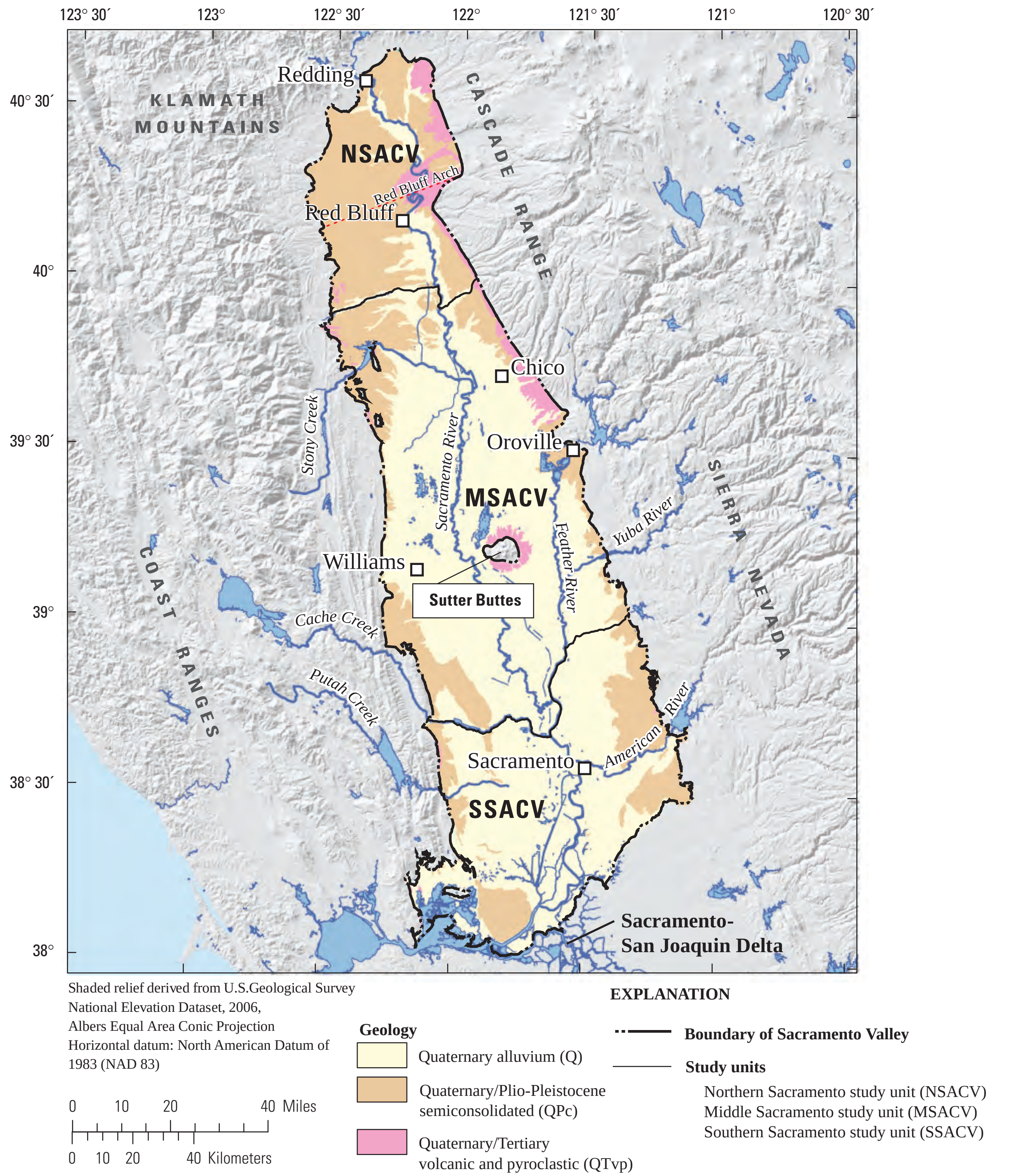


Figure 5. Geology of the of the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Geology of Eastern Sacramento Valley

Throughout the eastern portion of the central and northern Sacramento Valley, the Pliocene age Tuscan Formation ranges in thickness from 1 to 10,000 ft. It is a significant sedimentary unit composed of black volcanic sands, gravel, and tuffaceous clay that yields large quantities of water to wells in the Sacramento Valley and Redding groundwater basins (Olmstead and Davis, 1961; California Department of Water Resources, 1978; Pierce, 1983). The Tuscan Formation outcrops to the northeast of Red Bluff and south nearly to Oroville, and then dips in the subsurface southwestward. Fanglomerates overlying the Tuscan Formation deposits in the northeastern Sacramento Valley are composed of a heterogeneous mix of gravel, sand, silt, and clay derived from the Tuscan Formation (Harwood and others, 1981; Page, 1986). Wells pumping from these fanglomerates generally produce only moderate amounts of water because the fanglomerates are not very permeable (Olmstead and Davis, 1961; California Department of Water Resources, 1978; Page, 1986).

South of Oroville and extending beyond the southern boundary of SSACV, the Tertiary age Ione, Valley Springs, and Mehrten Formations outcrop along the eastern flank of the Sacramento Valley and dip to the southwest beneath the surface of the valley (Page, 1986). The Ione Formation is composed of clay, sand, sandstone, and conglomerate. Where exposed in the Sacramento Valley, the Ione Formation is up to 400 ft thick (Page, 1986). Owing to the degree of consolidation and clay content, the Ione Formation yields a limited quantity of water to wells (Davis and Hall, 1959; California Department of Water Resources, 1978; Page, 1986). The Valley Springs Formation is a sequence of mostly fluvial sediments that unconformably overlies the Ione Formation, and is composed of sandy clay, sand, rhyolitic ash, and siliceous gravel (Davis and Hall, 1959). On the basis of well-log information and outcrop exposure in the Sacramento Valley, the Valley Springs Formation is estimated to be up to 200 ft thick (Piper and others, 1939; California Department of Water Resources, 1978). Fine ash and clay in the Valley Springs Formation limit the quantity of water produced by wells (Page and Balding, 1973). The Mehrten Formation outcrops along the southeastern Sacramento Valley and Northern San Joaquin Valley. It overlies the Valley Springs Formation and dips into the subsurface to the southwest beneath the valley (Davis and Hall, 1959; Page, 1986). Two distinct units in the Mehrten Formation have been described in the Sacramento Valley—an upper unit composed of unconsolidated black sands interbedded with blue-to-brown clay, and a lower unit composed of hard, dense breccia (California Department of Water Resources, 1978; Page, 1986). Andesitic volcanic source material from the Sierra Nevada produces black sands that are characteristic of the Mehrten Formation. The thickness of the Mehrten Formation in the Sacramento Valley is about 200 ft where exposed, and ranges between 400 and 500 ft in thickness in the subsurface (Page, 1986). In the Sacramento Valley, the Mehrten Formation generally yields large quantities of water to wells, particularly from the upper sandy portion (Department of Water Resources, 1978). Quaternary-age alluvial-fan deposits overly the Ione, Valley Springs, and Mehrten Formations along the eastern edge of the Sacramento Valley. These alluvial-fan deposits are derived from the Sierra Nevada and from the reworking and erosion of the previously described sediments. Where saturated, the alluvial-fan deposits constitute a significant portion of aquifer system.

Geology of the Western Sacramento Valley

The Tehama Formation of the Pliocene to Pleistocene age outcrops along the western margin of the Sacramento Valley and Redding groundwater basins, and dips eastward beneath the Quaternary sediments in the center of the valley (Page and Bertoldi, 1983; Pierce, 1983; Page, 1986). The Tehama Formation is derived from the Coast Ranges to the west and is composed of poorly sorted deposits of clay, silt, sandy silt, and silty sand with thin lenses of gravel and sand (Helley and others, 1981; Pierce, 1983; Page, 1986). The average thickness of the Tehama Formation is approximately 2,000 ft, and the lower part of the Tehama Formation contains saline groundwater (Berkstresser, 1973; California Department of Water Resources, 1978). In the Redding groundwater basin, the Red Bluff Formation of Pleistocene age unconformably overlies the Tehama and Tuscan Formations and is composed of coarse gravels and boulders in a distinctly red sand, silt, and clay matrix. However, it is rarely in the zone of saturation and is therefore not a significant source of groundwater (Olmstead and Davis, 1961; Pierce, 1983). Younger Quaternary-age alluvial-fan deposits overlie the Tehama Formation along much of the western Sacramento Valley. These alluvial-fan deposits primarily are composed of sands and gravels derived from the Coast Ranges. Wells in the alluvial fan deposits generally also penetrate the underlying Tehama Formation (California Department of Water Resources, 1978; Page, 1986). Overall, the Tehama Formation and the overlying alluvial-fan deposits produce variable amounts of water to wells, with yields ranging from 500 to 2,000 gal/min (California Department of Water Resources, 1978; Page, 1986).

Land Use

The Sacramento Valley groundwater basin is dominated by agricultural land use, whereas the Redding groundwater basin is dominated by natural land use (fig. 6). Rice is the primary crop grown along the axis of the Sacramento Valley, where the sediments are fine grained. Orchards—which typically require well drained soils—are the dominant crops grown on the Valley margins, particularly on the upland alluvial deposits where the sediments tend to be coarse grained. The largest concentration of urban land use of the combined study units is the city of Sacramento, located at the southeastern end of the Sacramento Valley (fig. 6).

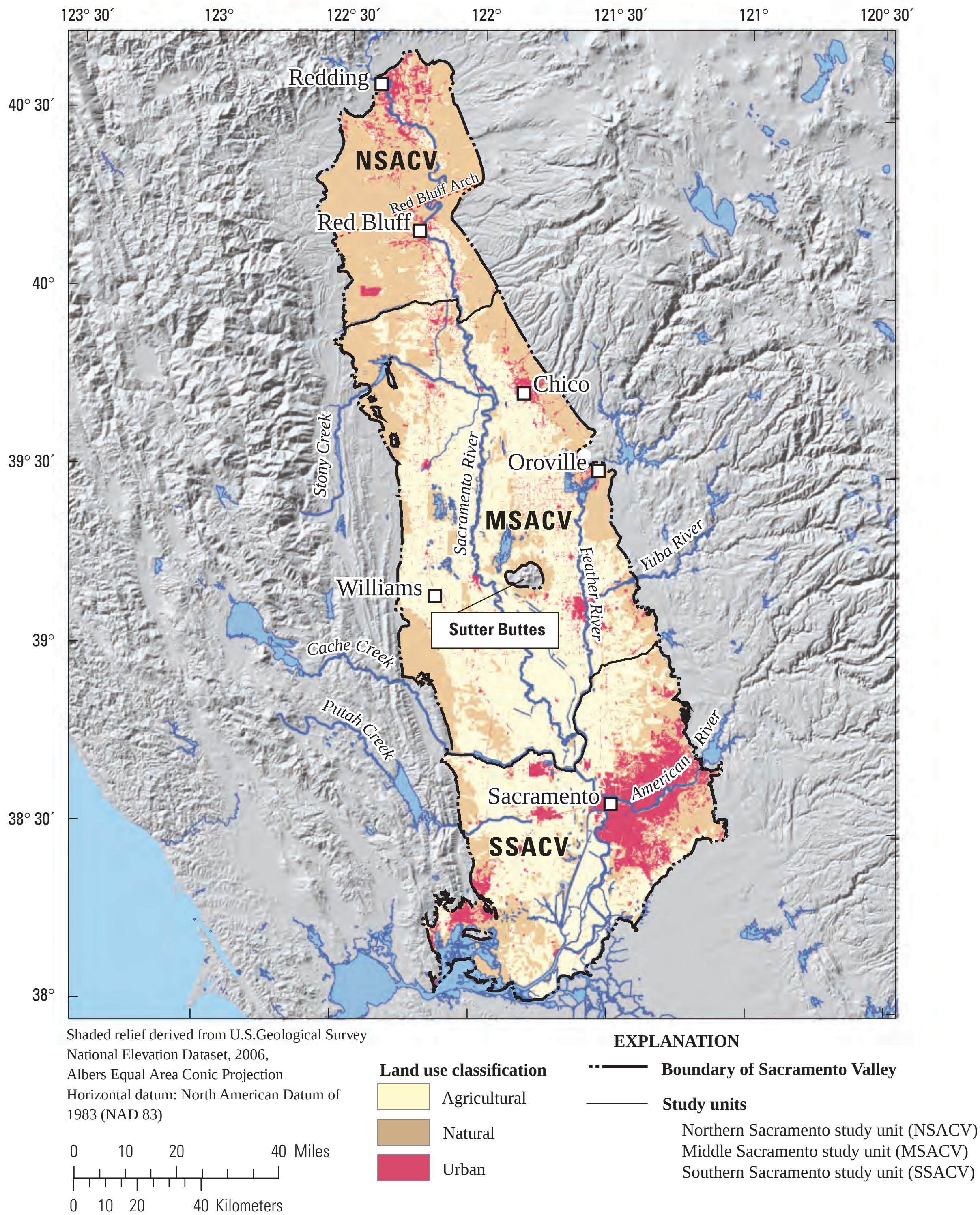


Figure 6. Land use of the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Methods

This section describes the methods used in the *status assessment* for (1) defining groundwater quality with respect to relative-concentrations, (2) assembling the datasets used for the assessment, (3) determining which constituents warrant additional evaluation, and (4) calculating aquifer-scale proportions. Methods used for compilation of data on potential explanatory factors are described in appendix A.

Relative-concentrations were used to reference constituent concentrations to regulatory and non-regulatory benchmarks used to evaluate drinking-water quality. Constituents were selected for additional evaluation in the *status assessment* on the basis of objective criteria by using these relative-concentrations. Groundwater-quality data collected by the USGS for the GAMA program (USGS-GAMA) and data compiled in the CDPH database were used in the *status assessment*. Two statistical methods based on spatially-unbiased grids with equal-area cells within each study area (grid cell sizes were unique to each study area) were used to calculate aquifer-scale proportions: (1) the “grid-based” method, which uses one value per cell to represent groundwater quality, and (2) the “spatially-weighted” method, which uses many values per cell.

The CDPH database contains historical records from more than 25,000 wells, necessitating targeted retrievals to effectively access water-quality data. For example, for the areas representing the SSACV, MSACV, and NSACV, the historical CDPH database contains more than 1.5 million records from 1,610 wells. The CDPH data were used in three ways in the *status assessment*: (1) to fill in gaps in USGS-GAMA data for the grid-based calculations of aquifer-scale proportions, (2) to help identify constituents for additional evaluation, and (3) to provide additional data used in the spatially-weighted calculations of aquifer-scale proportions. Methods used for selection of CDPH-well data for these three purposes are described in appendix A.

Relative-Concentrations and Water-Quality Benchmarks

Concentrations of constituents are presented as relative-concentrations in the *status assessment*:

$$\textit{Relative concentration} = \frac{\textit{Sample concentration}}{\textit{Benchmark concentration}}.$$

Relative-concentrations less than 1.0 indicate sample concentrations less than the benchmark, and relative-concentrations greater than 1.0 indicate sample concentrations greater than the benchmark. The use of relative-concentrations standardized to the benchmark of each constituent facilitates comparison between constituents that have water-quality benchmarks at different concentrations, even for benchmarks that differ by multiple orders of magnitude.

Toccalino and others (2004), Toccalino and Norman (2006), and Rowe and others (2007) previously used the ratio of measured concentration to a benchmark [either maximum contaminant levels (MCL)s or Health-Based Screening Levels (HBSL)s] and defined this ratio as the *benchmark quotient*. Relative-concentrations used in this report are equivalent to the benchmark quotient of Toccalino and others (2004) for constituents with U.S. Environmental Protection Agency (USEPA) MCL benchmarks; however, HBSLs were not used in this report, as they are not currently used as benchmarks by California drinking-water regulatory agencies. Relative-concentrations can be computed only for constituents with water-quality benchmarks; therefore, constituents lacking water-quality benchmarks were not included in the *status assessment*.

Regulatory and non-regulatory benchmarks for drinking water apply to the treated water that is served to the consumer, not to the untreated groundwater that was analyzed in this study. However, to provide some context for the results, concentrations of constituents measured in the untreated groundwater were compared with benchmarks established by the USEPA and CDPH (U.S. Environmental Protection Agency, 2009a, 2009b, 2009c; California Department of Public Health, 2008a, 2008b, 2010). The benchmarks used for each constituent were selected in the following order of priority:

1. Regulatory, health-based CDPH and USEPA maximum contaminant levels (MCL-CA and MCL-US) and action levels (AL-US).

2. Non-regulatory CDPH and USEPA secondary maximum contaminant levels (SMCL-CA and SMCL-US). For constituents with both recommended and upper SMCL-CA levels, the values for the upper levels were used.

3. Non-regulatory, health based CDPH notification levels (NL-CA), USEPA lifetime health advisory levels (HAL-US), and USEPA cancer risk-specific doses for 1:100,000 (RSD5-US).

For constituents with multiple types of benchmarks, this hierarchy may not result in selection of the benchmark with the lowest concentration. Additional information on the types of benchmarks and listings of the benchmarks for all constituents analyzed is provided by Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009).

For ease of discussion, relative-concentrations of constituents were classified into high, moderate, and low categories:

Category	Relative-concentrations for organic constituents	Relative-concentrations for inorganic constituents
High	> 1	> 1
Moderate	> 0.1 and ≤ 1	> 0.5 and ≤ 1
Low	≤ 0.1	≤ 0.5

The boundary between moderate and low relative-concentrations was set at 0.1 for organic and special-interest constituents for consistency with other studies and reporting requirements (U.S. Environmental Protection Agency, 1998; Toccalino, 2007). For organic constituents, detection at concentrations greater than one-tenth of a health-based benchmark value (relative-concentration greater than 0.1) commonly is used to identify constituents that may warrant additional monitoring to evaluate trends in their occurrences. Organic constituents generally are man-made, are ideally uncommon in groundwater, and are infrequently detected at relative-concentrations greater than 0.1. Of the three special-interest constituents, two are organic compounds: 1,2,3-trichloropropane (1,2,3-TCP) and *N*-nitrosodimethylamine (NDMA). The third, perchlorate, is an inorganic compound, but is grouped with 1,2,3-TCP and NDMA.

For inorganic constituents, the boundary between moderate and low relative-concentrations was set at 0.5. The primary reason for using a higher boundary value was to focus attention on the inorganic constituents of most immediate concern. In a national survey of water quality in aquifers used for public drinking-water supply, Toccalino and others (2010) found that organic constituents (pesticides and VOCs) were detected at high or moderate benchmark quotients (>0.1) in about 10% of the samples and that inorganic constituents (trace elements and radioactive constituents) were detected at high or moderate benchmark quotients in about 80% of the samples. By setting the boundary between low and moderate benchmark quotients at 0.1, Toccalino and others (2010) produced a conservative assessment of water quality that is protective of human health and provides an early indication of potential groundwater contamination issues.

Concentrations of the man-made organic constituents may change rapidly in groundwater; thus, early warning is vital for planning and implementing measures to protect aquifer systems from further contamination and to mitigate existing contamination. Resources may be focused on the 10% of wells with moderate or high benchmark quotients of organic constituents. However, a similar focusing of resources would not be possible for the 80% of wells with moderate or high benchmark quotients of inorganic constituents. Inorganic constituents generally are naturally occurring in groundwater and their concentrations generally are stable or change slowly compared to concentrations of organic constituents; thus, early warning of potential groundwater contamination may be less critical for management of potential water-quality problems. By choosing a boundary between low and moderate relative-concentrations (or benchmark quotient) that is greater than 0.5, inorganic constituents can be identified from among the many that may be present at concentrations approaching benchmarks that may warrant more immediate attention from water-resource managers.

Datasets for Status Assessment

Three datasets are used in the *status assessment*: USGS-grid wells, CDPH-grid wells, and additional non-grid wells from USGS or CDPH. Each dataset is described and summarized here, with a discussion comparing results from GAMA and CDPH sources presented in appendix B.

U.S. Geological Survey Grid Wells

The primary data used for the grid-based calculations of aquifer-scale proportions were data from wells sampled by USGS-GAMA. Detailed descriptions of the methods used to identify wells for sampling are given in Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009). Briefly, each study area in a study unit was divided into equal-area grid cells (grid cells sizes are unique to each study area); one well was randomly selected to represent each cell (Scott, 1990). Wells were selected from the population of wells in statewide databases maintained by CDPH and USGS. The three Sacramento Valley study units contained a total of 224 grid cells, and the USGS sampled wells in 181 of those cells (USGS-grid wells). Of the 181 USGS-grid wells, 123 were listed in the CDPH database; the other 58 were irrigation, domestic, industrial, or monitoring wells perforated at depths similar to the depths of CDPH wells in the cell or neighboring cells. USGS-grid wells were named with an alphanumeric GAMA-ID consisting of a prefix identifying the study unit or study area and a number indicating the order of sample collection (fig. A1; table A1). In the SSACV, the following prefixes were used to indicate study areas: NAM, North American study area; SAM, South American study area; SOL, Solano study area; SUI, Suisun-Fairfield study area; YOL, Yolo study area; and SSV-QPC, South Sacramento Uplands study area. In the MSACV, the study areas are identified with the following prefixes: ESAC, Eastern Sacramento study area; and WSAC, Western Sacramento study area. In the NSACV, the study areas are identified with the following prefixes: NSAC, Northern Sacramento study area, and RED, Redding study area.

Samples collected from USGS-grid wells were analyzed for 173 to 315 constituents (table 1). VOCs, pesticides, tritium, and stable isotopes of hydrogen and oxygen were analyzed in water samples from all wells. Additional pesticides, major and minor ions, trace elements, nutrients, noble gases, perchlorate, and redox species were analyzed in samples from many wells, and radiochemical constituents, carbon isotopes, and NDMA were analyzed in samples from some wells. The collection, analysis, and quality-control data for the analytes listed in table 1 are described by Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009).

Table 1. Summary of analyte groups and numbers of wells sampled for different analytical schedules, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[VOC, volatile organic compounds]

	Southern Sacramento Valley study unit schedule [1]			Middle Sacramento Valley study unit schedule [1]			Northern Sacramento Valley study unit schedule [1]	
	Fast	**Intermediate**	**Slow**	**Fast**	**Intermediate**	**Slow**	**Intermediate**	**Slow**
Total number of wells	40	23	20	26	52	8	54	12
Number of grid wells sampled	[2] 39	[3] 21	6	26	37	8	31	12
Number of understanding wells sampled	1	2	14	0	15	0	23	0
Analyte or Analyte Groups	**Number of constituents analyzed in each group**							
Pesticides and degradates	69	69	69	81	81	81	70	70
VOCs	85	85	85	85	85	85	85	85
Pharmaceuticals [4]	14	14	14		14	14		14
Specific conductance, temperature	2	2	2	2	2	2	2	2
Stable isotopes of hydrogen and oxygen in water	2	2	2	2	2	2	2	2
Tritium [5]	1	1	1	1	1	1	1	1
Polar pesticides and degradates [6]		54	54	54	54	54	54	54
Major and minor ions, and trace elements		35	35		35	35	35	35
Noble gases & tritium [7]		7	7	7	7	7	7	7
Arsenic, chromium, and iron species		6	6	6	6	6	6	6
Nutrients		5	5		5	5	5	5
Perchlorate		1	1	1	1	1	1	1
Low-level 1,2,3-trichloropropane		1	1		1	1		
Alkalinity, dissolved oxygen, and pH			3	3	3	3	3	3
Carbon isotopes			2		2	2	2	2
N-Nitrosodimethylamine (NDMA)			1		1	1		[8] 1
Gross alpha and beta particle activities			4			4		4
Microbial constituents			4			4		4
Radium isotopes			2			2		2
Radon-222			1			1		1
Turbidity			1			1		1
Gasoline oxygenates (additional VOCs) [9]			3			3		
Uranium isotopes							3	3
Sum:	173	282	303	242	300	315	276	303

[1] "Fast", "intermediate", and "slow" schedules refer to the relative amount of time required for a field crew to complete all work at a well.

[2] Includes three wells in the Suisun Study area not included in the calculation of aquifer proportion for the status assessment.

[3] Includes two wells in the Suisun Study area not included in the calculation of aquifer proportion for the status assessment.

[4] Not discussed in this report.

[5] Analyzed at U.S. Geological Survey Stable Isotope and Tritium Laboratory, Menlo Park, California.

[6] Does not include four constituents in common with pesticides and degradates.

[7] Analyzed at Lawrence Livermore National Laboratory, Livermore, California.

[8] NDMA was analyzed but the data did not meet quality control standards and are therefore not used in this report.

[9] Does not include five constituents in common with set of VOCs analyzed in all samples.

California Department of Public Health Grid Wells

Of the 224 grid cells in the three study units, 43 cells did not have a USGS-grid well, 64 cells had a USGS-grid well but no USGS data for major ions, trace elements, nutrients, and radiochemical constituents, and 70 cells had a USGS-grid well but incomplete USGS data for radiochemical constituents. The CDPH database was queried to identify wells that could provide these missing inorganic and radiochemical data. CDPH wells with data collected within 3 years of the USGS-GAMA sampling periods were considered. If more than one analysis for a constituent in a well was available in the 3-year interval, then the most recent data were selected. The 3-year intervals were as follows:

Study Unit	3-year interval prior to USGS-GAMA sample collection
Southern Sacramento Valley (SSACV)	June 1, 2002–June 30, 2005
Middle Sacramento Valley (MSACV)	August 1, 2003–August 31, 2006
Northern Sacramento Valley (NSACV)	January 1, 2005–February 5, 2008

The decision tree used to identify suitable CDPH wells is described in detail in appendix A. Briefly, the first choice was to use CDPH data from the same well as the USGS-grid well ("DG" CDPH-grid wells; fig. A1; table A1). If the DG well did not have all needed data, a second well was randomly selected from the subset of CDPH wells with data ("DPH" CDPH-grid wells; fig. A1; table A1). No more than one DPH CDPH-grid well was selected for each cell. The combination of the USGS-grid wells and the DG and DPH CDPH-grid wells produced a grid-well network covering 200 of the 224 grid cells in the three study units (fig. 7). Comparisons of data from USGS and CDPH wells to assess the validity of using these different sources in combination are presented in appendix B.

The CDPH database generally did not contain data for all missing inorganic constituents at every CDPH-grid well; therefore, the numbers of wells used for the grid-based assessment were different for different inorganic constituents (table 2). Although other organizations also collect water-quality data, the CDPH database is the only statewide database of groundwater-chemistry data available for comprehensive analysis.

CDPH data were not used to supplement USGS-grid well data for grid-based aquifer proportions of VOCs, pesticides, or perchlorate for the *status assessment*. A larger number of VOCs and pesticide compounds are analyzed for the USGS-GAMA program than are available from the CDPH database. USGS-GAMA collected data for 88 VOCs and 70 pesticides and pesticide degradates at every well, plus an additional 54 pesticides and pesticide degradates at most wells in the SSACV, MSACV, and NSACV study units (table 1). The CDPH database for the three study units contain data for as many as 61 VOCs and 27 pesticides for a subset of the wells in the database. In addition, long-term method detection levels for USGS-GAMA analyses of organic constituents typically were one to two orders of magnitude lower than the method detection levels for analyses compiled by CDPH (table B1).

Additional Data Used for Spatially-Weighted Calculation

The spatially-weighted calculations of aquifer-scale proportions used data from the USGS-grid wells, additional wells sampled by USGS-GAMA, and all wells in the CDPH database having water-quality data for the 3-year intervals prior to the USGS-GAMA sampling periods. For wells with USGS and CDPH data, only the USGS data were used.

In addition to the 181 USGS-grid wells, a total of 55 other wells were sampled in the three study units by the USGS. These additional wells were selected to increase sampling density in certain areas to help understand specific water-quality issues in those areas (fig. 7; Dawson and others, 2008; Schmitt and others, 2008; Bennett and others, 2009). These 55 wells were referred to as USGS-understanding wells and were numbered in the order of collection, with prefixes modified from those used for the USGS-grid wells (NAMFP, SSV-QPCFP, and YOLFP in the SSACV study unit; ESAC-FP and WSAC-FP in the MSACV study unit; and NSAC-MW, NSAC-U, RED-MW, and RED-U in the NSACV study unit) (fig. A1, table A1). Some of the USGS-understanding wells were selected along groundwater flow paths (FP included in the prefix), and some were monitoring wells selected to sample groundwater from different depths in the primary aquifers (MW included in the prefix). All of the USGS-understanding wells were included in the spatially-weighted calculations.

The Data Series report for the MSACV study unit also reports results for 22 monitoring wells numbered with the prefix RICE (Schmitt and others, 2008). The RICE wells were not included in the *status assessment* because they are shallow ($\leq$ 50 ft) and thus are not considered representative of the primary aquifers. This group of monitoring wells was part of a land-use study focused on the effect of rice agriculture on groundwater quality (Dawson, 2001).

Table 2. Numbers of grid wells used in the status assessments of inorganic constituents in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[CDPH, California Department of Public Health; USGS, U.S. Geological Survey; nc, not collected]

Constituent	Southern Sacramento Valley study unit (93 cells)		Middle Sacramento Valley study unit (87 cells)		Northern Sacramento Valley study unit (44 cells)	
	Number of grid wells sampled by GAMA	Number of grid wells selected from CDPH	Number of grid wells sampled by GAMA	Number of grid wells selected from CDPH	Number of grid wells sampled by GAMA	Number of grid wells selected from CDPH
Nutrients with health-based benchmarks						
Nitrite (as nitrogen)	27	39	45	25	43	0
Nitrate plus nitrite (as nitrogen)	27	42	45	29	43	0
Trace elements with health-based benchmarks						
Aluminum	27	31	45	19	43	0
Antimony	27	31	45	20	43	0
Arsenic	27	32	45	21	43	0
Barium	27	31	45	19	43	0
Beryllium	27	31	45	21	43	0
Boron	27	23	45	1	43	0
Cadmium	27	31	45	19	43	0
Chromium	27	27	45	14	43	0
Copper	27	30	45	15	43	0
Fluoride	27	31	45	20	43	0
Lead	27	29	45	5	43	0
Mercury	27	31	45	19	43	0
Molybdenum	27	5	45	0	43	0
Nickel	27	31	45	19	43	0
Selenium	27	31	45	19	43	0
Strontium	27	0	45	0	43	0
Thallium	27	31	45	21	43	0
Uranium	27	10	45	0	43	0
Vanadium	27	24	45	2	43	0
Trace elements with secondary maximum contaminant levels						
Iron	27	33	45	17	43	0
Manganese	27	33	45	18	43	0
Silver	27	30	45	15	43	0
Zinc	27	31	45	16	43	0
Radioactive constituents with health-based benchmarks						
Gross alpha particle activity	6	36	8	24	12	10
Gross beta particle activity	6	5	8	0	12	0
Radon-222	6	1	8	1	12	0
Radium-226 plus Radium-228	6	10	8	4	12	0
Uranium Isotopes (234, 235, 238)	nc	nc	nc	nc	43	nc
Major ions with secondary maximum contaminant levels						
Chloride	27	26	45	16	43	0
Sulfate	27	26	45	17	43	0
Total dissolved solids (measured as residue on evaporation)	[1] 67	3	[2] 71	4	43	0

[1] Includes 40 values of total dissolved solids calculated using measurements of specific conductance.

[2] Includes 26 values of total dissolved solids calculated using measurements of specific conductance.

Identification of Constituents for Status Assessment

As many as 315 constituents were analyzed in samples from SSACV, MSACV, and NSACV wells as part of the *status assessment*; however, only a subset of these constituents were selected for additional evaluation in this report. Three criteria were used to identify constituents for additional evaluation:

1. Constituents detected at high or moderate relative-concentrations in the CDPH database within the 3-year intervals prior to USGS-GAMA sampling periods,
2. Constituents detected at high or moderate relative-concentrations in the USGS-grid wells or USGS-understanding wells used in the *status assessment*, or
3. Organic constituents with detection frequencies greater than 10% in the USGS-grid well dataset for a particular study unit.

These criteria resulted in the identification of 14 organic constituents, 1 constituent of special interest, and 21 inorganic constituents for additional evaluation for at least one of the three study units (table 3). An additional 53 organic constituents and 23 inorganic constituents were detected by USGS-GAMA and are not selected for additional evaluation because they either have no established benchmarks, or were only detected at low relative-concentrations (table 4). The remaining constituents that were not detected by USGS-GAMA in any of the three study units are listed in Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009).

The CDPH database also was used to identify constituents that have been reported at high relative-concentrations historically. The historical period was defined as the earliest record maintained in the CDPH database to just prior to the 3-year intervals used for the *status assessments*.

Study unit	Historical period of record used in this report
Southern Sacramento Valley (SSACV)	April 7, 1984–May 31, 2002
Middle Sacramento Valley (MSACV)	February 8, 1984–July 31, 2003
Northern Sacramento Valley (NSACV)	February 9, 1984–December 31, 2004

Constituent concentrations may be historically high because of improvement in groundwater quality or because of abandonment of wells with high concentrations. Historically high constituents detected in wells in the SSACV, MSACV, and NSACV are shown in table 5. In the SSACV study unit, there were 14 historically high constituents. With the exception of mercury and selenium, the historically high constituents were detected at high relative-concentrations in less than 1% of the SSACV wells tested. One constituent, selenium, was also detected at moderate relative-concentrations currently. In the MSACV study unit, there were 10 historically high constituents, and with the exception of thallium, all were detected at high relative-concentrations in less than 1% of the MSACV wells tested. There were three historically high constituents in the NSACV study unit, each of which was detected at high relative-concentration in one well. Historically high constituents that do not otherwise meet the criteria for additional evaluation in the *status assessment* are not considered representative of potential groundwater-quality concerns in the three study units during the current periods.

Calculation of Aquifer-Scale Proportions

The *status assessment* is intended to characterize the quality of groundwater resources in the primary aquifers of the SSACV, MSACV, and NSACV study units. The primary aquifers are defined by the depth intervals over which wells listed in the CDPH database are perforated. The use of the term “primary aquifer” does not imply that there is a single discrete aquifer unit. In most groundwater basins, municipal and community supply wells generally are perforated at greater depths than domestic wells (for example, Burow and others, 2008). Thus, because domestic wells are not listed in the CDPH database, the primary aquifer generally corresponds to the portion of the aquifer system tapped by municipal and community supply wells. However, to the extent that domestic wells in the three study units are perforated over the same depth intervals as the CDPH wells, the assessments presented in this report also may be applicable to the portions of the aquifer systems used for domestic drinking-water supplies.

Two statistical approaches, grid-based and spatially-weighted, were selected to determine the proportions of the primary aquifers in the three study units with high and moderate relative-concentrations of constituents. These proportions are referred to as high and moderate aquifer-scale proportions. Calculations of aquifer-scale proportions were made for individual constituents and for classes of constituents. Classes of constituents with health-based benchmarks included: VOCs, pesticides, any organic constituent (VOCs and pesticides combined), radioactive constituents, trace elements, nutrients, and any inorganic constituent (radioactive constituents, trace elements, and nutrients combined).

Table 3. Benchmark type and benchmark value for constituents selected for additional evaluation in the status assessment of groundwater quality in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Thresholds and threshold values as of September 12, 2008. **Benchmark type:** MCL-US, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; MCL-CA, California Department of Public Health (CDPH) maximum contaminant level; HAL-US, USEPA lifetime health advisory level; NL-CA, CDPH notification level; RSD5-US, USEPA risk-specific dose at a risk factor of 10^{-5}. **Benchmark units:** µg/L, microgram per liter; mg/L, milligram per liter; pCi/L, picocurie per liter. **Other Abbreviations:** D, detected, MSACV, Middle Sacramento Valley; na, not analyzed; NSACV, Northern Sacramento Valley; SSACV, Southern Sacramento Valley; —, not detected]

Constituent	Typical use or source	Benchmarks			Study unit		
		Type	Value	Units	SSACV	MSACV	NSACV
Trace elements with health-based benchmarks							
Aluminum	Naturally occurring	MCL-CA	1,000	µg/L	D	D	D
Arsenic	Naturally occurring	MCL-US	10	µg/L	D	D	D
Barium	Naturally occurring	MCL-CA	1,000	µg/L	D	D	D
Boron	Naturally occurring	NL-CA	1,000	µg/L	D	D	D
Cadmium	Naturally occurring	MCL-US	5	µg/L	D	D	D
Chromium	Naturally occurring	MCL-CA	50	µg/L	D	D	D
Fluoride	Naturally occurring	MCL-CA	2	mg/L	D	D	D
Lead	Naturally occurring	MCL-US	15	µg/L	D	D	D
Nickel	Naturally occurring	MCL-CA	100	µg/L	D	D	D
Selenium	Naturally occurring	MCL-US	50	µg/L	D	D	D
Vanadium	Naturally occurring	NL-CA	50	µg/L	D	D	D
Nutrients							
Nitrate plus nitrite (as nitrogen) [1]	Naturally occurring or from human activity	MCL-US	10	mg/L	D	D	D
Nitrite (as nitrogen)	Naturally occurring or from human activity	MCL-US	1	mg/L	D	D	D
Radioactive constituents							
Gross alpha particle activity	Naturally occurring	MCL-US	15	pCi/L	D	D	D
Radium	Naturally occurring	MCL-US	5	pCi/L	D	D	D
Radon-222	Naturally occurring	Prop MCL-US	4,000	pCi/L	D	D	D
Inorganic constituents with aesthetic/technical benchmarks							
Chloride	Naturally occurring	SMCL-CA	500	mg/L	D	D	D
Iron	Naturally occurring	SMCL-CA	300	µg/L	D	D	D
Manganese	Naturally occurring	SMCL-CA	50	µg/L	D	D	D
Sulfate	Naturally occurring	SMCL-CA	500	mg/L	D	D	D
Total dissolved solids (TDS) [2]	Naturally occurring	SMCL-CA	1,000	mg/L	D	D	D

Table 3. Benchmark type and benchmark value for constituents selected for additional evaluation in the status assessment of groundwater quality in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Thresholds and threshold values as of September 12, 2008. **Benchmark type:** MCL-US, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; MCL-CA, California Department of Public Health (CDPH) maximum contaminant level; HAL-US, USEPA lifetime health advisory level; NL-CA, CDPH notification level; RSD5-US, USEPA risk-specific dose at a risk factor of 10^{-5}. **Benchmark units:** µg/L, microgram per liter; mg/L, milligram per liter; pCi/L, picocurie per liter. **Other Abbreviations:** D, detected, MSACV, Middle Sacramento Valley; na, not analyzed; NSACV, Northern Sacramento Valley; SSACV, Southern Sacramento Valley; —, not detected]

Constituent	Typical use or source	Benchmarks			Study unit		
		Type	Value	Units	SSACV	MSACV	NSACV
Volatile organic compounds (VOCs)							
Benzene[3]	Gasoline hydrocarbon	MCL-CA	1	µg/L	D	D	D
cis-1,2-Dichloroethylene	Solvent, PCE breakdown	MCL-CA	6	µg/L	D	D	—
Tetrachloroethylene (PCE)	Dry-cleaning, metal degreasing	MCL-US	5	µg/L	D	D	D
Trichloroethylene (TCE)	Solvent, PCE breakdown	MCL-US	5	µg/L	D	D	—
Chloroform	Disinfection by-product	MCL-US	80	µg/L	D	D	D
Dibromochloromethane[3]	Disinfection by-product	MCL-US	80	µg/L	D	—	D
tert-Butyl alcohol (TBA)[3]	Gasoline oxygenate	NL-CA	12	µg/L	—	—	na
Methylene chloride (dichloromethane)[3]	Solvent	MCL-US	5	µg/L	—	—	D
Methyl *tert*-butyl ether (MTBE)[3]	Gasoline oxygenate	MCL-CA	13	µg/L	D	D	D
Methyl bromide (bromomethane)[3]	Fumigant	HAL-US	10	µg/L	—	—	—
Pesticides							
Atrazine	Herbicide	MCL-CA	1	µg/L	D	D	D
Bentazon	Herbicide	MCL-CA	18	µg/L	D	D	—
Dieldrin	Insecticide	RSD5-US	0.02	µg/L	D	—	—
Simazine	Herbicide	MCL-US	4	µg/L	D	D	D
Special-interest constituents							
Perchlorate	Natural, rocket fuel, flares	MCL-CA	6	µg/L	D	D	D

[1] Concentrations of “nitrate plus nitrite” are assumed to predominantly be in the form of nitrate; therefore, the benchmark for nitrate is used.

[2] Measured as residue on evaporation.

[3] Constituent selected for additional evaluation in status assessment because it occurred in the CDPH database at high or moderate relative-concentrations in at least one of the three study units.

Table 4. Constituents detected in samples collected but not selected for additional evaluation in the status assessment for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Thresholds and threshold values as of September 12, 2008. **Benchmark type:** MCL-US, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; MCL-CA, California Department of Public Health (CDPH) maximum contaminant level; HAL-US, USEPA lifetime health advisory level; NL-CA, CDPH notification level; RSD5-US, USEPA risk-specific dose at a risk factor of 10^{-5}. **Other Abbreviations:** D, detected, MSACV, Middle Sacramento Valley Study Unit; na, not analyzed; NSACV, Northern Sacramento Valley Study Unit; SSACV, Southern Sacramento Valley Study Unit. —, not detected]

Constituent	Typical use or source	Benchmark type	SSACV	MSACV	NSACV
Inorganic constituents with health-based benchmarks					
Ammonia (as nitrogen)	Naturally occurring	HAL-US	D	D	D
Beryllium	Naturally occurring	MCL-US	D	—	—
Copper	Naturally occurring	AL-US	D	D	D
Gross beta particle activity	Naturally occurring	MCL-US	D	D	D
Mercury	Naturally occurring	MCL-US	D	—	D
Thallium	Naturally occurring	MCL-US	D	D	—
Tritium	Naturally occurring	MCL-CA	D	D	D
Inorganic constituents with secondary maximum contaminant levels					
Silver	Naturally occurring	SMCL-CA	—	—	D
Inorganic constituents with no benchmarks					
Total nitrogen	Naturally occurring or from human activity	None	D	D	D
Orthophosphate (as phosphorus)	Naturally occurring or from human activity	None	D	D	D
Dissolved organic carbon	Naturally occurring	None	—	D	na
Bicarbonate	Naturally occurring	None	D	D	D
Bromide	Naturally occurring	None	D	D	D
Calcium	Naturally occurring	None	D	D	D
Carbonate	Naturally occurring	None	D	D	D
Cobalt	Naturally occurring	None	D	D	D
Iodide	Naturally occurring	None	D	D	D
Lithium	Naturally occurring	None	D	D	D
Magnesium	Naturally occurring	None	D	D	D
Potassium	Naturally occurring	None	D	D	D
Silica	Naturally occurring	None	D	D	D
Sodium	Naturally occurring	None	D	D	D
Tungsten	Naturally occurring	None	D	D	D
Organic constituents with health-based benchmarks					
Bromacil	Herbicide	HAL-US	D	—	—
Bromodichloromethane	Disinfection by-product	MCL-US	D	D	D
Bromoform (tribromomethane)	Disinfection by-product	MCL-US	D	D	—
Carbaryl	Insecticide	RSD5-US	—	D	—
Carbon disulfide[1]	Natural, industrial	NL-CA	D	D	D
Carbon tetrachloride (tetrachloromethane)	Solvent	MCL-CA	D	D	—
Chlorpyrifos	Insecticide	HAL-US	—	D	—
1,1-Dichloroethane	Solvent	MCL-CA	D	D	—
1,1-Dichloroethylene	Organic systhesis	MCL-CA	D	—	—
trans-1,2-Dichloroethylene	Solvent	MCL-CA	—	D	—
1,2-Dichloropropane (1,2-DCP)	Solvent	MCL-US	D	—	—
Dichlorodifluoromethane (CFC-12)	Refrigerant	NL-CA	D	—	—
Dinoseb	Herbicide	MCL-US	—	D	—
Diphenamid	Herbicide	HAL-US	D	—	—
Hexazinone	Herbicide	HAL-US	D	D	—
Isopropylbezene	Organic systhesis	NL-CA	D	—	—
Metolachlor	Herbicide	HAL-US	D	D	—
2-Methyl-4-chlorophenoxyacetic acid (MCPA)	Herbicide	HAL-US	—	D	—

Table 4. Constituents detected in samples collected but not selected for additional evaluation in the status assessment for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Thresholds and threshold values as of September 12, 2008. **Benchmark type:** MCL-US, U.S. Environmental Protection Agency (USEPA) maximum contaminant level; MCL-CA, California Department of Public Health (CDPH) maximum contaminant level; HAL-US, USEPA lifetime health advisory level; NL-CA, CDPH notification level; RSD5-US, USEPA risk-specific dose at a risk factor of 10^{-5}. **Other Abbreviations:** D, detected, MSACV, Middle Sacramento Valley Study Unit; na, not analyzed; NSACV, Northern Sacramento Valley Study Unit; SSACV, Southern Sacramento Valley Study Unit. —, not detected]

Constituent	Typical use or source	Benchmark type	SSACV	MSACV	NSACV
Organic constituents with health-based benchmarks—Continued					
4-Methyl-2-pentanone (methyl isobutyl ketone, MIBK)	Solvent	NL-CA	D	—	—
Metribuzin	Herbicide	HAL-US	—	D	—
Molinate	Pesticide	MCL-CA	D	D	—
Prometon	Herbicide	HAL-US	D	D	—
Tebuthiuron	Herbicide	HAL-US	D	D	—
1,2,3-Trichloropropane (1,2,3-TCP)	Solvent, organic synthesis	HAL-US	D	—	—
1,1,2-Trichlorotrifluoroethane (CFC-113)	Refrigerant	MCL-CA	D	—	—
Trichlorofluoromethane (CFC-11)	Refrigerant	MCL-CA	D	D	—
1,3,5-Trimethylbenzene	Gasoline	NL-CA	—	D	—
Organic constituents with no benchmarks					
Acetochlor	Herbicide	None	—	D	—
Benfluralin	Degradate	None	D	—	—
Bensulfuron-methyl	Herbicide	None	—	D	—
sec-Butylbenzene	Organic systhesis	None	D	—	—
tert-Butylbenzene	Organic systhesis	None	D	—	—
Chlorimuron-ethyl	Herbicide	None	—	D	—
Deethylatrazine (2-Chloro-4-isopropylamino-6-amino-*s*-triazine)	Degradate	None	D	D	D
Deisopropyl atrazine (2-Chloro-6-ethylamino-4-amino-*s*-triazine)	Degradate	None	D	D	—
Desulfinylfipronil	Degradate	None	—	D	—
3,4-Dichloroaniline	Degradate	None	D	D	—
o-Ethyltoluene	Gasoline	None	D	D	—
Fenuron	Herbicide	None	D	—	—
Fipronil	Insecticide	None	—	D	—
Fipronil sulfide	Degradate	None	—	D	—
Fipronil sulfone	Degradate	None	—	D	—
Hydroxyatrazine (2-Hydroxy-4-isopropylamino-6-ethylamino-*s*-triazine)	Degradate	None	D	D	—
Isofenphos	Insecticide	None	D	—	—
4-Isopropyl-1-methylbenzene	Organic systhesis	None	D	D	—
Metalaxyl	Fungicide	None	D	—	—
Phosmet	Insecticide	None	—	D	—
Propanil	Herbicide	None	—	D	—
Propiconazole	Fungicide	None	—	D	—
1,2,3,4-Tetramethylbenzene	Organic systhesis	None	D	D	—
1,2,3,5-Tetramethylbenzene	Organic systhesis	None	D	D	—
Triclopyr	Herbicide	None	—	D	—
1,2,3-Trimethylbenzene	Organic systhesis	None	D	—	—

[1] The detection frequency of carbon disulfide in the SSACV study unit was originally reported as greater than 10% (Dawson and others, 2008). However, subsequent evaluation of data from field, source-solution, and laboratory instrument blanks resulted in application of a study reporting limit (SRL) for carbon disulfide that was higher than the reporting limit used by the laboratory (Miranda Fram and Lisa Olsen, USGS-CAWSC, written commun., December 2010). Detections of carbon disulfide with concentrations less than the SRL were reclassified as non-detections less than the SRL and were counted as non-detections for calculation of detection frequencies. After application of the SRL, the detection frequency of carbon disulfide in SSACV was less than 10 %.

Table 5. Constituents reported in the California Department of Public Health database for regions corresponding to the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units that had high relative-concentrations historically, but do not have high relative-concentrations within the three-year interval prior to GAMA sample collection.

[Wells with historically high constituent concentrations have had one or more high values over the history of the available data prior to the 3-year period preceding the U.S. Geological Survey (USGS)-GAMA sampling. **Benchmark type:** AL-US, U.S. Environmental Protection Agency (USEPA) action level; HAL-US, USEPA Lifetime Health Advisory; MCL-CA, California Department of Public Health maximum contaminant level; MCL-US, USEPA maximum contaminant level; prop-MCL-US, proposed USEPA maximum contaminant level. "High value" means having a relative concentration greater than 1, with relative concentration defined as the measured concentration divided by the benchmark value. **Other abbreviations:** mg/L, milligram per liter; PCE, tetrachloroethylene; µg/L, microgram per liter; pCi/L, picocurie per liter]

Constituent	Typical use or source	Benchmark type	Benchmark value	Units	Date of most recent high value	Number of wells with analysis	Total number of analyses	Wells with historically high constituent concentrations
Southern Sacramento Valley study unit								
Aldicarb	Insecticide	MCL-US	3	µg/L	12/20/2001	346	1,085	3
Antimony	Naturally occurring	MCL-US	6	µg/L	05/21/1998	555	1,980	1
Beryllium	Naturally occurring	MCL-US	4	µg/L	12/29/1993	555	1,974	1
Bromoform	Disinfection by-product	MCL-US	80	µg/L	08/22/2001	621	5,716	1
Cadmium	Naturally occurring	MCL-US	5	µg/L	02/10/1998	577	2,655	4
Carbon tetrachloride	Solvent	MCL-CA	0.5	µg/L	09/20/2000	621	5,675	3
Copper	Naturally occurring	AL-US	1,300	µg/L	11/02/1999	586	2,695	1
1,2-Dibromoethane (EDB)	Fumigant	MCL-US	0.05	µg/L	06/02/1987	361	1,293	1
1,2-Dichloroethane	Solvent	MCL-CA	0.5	µg/L	02/16/2001	621	5,674	3
cis-1,2-Dichloroethylene	Solvent	MCL-CA	6	µg/L	09/28/1994	594	5,365	1
Mercury	Naturally occurring	MCL-US	2	µg/L	04/30/1992	577	2,672	8
Methyl bromide (bromomethane)	Fumigant	HAL-US	10	µg/L	08/07/2001	617	5,440	1
Selenium	Naturally occurring	MCL-US	50	µg/L	02/26/2002	577	2,911	6
Vinyl Chloride	Solvent, organic synthesis	MCL-CA	0.5	µg/L	02/27/1990	619	5,749	1
Middle Sacramento Valley study unit								
Aldicarb	Insecticide	MCL-US	3	µg/L	05/26/1992	117	162	1
Aluminum	Naturally occurring	MCL-CA	1,000	µg/L	10/10/1987	368	1,278	1
Carbon tertachloride	Solvent	MCL-CA	0.5	µg/L	07/17/1989	391	3,699	1
Dichloromethane	Solvent	MCL-US	5	µg/L	09/20/1989	391	3,654	2
1,1-Dichloroethylene	Solvent	MCL-CA	6	µg/L	11/04/1988	391	3,687	1
1,2-Dichloroethane	Solvent	MCL-CA	0.5	µg/L	10/17/2001	391	3,678	2
Methyl-*tert*-butyl-ether (MTBE)	Gasoline oxygenate	MCL-CA	13	µg/L	08/13/1999	639	2,978	1
1,1,2,2-Tertachloroethane	Solvent	MCL-CA	1	µg/L	05/02/1990	391	3,675	1
Thallium	Naturally occurring	MCL-US	2	µg/L	03/24/1999	365	1,059	7
Trichloroethylene (TCE)	Solvent, PCE breakdown	MCL-US	5	µg/L	03/27/2002	392	3,828	2
Northern Sacramento Valley study unit								
Fluoride	Naturally occurring	MCL-CA	2	µg/L	12/12/2003	203	546	1
Radon-222	Naturally occurring	prop-MCL-US	4,000	pCi/L	11/20/1997	16	19	1
Uranium	Naturally occurring	MCL-US	20	pCi/L	01/23/1989	33	118	1

The grid-based calculation uses the grid-well dataset assembled from the USGS-grid and CDPH-grid wells as described in section "Datasets for Status Assessment." For each constituent, the high aquifer-scale proportion was calculated by dividing the number of cells represented by a high relative-concentration for that constituent by the total number of grid cells with data for that constituent (Belitz and others, 2010). The moderate aquifer-scale proportion was calculated similarly. Confidence intervals for the high aquifer-scale proportions were computed by using the Jeffrey's interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010). The grid-based estimate is spatially-unbiased. However, the grid-based approach may not detect constituents that are present at high concentrations in small proportions of the primary aquifers. For calculation of high aquifer-scale proportion for a class of constituents, cells were considered high if the relative-concentration of any constituents in the class was high. Cells were considered moderate if the relative-concentration of any constituents was moderate and if the relative-concentration for none of the constituents was high.

The spatially-weighted calculation uses the dataset assembled from all of the CDPH and USGS wells as described in section "Datasets for Status Assessment." For each constituent, the high aquifer-scale proportion was calculated by computing the proportion of high wells in each cell and then averaging together the proportions for all cells for a particular study unit (Isaaks and Srivastava, 1989). The moderate aquifer-scale proportion was calculated similarly. For calculation of high aquifer-scale proportion for a class of constituents, wells were considered high if any constituent had a high relative-concentration. Wells were considered moderate if any constituent had a moderate relative-concentration of any constituent and none had a high relative-concentration.

In addition, for each constituent, the raw detection frequencies (number of detections divided by number of analyses) of high and moderate relative-concentrations were calculated from the same dataset as was used for the spatially-weighted calculations. However, raw detection frequencies are not spatially-unbiased because the wells in the CDPH database are not uniformly distributed (fig. 7). For example, if a constituent was present at high relative-concentrations in a small region of the aquifer with a high density of wells, the raw detection frequency of high relative-concentrations would be greater than the high aquifer-scale proportion. Raw detection frequencies are provided for reference but were not used to assess aquifer-scale proportions.

The MSACV and NSACV study units each consisted of two study areas and the sizes of the grid cells in the study areas in each study unit were nearly identical. The SSACV study unit, however, consisted of six study areas with different grid cell sizes. The Suisun-Fairfield study area in SSACV is unrepresentative of the primary aquifer delineated by the other five study areas in SSACV because groundwater is not a significant source of drinking water in the study area. Of the five wells sampled by GAMA in the basin, only two are used for public supply. Drinking water in the Suisun-Fairfield study area primarily comes from surface-water sources (Suisun Solano Water Authority, 2006). Therefore, calculations of grid-based and spatially-weighted aquifer proportions in SSACV do not include results from the Suisun-Fairfield study area. To obtain grid-based spatially-unbiased results for the remaining five study areas in the SSACV study unit, grid-based aquifer-scale proportions were calculated for each study area separately, and then combined, weighted by the relative areas of the study area (see appendix C).

The grid-based high aquifer-scale proportions were used to represent proportions in the primary aquifer unless the spatially-weighted proportions were significantly different than the grid-based values. Significantly different results were defined as follows:

- If the grid-based high aquifer-scale proportion was zero and the spatially-weighted proportion was greater than zero, then the spatially-weighted result was used. This situation can arise when a constituent is present at high relative-concentrations in a small fraction of the primary aquifer.
- If the grid-based high aquifer-scale proportion was greater than zero and the spatially-weighted proportion was outside of the 90% confidence interval of the grid-based result, then the spatially-weighted proportion was used. The situation of a spatially-weighted proportion being significantly higher or lower than the grid-based result can arise if the grid-based result (from random selection) used a set of wells with a different distribution of the contaminant than was observed in the larger population of wells.

The grid-based approach was used for the moderate and low proportions in most cases because the reporting limits for many organic constituents and some inorganic constituents in the CDPH database (relative to benchmarks) were higher than the relative-concentration boundaries between the moderate and low categories. However, if the grid-based moderate proportion was zero and the spatially-weighted proportion was great than zero, then the result of the spatially-weighed approach was used as a minimum estimate for the moderate proportion.

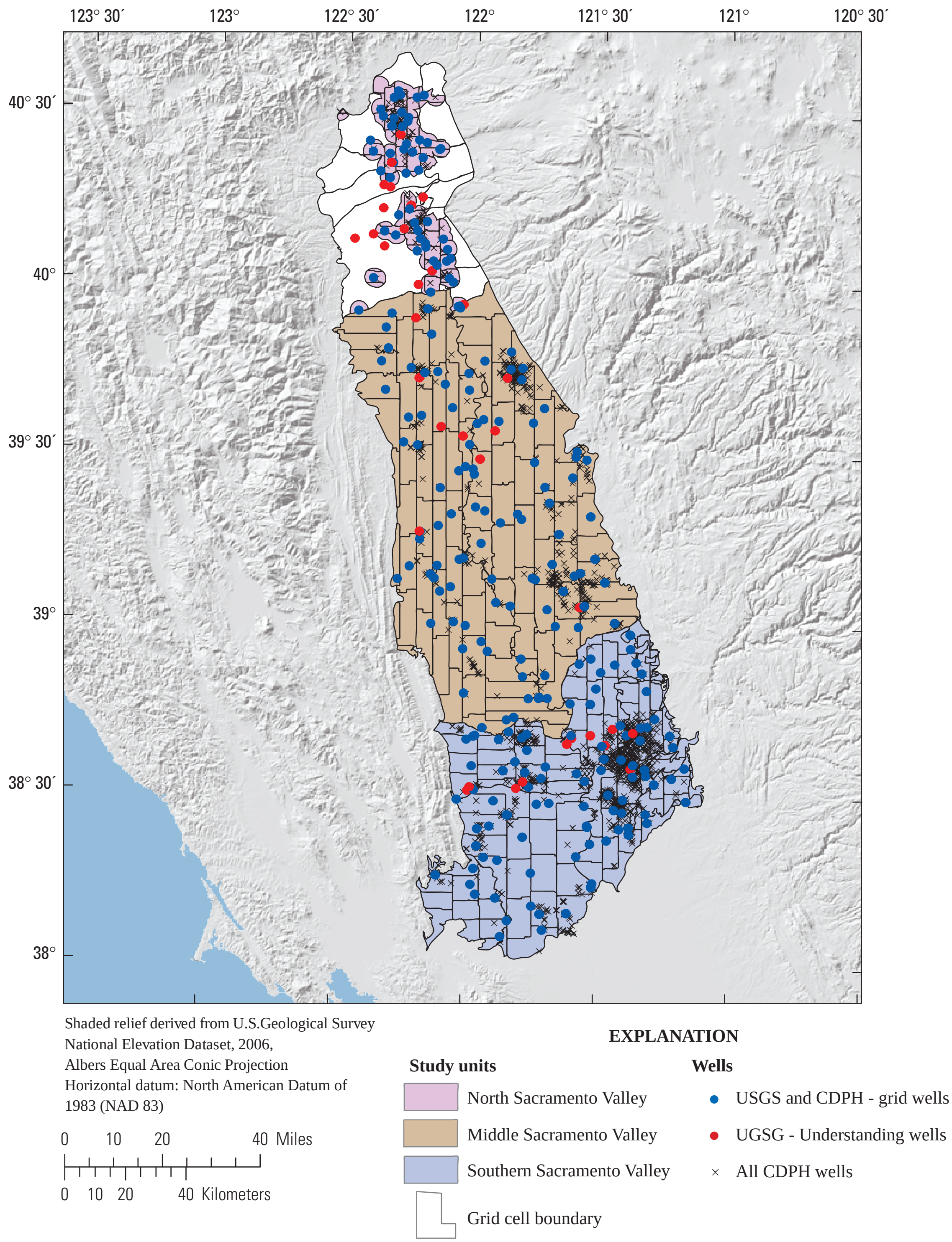


Figure 7. Locations of USGS- and CDPH-grid wells, USGS-understanding wells, and all wells in the California Department of Public Health (CDPH) database in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Status of Water Quality

The *status assessment* was designed to identify the constituents or classes of constituents most likely to be water-quality concerns because of their high concentrations or their prevalence. The *status assessment* applies only to constituents with regulatory or non-regulatory health-based or aesthetic/technical based benchmarks established by the USEPA or CDPH (as of 2009). The objective of the spatially-distributed, randomized approach to well selection and data analysis is to provide a view of groundwater quality in which all areas of the public-supply aquifers are weighted equally; regions with a high density of groundwater use or with high density of potential contaminants were not preferentially sampled. The following discussion of the *status assessment* results is divided into two parts—inorganic and organic constituents—and each part has a tiered structure. The assessment begins with a survey of how many constituents were detected at any concentration compared to the number analyzed, and a graphical summary of the relative-concentrations of constituents detected in the grid wells. Results are then presented for the subset of constituents that met criteria for selection for additional evaluation based on concentration, or for organic constituents, prevalence.

Inorganic Constituents

Inorganic constituents generally occur naturally in groundwater, although their concentrations may be influenced by human activities as well as by natural factors. All 49 inorganic constituents analyzed by USGS-GAMA were detected in at least one of the three study units, and most were detected in all three study units (table 6). Of these 49 inorganic constituents, 30 had regulatory or non-regulatory health-based benchmarks, 7 had non-regulatory aesthetic/technical-based benchmarks, and 12 had no established benchmarks. Of the 30 inorganic constituents with benchmarks, 17 were identified for additional evaluation in the *status assessment* (figs. 8*A*, 8*B*, and 8*C*; tables 7A, 7B, and 7C). The 17 constituents were the nutrients—nitrate-plus-nitrite as nitrogen (hereinafter referred to as nitrate) and nitrite as nitrogen (hereinafter referred to as nitrite); the trace elements—arsenic, barium, boron, cadmium, chromium, fluoride, and vanadium; the radioactive constituents—gross alpha particle activity, radium, and radon-222; and the inorganic constituents with aesthetic benchmarks (SMCLs)—chloride, iron, manganese, sulfate, and total dissolved solids (TDS). TDS was measured directly or calculated from specific conductance (see appendix D).

Four additional inorganic constituents were selected for additional evaluation because they were reported at high or moderate relative-concentrations in the CDPH databases for at least one of the study units during the 3-year interval prior to USGS-sampling: aluminum, lead, nickel, and selenium (tables 7A,7B, and 7C).

For any inorganic constituent with health-based benchmarks (nutrients, trace elements, and radioactive constituents), relative-concentrations of at least one constituent were high in 30, 24, and 2.1% of the primary aquifers in the SSACV, MSACV, and NSACV study units, respectively (table 8A). For any inorganic constituent with non-health-based benchmarks (SMCL constituents), relative-concentrations of at least one constituent were high in 32, 27, and 4.6% of the public-supply aquifers in SSACV, MSACV, and NSACV, respectively (table 8A).

Trace Elements

Trace elements with health-based benchmarks had high relative-concentrations in 30, 24, and 2.1% of the primary aquifers in SSACV, MSACV, and NSACV, respectively (table 8A). One trace element, arsenic, was detected at high relative-concentrations in all three study units. Other trace elements detected at high concentrations in one or more of the three study units were aluminum, boron, chromium, fluoride, and lead. Two trace elements were detected moderate concentrations; barium and vanadium.

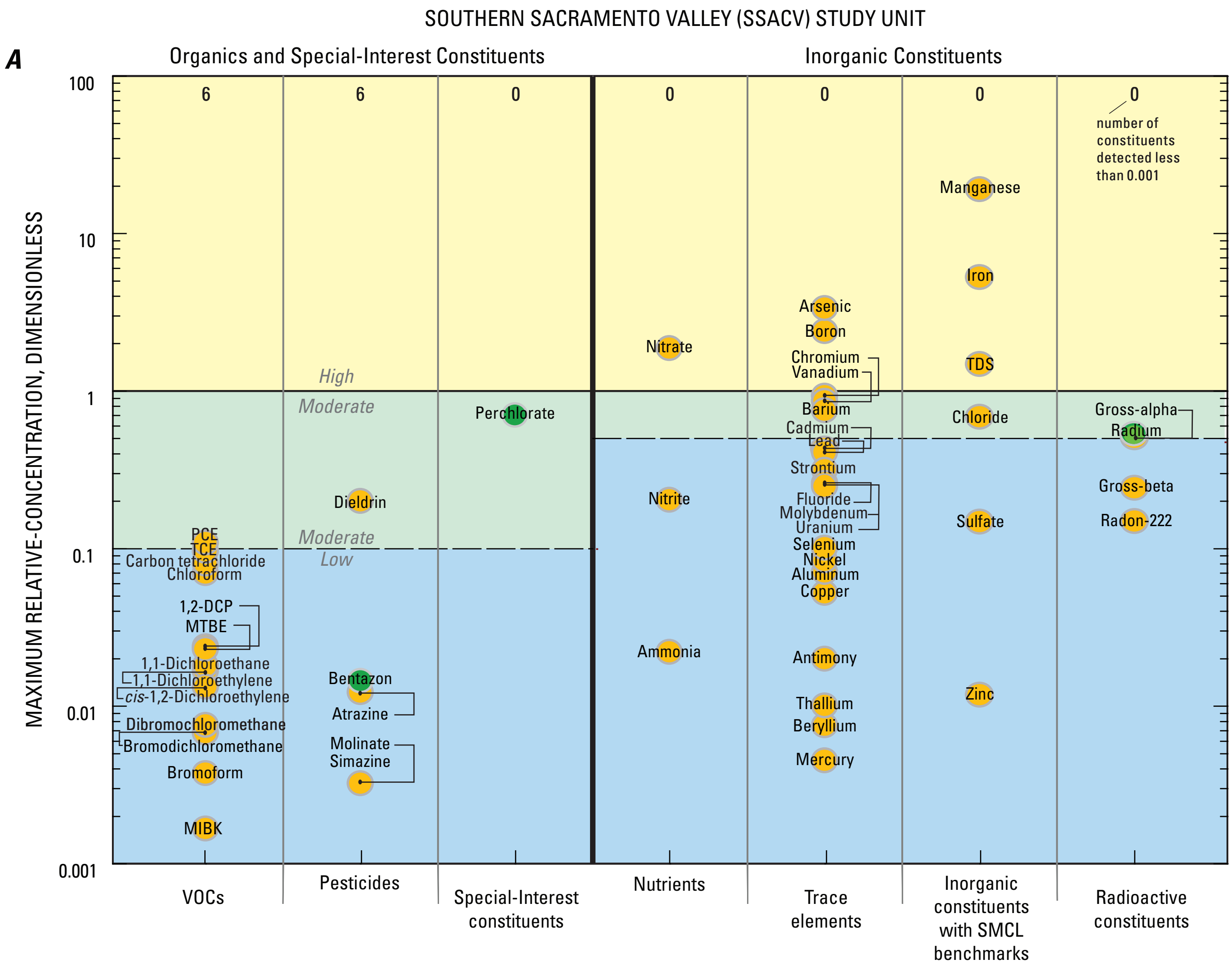
Arsenic is a naturally occurring semi-metallic trace element often associated with iron-sulfide minerals, such as pyrite. Generally, aquifer sediments derived from granitic, volcanic, and metamorphic sources have arsenic-bearing minerals that become part of the aquifer. Industrially, arsenic is most often used as a wood preservative, but it also can be used in paints, dyes, metals, drugs, soaps, semi-conductors, and in the mining of copper and gold. Arsenic concentrations are greater than 10 µg/L (the health-based benchmark used in this study) in an estimated 8% of groundwater resources used for drinking water in the United States (Focazio and others, 1999). High relative-concentrations of arsenic were found in wells located in the center of the Sacramento Valley along the Sacramento and Feather Rivers, and in wells located along the margin of the Sacramento-San Joaquin Delta. Groundwater in the fine-grained sediments along the major rivers and in the Delta commonly has low dissolved oxygen content (reducing conditions), and reducing conditions are correlated with elevated arsenic concentrations in Sacramento Valley groundwater (Dawson, 2001). Arsenic had high-aquifer scale proportions in SSACV, MSACV, and NSACV of 16, 22, and 2.1% respectively (fig. 9 and tables 7A,B,C). Moderate aquifer-scale proportions for arsenic in the SSACV, MSACV, and NSACV study units were 12, 15, and 4.6%, respectively.

Table 6. Number of inorganic constituents analyzed and detected, listed by health-based benchmark type and constituent type, in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Regulatory health-based benchmarks include U.S. Environmental Protection Agency (USEPA) and California Department of Public Health (CDPH) maximum contaminant levels. Non-regulatory health-based benchmarks include USEPA lifetime health advisory levels and risk specific dose level at 10^{-5} and CDPH notification level. Nonregulatory aesthetic-based benchmarks include USEPA and CDPH secondary maximum contaminant levels. **Abbreviations**: SSACV, Southern Sacramento Valley study unit; MSACV, Middle Sacramento Valley study unit; NSACV, Northern Sacramento Valley study unit]

Benchmark type	Number analyzed	SSACV	MSACV	NSACV	Number detected in all study units
		Number detected (any concentration)			
Major, minor, and trace elements					
Regulatory, health-based	13	13	13	13	13
Non-regulatory, health-based	6	6	6	6	6
Non-regulatory, aesthetic based	7	7	7	7	7
No benchmark	10	10	10	10	10
Total	36	36	36	36	36
Nutrients					
Regulatory, health-based	3	2	3	3	3
Non-regulatory, health-based	0	0	0	0	0
Non-regulatory, aesthetic based	0	0	0	0	0
No benchmark	2	2	2	2	2
Total	5	4	5	5	5
Radioactive constituents					
Regulatory, health-based	[1]8	5	5	[1]8	[1]8
Non-regulatory, health-based	0	0	0	0	0
Non-regulatory, aesthetic based	0	0	0	0	0
No benchmark	0	0	0	0	0
Total	[1]8	5	5	[1]8	[1]8
Sum Inorganic constituents					
Regulatory, health-based	[1]24	20	21	24	[1]24
Non-regulatory, health-based	6	6	6	6	6
Non-regulatory, aesthetic based	7	7	7	7	7
No benchmark	12	12	12	12	12
Total	[1]49	45	46	49	[1]49

[1] Includes three isotopes of uranium analyzed only in Northern Sacramento Valley study unit



EXPLANATION

Relative-Concentration

- High
- Moderate
- Low

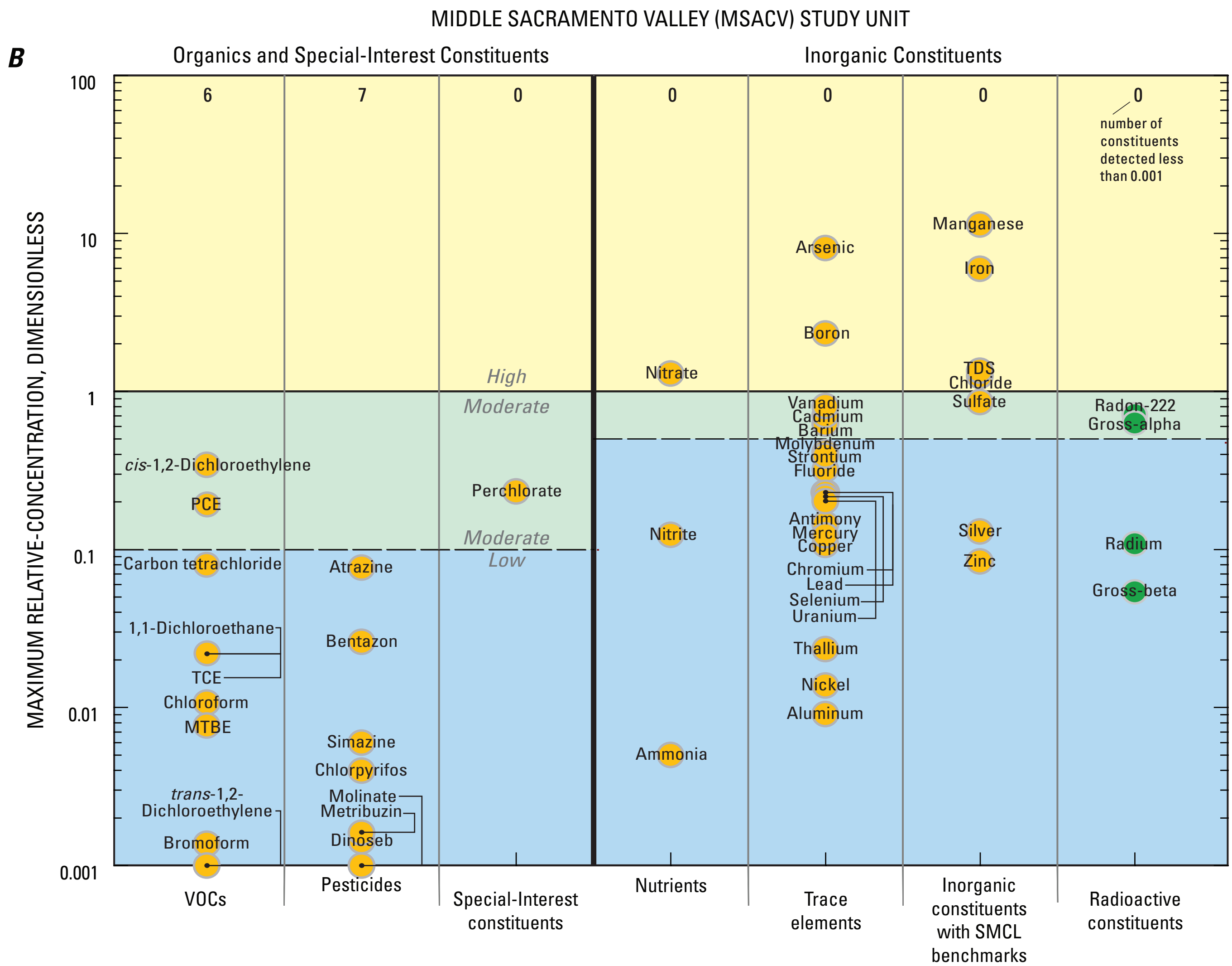
PCE **Constituents with analyses in >30 grid wells and wells are spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Strontium **Constituents with analyses in <30 grid wells and wells are not spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Abbreviations

VOC, volatile organic compound; TCE, trichloroethene; PCE, tetrachloroethene; 1,2-DCP, 1,2-dichloropropane; SMCL, secondary maximum contaminant level; MTBE, methyl *tert*-butyl ether; MIBK, 4-methyl-2-pentanone; TDS, total dissolved solids.

Figure 8. Maximum relative-concentrations for constituents detected, graphed by type of constituent, in grid wells (GAMA and CDPH) for the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.



EXPLANATION

Relative-Concentration

- High
- Moderate
- Low

PCE **Constituents with analyses in >35 grid wells and wells are spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Radon **Constituents with analyses in <35 grid wells and wells are not spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Abbreviations

VOC, volatile organic compound; TCE, trichloroethene; PCE, tetrachloroethene; SMCL, secondary maximum contaminant level; MTBE, methyl *tert*-butyl ether; TDS, total dissolved solids.

Figure 8.—Continued.

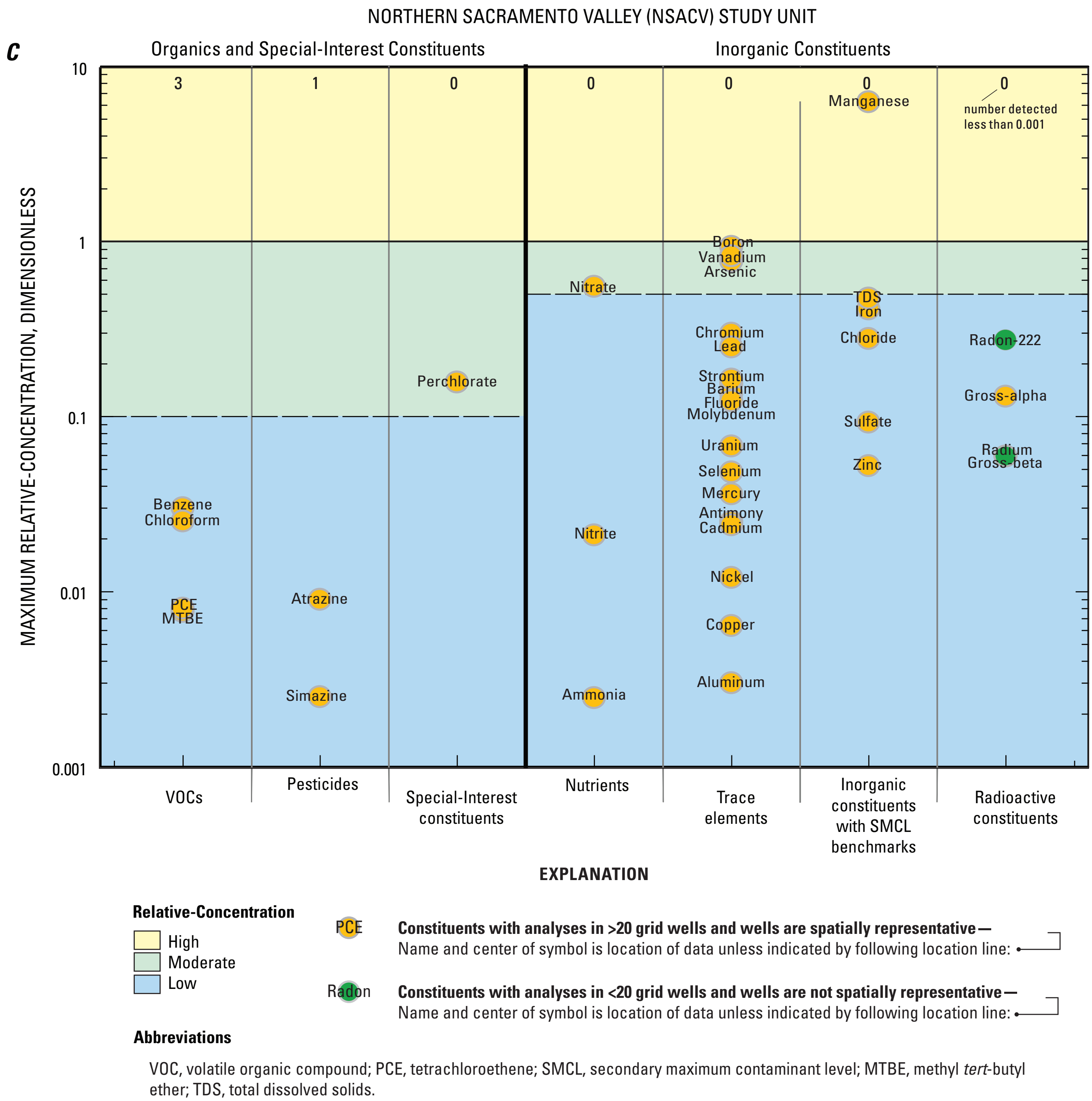


Figure 8.—Continued.

Table 7A. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Southern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 61 grid wells during March–June 2005. Raw detection frequency and spatially weighted aquifer proportions are based on CDPH data from June 1, 2002, to June 30, 2005 (the 3 years preceding GAMA sampling for the Southern Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High, concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency [1,2]			Spatially weighted [1,2]			Grid-based [2,3]			90-percent confidence interval for grid-based high proportion [4]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Trace elements												
Aluminum	Naturally occurring	465	0.4	0.2	56	0.4	<0.1	56	0	0	0	2.3
Arsenic	Naturally occurring	472	8.9	8.1	57	9.7	16	57	12	16	6	20
Barium	Naturally occurring	465	0.2	0	56	0.4	0	56	1.7	0	0	2.3
Boron	Naturally occurring	393	13	10	53	13	12	49	13	19	12	30
Chromium	Naturally occurring	454	4.4	0.2	53	3.3	<0.1	52	3.4	0	0	2.5
Fluoride	Naturally occurring	415	0.5	0	55	1.5	0	55	0	0	0	2.3
Lead	Naturally occurring	463	0.4	0.2	54	0.2	<0.1	54	0	0	0	2.4
Selenium	Naturally occurring	465	0.4	0	56	0.2	0	56	0	0	0	2.3
Vanadium	Naturally occurring	390	3.6	0	53	4.5	0	49	5.3	0	0	2.6
Radioactive constituents												
Gross alpha particle activity	Naturally occurring	372	1.1	0	48	0.6	0	46	1.8	0	0	3.2
Radium	Naturally occurring	103	0.9	0	25	4.0	0	22	9	0	0	8.0
Nutrients												
Nitrate plus nitrite (as nitrogen)	Naturally occurring or from human activity	649	11	1.1	63	9.2	1.3	63	11	1.4	0.8	6.5
Nitrite (as nitrogen)	Naturally occurring or from human activity	547	0	0	61	0	0	61	0	0	0	2.0
Inorganic constituents with SMCLs												
Chloride	Naturally occurring	414	0.7	0	52	1.7	0	51	1.7	0	0.0	2.5
Iron	Naturally occurring	467	6.9	6.4	58	4.8	6.2	57	1.5	16	7.4	22
Manganese	Naturally occurring	467	4.7	14	58	3.4	20	57	0	27	15	33
Total dissolved solids (TDS)	Naturally occurring	461	13	0	63	16	1.6	59	22	1.1	0.0	2.6

Table 7A. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Southern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 61 grid wells during March–June 2005. Raw detection frequency and spatially weighted aquifer proportions are based on CDPH data from June 1, 2002, to June 30, 2005 (the 3 years preceding GAMA sampling for the Southern Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High, concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency [1,2]			Spatially weighted [1,2]			Grid-based [2,3]			90-percent confidence interval for grid-based high proportion [4]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Volatile organic compounds (VOCs)												
tert-Butyl alcohol (TBA)	Gasoline oxygenate	256	0	0.4	42	0	0.1	7	0	0	0	2.0
Chloroform	Disinfection by-product	520	2.1	0	65	2.6	0	62	0	0	0	2.0
Methyl-*tert*-butyl-ether (MTBE)	Gasoline oxygenate	559	0.4	0	67	0.1	0	62	0	0	0	2.0
Tetrachloroethylene (PCE)	Dry-cleaning, metal degreasing	523	2.7	1.5	65	2.9	0.7	62	1.3	0	0	2.0
Trichloroethylene (TCE)	Solvent, PCE breakdown	521	1.2	0	65	0.4	0	62	0	0	0	2.0
Pesticides												
Atrazine	Herbicide	353	0	0	62	0	0	61	0	0	0	2.0
Bentazon	Herbicide	288	0	0	46	0	0	25	0	0	0	4.8
Dieldrin	Insecticide	301	0.3	0	62	0.3	0	61	1.3	0	0	2.0
Special-interest constituents												
Perchlorate	Natural, rocket fuel, flares	342	4.1	0	44	4.6	0	25	14	0	0	4.8

[1] Based on most recent CDPH analysis from June 1, 2002, to June 30, 2005 (most recent data available at time of analysis) combined with USGS data.

[2] Results from the Suisun study area not included in the calculation of raw detection frequency, spatially weighted, or grid-based aquifer-scale proportions.

[3] Grid-based proportions for the Southern Sacramento Valley study unit are based on the sum of individual constituent proportions normalized by each study areas' areal proportion of the study unit as a whole.

[4] Based on the Jeffrey's interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010).

Table 7B. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Middle Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 71 grid wells during June 2006–August 2006. Raw detection frequency and spatially weighted aquifer proportions are based on CDPH data from August 1, 2003, to August 31, 2006 (the 3 years preceding GAMA sampling for the Middle Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency[1]			Spatially weighted[1]			Grid-based			90-percent confidence interval for grid-based high proportion[2]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Trace elements												
Arsenic	Naturally occurring	311	14	15	69	19	21	65	15	22	14	30
Barium	Naturally occurring	269	0.7	0	68	0.8	0	63	1.6	0.0	0.0	2.1
Boron	Naturally occurring	95	7.3	5.3	52	8.3	6.4	46	8.7	6.5	2.4	15
Cadmium	Naturally occurring	268	0.7	0	68	2.2	0	63	1.6	0	0	2.1
Fluoride	Naturally occurring	270	0	0.4	67	0	0.2	64	0	0	0	2.1
Vanadium	Naturally occurring	119	18	0	52	17	0	47	15	0	0	2.8
Nutrients												
Nitrate plus nitrite (as nitrogen)	Naturally occurring or from human activity	471	9.3	4.0	74	9.6	4.3	74	11	2.7	0.8	7.3
Radioactive constituents												
Gross alpha particle activity	Naturally occurring	217	1.3	0.5	38	3.2	0.4	36	2.8	0	0	4.1
Radon-222	Naturally occurring	9	11	0	9	11	0	9	11	0	0	14
Major and minor elements (SMCLs)												
Chloride	Naturally occurring	257	1.1	0.4	66	1.9	1.5	60	1.7	1.7	0.3	6.2
Iron	Naturally occurring	271	4.7	8.9	66	5.7	5.2	61	3.3	3.3	0.9	8.6
Manganese	Naturally occurring	276	2.5	26	68	6.5	28	62	6.5	27	19	37
Sulfate	Naturally occurring	257	1.1	0	67	2.5	0	61	1.6	0.0	0	2.1
Total dissolved solids (TDS)	Naturally occurring	256	6.6	1.6	75	13	3.3	75	11	4.0	0.9	8.6

Table 7B. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Middle Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 71 grid wells during June 2006–August 2006. Raw detection frequency and spatially weighted aquifer proportions are based on CDPH data from August 1, 2003, to August 31, 2006 (the 3 years preceding GAMA sampling for the Middle Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency[1]			Spatially weighted[1]			Grid-based			90-percent confidence interval for grid-based high proportion[2]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Volatile organic compounds (VOCs)												
Tetrachloroethylene (PCE)	Dry-cleaning, metal degreasing	298	2.5	1.3	76	0.8	0.3	71	2.8	0	0	1.9
cis-1,2-Dichloroethylene	Solvent, PCE breakdown	297	1.3	0.0	76	0.2	0	71	1.4	0	0	1.9
Benzene	Gasoline hydrocarbon	272	0	0.4	76	0	0.1	71	0	0	0	1.9
Chloroform	Disinfection by-product	287	0	0	74	0	0	68	0	0	0	2.0
Pesticides												
Atrazine	Herbicide	149	0	0	72	0	0	71	0	0	0	1.9
Bentazon	Herbicide	133	0	0	71	0	0	71	0	0	0	1.9
Simazine	Herbicide	151	0	0	72	0	0	71	0	0	0	1.9
Special-interest constituents												
Perchlorate	Natural, rocket fuel, flares	100	2.0	0	69	2.9	0	71	2.8	0	0	1.9

[1] Based on the most recent CDPH analysis from August 1, 2003, to August 31, 2006 (most recent data available at time of analysis) combined with USGS data.

[2] Based on the Jeffrey's interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010).

Table 7C. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 43 grid wells during December 2007–January 2008. Raw detection frequency and spatially weighted aquifer proportions are based CDPH data from January 1, 2005, to February 5, 2008 (the 3 years preceding GAMA sampling for the Northern Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent; values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency [1]			Spatially weighted [1]			Grid-based			90-percent confidence interval for grid-based high proportion [2]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Trace elements												
Aluminum	Naturally occurring	145	0.7	0	44	0.3	0	43	0	0	0	3.1
Arsenic	Naturally occurring	155	5.8	4.5	44	3.0	2.1	43	4.6	0	0	3.1
Boron	Naturally occurring	71	2.8	0	44	2.5	0	43	2.3	0	0	3.1
Cadmium [3]	Naturally occurring	147	0	0	44	0	0	43	0	0	0	3.1
Chromium	Naturally occurring	144	1.4	0	44	0.5	0	43	0	0	0	3.1
Lead	Naturally occurring	107	0.9	0	44	1.1	0	43	0	0	0	3.1
Nickel [3]	Naturally occurring	147	0	0	44	0	0	43	0	0	0	3.1
Vanadium	Naturally occurring	85	4.7	0	44	2.3	0	43	2.3	0	0	3.1
Nutrients												
Nitrate plus nitrite (as nitrogen)	Naturally occurring or from human activity	228	3.5	0	44	2.8	0	43	2.3	0	0	3.1
Major and minor elements (SMCLs)												
Iron	Naturally occurring	138	2.2	3.6	44	2.3	2.3	43	0	0	0	3.1
Manganese	Naturally occurring	137	5.8	5.1	44	5.2	6.1	43	4.8	4.6	1.3	12.3
Volatile organic compounds (VOCs)												
tert-butyl alcohol (TBA)	Gasoline oxygenate	142	1.1	1.1	30	0.5	0.6	0	0	0	0	3.1
Chloroform	Disinfection by-product	166	0	0	44	0	0	43	0	0	0	3.1
Dibromochloro-methane	Disinfection by-product	148	0.7	0	44	0.3	0	43	0	0	0	3.1

Table 7C. Aquifer-scale proportions determined by using grid-based and spatially weighted methods for constituents reported at high or moderate relative-concentrations during the most recent 3-year period from the California Department of Health Services database or detected at high or moderate relative-concentrations in samples collected by the U.S. Geological Survey for the Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Grid-based aquifer proportions for organic constituents are based on samples collected by the U.S. Geological Survey (USGS) from 43 grid wells during December 2007–January 2008. Raw detection frequency and spatially weighted aquifer proportions are based CDPH data from January 1, 2005, to February 5, 2008 (the 3 years preceding GAMA sampling for the Northern Sacramento Valley) in combination with USGS well data. All values greater than 10 percent are rounded to the nearest 1 percent; values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High concentrations greater than water-quality benchmark; moderate, concentrations less than benchmark but greater than or equal to 0.1 (for organic and special-interest constituents) or 0.5 (for inorganic constituents). **Abbreviations:** SMCL, secondary maximum contaminant level; <, less than]

Constituent	Typical use or source	Raw detection frequency [1]			Spatially weighted [1]			Grid-based			90-percent confidence interval for grid-based high proportion [2]	
		Number of wells	Moderate (in percent)	High (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of cells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)
Volatile organic compounds (VOCs)—Continued												
Methyl bromide (bromomethane)	Fumigant	148	1.3	0	44	0.6	0	43	0	0	0	3.1
Methylene chloride (dichloromethane)	Solvent	166	1.4	0	44	0.6	0	43	0	0	0	3.1
Pesticides												
Atrazine	Herbicide	68	0	0	44	0	0	43	0	0	0	3.1
Simazine	Herbicide	68	0	0	44	0	0	43	0	0	0	3.1
Special-interest constituents												
Perchlorate	Natural, rocket fuel, flares	57	1.7	0	43	2.3	0	43	2.3	0	0	3.1

[1] Based on most recent CDPH analysis from January 1, 2005, to February 5, 2008 (most recent data available at time of analysis) combined with USGS data obtained during the study.

[2] Based on the Jeffrey's interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010).

[3] High value occurred in at least one well in 3-year period of CDPH data analyzed but not in the most recent sample.

Table 8A. Summary of aquifer-scale proportions for inorganic constituent classes for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Aquifer-scale proportions by class are based on any "one or more" constituents within the class having high or moderate relative-concentrations. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent, because of rounding, proportions may not add up to 100 percent. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.5 of benchmark but less than benchmark; low, concentrations less than 0.5 of benchmark. **Abbreviations:** SMCL, secondary maximum contaminant level]

	Number of cells	Aquifer-scale proportion, in percent		
		Low	Moderate	High
Trace elements with health-based benchmarks				
Southern Sacramento [1]	60	46	24	30
Middle Sacramento	66	52	24	24
Northern Sacramento	43	89	9.3	[2] 2.1
Nutrients with health-based benchmarks				
Southern Sacramento [1]	69	88	11	1.5
Middle Sacramento	74	87	11	2.7
Northern Sacramento	43	98	2.3	0
Radioactive constituents with health-based benchmarks				
Southern Sacramento [1]	47	95	5	0
Middle Sacramento	32	97	3.1	[2] 0.4
Northern Sacramento	12	100	0	0
All inorganic constituents with health-based benchmarks				
Southern Sacramento [1]	69	40	30	[3] 30
Middle Sacramento	74	38	38	[3] 24
Northern Sacramento	43	86	12	[2] 2.1
Major ions with aesthetic (SMCL) benchmarks				
Southern Sacramento [1]	70	81	18	1.2
Middle Sacramento	75	82	13	5.3
Northern Sacramento	43	100	0	0
Trace elements with aesthetic (SMCL) benchmarks				
Southern Sacramento [1]	60	67	1.3	32
Middle Sacramento	63	64	9.5	27
Northern Sacramento	43	89	4.8	4.6
All constituents with aesthetic (SMCL) benchmarks				
Southern Sacramento [1]	70	49	19	[4] 32
Middle Sacramento	75	56	20	[4] 27
Northern Sacramento	43	89	4.8	4.6

[1] Area-normalized grid-based proportions.

[2] Based on spatially weighted calculation.

[3] High proportion set equal to high proportion calculated for trace elements with health-based benchmarks. More cells had data for nutrients than for trace elements with health-based benchmarks, which results in a calculated high proportion for all inorganics with health-based benchmarks less than the high proportion for trace elements with health-based benchmarks.

[4] High proportion set equal to high proportion calculated for trace elements with aesthetic (SMCL) benchmarks. More cells had data for major ions with aesthetic (SMCL) benchmarks than for trace elements with aesthetic (SMCL) benchmarks, which results in a calculated high proportion for all inorganics with aesthetic (SMCL) benchmarks less than the high proportion for trace elements with aesthetic (SMCL) benchmarks.

Table 8B. Summary of aquifer-scale proportions for organic constituent classes for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Aquifer proportions by class are based on any "one or more" constituents within the class having high or moderate concentrations. All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding, proportions may not add up to 100 percent. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark; low, concentrations less than 0.1 of benchmark]

	Number of cells	Not detected	Aquifer-scale proportion, in percent		
			Low	Moderate	High
Volatile organic compounds (VOCs)					
Southern Sacramento [1]	62	42	57	1.3	[2] 0.8
Middle Sacramento	71	73	27	2.8	[2] 0.4
Northern Sacramento	43	77	23	[2] 0.6	[2] 0.6
Pesticides					
Southern Sacramento [1]	62	70	29	1.3	0
Middle Sacramento	71	48	52	0	0
Northern Sacramento	43	67	33	[3] 0.6	0
All organic constituent (VOCs and pesticides)					
Southern Sacramento [1]	62	29	69	2.6	[2] 0.8
Middle Sacramento	71	32	65	2.8	[2] 0.4
Northern Sacramento	43	51	49	[2] 0.9	[2] 0.6

[1] Area-normalized grid-based proportions unless otherwise noted.

[2] Based on spatially weighted calculation.

[3] Includes the VOC methyl bromide (bromomethane), which is classified as an agricultural fumigant.

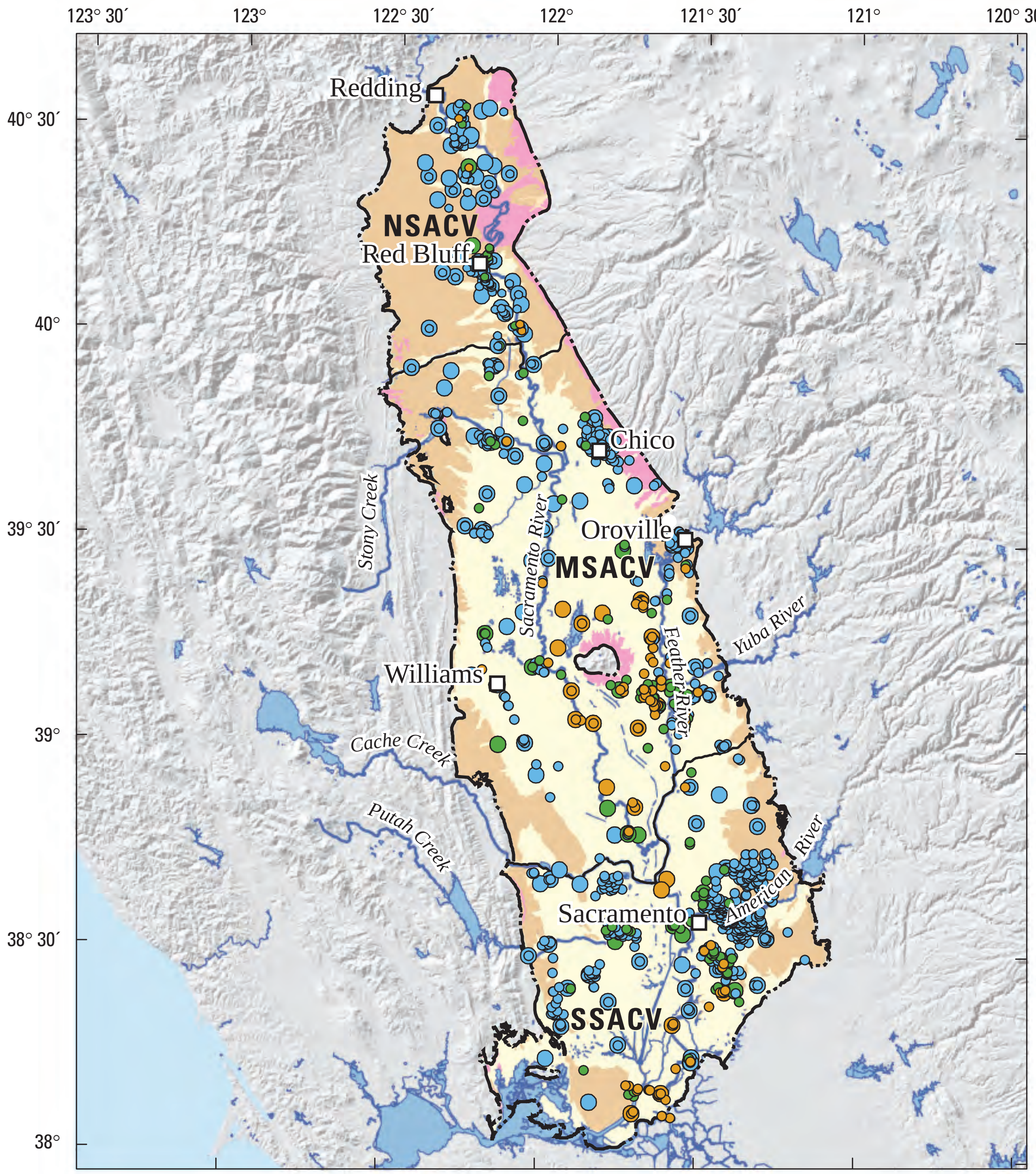
Table 8C. Summary of aquifer-scale proportions for special-interest constituents for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[All values greater than 10 percent are rounded to the nearest 1 percent, values less than 10 percent are rounded to the nearest 0.1 percent; because of rounding values may not add up to 100 percent. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark)]

	Number of cells	Aquifer-scale proportion, in percent		
		Low	Moderate	High
Constituents of special interest				
Southern Sacramento [1]	26	95	[2] 4.6	0
Middle Sacramento	71	97	2.8	0
Northern Sacramento	43	98	2.3	0

[1] Area-normalized grid-based proportions.

[2] Based on spatially weighted calculation.



Shaded relief derived from U.S.Geological Survey National Elevation Dataset, 2006,
Albers Equal Area Conic Projection
Horizontal datum: North American Datum of 1983 (NAD 83)

0 10 20 40 Miles

0 10 20 40 Kilometers

EXPLANATION

Geology

Quaternary alluvium (Q)

Quaternary/Plio-Pleistocene semiconsolidated (QPc)

Quaternary/Tertiary volcanic pyroclastic (QTvp)

Relative-concentration of arsenic in:

USGS-Grid wells		**CDPH wells**
●	High	●
●	Moderate	●
●	Low	●

Boundary of Sacramento Valley

Study units

Northern Sacramento Valley study unit (NSACV)
Middle Sacramento Valley study unit (MSACV)
Southern Sacramento Valley study unit (SSACV)

Figure 9. Relative-concentrations of arsenic in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Boron is a trace element that occurs naturally in many minerals, primarily borax; it is mined principally in California and Turkey. Boron is an essential plant nutrient in small amounts; however, large amounts can be harmful or even toxic to some plants (Hem, 1985). Boron has numerous uses, including glass and silicate production, fire retardants, laundry and cleaning products, and insecticides. Most of the wells with boron present at concentrations greater than the non-regulatory human-health NL-CA benchmark of 1,000 µg/L were in the SSACV study unit (fig. 10). High concentrations of boron in wells located along Cache and Putah Creeks are likely associated with old marine sediments from the Coast Ranges. High concentrations of boron found in wells located in the Delta are likely associated with estuarine sediments of the San Francisco Bay and Sacramento-San Joaquin Delta system. Boron was not detected at high relative-concentrations in NSACV but did have high aquifer-scale proportions in SSACV and MSACV of 19 and 6.5%, respectively (fig. 12*A*,*B*,*C* and table 7A,B,C). In the SSACV, MSACV, and NSACV study units boron had moderate aquifer-scale proportions in 13, 8.7, and 2.3% of the primary aquifers, respectively.

Vanadium is a metallic trace element that occurs naturally in many minerals and is used industrially to strengthen metals. Moderate concentrations of vanadium were detected along the eastern edge of the Sacramento Valley, generally south of the transition between the Cascade and Sierra Nevada mountain ranges (fig. 11). An evaluation of factors controlling the regional distribution of vanadium in groundwater throughout California by Wright and Belitz (2010) showed that high and moderate concentrations of vanadium in the Sacramento and San Joaquin Valleys were often associated with groundwater samples collected from sediments derived from andesitic and basaltic rocks; rocks that are common in the Sierra Nevada. Vanadium was not detected at high relative-concentrations in any of the three Sacramento Valley study units; however, moderate aquifer-scale proportions were detected in 5.3, 15, and 2.3% of the SSACV, MSACV, and NSACV primary aquifers, respectively (table 7A,B,C).

Although detected at high relative-concentrations in SSACV, aluminum, chromium, and lead had high aquifer-scale proportions of less than 0.1% (table 7A, spatially-weighted). In MSACV, high relative-concentrations of fluoride were detected in 0.2% of the primary aquifer (table 7B, spatially-weighted). Also in MSACV, barium and cadmium each were detected at moderate relative-concentrations in less than 2% of the primary aquifer.

Nutrients

Nitrate was the only nutrient detected at a high relative-concentrations in any of the three study units. High relative-concentrations of nitrate were detected in 1.4 and 2.7% of the primary aquifers in the SSACV and MSACV study units, respectively (tables 7A and 7B). Moderate relative-concentrations of nitrate were detected in 11, 11, and 2.3% of the primary aquifer in the SSACV, MSACV, and NSACV study units, respectively (tables 7A, 7B, and 7C). High and moderate relative-concentrations of nitrate occurred most often in the southern and western parts of the Sacramento Valley (fig. 13).

Radioactive Constituents

Radioactive constituents were detected at high relative concentrations in the MSAC study unit (0.4%), but were not detected at high relative concentrations in the SSACV or NSACV study units. Moderate relative concentrations for gross alpha particle activity and radium occurred in 1.8 and 9.0%, respectively, of the primary aquifer in the SSACV study unit. Gross alpha particle activity was detected at moderate relative-concentrations in 2.8% of the primary aquifer in the MSACV study unit (figs. 12*A*, 12*B*, and 14). Radioactive constituents were not detected at moderate relative-concentrations in the NSACV study unit. Radon-222 data were available for only 10–30% of the grid cells in each study unit (table 2); thus, the high and moderate aquifer-scale proportions for radon-222 could not be reliably estimated.

Major Ions and Trace Elements with SMCL Benchmarks

CDPH SMCL benchmarks for TDS, specific conductance, sulfate, and chloride have recommended and upper values. In this report, data were compared with the upper values. The SMCLs for these constituents and for the trace elements iron, manganese, and zinc are based on aesthetic and technical considerations, and are not health based. One or more of the constituents with SMCL benchmarks were present at high relative-concentrations in 32, 27, and 4.6% of the primary aquifers in the SSACV, MSACV, and NSACV study units, respectively (table 8A).

Manganese and iron can occur at high relative-concentrations in those parts of the aquifer that are chemically reduced. Manganese was present at high relative-concentrations in 27, 27, and 4.6% of the three study units, respectively (figs. 15*A*, 15*B*, and 15*C* and tables 7A, 7B, and 7C). High and moderate concentrations of manganese were concentrated along the axis of the Sacramento Valley beginning near the Sutter Buttes and continuing south along the Sacramento River (fig. 16). The geographic distribution of high and moderate concentrations of iron is very similar to that of manganese. Iron was present at high relative-concentrations in 16, 3.3, and 0%, respectively, of the primary aquifers of the three study units (figs.15*A*, 15*B*, and 15*C*; tables 7A, 7B, and 7C).

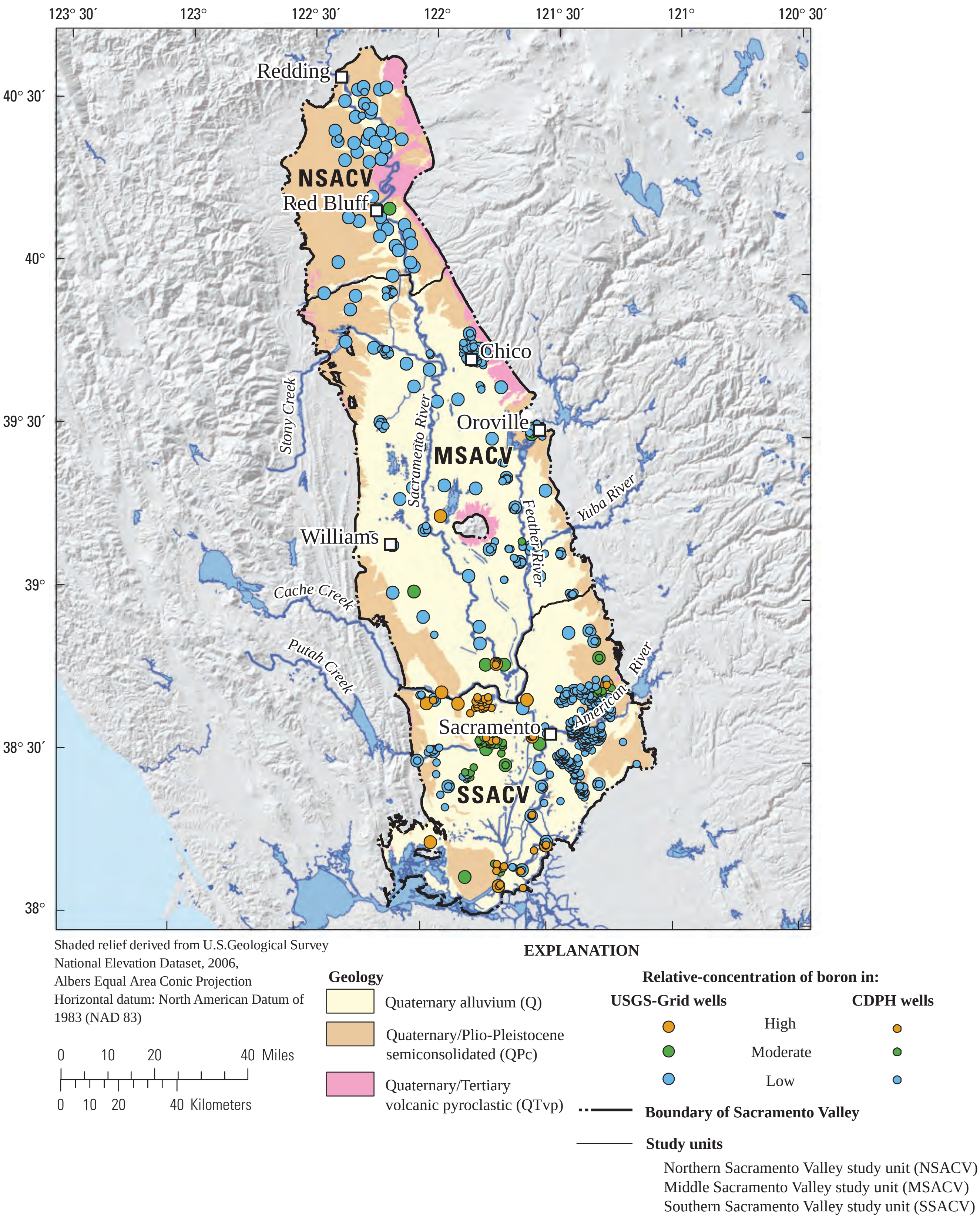


Figure 10. Relative-concentrations of boron in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

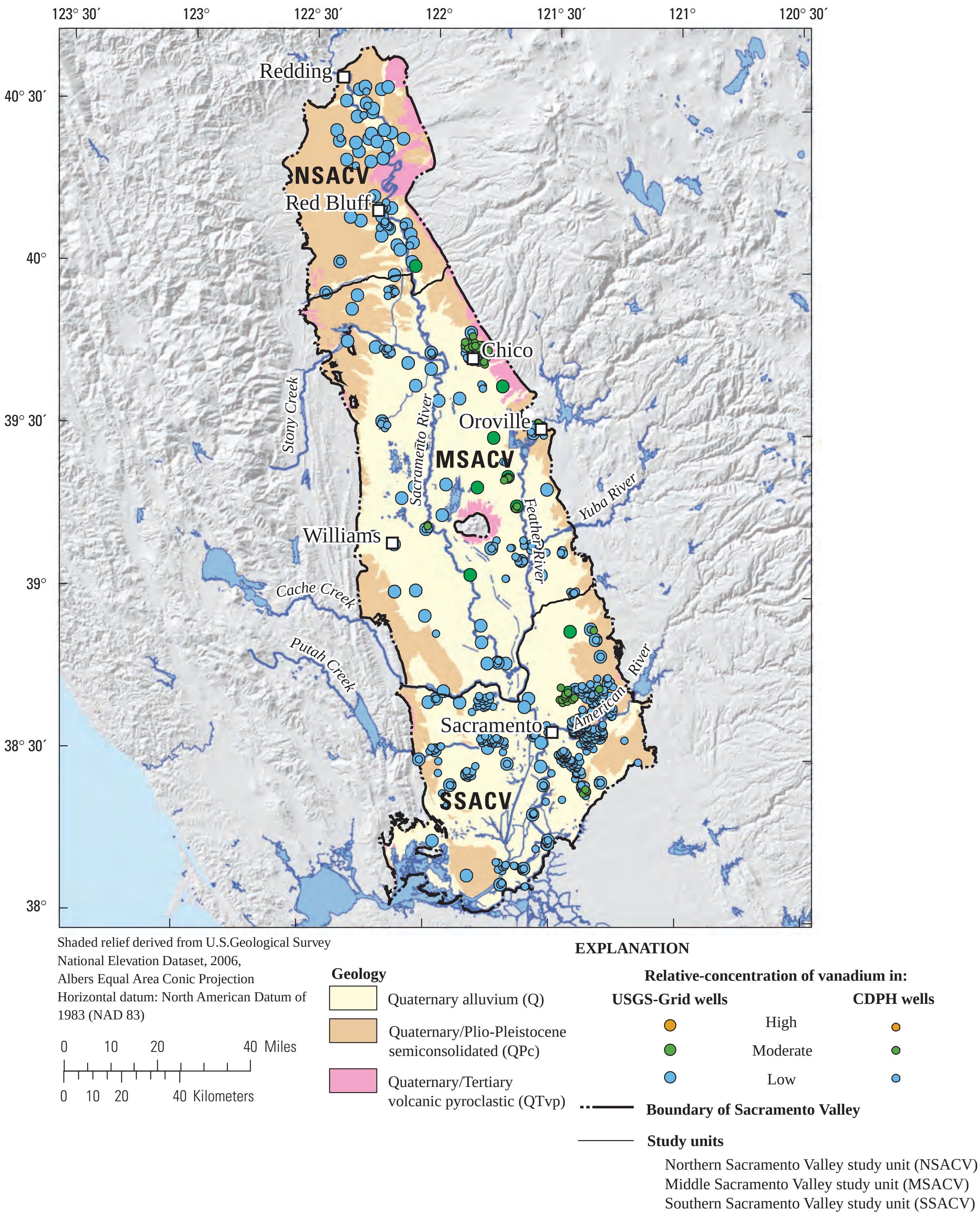


Figure 11. Relative-concentrations of vanadium in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

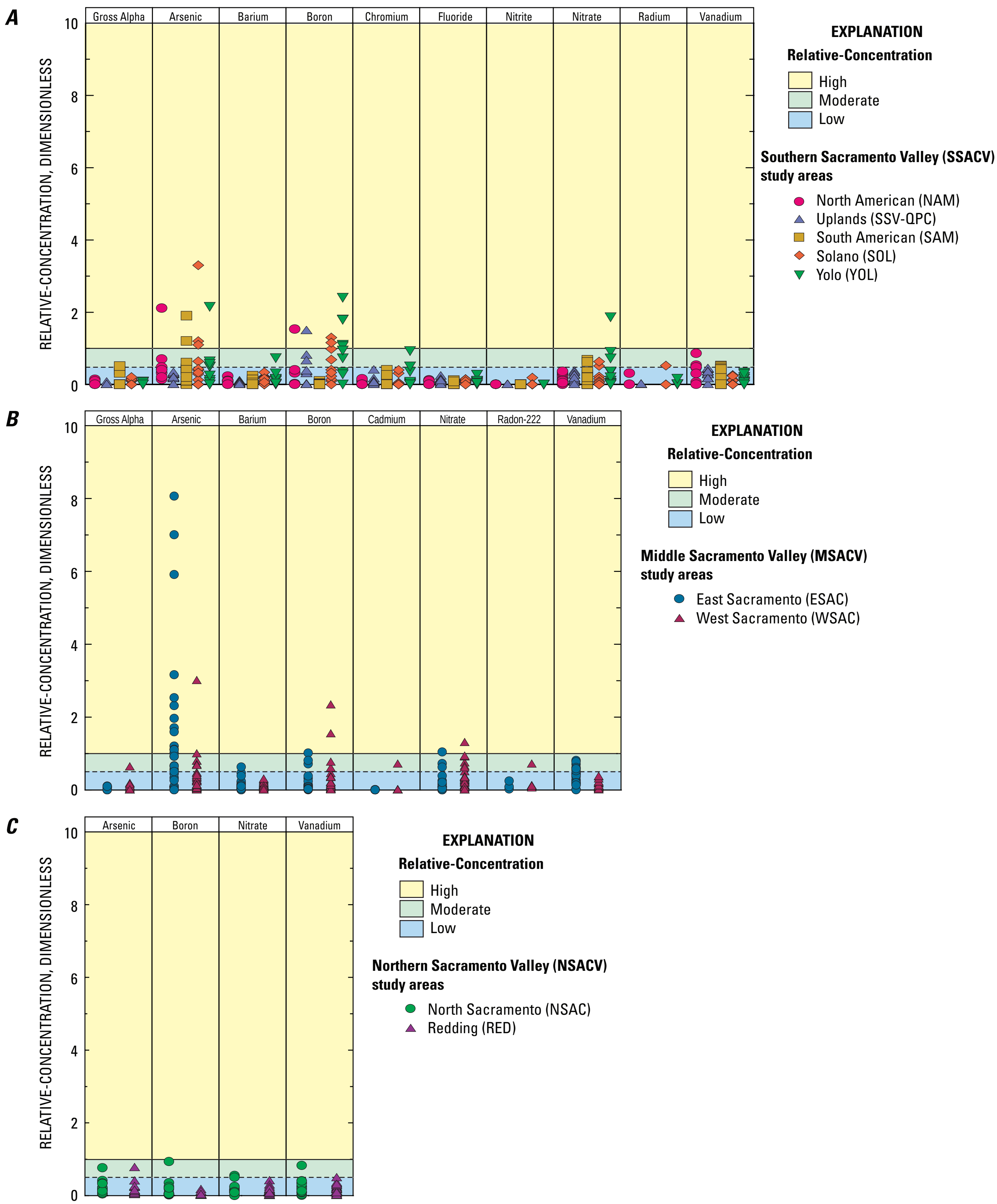


Figure 12. Relative-concentrations of trace elements, radioactive constituents, nutrients, and minor elements with health-based benchmarks in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

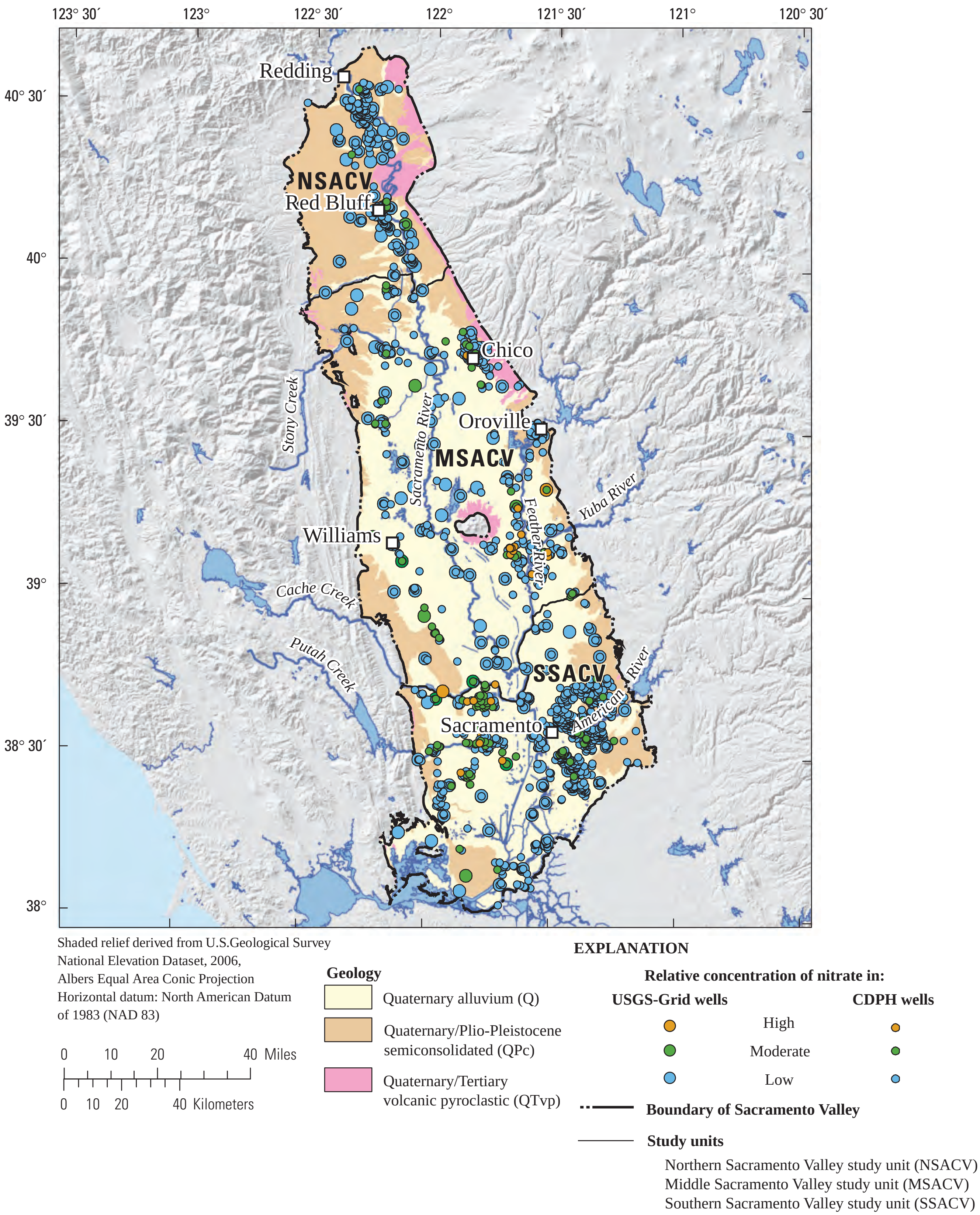


Figure 13. Relative-concentrations of nitrate in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

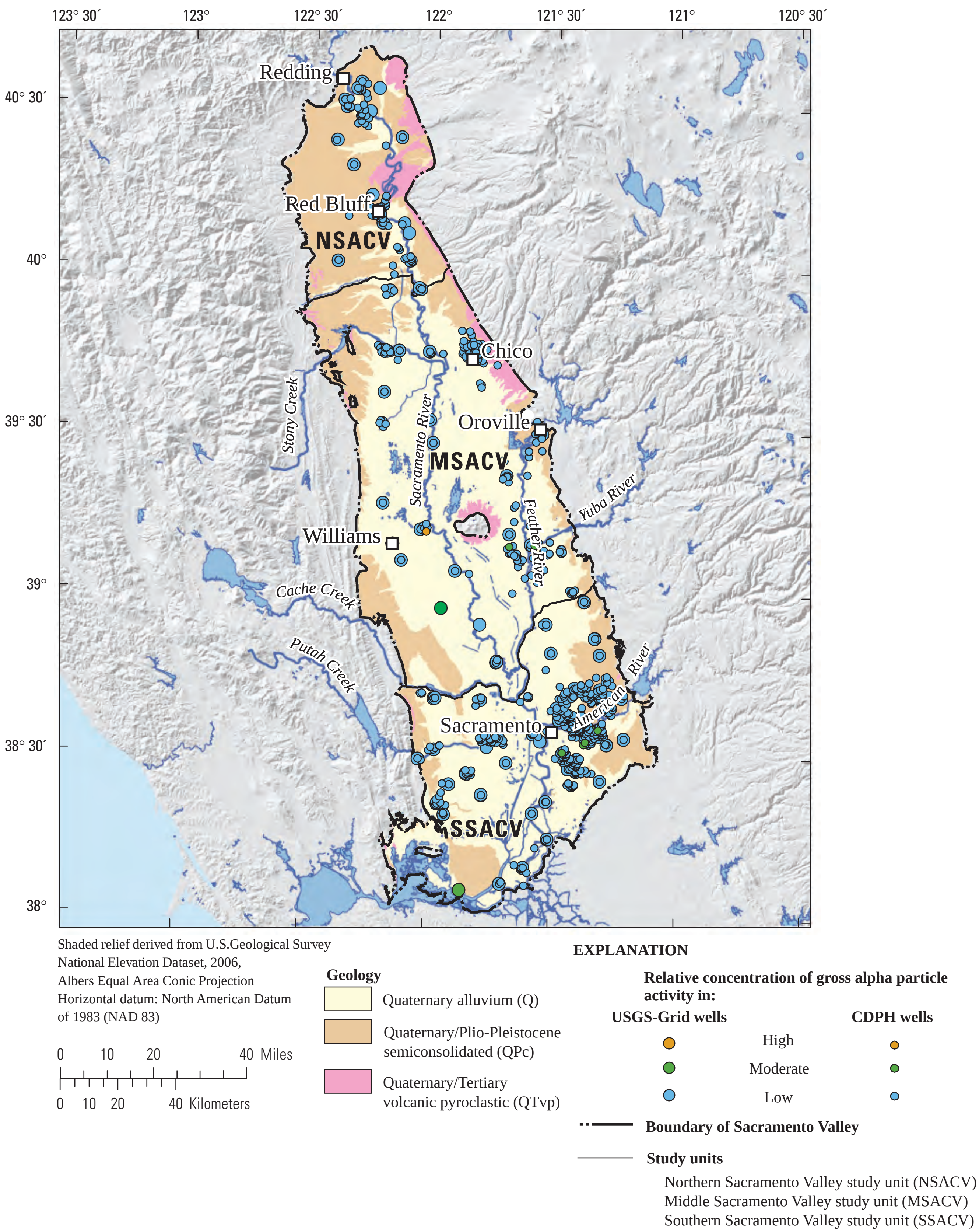


Figure 14. Relative-concentrations of gross alpha particle activity in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

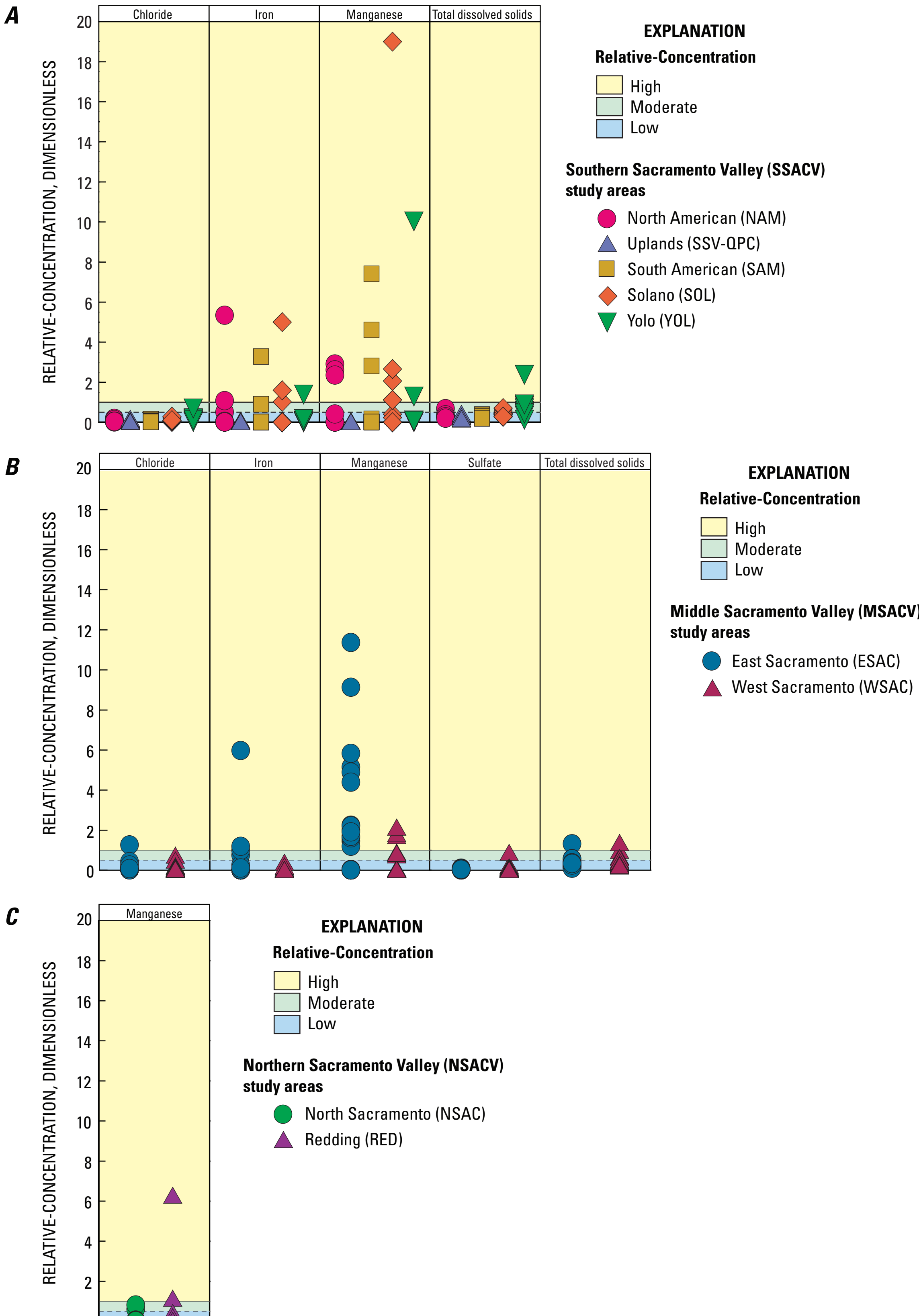


Figure 15. Relative-concentrations of major ions and total dissolved solids (TDS) with aesthetic benchmarks and maximum relative-concentrations greater than 0.5 in grid wells in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

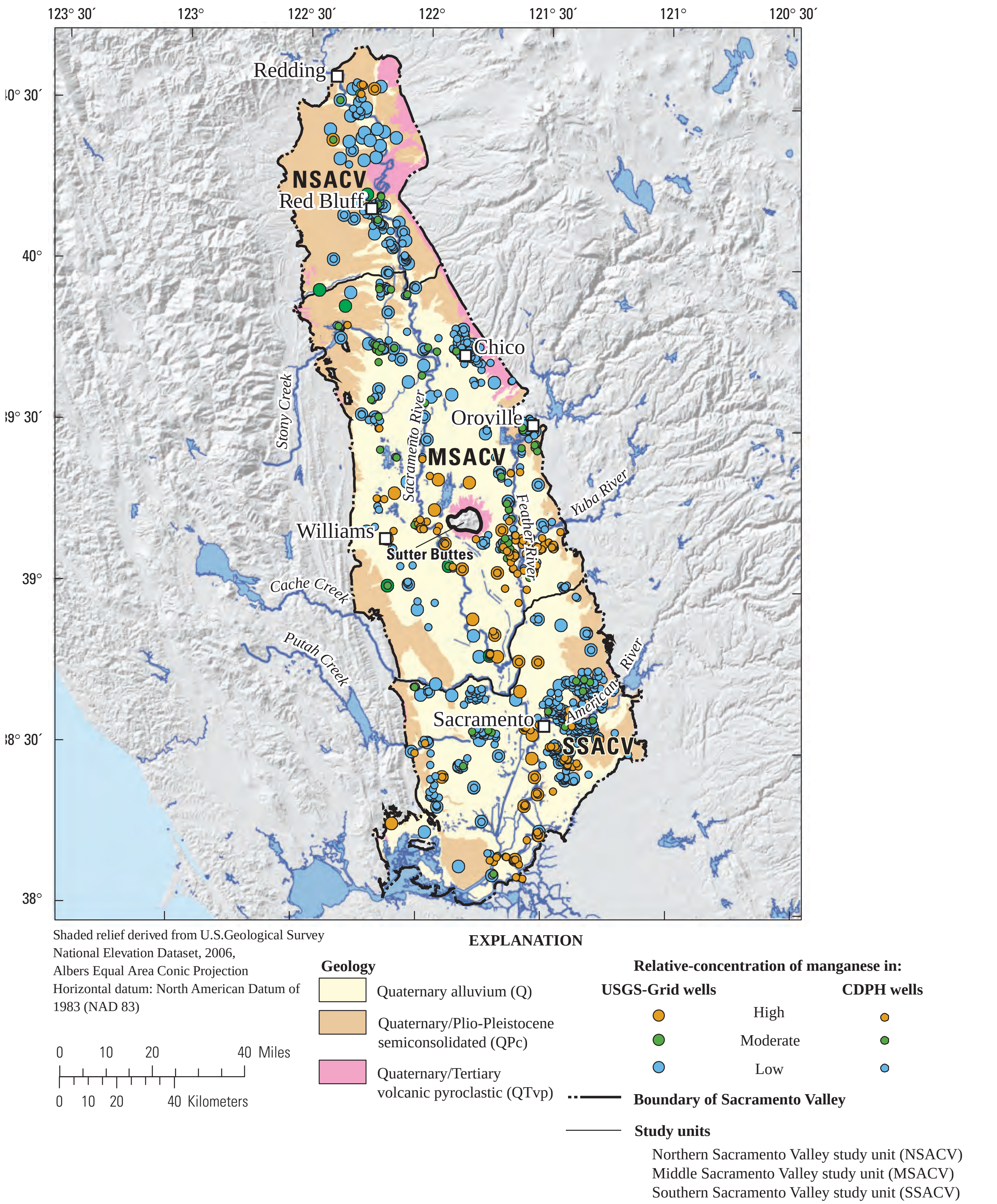


Figure 16. Relative-concentrations of manganese in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

TDS was detected at high relative-concentrations in 1.1 and 4.0% of the primary aquifers of the SSACV and MSACV study units (figs.15*A* and 15*B*; tables 7A and 7B). Moderate concentrations were detected in 22 and 11% of the primary aquifers of the SSACV and MSACV study units (figs.15*A* and 15*B* and tables 7A and 7B). High and moderate relative-concentrations occurred most often to the south and west of the Sutter Buttes, with a high density of occurring between Cache and Putah Creeks west of Sacramento (fig. 17). In the NSACV study unit TDS occurred only at low concentrations.

Organic and Special-Interest Constituents

The organic and special-interest constituents are discussed in this report by constituent group: VOCs, pesticides, and special interest. VOCs can be present in paints, solvents, fuels, fuel additives, refrigerants, fumigants, and disinfected water, and are characterized by their tendency to evaporate. VOCs generally persist longer in groundwater than in surface water because groundwater is isolated from the atmosphere. Pesticides include herbicides, insecticides, and fungicides, and are used to control weeds, insects, fungi, and other pests in agricultural, urban, and suburban settings. VOCs and pesticides were analyzed for in samples from all USGS-grid and USGS-understanding wells in the three study units. The special-interest constituents are three chemically unrelated constituents that are of interest because they have been detected in, or are considered to have the potential to be detected in, drinking-water supplies: 1,2,3-trichloropropane (1,2,3-TCP), *N*-nitrosodimethylamine (NDMA), and perchlorate (California Department of Public Health, 2009a, 2009b; California Department of Public Health, 2010). Special-interest constituents were analyzed only in a subset of wells from the three study units.

Of the 88 VOCs analyzed, 40 were detected in at least one sample from the Sacramento Valley study units. Of these 40 compounds, 20 had regulatory, health-based benchmarks and 12 had non-regulatory health-based benchmarks (table 9). No VOCs were detected at high relative-concentrations, and two VOCs, the solvents tetrachloroethylene (PCE) and *cis*-1,2-dichloroethylene, were detected at moderate relative-concentrations in at least one of the three study units (figs. 18*A-C*; 19*A-C*). PCE, the solvent trichloroethylene (TCE), and the trihalomethane chloroform were each detected in more than 10% of the primary aquifers in at least one of the three study units (figs. 18*A-C*; 19*A-C*). In addition to these four VOCs selected for additional evaluation in the status assessment on the basis of their relative-concentrations or detection frequencies in samples collected by USGS-GAMA, six other VOCs were included because they were reported in the CDPH database at high or moderate relative-concentrations in at least one of the three study units during the current period: the gasoline additives *tert*-butyl alcohol (TBA), benzene, and methyl *tert*-butyl ether (MTBE); the solvent methylene chloride; the fumigant methyl bromide; and the trihalomethane bromodichloromethane (table 3).

Of the 135 pesticides and pesticide degradates analyzed, 37 were detected in at least one sample from the Sacramento Valley study units. Of these 37 compounds, 7 had regulatory, health-based benchmarks and 12 had non-regulatory health based benchmarks (table 9). No pesticides were detected at high relative-concentrations, and one insecticide, dieldrin, was detected at moderate relative-concentrations in the SSACV study unit (fig. 18*A*; 19*A*). The herbicides atrazine, bentazon, and simazine were each detected in more than 10% of the primary aquifers in at least one of the three study units (figs. 18*A-C*; 19*A-C*). No pesticides were reported at moderate or high relative-concentrations in the CDPH database.

Of the 3 constituents of special interest analyzed, 2 were detected in at least one sample from the Sacramento Valley study units (table 9). Perchlorate was detected at moderate relative-concentrations in all three study units, and in greater than 10% of the primary aquifer of the NSACV study unit (figs. 18*A-C*; 19*A-C*). Bennett and others (2009) reported detections of NDMA with moderate and high relative-concentrations in the NSACV study unit; however, based on subsequent evaluation of results from quality-control samples, these detections were considered suspect.

Aquifer-scale proportions for individual organic and special-interest constituents are listed in tables 7A, 7B, and 7C and for constituent classes in tables 8B and 8C. The proportions of the aquifer with high relative-concentration of any organic constituent (VOCs and pesticides) were less than 1% in all three study units (table 8B). The proportions of the aquifer with moderate relative-concentration of any organic constituent were 2.6% in SSACV, 2.8% in MSACV, and 0.9% in NSACV. The proportions of the primary aquifers with high or moderate relative-concentrations of *organic* constituents were significantly less than the proportions with high or moderate relative-concentration of *inorganic* constituents for all three study units (tables 8A, 8B, and 8C). One or more organic constituents were detected at low relative-concentrations in 69, 65, and 49% of the primary aquifer in SSACV, MSACV, and NSACV, respectively.

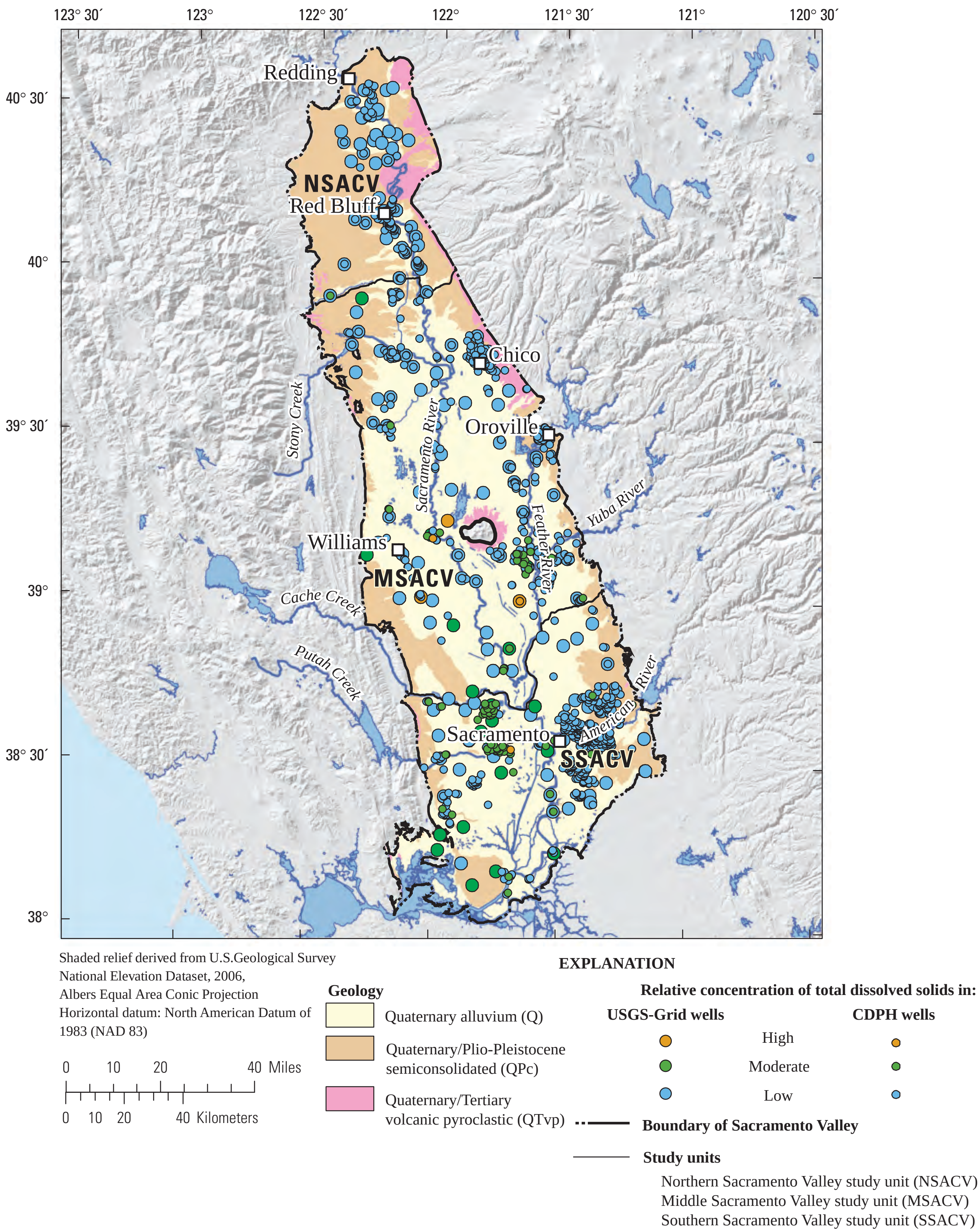


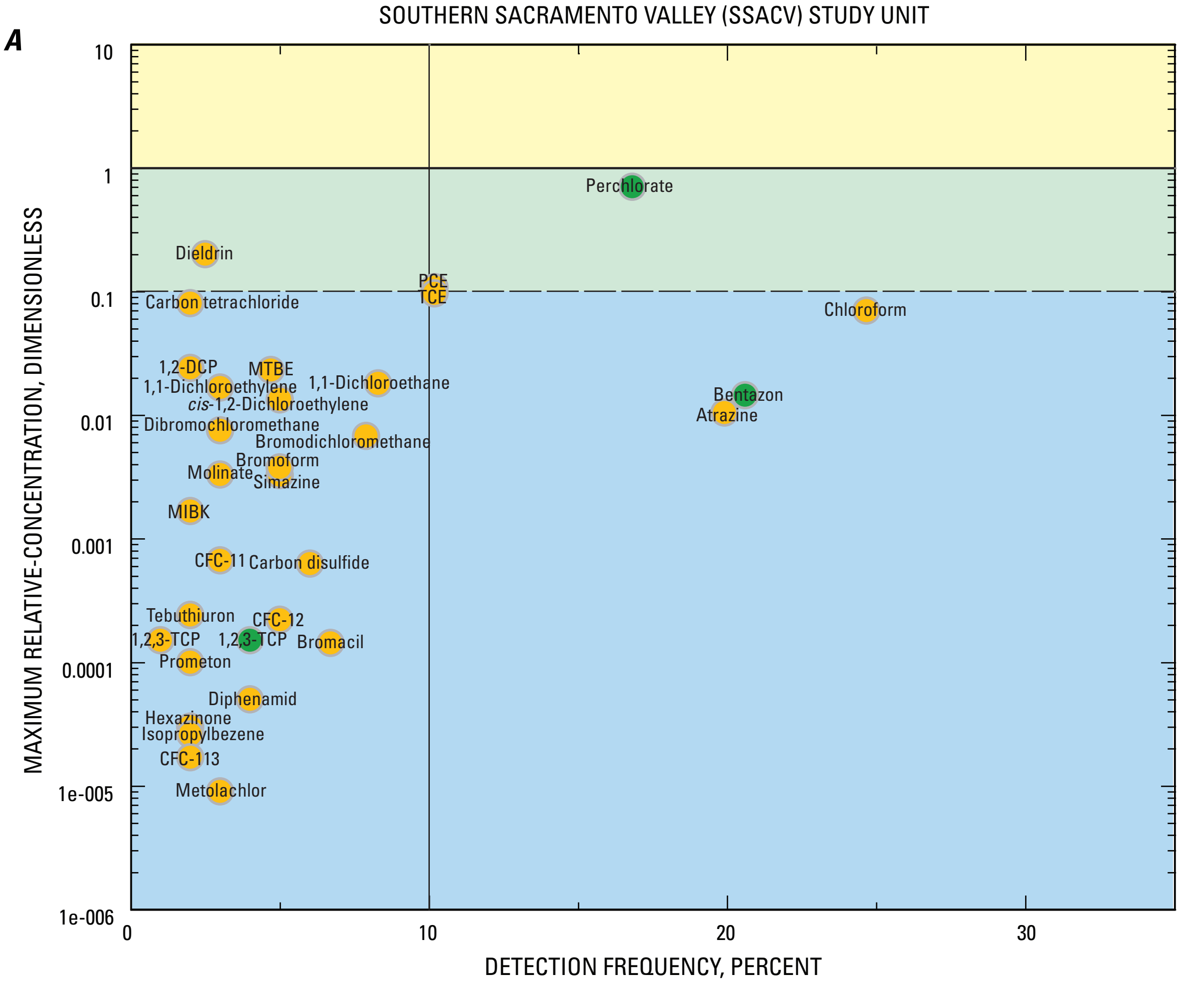
Figure 17. Relative-concentrations of total dissolved solids in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Table 9. Number of organic constituents analyzed and detected, listed by health-based-benchmark type and constituent type, in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Regulatory health-based benchmarks include U.S. Environmental Protection Agency (USEPA) and California Department of Public Health (CDPH) maximum contaminant levels. Non-regulatory health-based benchmarks include USEPA lifetime health advisory levels and risk specific dose level at 10^{-5} and CDPH notification level. **Abbreviations**: SSACV, Southern Sacramento Valley study unit; MSACV, Middle Sacramento Valley study unit; NSACV, Northern Sacramento Valley study unit]

Benchmark type	SSACV		MSACV		NSACV		Number detected in all study units
	Number of constituents (any concentration)						
	Analyzed	Detected[1]	Analyzed	Detected[1]	Analyzed	Detected[1]	
Volatile organic compounds (VOCs)							
Regulatory, health-based	33	16	33	12	33	11	20
Non-regulatory, health-based	26	11	26	4	25	3	12
No benchmark	29	8	29	6	27	1	8
Total	88	35	88	22	85	15	40
Pesticides and degradates							
Regulatory, health-based	16	6	15	6	15	2	7
Non-regulatory, health-based	29	8	30	9	28	1	12
No benchmark	78	7	90	15	81	1	18
Total	123	21	135	30	124	4	37
Special-interest constituents							
Regulatory, health-based	1	1	1	1	1	1	1
Non-regulatory, health-based	2	1	2	0	1	1	2
No benchmark	0	0	0	0	0	0	0
Total	3	2	3	1	2	2	3
Sum of all organic and special-interest constituents							
Regulatory, health-based	50	23	49	19	49	14	28
Non-regulatory, health-based	57	20	58	13	54	5	26
No benchmark	107	15	119	21	108	2	26
Total	214	58	226	53	211	21	80

[1] Number includes detections in understanding wells.



EXPLANATION

Relative-Concentration

- High
- Moderate
- Low

Abbreviations

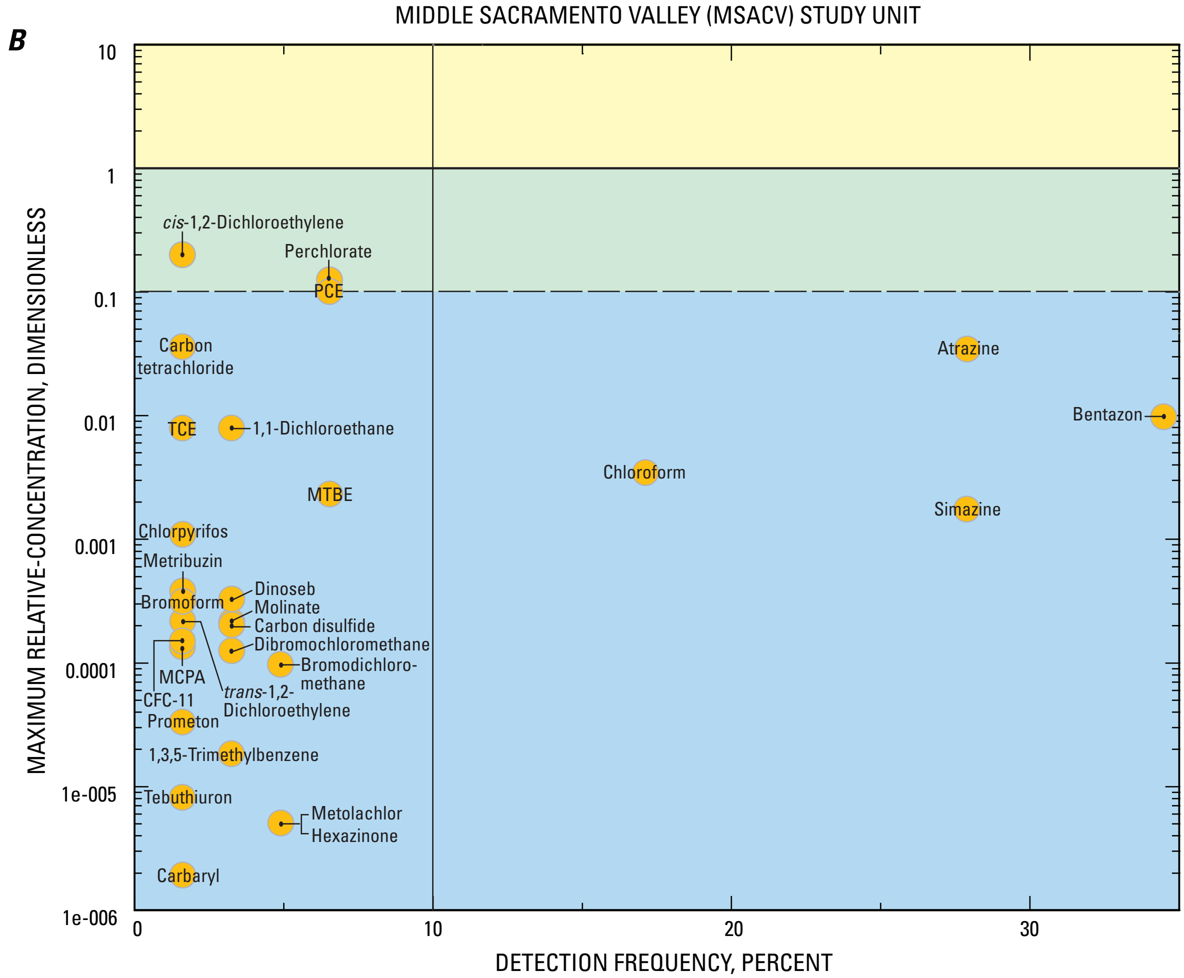
TCE, trichloroethene; PCE, tetrachloroethene; 1,2-DCP, 1,2-dichloropropane; MTBE, methyl *tert*-butyl ether; MIBK, 4-methyl-2-pentanone; CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; **1,2,3-TCP, 1,2,3-trichloropropane; CFC-113, 1,1,2-trichlorotrifluoroethane.

**1,2,3-TCP analyzed at all wells at a reporting level of 0.18 µg/L and at a subset of wells at a reporting level of 0.005 µg/L.

PCE **Constituents with analyses in >30 grid wells and wells are spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Perchlorate **Constituents with analyses in <30 grid wells and wells are not spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Figure 18. Detection frequency and maximum relative-concentration for organic and special- interest constituents in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.



EXPLANATION

Relative-Concentration

- High
- Moderate
- Low

Abbreviations

TCE, trichloroethene; PCE, tetrachloroethene; MTBE, methyl *tert*-butyl ether; CFC-11, trichlorofluoromethane; MCPA, 2-methl-4-chlorophenoxyacetic acid.

PCE **Constituents with analyses in >35 grid wells and wells are spatially representative—** Name and center of symbol is location of data unless indicated by following location line:

Figure 18.—Continued.

C

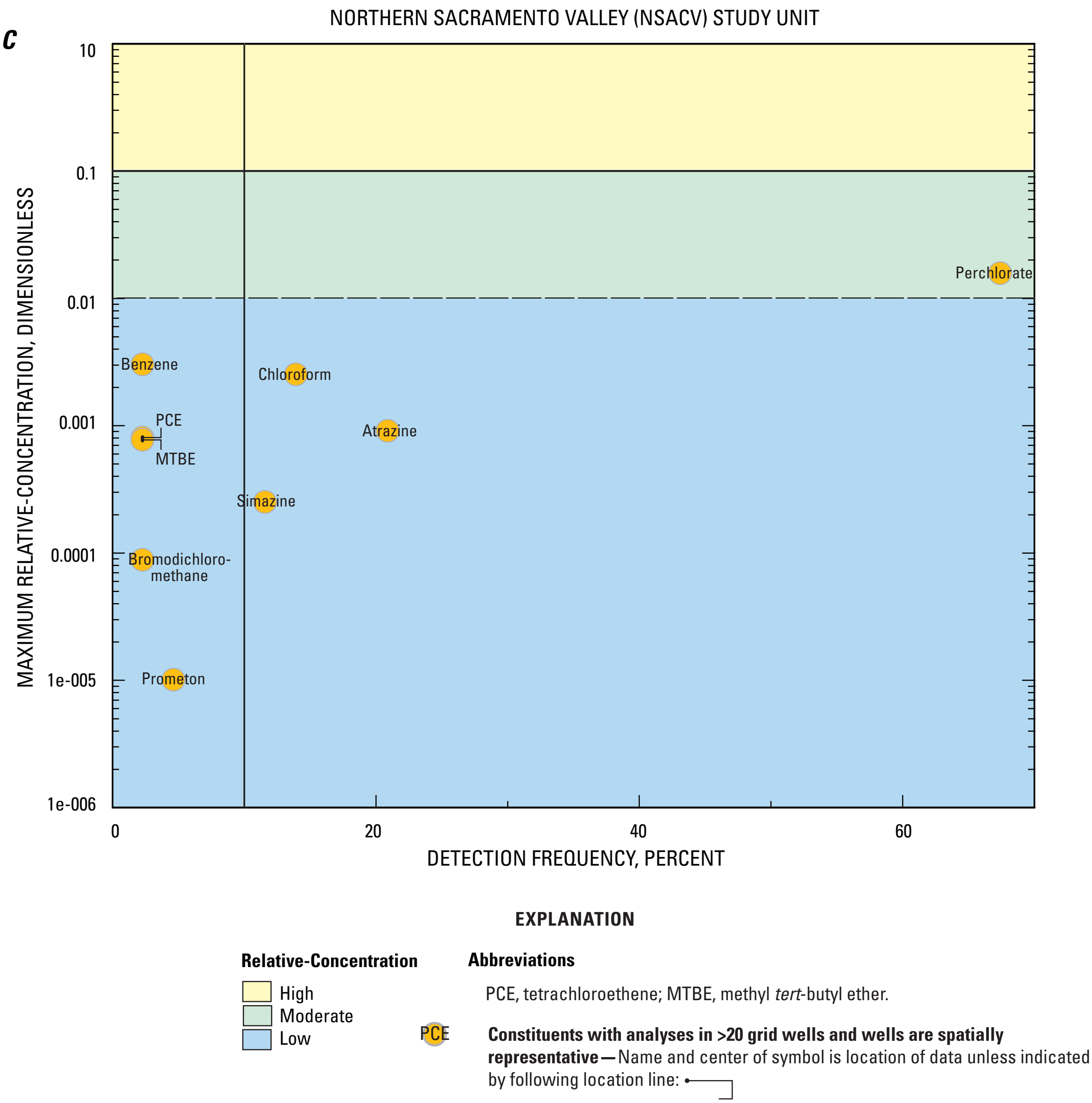


Figure 18.—Continued.

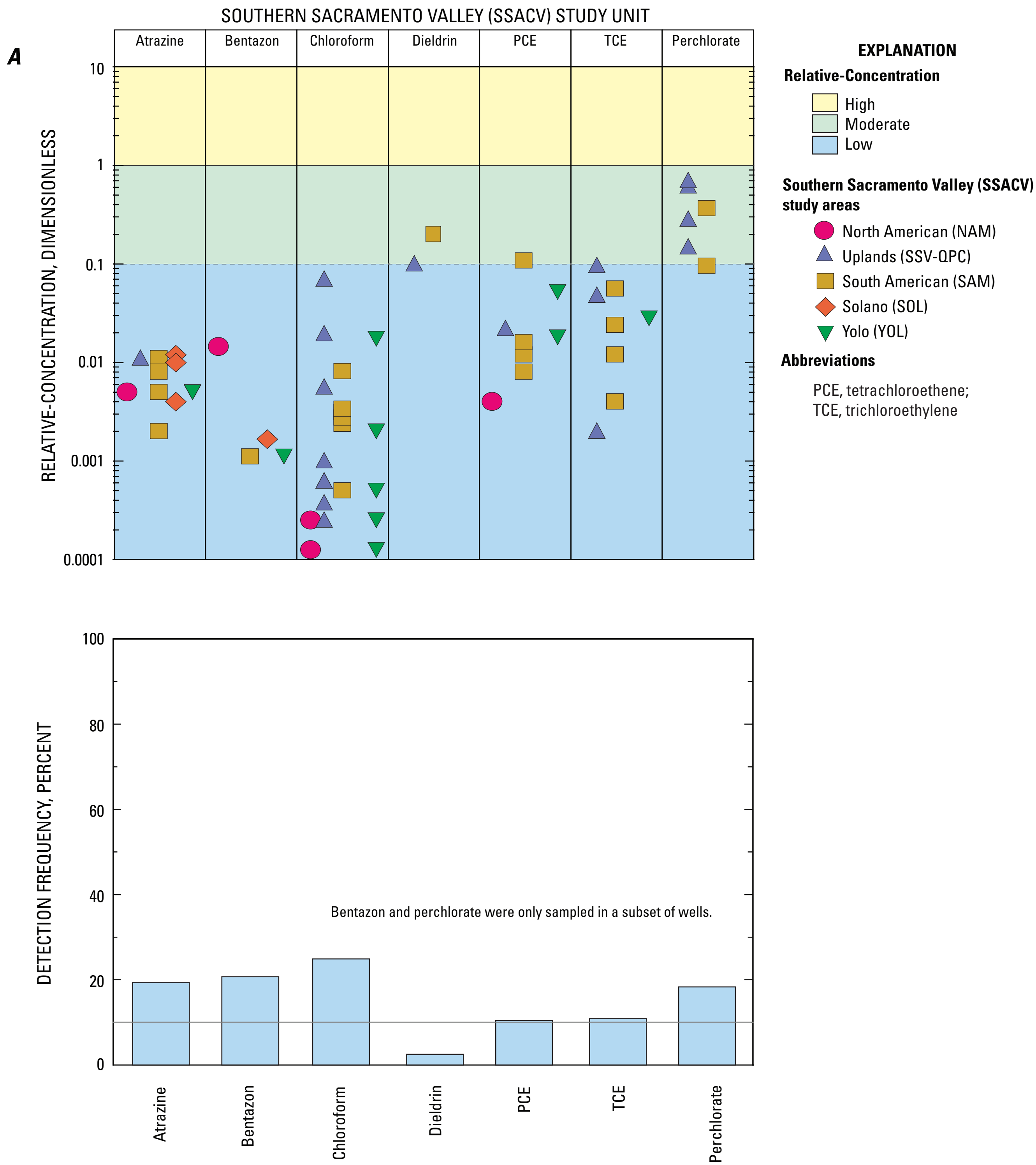


Figure 19. Relative-concentration and study unit detection frequency of selected organic and special-interest constituents in grid wells for the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

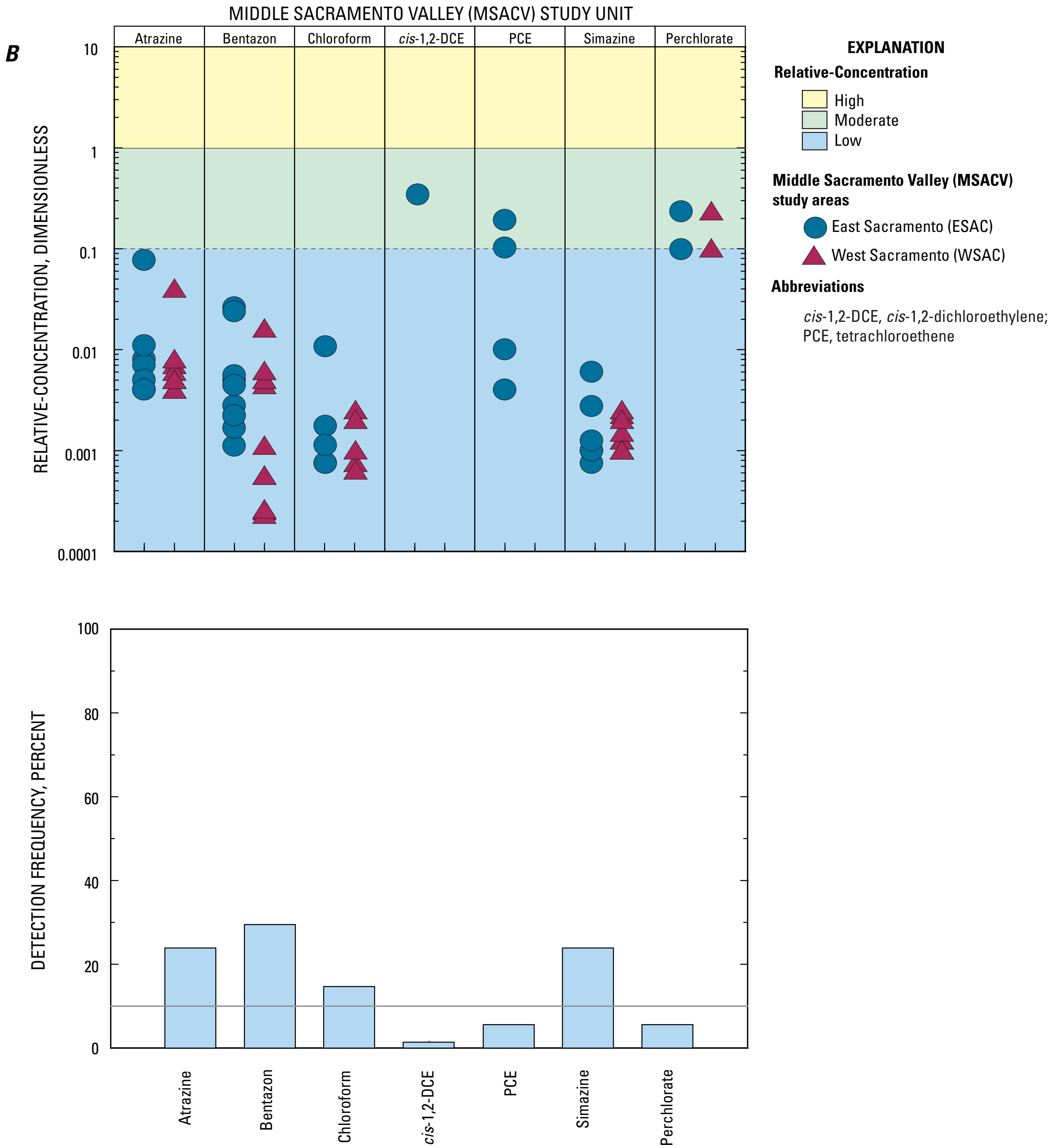


Figure 19.—Continued.

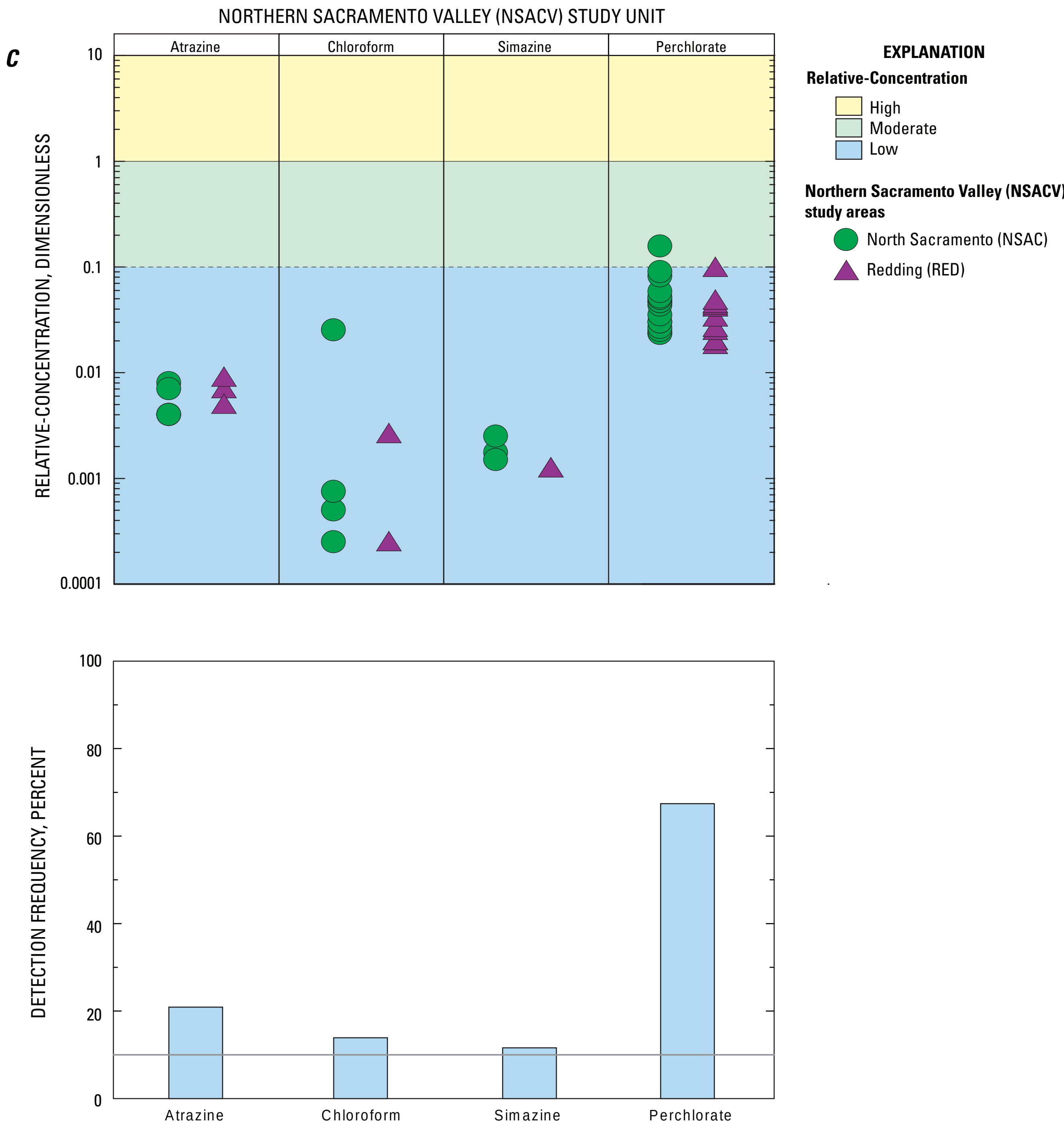


Figure 19.—Continued.

Solvents

Organic solvents are used for a variety of industrial, commercial, and domestic purposes to dissolve other solids, liquids, or gases. PCE primarily is used for dry-cleaning of fabrics and degreasing of metal parts, and is an ingredient in a wide range of products including paint removers, polishes, printing inks, lubricants, and adhesives (Doherty, 2000). TCE has similar uses as PCE, and like *cis*-1,2-dichloroethylene may be formed by degradation of PCE in groundwater (Vogel and McCarty, 1985; Wiedemeier and others, 1999). Most solvent detections were in the urbanized eastern part of the SSACV study unit (fig. 20).

Only one solvent, PCE, was detected at high relative-concentrations. SSACV and MSACV had high aquifer-scale proportions of PCE of 0.7 and 0.3%, respectively (table 7A,B). Moderate aquifer-scale proportions of PCE were detected in 1.3 and 0.8% of SSACV and MSACV, respectively (table 7 A,B). PCE was detected in more than 10% of the primary aquifer in the SSACV study unit (fig. 19*A*).

Three solvents, *cis*-1,2-dichloroethylene (MSACV), methylene chloride (NSACV), and TCE (SSACV) were detected at moderate relative-concentrations. Moderate aquifer-scale proportions for these three solvents were 1.4, 0.6, and 0.4%, respectively (table 7A,B,C). TCE was also detected in more than 10% of the primary aquifer in the SSACV study unit (fig. 19*A*).

Eight solvents—carbon tetrachloride, 1,2-dichloroethane, *cis*-1,2-dichloroethylene, dichloromethane, 1,1-dichloroethylene, 1,1,2,2-tetrachloroethane, TCE, and vinyl chloride—were reported at high relative-concentrations in the historical CDPH database, but are not reported at high relative-concentrations in the most recent 3-year interval in the database (table 5).

Trihalomethanes

Water for drinking and other household uses that comes from domestic or municipal and community systems commonly is disinfected with solutions that contain chlorine. In addition to disinfecting the water, the chlorine can react with organic matter to produce THMs and other chlorinated and/or brominated disinfection byproducts. THMs were not detected at high relative-concentrations in the Sacramento Valley; however, they were detected in greater than 10% of the primary aquifers in all three study units. Many of the detections were near population centers, particularly the city of Sacramento (fig. 21).

Two THMs, chloroform and dibromochloromethane, were detected at moderate relative-concentrations in the Sacramento Valley. Chloroform was detected at moderate relative-concentrations in 2.6% of the SSACV study unit (spatially-weighted). Chloroform was only detected at low relative-concentrations in MSACV and NSACV; however, chloroform was detected in 25, 14, and 14% in the SSACV, MSACV, and NSACV study units, respectively. The moderate aquifer-scale proportion of the brominated THM, dibromochloromethane was 0.3% in the NSACV study unit (spatially-weighted). Dibromochloromethane was only detected at low relative-concentrations in SSACV.

Other Volatile Organic Compounds

Two fuel components, TBA (gasoline oxygenate) and benzene (gasoline hydrocarbon) were detected at high relative-concentrations in the Sacramento Valley. TBA had high aquifer-scale proportions of 0.1 and 0.6% in the SSACV and NSACV study units (spatially-weighted), respectively (table 7A,C). Benzene had high aquifer-scale proportions of 0.1% in MSACV (spatially-weighted) (table 7B). The gasoline oxygenate MTBE was reported at high relative-concentrations during the historical period but was not reported at high relative-concentrations in the most recent 3-year interval in the database (table 5).

One agricultural fumigant, methyl bromide, was detected at moderate relative-concentrations. Methyl bromide had a moderate aquifer-scale proportion of 0.6% in the NSACV study unit (spatially-weighted) (table 7C). For the SSACV study unit, historically high values for the agricultural fumigants 1,2-dibromoethane (EDB) and methyl bromide were reported in the CDPH database, but not during the current period of study (table 5).

Pesticides

Detection frequencies for the herbicide atrazine were 20, 24, and 21% in the SSACV, MSACV, and NSACV study units, respectively. Detection frequencies of the herbicide simazine were 24% in the MSACV study unit and 12% in the NSACV study unit. Atrazine and simazine are chlorinated triazines that share a common mechanism of toxicity. Eighty-five percent of the samples containing atrazine also contained low concentrations of deethylatrazine, a degradation product of atrazine that does not have a benchmark. Co-occurrence of atrazine and deethylatrazine may reflect the relatively high degree of persistence of atrazine in groundwater environments (Kolpin and others, 1998). Deethylatrazine, atrazine, and simazine were the most frequently detected pesticide compounds in groundwater in major aquifers across the United States (Gilliom and others, 2006). Simazine most commonly is used on orchards and vineyards and on rights-of-way for weed control; atrazine most commonly is used on forage grasses, corn, and managed forests (Pesticide Action Network, 2010). Wells with detections of atrazine and/or simazine were fairly evenly distributed throughout the Sacramento Valley (fig. 22).

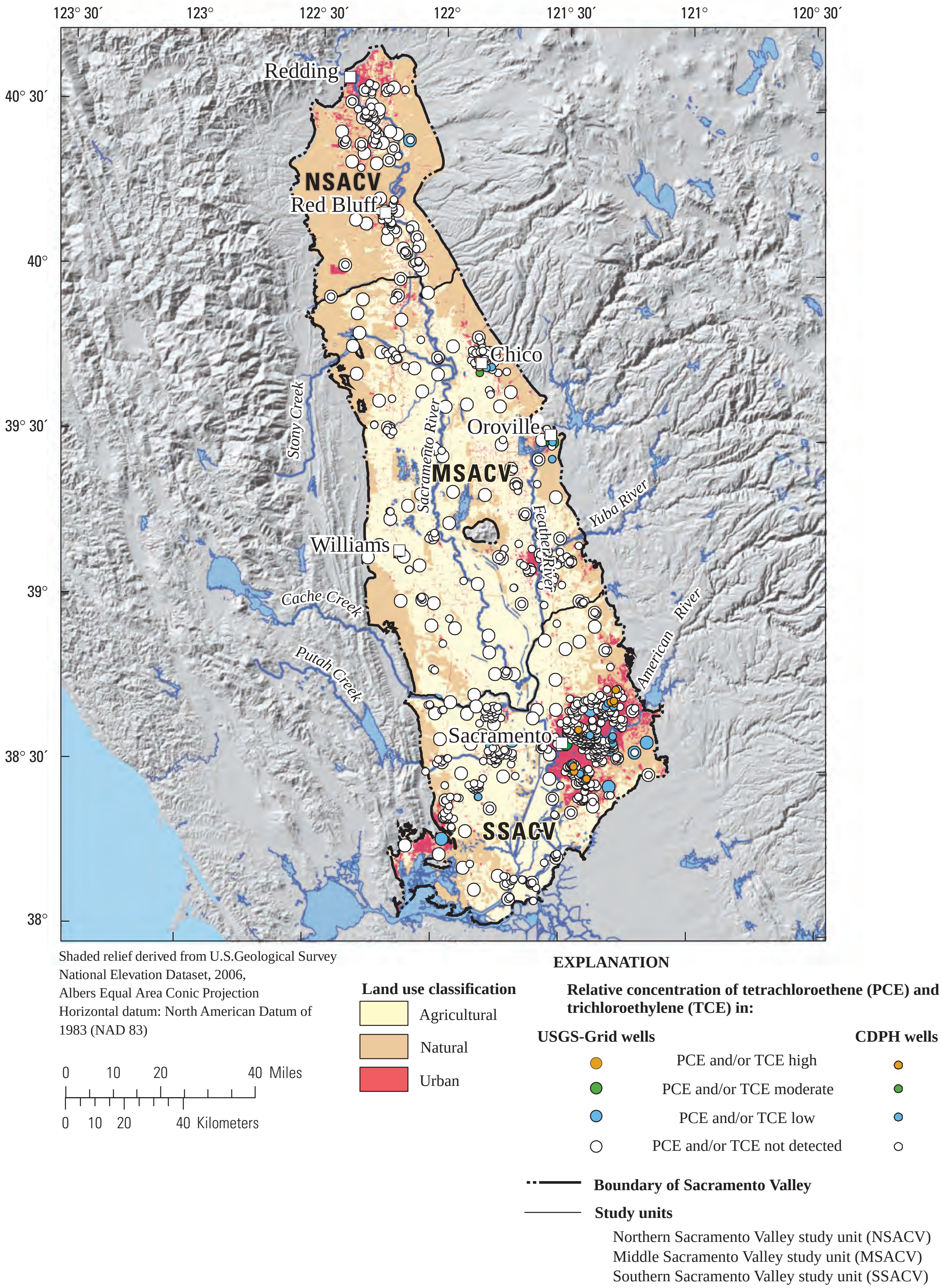


Figure 20. Relative-concentrations of tetrachloroethene (PCE) and trichloroethylene (TCE) in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

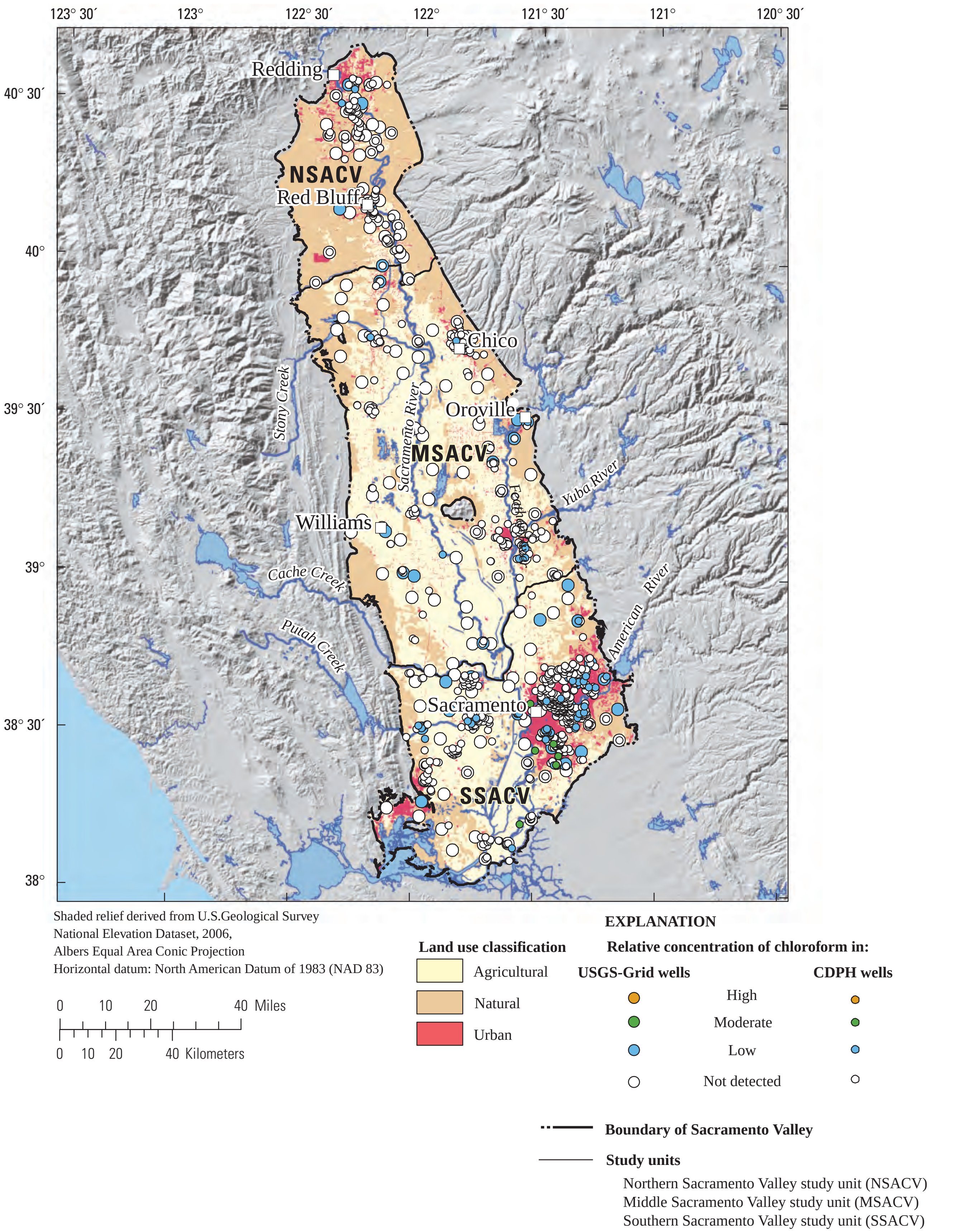


Figure 21. Relative-concentrations of chloroform in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

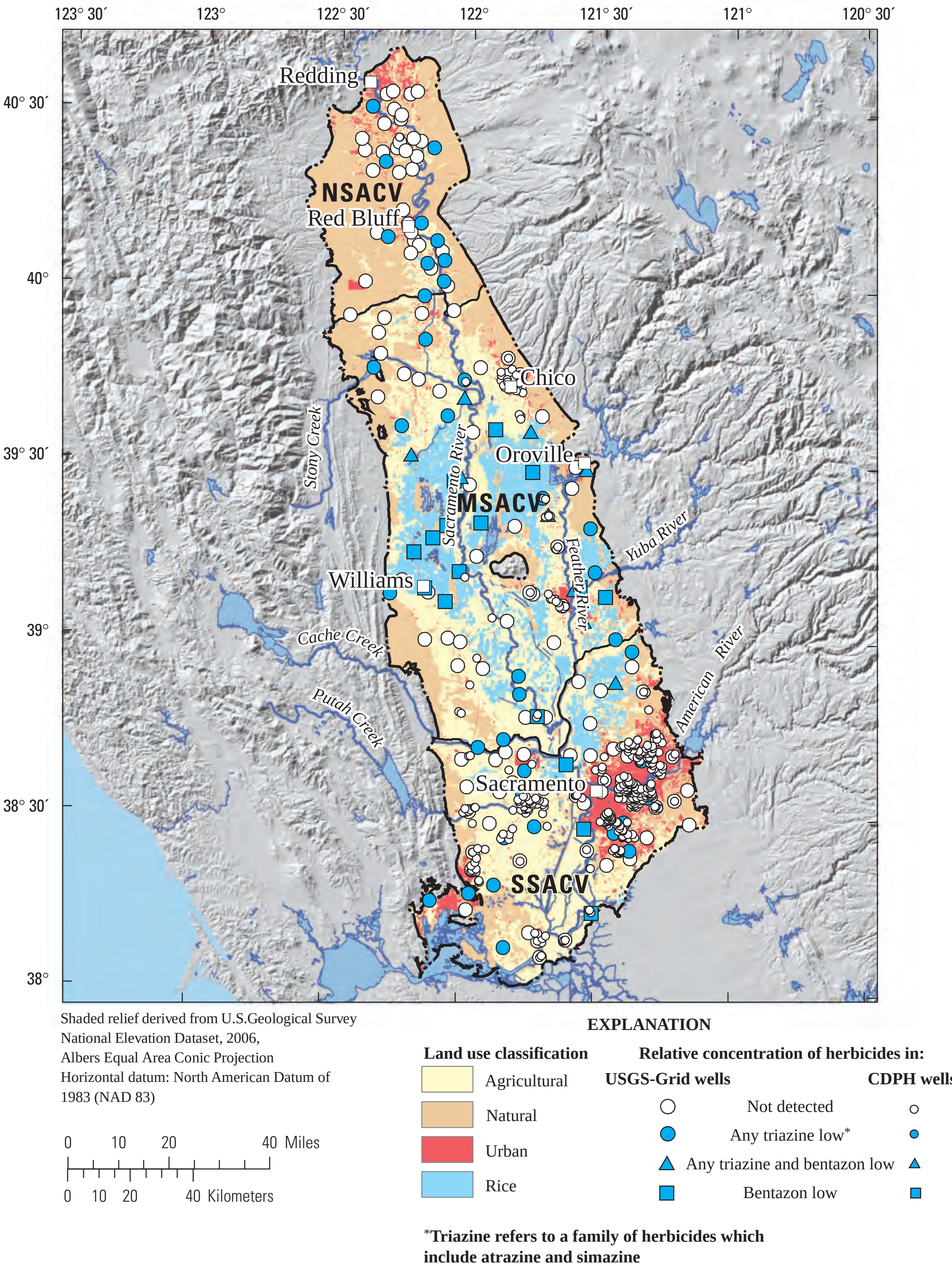


Figure 22. Relative-concentrations of pesticides in USGS-grid wells and CDPH wells, Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

Detection frequencies for the herbicide bentazon were 21% in the SSACV study unit and 30% in the MSACV study unit. Bentazon was not analyzed at all wells in the SSACV study unit; therefore, the detection frequency and sampling distribution in SSACV may not be representative of the entire study unit. Bentazon was analyzed at all wells in MSACV. Bentazon most commonly was used on rice fields to control sedges and other weeds; the use of bentazon in the production of rice was banned in California in 2004 (California Office of Administrative Law, 2010). Most of the wells with detections of bentazon were located in areas where major land use was rice farming (fig. 22).

One insecticide, dieldrin, was detected at moderate relative-concentrations. Dieldrin had moderate aquifer-scale proportions in 1.3% of the primary aquifer in the SSACV study unit (table 7A). The insecticide aldicarb was reported at high relative-concentrations in the historical CDPH databases of SSACV and MSACV, but was not reported at moderate or high relative-concentrations in the most recent 3-year intervals of those databases (table 5).

Special-Interest Constituents

Perchlorate was detected at moderate relative-concentrations in all three Sacramento Valley study units. The maximum relative-concentration for perchlorate was 0.7 which was detected in the SSACV study unit (fig. 8*A*). Perchlorate had moderate aquifer-scale proportions of 14, 2.8, and 2.3% in the SSACV, MSACV, and NSACV study units, respectively (table 7A,B,C).

Perchlorate was analyzed for at a detection limit of 0.5 µg/L in samples collected in SSACV and MSACV, and had detection frequencies of 17 and 6%, respectively. The detection frequency in SSACV may not be representative because perchlorate was analyzed at less than one-half of the grid wells. Samples from the NSACV study unit were analyzed with a detection limit of 0.1 µg/L and the detection frequency was 70%; the detection frequency for concentrations greater than 0.5 µg/L was 7%.

Compilation of Explanatory Factors

A finite set of potential explanatory factors, including land use, well-construction information, groundwater-age classification, and geochemical conditions, were compiled and assigned to wells in each of the three study units. A brief discussion of each explanatory factor and of the data attributed to each well is presented in appendix E. The explanatory factors included here may be useful for placing water-quality results in the context of physical and chemical process.

Summary

Groundwater quality in the Southern, Middle, and Northern Sacramento Valley study units was investigated as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) program. The project provides a spatially-unbiased characterization of untreated groundwater quality in the primary aquifers. The assessment is based on water-quality data collected by the U.S. Geological Survey (USGS) from a total of 235 wells in the three study units in 2005-2008, and water-quality data reported in the California Department of Public Health (CDPH) database.

The *status assessment* of groundwater quality described in this report was based on data from samples analyzed for anthropogenic constituents, such as volatile organic compounds (VOCs) and pesticides, and naturally occurring inorganic constituents, such as major ions and trace elements. The status assessment characterizes the quality of groundwater resources within the primary aquifers of the three Sacramento Valley study units, not the treated drinking water delivered to consumers by water purveyors.

Relative-concentrations (sample concentration divided by the benchmark concentration) were used for evaluating groundwater quality for those constituents that have Federal and (or) California benchmarks for drinking-water quality. Aquifer-scale proportion was used as a metric for evaluating regional-scale groundwater quality. High aquifer-scale proportion is defined as the percentage of the primary aquifers with relative-concentration greater than 1.0 for a particular constituent or class of constituents; proportion is based on an areal rather than a volumetric basis. Moderate and low aquifer-scale proportions were defined as the percentage of the aquifer with moderate and low relative-concentrations, respectively. Two statistical approaches, grid-based and spatially-weighted, were used to evaluate aquifer-scale proportion for individual constituents and classes of constituents.

Inorganic constituents with health-based benchmarks occurred at high relative-concentrations, in 30, 24, and 2.1% of the primary aquifers in the Southern, Middle, and Northern Sacramento Valley study units, respectively. The constituent contributing most frequently to these high aquifer-scale proportions was arsenic. Inorganic constituents with non-regulatory, aesthetic/technical-based benchmarks were high in 32, 27, and 4.6% of the primary aquifers in the Southern, Middle, and Northern Sacramento Valley study units, respectively. The primary constituent contributing to these high aquifer-scale proportions was manganese.

Organic constituents were present at high relative-concentrations in less than 1% of the primary aquifers in the Southern, Middle, and Northern Sacramento study units. Moderate relative-concentrations occurred in 2.6, 2.8, and

0.9% for the three study units, respectively. The detection frequencies for seven organic and special-interest constituents were greater than or equal to 10%—atrazine and chloroform in all three study units; simazine in the Middle and Northern Sacramento Valley study units; perchloroethene, and trichloroethene in the Southern Sacramento Valley study unit; bentazon in the Middle Sacramento Valley; and perchlorate in the Northern Sacramento Valley study unit.

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Appendix A. Selection of CDPH-Well Data for Grid-Based Approach for Status Assessments

In the Southern, Middle, and Northern Sacramento Valley study units (SSACV, MSACV, and NSACV, respectively), the historical CDPH database contains more than 1.5 million records (1,528,042) distributed across more than 105,000 wells, requiring targeted retrievals to manageably use the data to assess water quality. The paragraphs below summarize the selection process for wells and data from the CDPH database for use in the grid-based assessment of status.

The strategy used to select CDPH inorganic data for a single well in each cell where the USGS did not obtain a sample for analysis for inorganic constituents involved prioritizing data from different sources. The first choice was to select CDPH data for the grid well sampled by the USGS for other constituents, provided the CDPH data met quality-control criteria. Cation-anion balance was used as the quality-control assessment metric. Because water is electrically neutral and must have a balance between positive (cations) and negative (anions) electrically charged dissolved species, the cation/anion imbalance commonly is used as a quality-assurance check for water sample analysis (Hem, 1985). An imbalance of greater than or equal to 10% indicates an unacceptable level of uncertainty in the quality of the data. The most recent CDPH data from the well were evaluated to determine whether the cation/anion imbalance for the CDPH data was less than10%. If so, the CDPH inorganic data from the well were selected for use as grid well data for inorganic constituents. It was assumed that analyses with high-quality major-ion data also had acceptable data for trace elements, nutrients, and radiochemical constituents. For identification purposes, data from the CDPH for these grid wells were assigned identifications numbers equivalent to the USGS-grid well and the second prefix ‘DG’ inserted between the study area prefix and sequence number (for example, CDPH-grid well NAM-DG-01 is the same well as USGS-grid well NAM-01, table A1).

If the first step did not yield inorganic data for a grid cell, the second step was to identify the highest randomly ranked well in the CDPH database (other than the USGS-grid well for that cell) with a cation/anion imbalance less than 10%. If no CDPH wells in a grid cell met the charge-balance criteria or if data were insufficient to evaluate charge balance, the third choice was to select the highest randomly ranked CDPH well with any of the needed inorganic data. These wells may not have met the charge-balance criteria because a complete set of major-ion data was not available to calculate a charge balance. For identification purposes, data from the CDPH for these grid wells were assigned identifications numbers similar to the USGS-grid wells and the second prefix ‘DPH’ inserted between the study area prefix and sequence number (for example, CDPH-grid well NAM-DPH-03 is in the same cell, but is not the same well, as USGS-grid well NAM-03, table A1).

Cells lacking a USGS-grid well were checked for CDPH wells that could be added to the grid by using the steps described above. For identification purposes, these CDPH-grid wells were assigned identifications numbers equivalent to next available sequence number in the study area and the second prefix ‘DPH’ inserted between the study area prefix and sequence number.

Analysis of the combined datasets to evaluate the occurrence of relatively high or moderate concentrations was not affected by differences in laboratory reporting levels between USGS-GAMA and CDPH data because concentrations greater than one-half of water-quality benchmarks generally were substantially higher than the highest reporting levels. The locations and identification numbers of grid and USGS-understanding wells are show in figure A1. Several types of comparisons between USGS-collected and CDPH data are described in appendix B, “Comparison of Data from California Department of Public Health and Groundwater Ambient Monitoring and Assessment Program.”

Table A1. Nomenclature for wells sampled by U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[na, not applicable; —, no wells sampled or selected]

Grid or understanding well sampled by GAMA	Grid cell supplemented by CDPH data from:	
	USGS-grid well	Different well
Southern Sacramento Valley grid wells		
NAM-01	NAM-DG-01	—
NAM-02	NAM-DG-02	—
NAM-03	—	NAM-DPH-03
NAM-04	NAM-DG-04	—
NAM-05	NAM-DG-05	—
NAM-06	—	—
NAM-07	—	—
NAM-08	—	—
NAM-09	—	NAM-DPH-09
NAM-10	NAM-DG-10	—
NAM-11	NAM-DG-11	—
—	—	NAM-DPH-12
—	—	NAM-DPH-13
—	—	NAM-DPH-14
SAM-01	SAM-DG-01	—
SAM-02	SAM-DG-02	—
SAM-03	—	—
SAM-04	SAM-DG-04	—
SAM-05	SAM-DG-05	—
SAM-06	SAM-DG-06	—
SAM-07	SAM-DG-07	—
SAM-08	SAM-DG-08	—
SAM-09	—	SAM-DPH-09
SAM-10	SAM-DG-10	—
SAM-11	SAM-DG-11	—
SAM-12	—	—
—	—	SAM-DPH-13
—	—	SAM-DPH-14
SOL-01	SOL-DG-01	—
SOL-02	SOL-DG-02	—
SOL-03	SOL-DG-03	—
SOL-04	SOL-DG-04	—
SOL-05	SOL-DG-05	—
SOL-06	SOL-DG-06	—
SOL-07	SOL-DG-07	—
SOL-08	SOL-DG-08	—
SOL-09	—	—
SOL-10	—	SOL-DPH-10
Southern Sacramento Valley grid wells—Continued		
SOL-11	—	SOL-DPH-11
SOL-12	SOL-DG-12	—
SOL-13	—	SOL-DPH-13
—	—	SOL-DPH-14
—	—	SOL-DPH-15
SSV-QPC-01	SSV-QPC-DG-01	—
SSV-QPC-02	SSV-QPC-DG-02	—
SSV-QPC-03	SSV-QPC-DG-03	—
SSV-QPC-04	—	SSV-QPC-DPH-04
SSV-QPC-05	SSV-QPC-DG-05	—
SSV-QPC-06	—	—
SSV-QPC-07	—	—
SSV-QPC-08	SSV-QPC-DG-08	—
SSV-QPC-09	SSV-QPC-DG-09	—
SSV-QPC-10	SSV-QPC-DG-10	—
SSV-QPC-11	SSV-QPC-DG-11	—
—	—	SSV-QPC-DPH-12
SUI-01	—	—
SUI-02	—	SUI-DPH-02
SUI-03	SUI-DG-03	—
SUI-04	SUI-DG-04	—
SUI-05	SUI-DG-05	—
—	—	SUI-DPH-06
YOL-01	YOL-DG-01	—
YOL-02	—	YOL-DPH-02
YOL-03	—	—
YOL-04	—	—
YOL-05	YOL-DG-05	—
YOL-06	—	—
YOL-07	YOL-DG-07	—
YOL-08	—	—
YOL-09	YOL-DG-09	—
YOL-10	—	—
YOL-11	—	YOL-DPH-11
YOL-12	—	—
YOL-13	—	YOL-DPH-13
YOL-14	—	—
YOL-15	—	—

Table A1. Nomenclature for wells sampled by U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[na, not applicable; —, no wells sampled or selected]

Grid or understanding well sampled by GAMA	Grid cell supplemented by CDPH data from:	
	USGS-grid well	Different well
Southern Sacramento Valley understanding wells		
NAMFP-05	na	na
NAMFP-06	na	na
NAMFP-07	na	na
NAMFP-08	na	na
NAMFP-09	na	na
NAMFP-10	na	na
NAMFP-11	na	na
NAMFP-16	na	na
SSV-QPCFP-01	na	na
SSV-QPCFP-02	na	na
SSV-QPCFP-03	na	na
SSV-QPCFP-04	na	na
YOLFP-12	na	na
YOLFP-13	na	na
YOLFP-14	na	na
YOLFP-15	na	na
Middle Sacramento Valley grid wells		
ESAC-01	ESAC-DG-01	—
ESAC-02	ESAC-DG-02	—
ESAC-03	ESAC-DG-03	—
ESAC-04	ESAC-DG-04	—
ESAC-05	ESAC-DG-05	—
ESAC-06	ESAC-DG-06	—
ESAC-07	ESAC-DG-07	—
ESAC-08	—	ESAC-DPH-08
ESAC-09	—	—
ESAC-10	ESAC-DG-10	—
ESAC-11	—	ESAC-DPH-11
ESAC-12	—	ESAC-DPH-12
ESAC-13	—	ESAC-DPH-13
ESAC-14	ESAC-DG-14	—
ESAC-15	ESAC-DG-15	—
ESAC-16	ESAC-DG-16	—
ESAC-17	ESAC-DG-17	—
ESAC-18	ESAC-DG-18	—
ESAC-19	ESAC-DG-19	—
ESAC-20	ESAC-DG-20	—
ESAC-21	—	—
Middle Sacramento Valley grid wells—Continued		
ESAC-22	ESAC-DG-22	—
ESAC-23	—	ESAC-DG-23
ESAC-24	ESAC-DG-24	—
ESAC-25	—	—
ESAC-26	—	—
ESAC-27	—	—
ESAC-28	—	—
ESAC-29	—	—
ESAC-30	ESAC-DG-30	—
ESAC-31	—	ESAC-DPH-31
ESAC-32	ESAC-DG-32	—
ESAC-33	ESAC-DG-33	—
ESAC-34	—	—
ESAC-35	—	—
—	—	ESAC-DPH-36
—	—	ESAC-DPH-37
—	—	ESAC-DPH-38
—	—	ESAC-DPH-39
WSAC-01	—	—
WSAC-02	—	—
WSAC-03	—	—
WSAC-04	—	—
WSAC-05	WSAC-DG-05	—
WSAC-06	WSAC-DG-06	—
WSAC-07	WSAC-DG-07	—
WSAC-08	—	—
WSAC-09	WSAC-DG-09	—
WSAC-10	WSAC-DG-10	—
WSAC-11	WSAC-DG-11	—
WSAC-12	—	—
WSAC-13	—	WSAC-DPH-13
WSAC-14	—	—
WSAC-15	—	—
WSAC-16	WSAC-DG-16	—
WSAC-17	—	WSAC-DPH-17
WSAC-18	—	—
WSAC-19	—	—
WSAC-20	—	WSAC-DPH-20

Table A1. Nomenclature for wells sampled by U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[na, not applicable; —, no wells sampled or selected]

Grid or understanding well sampled by GAMA	Grid cell supplemented by CDPH data from:	
	USGS-grid well	Different well
Middle Sacramento Valley grid wells—Continued		
WSAC-21	—	WSAC-DPH-21
WSAC-22	WSAC-DG-22	—
WSAC-23	—	—
WSAC-24	—	—
WSAC-25	WSAC-DG-25	—
WSAC-26	—	—
WSAC-27	—	WSAC-DPH-27
WSAC-28	—	—
WSAC-29	WSAC-DG-29	—
WSAC-30	—	—
WSAC-31	—	—
WSAC-32	—	WSAC-DPH-32
WSAC-33	—	WSAC-DPH-33
WSAC-34	—	—
WSAC-35	—	—
WSAC-36	—	—
—	—	WSAC-DPH-37
—	—	WSAC-DPH-38
—	—	WSAC-DPH-39
—	—	WSAC-DPH-40
—	—	WSAC-DPH-41
—	—	WSAC-DPH-42
Middle Sacramento Valley understanding wells		
ESAC-FP-01	na	na
ESAC-FP-02	na	na
ESAC-FP-03	na	na
ESAC-FP-04	na	na
ESAC-FP-05	na	na
ESAC-FP-06	na	na
ESAC-FP-07	na	na
WSAC-FP-01	na	na
WSAC-FP-02	na	na
WSAC-FP-03	na	na
WSAC-FP-04	na	na
WSAC-FP-05	na	na
WSAC-FP-06	na	na
WSAC-FP-07	na	na
WSAC-FP-08	na	na

Grid or understanding well sampled by GAMA	Grid cell supplemented by CDPH data from:	
	USGS-grid well	Different well
Northern Sacramento Valley grid wells		
NSAC-01	—	—
NSAC-02	—	—
NSAC-03	—	—
NSAC-04	—	—
NSAC-05	NSAC-DG-05	—
NSAC-06	NSAC-DG-06	—
NSAC-07	NSAC-DG-07	—
NSAC-08	—	—
NSAC-09	—	—
NSAC-10	NSAC-DG-10	—
NSAC-11	NSAC-DG-11	—
NSAC-12	NSAC-DG-12	—
NSAC-13	—	NSAC-DPH-13
NSAC-14	NSAC-DG-14	—
NSAC-15	—	NSAC-DPH-15
NSAC-16	—	—
NSAC-17	NSAC-DG-17	—
NSAC-18	—	—
NSAC-19	NSAC-DG-19	—
NSAC-20	—	—
RED-01	RED-DG-01	—
RED-02	RED-DG-02	—
RED-03	—	—
RED-04	RED-DG-04	—
RED-05	RED-DG-05	—
RED-06	—	—
RED-07	—	—
RED-08	RED-DG-08	—
RED-09	RED-DG-09	—
RED-10	RED-DG-10	—
RED-11	RED-DG-11	—
RED-12	—	—
RED-13	RED-DG-13	—
RED-14	—	—
RED-15	—	RED-DPH-15
RED-16	—	
RED-17	—	RED-DPH-17
RED-18	RED-DG-18	—

Table A1. Nomenclature for wells sampled by U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[na, not applicable; —, no wells sampled or selected]

Grid or understanding well sampled by GAMA	Grid cell supplemented by CDPH data from:	
	USGS-grid well	Different well
Northern Sacramento Valley grid wells—Continued		
RED-19	—	—
RED-20	—	RED-DPH-20
RED-21	—	—
RED-22	—	—
RED-23	—	—
Northern Sacramento Valley understanding wells		
NSAC-MW-01	na	na
NSAC-MW-02	na	na
NSAC-MW-03	na	na
NSAC-MW-04	na	na
NSAC-MW-05	na	na
NSAC-MW-06	na	na
NSAC-U-01	na	na
NSAC-U-02	na	na
NSAC-U-03	na	na
Northern Sacramento Valley understanding wells—Continued		
NSAC-U-04	na	na
NSAC-U-05	na	na
NSAC-U-06	na	na
NSAC-U-07	na	na
NSAC-U-08	na	na
RED-MW-01	na	na
RED-MW-02	na	na
RED-MW-03	na	na
RED-MW-04	na	na
RED-MW-05	na	na
RED-MW-06	na	na
RED-MW-07	na	na
RED-U-01	na	na
RED-U-02	na	na

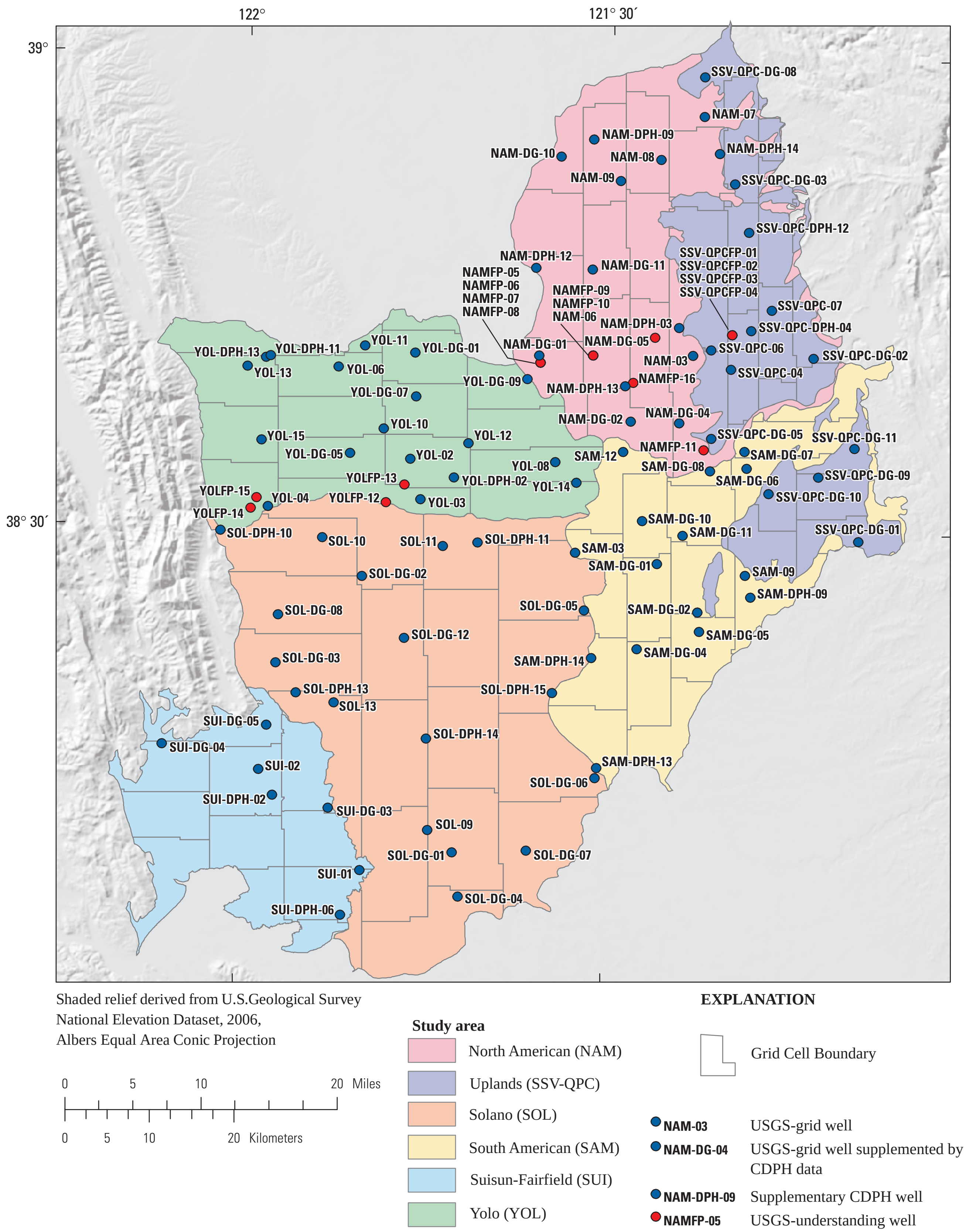
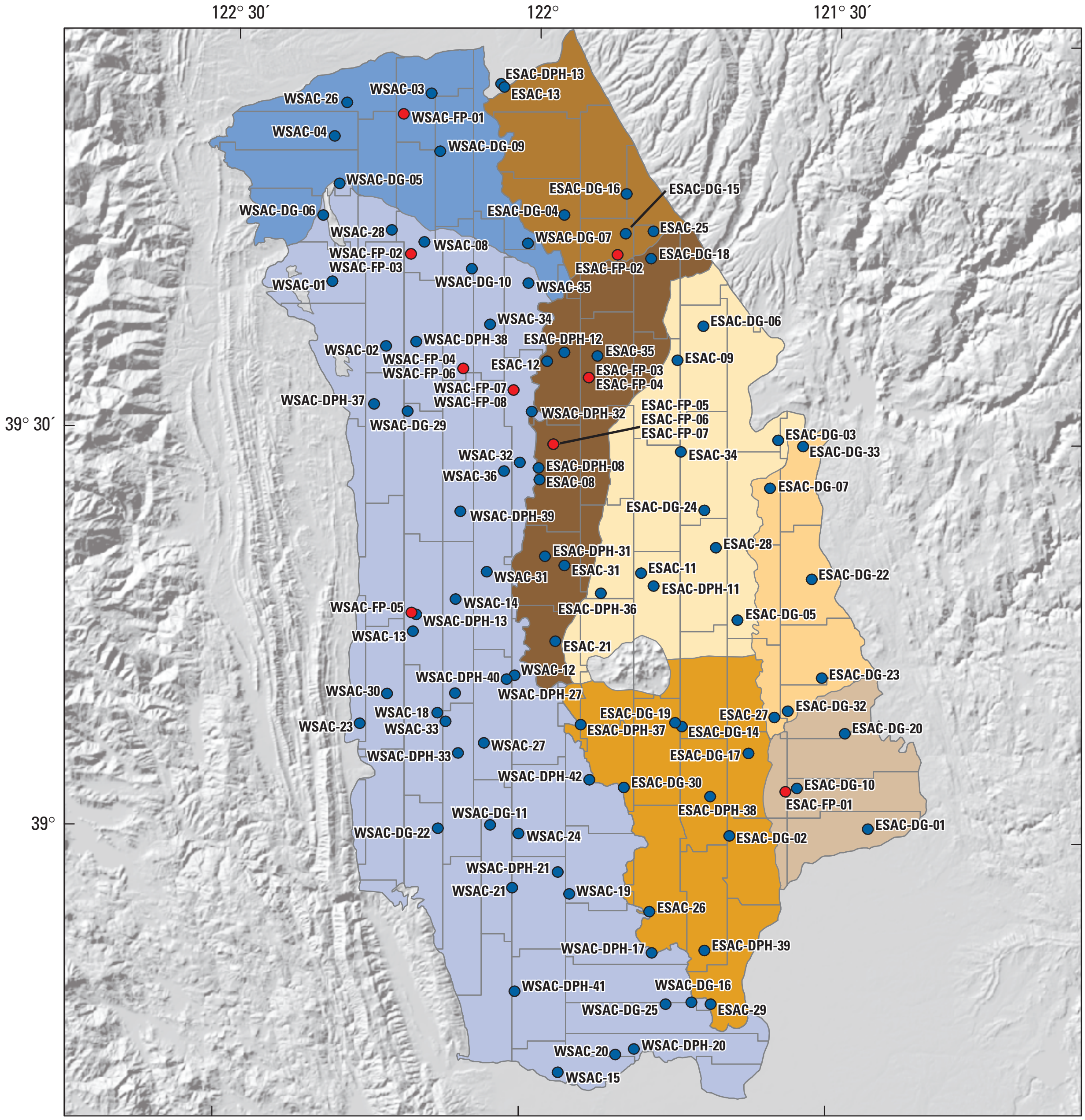


Figure A1. Map showing identifiers and locations of USGS-grid wells, USGS-grid wells supplemented with CDPH data, supplementary CDPH wells, and USGS-understanding wells sampled during 2005–08 in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.



Shaded relief derived from U.S.Geological Survey
National Elevation Dataset, 2006,
Albers Equal Area Conic Projection
Horizontal datum: North American Datum
of 1983 (NAD 83)

0 5 10 20 Miles

0 5 10 20 Kilometers

EXPLANATION

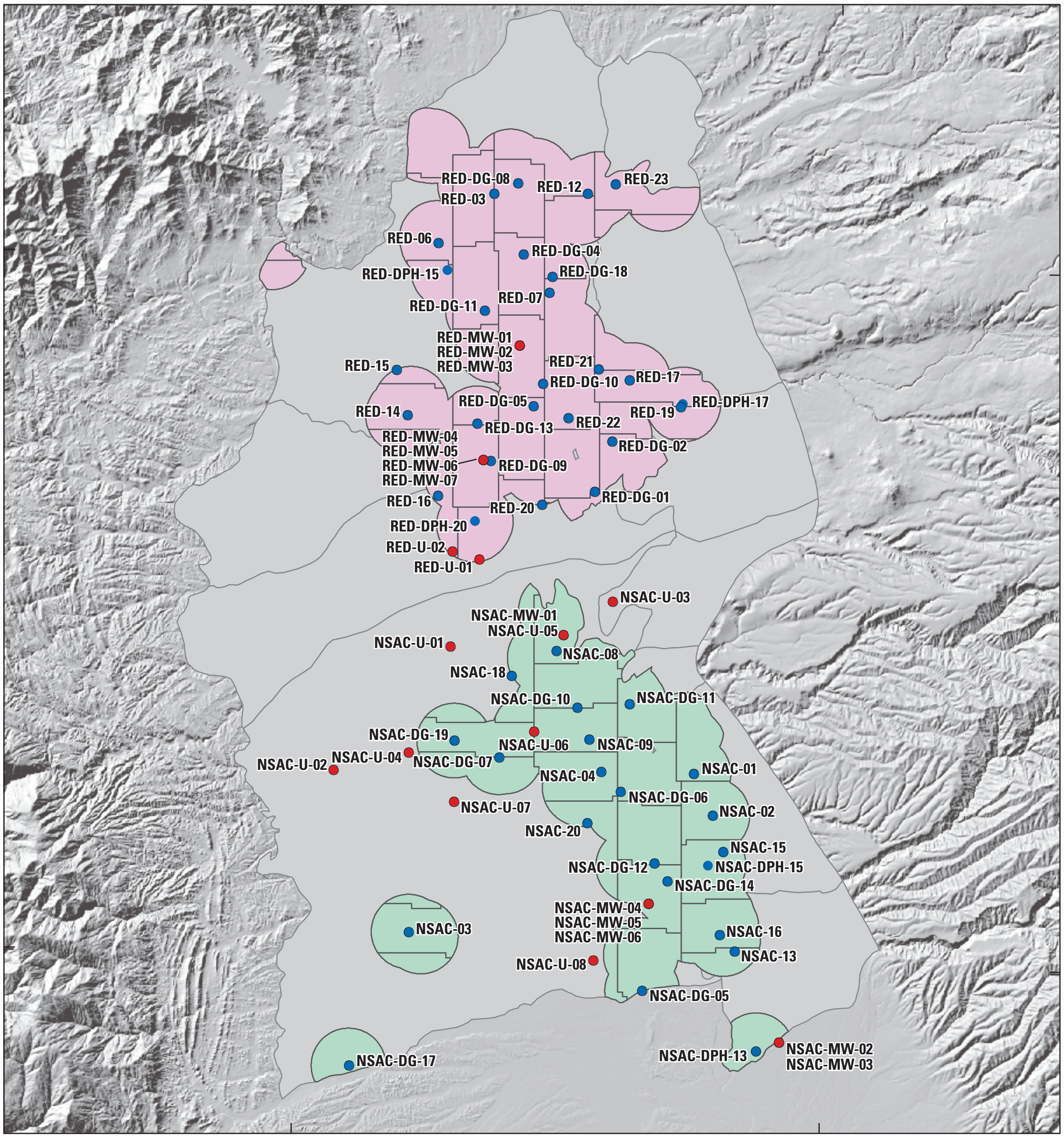
West study area sub-basins
- Colusa
- Corning

East study area sub-basins
- East Butte
- North Yuba
- South Yuba
- Sutter
- Vina
- West Butte

Grid Cell Boundary

- ESAC-08 USGS-grid well
- ESAC-DG-10 USGS-grid well supplemented by CDPH data
- ESAC-DPH-11 Supplementary CDPH well
- ESAC-FP-01 USGS-understanding well

Figure A1.—Continued.



Shaded relief derived from U.S.Geological Survey
National Elevation Dataset, 2006,
Albers Equal Area Conic Projection
Horizontal datum: North American Datum of 1983 (NAD 83)

0 5 10 20 Miles

0 5 10 20 Kilometers

EXPLANATION

North Sacramento Valley Study Unit (NSACV)	Grid Cell Boundary
North Sacramento (NSAC)	**NSAC-01** USGS-grid well
	NSAC-DG-05 USGS-grid well supplemented by CDPH data
Redding (RED)	**NSAC-DPH-13** Supplementary CDPH well
	NSAC-MW-01 USGS-understanding well

Figure A1.—Continued.

Appendix B. Comparison of Data from California Department of Public Health and Groundwater Ambient Monitoring and Assessment Program

Comparisons of CDPH and USGS-GAMA data were done to assess the validity of using data from these different sources in combination. Because laboratory reporting levels for most organic constituents were substantially lower for USGS-GAMA data than for CDPH data (table B1), it generally was not possible to meaningfully directly compare measured concentrations of these constituent types in individual wells. However, concentrations of major ions and nitrate, which generally are prevalent and have concentrations well above reporting levels, were compared for each well with data from both sources.

The paired analyses of eight different constituents (calcium, magnesium, sodium, alkalinity, chloride, sulfate, TDS, nitrate) with values greater than the reporting levels in both databases were combined into one dataset for each study unit so that the dataset was large enough for meaningful statistical comparison (figs. B1*A*, B1*B*, and B1*C*).

Non-parametric signed rank tests (Wilcoxon rank sum) indicated no significant differences between the paired datasets of SSACV, MSACV, and NSACV, with p-values greater than 0.05 in all cases. Although differences between the paired datasets occurred for a few wells, most sample pairs plotted close to a 1-to-1 line (figs. B1*A*, B1*B*, and B1*C*). Additionally, the relative standard deviation (RSD) was calculated for each data pair. In SSACV, the median RSD was 4.2% with greater than 90% of the RSD values less than 20%. In MSACV, the median RSD was 5.8% with 88% of the RSD values less than 20%. In NSACV, the median RSD was 5.2% with 86% of the RSD values less than 20%. These direct comparisons indicated that the USGS-GAMA and CDPH data for inorganic constituents were not significantly different.

Combined USGS-GAMA and CDPH major-ion data for grid wells were plotted on trilinear diagrams (Piper, 1944) to determine whether the grid wells sampled the full distribution of groundwater types that have historically been detected in the study unit. Trilinear diagrams show the relative contribution of major cations and anions (on a charge equivalent basis) as a percentage of the total ion content of the water (figs. B2*A*, B2*B*, and B2*C*). Trilinear diagrams are often used to determine groundwater type (Hem, 1985). All recent CDPH data (2002–2008) from each study unit having cation/anion data and a cation/anion balance of less than 10% were retrieved and plotted on the trilinear diagrams for comparison with grid-well data.

The range of groundwater types represented by the grid wells (USGS and CDPH combined) was similar to the range of groundwater types reported in the CDPH database for each of the three study units (figs. B2*A*,B2*B*, and B2*C*). The anion compositions of the majority of CDPH and grid wells from all three study units were classified as bicarbonate-type waters (anion composition greater than 60% bicarbonate). Some bicarbonate-chloride-type waters were present in the SSACV and MSACV study units, and a few bicarbonate-sulfate-type and mixed anion-type waters were present in the MSACV study unit. The cation composition of most CDPH and grid wells was classified as mixed-cation-type in the SSACV and NSACV study units, and as calcium-magnesium-type or mixed-cation-type in the MSACV study unit. All three study units also contained some sodium-potassium-type waters.

Table B1. Comparison of number of compounds and median method detection limit or long-term method detection level by type of constituent for data stored in the California Department of Public Health (CDPH) database and data collected by the Ground water Ambient Monitoring and Assessment (GAMA) study.

[CDPH, California Department of Public Health; MDL, method detection limit; LT-MDL, long-term method detection level; µg/L, microgram per liter; nc, not collected]

Constituent type	CDPH		GAMA		Median units
	Number of compounds	Median MDL	Number of compounds	Median LT-MDL	
Volatile organic compounds plus gasoline oxygenates (including fumigants)	61	0.5	88	0.03	µg/L
Pesticides plus degradates	27	2	135	0.01	µg/L
Perchlorate	1	4	1	[1] 0.5	µg/L
N-Nitrosodimethylamine (NDMA)	nc	nc	1	[1] 0.002	µg/L

[1] Method detection limit (MDL).

In the SSACV study unit, proportions of chloride for four grid wells were higher than for the CDPH wells used in the comparison; however, three of these four wells were CDPH wells and are therefore still representative of the primary aquifer. The fourth well was a non-CDPH well located in the Suisun-Fairfield study area. The Suisun-Fairfield study area contained a limited number of CDPH wells and is on the fringes of the Sacramento-San Joaquin Delta, which is a more saline environment than is typical throughout the rest of the study unit. In the MSACV study unit, the proportion of sodium plus potassium for one grid well was higher than for any of the CDPH wells used in the comparison and proportions of bicarbonate for two grid wells were lower than for any of the CDPH wells. These three wells were not in the CDPH database and were located in areas with relatively few CDPH wells.

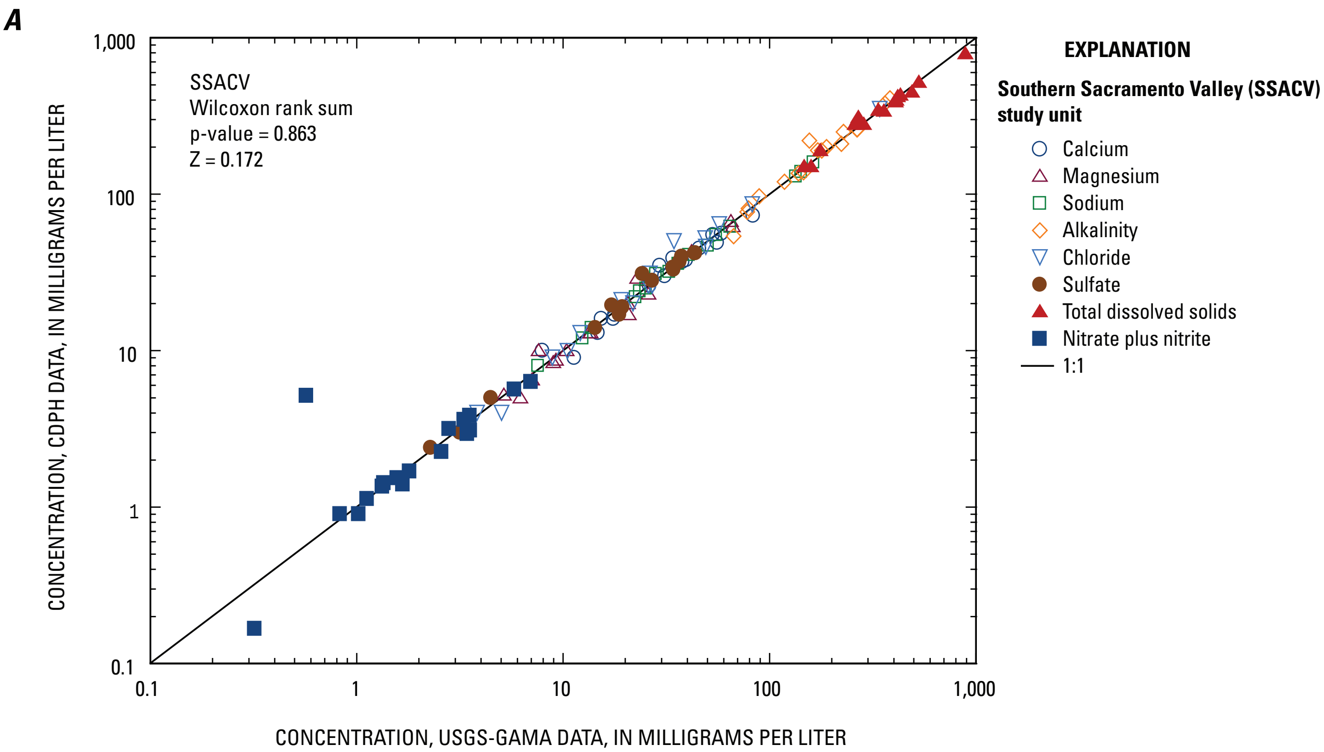


Figure B1. Graphs showing paired inorganic concentrations from wells sampled by the Groundwater Ambient Monitoring and Assessment (GAMA) Program between 2005–08 and the most recent available analysis in the California Department of Health Services (CDPH) database for the same wells in the (*A*) Southern , (*B*) Middle and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment study units, California.

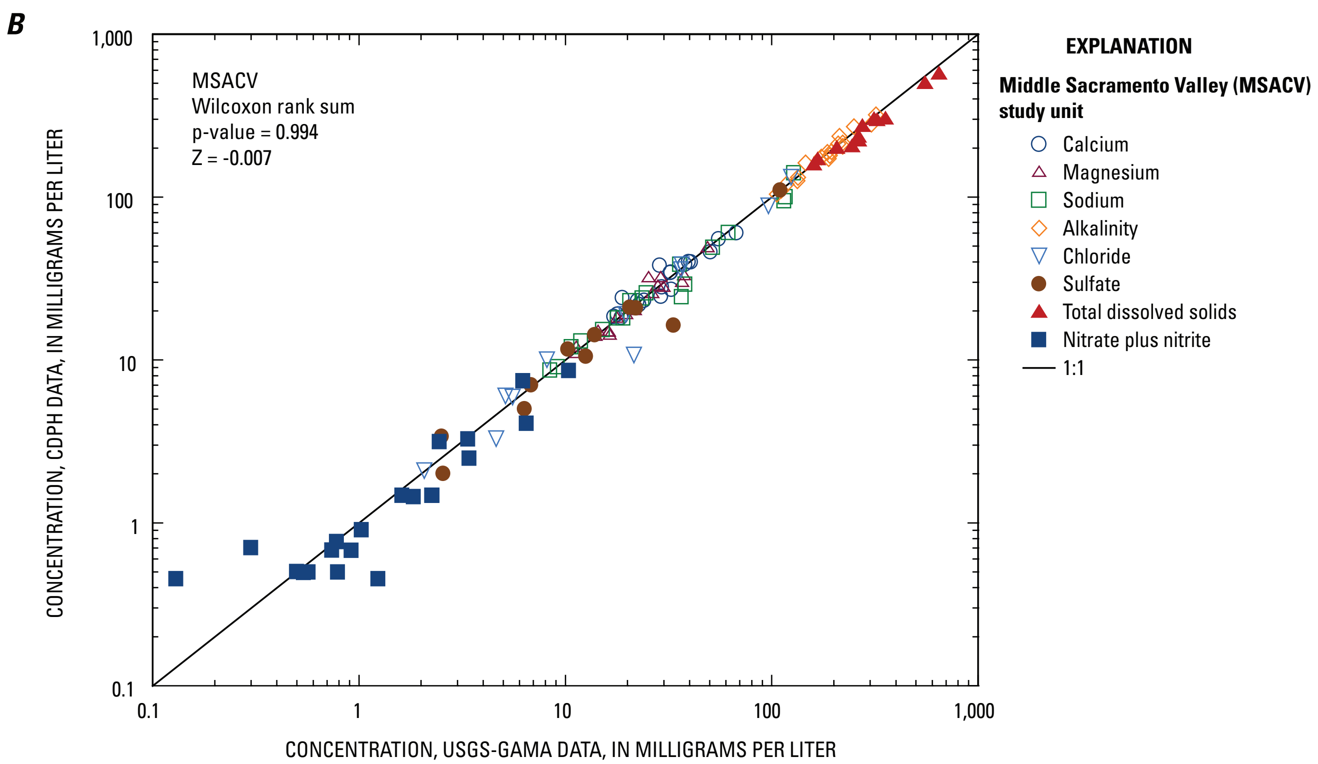


Figure B1.—Continued.

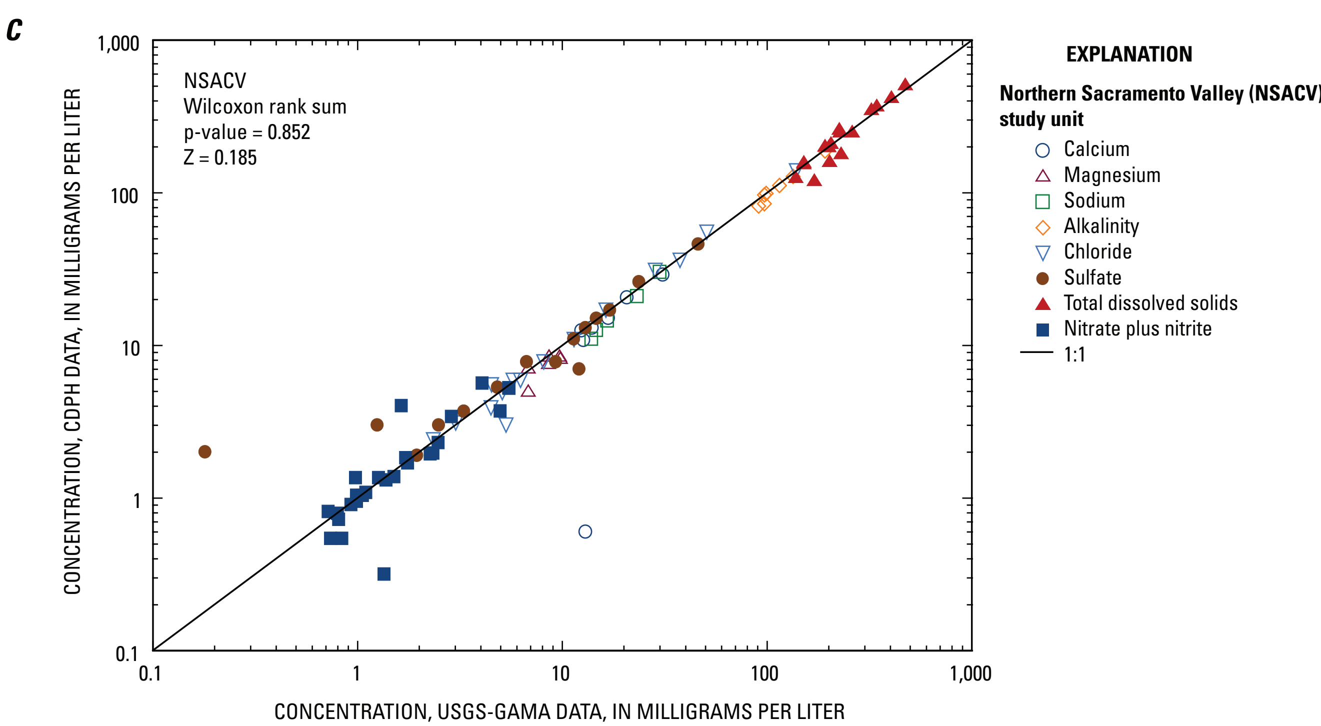


Figure B1.—Continued.

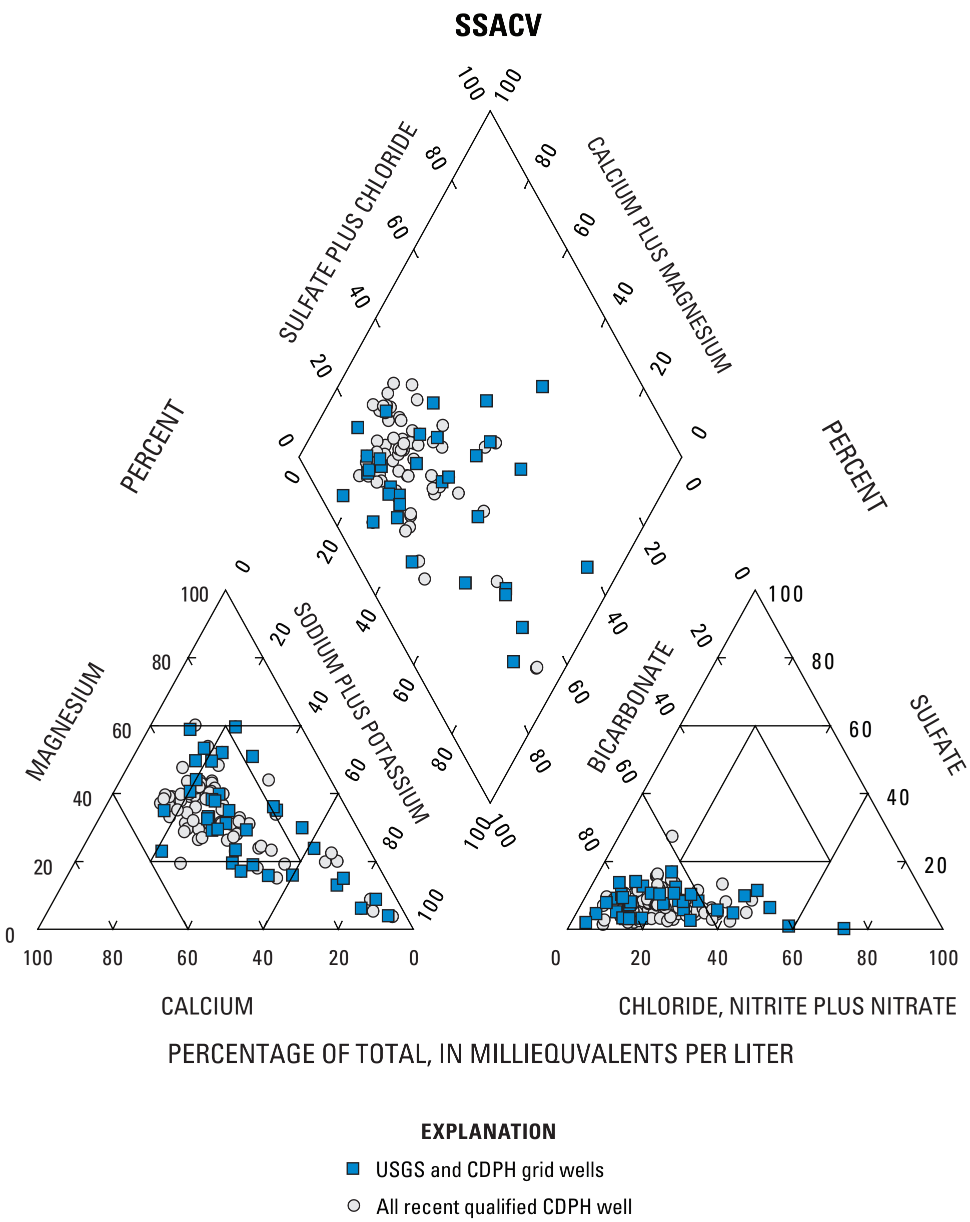


Figure B2. Trilinear diagrams comparing water types in grid wells with water types in all wells in the California Department of Public Health (CDPH) database that have a charge imbalance of less than 10 percent in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

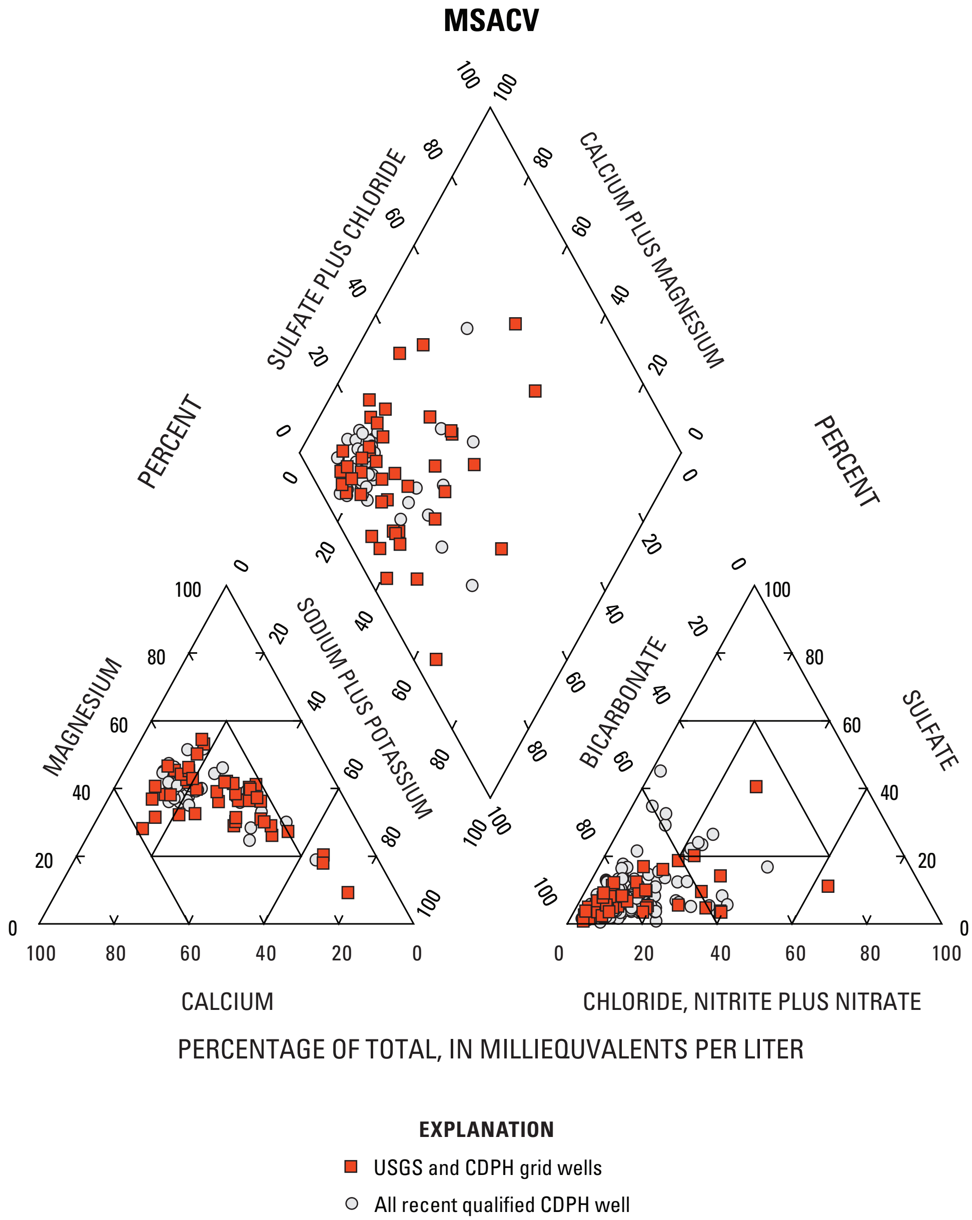


Figure B2.—Continued.

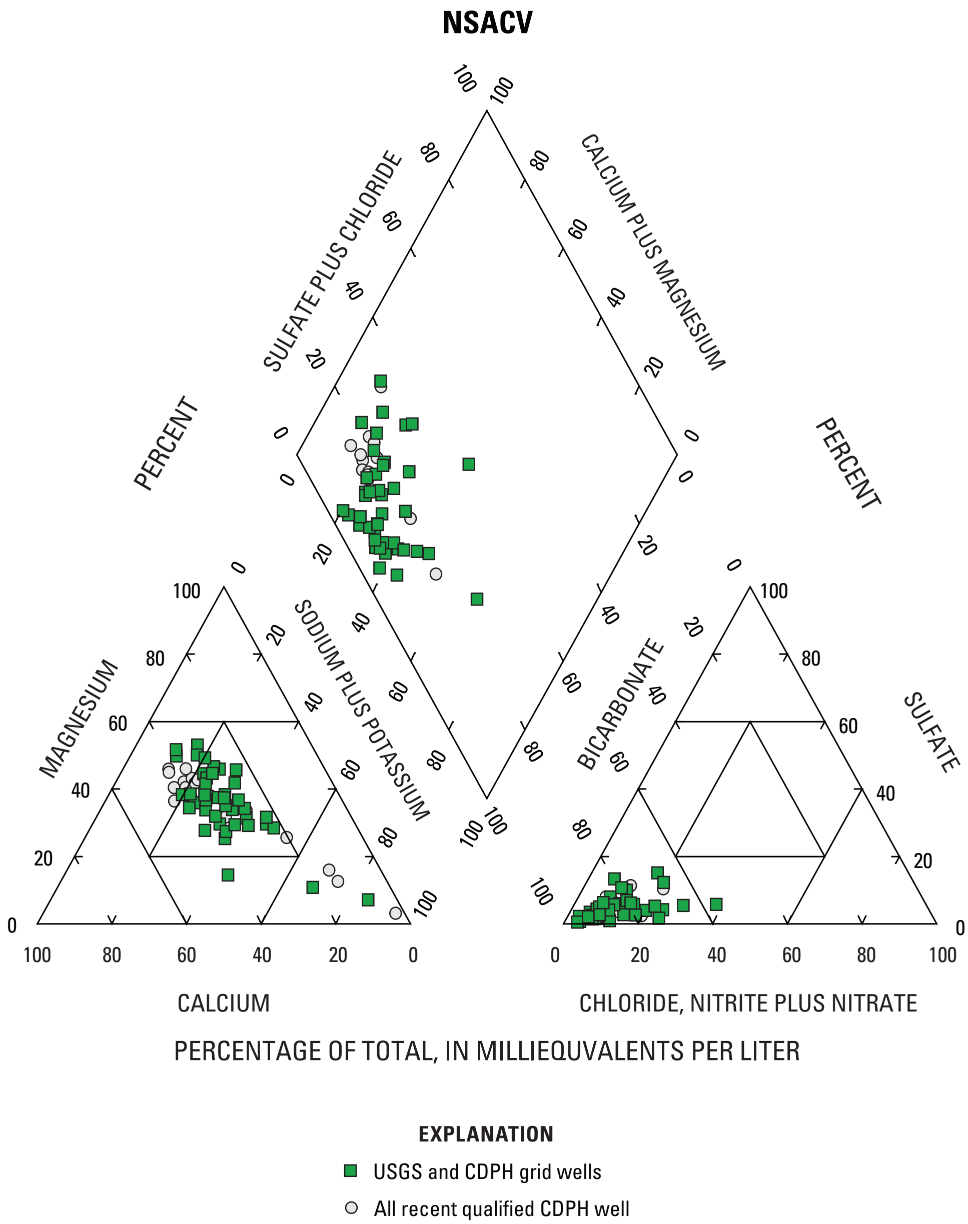


Figure B2.—Continued.

Appendix C. Area-Weighting

The MSACV and NSACV study units each consisted of two study areas, and the sizes of the grid cells in the study areas in each study unit were nearly identical: 39 mi^2 and 38 mi^2 in the ESAC and WSAC study areas of the MSACV study unit, and 9 mi^2 in both the NSAC and RED study areas of the NSACV study unit. Because every grid well in the study unit represented the same amount of area, aquifer scale-proportions for the study unit could be calculated directly by dividing the number of grid cells with a high relative-concentration of a constituent by the total number of grid cells with data for the constituent. The SSACV study unit, however, consisted of study areas that each had different grid cell sizes. Thus, calculation of aquifer-scale proportions required correcting for the fact that grid wells in the different study areas represented different amounts of area.

Southern Sacramento Valley (SSACV): studyarea grid cells sizes	
North American (NAM)	23 mi^2
South American (SAM)	21 mi^2
Uplands (QPC)	18 mi^2
Yolo (YOL)	24 mi^2
Solano (SOL)	39 mi^2
Suisun-Fairfield (SUI)[1]	22 mi^2

[1]Study area not included in area weighting procedure.

Grid-based aquifer-scale proportions for the SSACV study unit were determined by calculating the grid-based aquifer-scale proportions in each study area separately, and then calculating the area-weighted sum:

$$P_{SU} = \sum P_{SA} F_{SA}, \qquad \text{(C1)}$$

where

P_{SU} is the grid-based aquifer-scale proportion for the study unit,

P_{SA} is the grid-based aquifer-scale proportion for a study area, and

F_{SA} is the fraction of the total study unit area occupied by the study area.

Values of F_{SA} were calculated as follows:

$$F_{SA_k} = \frac{A_{SA_k} C_{SA_k}}{\sum_{k=1}^{k=5} A_{SA_k} C_{SA_k}}, \qquad \text{(C2)}$$

where

A_{SA_k} is the area of the cells in the study area, k,

C_{SA_k} is the median number of cells in study unit k, with data for the water-quality constituents, and

k is the study area.

Study area	Cell area (mi^2)	Median number of cells with data	F_{SA}	Percent of the median total number of cells with data
North American (NAM)	23	9	15%	16%
South American (SAM)	21	12	18%	22%
Solano (SOL)	39	13	36%	24%
Yolo (YOL)	24	10	17%	18%
Uplands (SSV-QPC)	18	11	14%	20%

The Suisun-Fairfield (SUI) study area was not included in the calculation of aquifer-scale proportions for the SSACV study unit. Results from the Suisun-Fairfield (SUI) study area were removed from the calculations because they were not considered representative of the SSACV as defined by the other five study areas. Only five wells were sampled in the SUI study area and of those five only two are used for public-supply. Drinking water in the SUI study area primarily comes from surface-water sources (Suisun Solano Water Authority, 2006).

A comparison between the study unit grid-based proportions with and without area-weighting is shown in table C1. Grid-based proportions in the six individual study areas of SSACV study unit are listed in table C2. If the area-weighting calculation had not been done, then cells in the SOL study area would have contributed less to the overall study unit aquifer-scale proportions than warranted for an equal area result, and cells in the SSV-QPC study area would have contributed more.

Table C1. Comparison between aquifer-scale proportions determined by using grid-based methods with and without areal weighting for constituents that have ever had concentrations above water-quality benchmarks from March 14, 1984, to June 30, 2005, from the California Department of Health Services database, Southern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

[Grid-based aquifer proportions of organic constituents are based on samples collected by the U.S. Geological Survey from wells between March and June 2005. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark)]

Constituent	Typical use or source	Total number of wells	Southern Sacramento Valley (SSACV) areally weighted proportions [1]		Southern Sacramento Valley (SSACV) proportions without areal weighting [1]	
			Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)
Trace elements						
Aluminum	Naturally occurring	56	0	0	0	0
Arsenic	Naturally occurring	57	12	16	12	14
Barium	Naturally occurring	56	1.7	0	1.8	0
Boron	Naturally occurring	49	13	19	12	18
Chromium	Naturally occurring	52	3.4	0	3.8	0
Fluoride	Naturally occurring	55	0	0	0	0
Lead	Naturally occurring	54	0	0	0	0
Selenium	Naturally occurring	56	0	0	0	0
Vanadium	Naturally occurring	49	5.3	0	6.1	0
Radioactive constituents						
Gross alpha particle activity	Naturally occurring	46	1.8	0	2.2	0
Radium	Naturally occurring	22	9.0	0	4.5	0
Nutrients						
Nitrate plus nitrite (as nitrogen)	Naturally occurring or from human activity	63	11	1.4	9.5	1.6
Nitrite (as nitrogen)	Naturally occurring or from human activity	61	0.0	0	0.0	0
Major ions, elements, and total dissolved solids (SMCLs)						
Chloride	Naturally occurring	51	1.7	0	2.0	0
Iron	Naturally occurring	57	1.5	16	1.8	12
Manganese	Naturally occurring	57	0	27	0	25
Total dissolved solids (TDS)	Naturally occurring	59	22	1.1	22	1.7
Volatile organic compounds (VOCs)						
tert-Butyl alcohol (TBA)	Gasoline oxygenate	7	0	0	0	0
Carbon disulfide	Natural, industrial	62	0	0	0	0
Chloroform	Disinfection by-product	62	0	0	0	0
Methyl-*tert*-butyl-ether (MTBE)	Gasoline oxygenate	62	0	0	0	0
Tetrachloroethylene (PCE)	Dry-cleaning, metal degreasing	62	1.3	0	1.6	0
Trichloroethylene (TCE)	Solvent, PCE breakdown	62	0	0	0	0
Pesticides						
Atrazine	Herbicide	61	0	0	0	0
Bentazon	Herbicide	25	0	0	0	0
Dieldrin	Insecticide	61	1.3	0	1.6	0
Constituents of special interest						
Perchlorate	Natural, rocket fuel, flares	25	14	0	20	0

[1] Proportions do not include results from the Suisun–Fairfield study area.

Table C2. Grid-based proportions for individual study areas within the South Sacramento Valley study unit (not including the Suisun-Fairfield study area) for constituents that have ever had concentrations greater than water-quality benchmarks from March 14, 1984, to June 30, 2005, from the California Department of Public Health database.

[Grid-based aquifer proportions of organic constituents are based on samples collected by the U.S. Geological Survey from wells during March–June 2005. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark). **Abbreviations:** SMCL, secondary maximum contaminant level]

Constituent	North American study area (NAM)			South American study area (SAM)			Solano study area (SOL)		
	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)
Trace elements									
Aluminum	9	0	0	13	0	0	13	0	0
Arsenic	9	22	11	13	7.6	15	14	7.1	28
Barium	9	0	0	13	0	0	13	0	0
Boron	8	0	13	11	0	0	10	20	20
Chromium	8	0	0	13	0	0	12	0	0
Fluoride	11	0	0	11	0	0	12	0	0
Lead	7	0	0	13	0	0	13	0	0
Selenium	9	0	0	13	0	0	13	0	0
Vanadium	8	25	0	11	9.0	0	10	0	0
Radioactive constituents									
Gross alpha particle activity	8	0	0	10	10	0	10	0	0
Radium	6	0	0	1	0	0	4	25	0
Nutrients									
Nitrate plus nitrite (as nitrogen)	12	0	0	13	15	0	14	14	0
Nitrite (as nitrogen)	12	0	0	13	0	0	14	0	0
Major ions, elements, and total dissolved solids (SMCLs)									
Chloride	9	0	0	10	0	0	12	0	0
Iron	10	0	20	12	8.3	8.3	14	0	21
Manganese	10	0	30	12	0	33	14	0	36
Total dissolved solids (TDS)	11	9.0	0	10	0	0	13	31	0

Table C2. Grid-based proportions for individual study areas within the South Sacramento Valley study unit (not including the Suisun-Fairfield study area) for constituents that have ever had concentrations greater than water-quality benchmarks from March 14, 1984, to June 30, 2005, from the California Department of Public Health database.—Continued

[Grid-based aquifer proportions of organic constituents are based on samples collected by the U.S. Geological Survey from wells during March–June 2005. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark). **Abbreviations:** SMCL, secondary maximum contaminant level]

Constituent	North American study area (NAM)			South American study area (SAM)			Solano study area (SOL)		
	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)
Volatile organic compounds (VOCs)									
tert-Butyl alcohol (TBA)	0	0	0	0	0	0	0	0	0
Carbon disulfide	11	0	0	12	0	0	13	0	0
Chloroform	11	0	0	12	0	0	13	0	0
Methyl-*tert*-butyl-ether (MTBE)	11	0	0	12	0	0	13	0	0
Tetrachloroethylene (PCE)	11	9.1	0	12	0	0	13	0	0
Trichloroethylene (TCE)	11	0	0	12	0	0	13	0	0
Pesticides									
Atrazine	11	0	0	12	0	0	13	0	0
Bentazon	4	0	0	4	0	0	3	0	0
Dieldrin	11	9.1	0	12	0	0	13	0	0
Constituents of special interest									
Perchlorate	4	0	0	4	25	0	3	0	0

Table C2. Grid-based proportions for individual study areas within the South Sacramento Valley study unit (not including the Suisun-Fairfield study area) for constituents that have ever had concentrations greater than water-quality benchmarks from March 14, 1984, to June 30, 2005, from the California Department of Public Health database.—Continued

[Grid-based aquifer proportions of organic constituents are based on samples collected by the U.S. Geological Survey from wells during March–June 2005. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark). **Abbreviations:** SMCL, secondary maximum contaminant level]

Constituent	Yolo study area (YOL)			Uplands study area (SSV-QPC)			Suisun-Fairfield study area (SUI)[1]		
	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)
Trace elements									
Aluminum	10	0	0	11	0	0	2	0	0
Arsenic	10	30	10	11	0	0	2	0	50
Barium	10	10	0	11	0	0	2	5	0
Boron	10	20	50	10	20	10	2	50	50
Chromium	10	20	0	9	0	0	2	0	0
Fluoride	10	0	0	11	0	0	3	3.3	0
Lead	10	0	0	11	0	0	2	0	0
Selenium	10	0	0	11	0	0	2	0	0
Vanadium	10	0	0	10	0	0	2	0	0
Radioactive constituents									
Gross alpha radioactivity	8	0	0	10	0	0	1	100	0
Radium	6	0	0	5	0	0	0	0	0
Nutrients									
Nitrate plus nitrite (as nitrogen)	12	16	8.3	12	0	0	6	33.3	16.6
Nitrite (as nitrogen)	10	0	0	12	0	0	5	20	0
Major ions, elements, and total dissolved solids (SMCLs)									
Chloride	10	10	0	10	0	0	2	0	0
Iron	10	0	20	11	0	0	3	0	66.6
Manganese	10	0	20	11	0	0	3	0	66.6
Total dissolved solids (TDS)	15	53	6.7	10	0	0	5	80	0

Table C2. Grid-based proportions for individual study areas within the South Sacramento Valley study unit (not including the Suisun-Fairfield study area) for constituents that have ever had concentrations greater than water-quality benchmarks from March 14, 1984, to June 30, 2005, from the California Department of Public Health database.—Continued

[Grid-based aquifer proportions of organic constituents are based on samples collected by the U.S. Geological Survey from wells during March–June 2005. High, concentrations greater than water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of benchmark but less than benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark); low, concentrations less than 0.1 of benchmark for organic constituents (threshold for inorganic constituents is 0.5 of benchmark). **Abbreviations:** SMCL, secondary maximum contaminant level]

Constituent	Yolo study area (YOL)			Uplands study area (SSV-QPC)			Suisun-Fairfield study area (SUI)[1]		
	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)	Number of wells	Moderate aquifer proportion (in percent)	High aquifer proportion (in percent)
Volatile organic compounds (VOCs)									
tert-Butyl alcohol (TBA)	5	0	0	2	0	0	0	0	0
Carbon disulfide	15	0	0	11	0	0	5	0	0
Chloroform	15	0	0	11	0	0	5	0	0
Methyl-*tert*-butyl-ether (MTBE)	15	0	0	11	0	0	5	0	0
Tetrachloroethylene (PCE)	15	0	0	11	0	0	5	0	0
Trichloroethylene (TCE)	15	0	0	11	0	0	5	0	0
Pesticides									
Atrazine	14	0	0	11	0	0	4	0	0
Bentazon	8	0	0	6	0	0	2	0	0
Dieldrin	14	0	0	11	0	0	4	0	0
Special-interst constituents									
Perchlorate	8	0	0	6	67	0	2	0	0

[1] Results from the Suisun-Field study area shown here are not included in the calculation of raw detection frequency, spatially weighted, or grid-based aquifer-scale proportions.

Appendix D. Calculating Total Dissolved Solids For Wells Without Measured Total Dissolved Solids

Direct measurements of total dissolved solids (TDS) as residue on evaporation were only available for 169 USGS-GAMA wells, leaving 66 wells without measured TDS (40 wells in SSACV and 26 wells in MSACV). Specific conductance (SC), the ability of a water sample to conduct electricity, is related to TDS and was available in all 235 USGS-grid and USGS-understanding wells. For wells in SSACV and MSACV with no measured TDS values, TDS was calculated from SC values by using linear regression equations derived from the comparison of TDS and SC values obtained from the USGS-GAMA wells (Hem, 1985). In SSACV, the correlation coefficient (r^2) for the linear regression equation (TDS = 0.559*SC +48.16) was 0.968. In MSACV, the r^2 value for the linear regression equation (TDS = 0.573*SC +32.12) was 0.989. Measured TDS values from selected CDPH wells were combined with USGS measured and calculated TDS values.

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Appendix E. Ancillary Datasets

Land-Use Classification

Land use was classified by using an “enhanced” version of the satellite-derived (30-m pixel resolution), nationwide USGS National Land Cover Dataset (Nakagaki and others, 2007). This dataset has been used in previous national and regional studies relating land use to water quality (Gilliom and others, 2006; Zogorski and others, 2006). The data represent land use during about the early 1990s. The imagery is classified into 25 land-cover classifications (Nakagaki and Wolock, 2005). These 25 land-cover classifications were assigned to 3 general classifications for the purpose of general categorization of principal land use: urban, agricultural, and natural. Land-use statistics for the study unit, study areas, and for circles with a radius of 500 m around each grid, USGS-understanding, and all CDPH wells were calculated for classified datasets by using ArcGIS (version 9.2) (Johnson and Belitz, 2009).

SSACV and MSACV primarily are agricultural study units with 53 and 67% agricultural land use, respectively, whereas NSACV primarily is natural with 61% natural land use (fig. E1). The proportion of urban land use in the SSACV study unit is the largest at 14%. Land use in areas in the 500-m buffers surrounding grid wells was less agricultural and natural and more urban than the land use in the study units as a whole (fig. E1). Further increases in the amount of urbanization around wells are observed when looking at the 500-m buffer area around all CDPH wells (compared to only the grid wells) in each study unit (fig. E1).

Individual study areas within each of the study units generally show the same increase in urbanization within the buffer areas around grid and CDPH wells (figs. E2*A*, E2*B*, and E2*C*), because wells often are located near population centers. Unlike the other study areas in SSACV, land-use proportions within the buffer areas of the Suisun-Fairfield study area shift more towards agricultural land use (fig. E2*A*) rather than towards urban land use, compared to the land use for the study area as a whole. Relatively few grid wells (five wells) were sampled in the Suisun-Fairfield study area because of the small size and location on the periphery of the Sacramento-San Joaquin delta (fig. 2). Land use for two of the five wells sampled was greater than 80% agricultural and the other three wells were in areas of predominately natural land use (fig E2*A*). Land-use proportions for all individual wells are listed in table E1 and are plotted on figures E2*A*, E2*B*, and E2*C*.

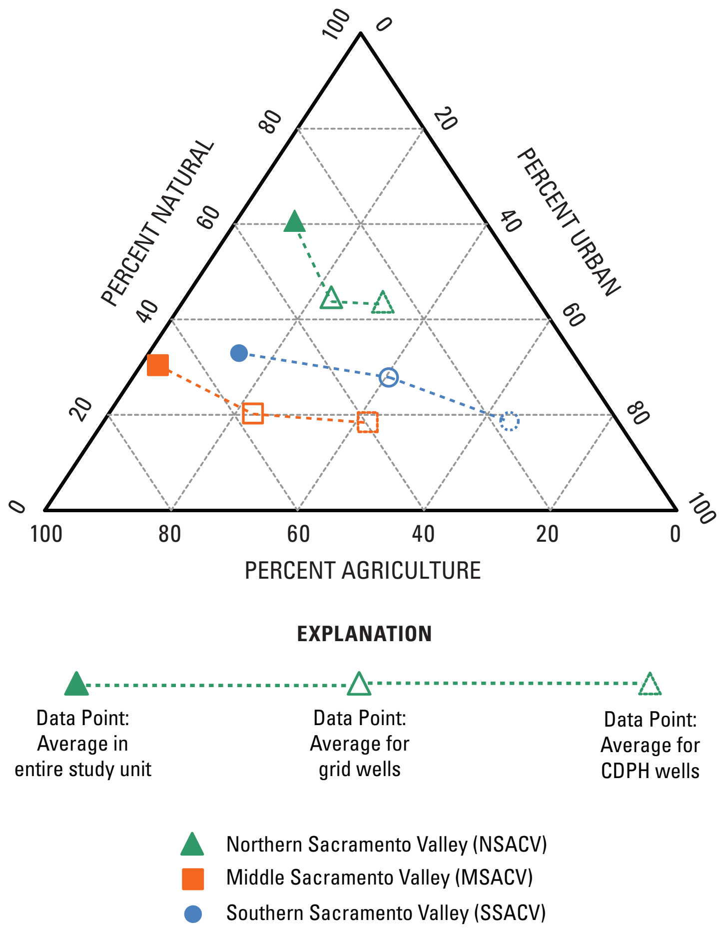

Figure E1. Proportions of urban, agricultural, and natural land use in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

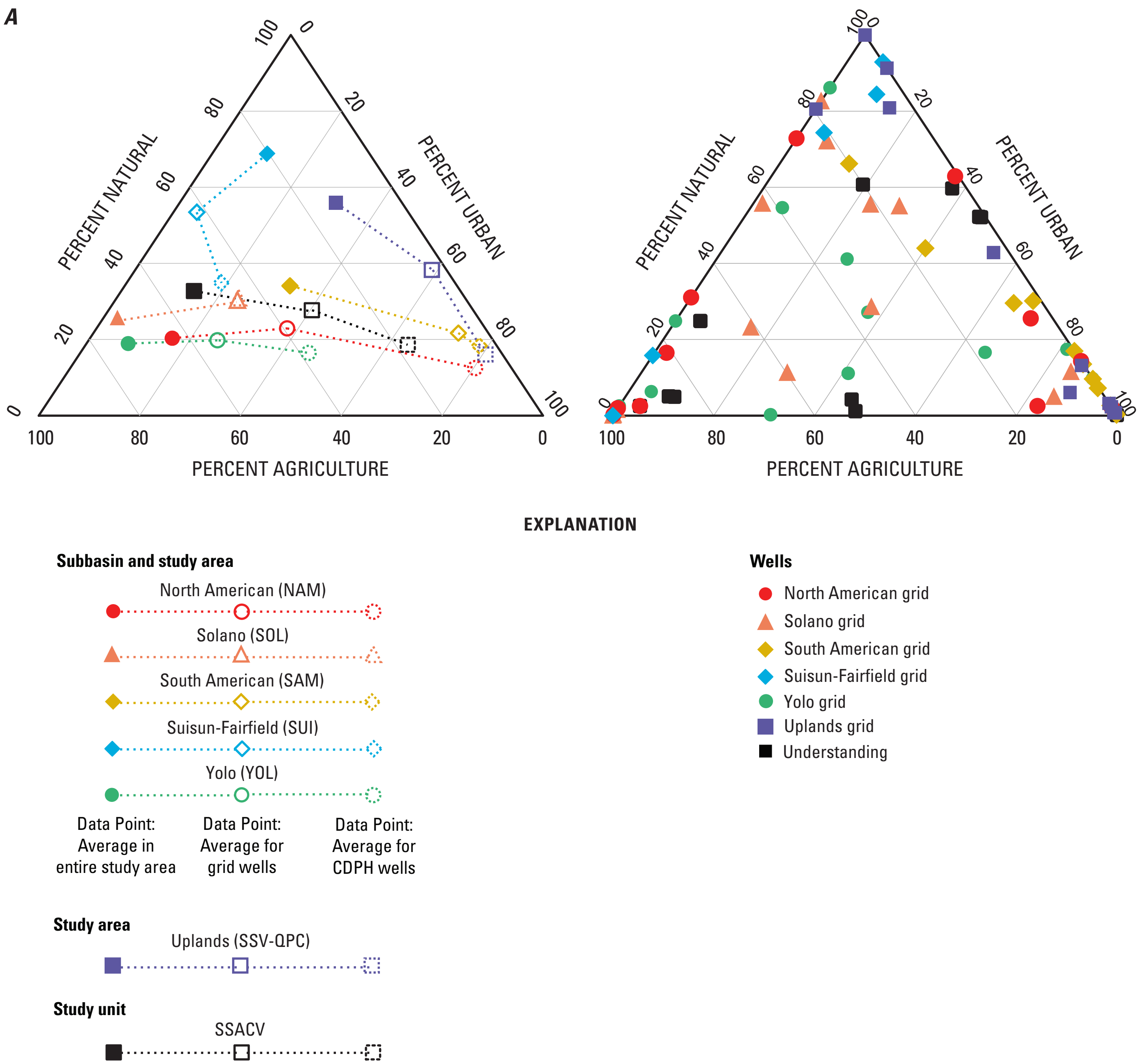

Figure E2. Proportions of urban, agricultural, and natural land use in the (*A*) Southern, (*B*) Middle, and (*C*) Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

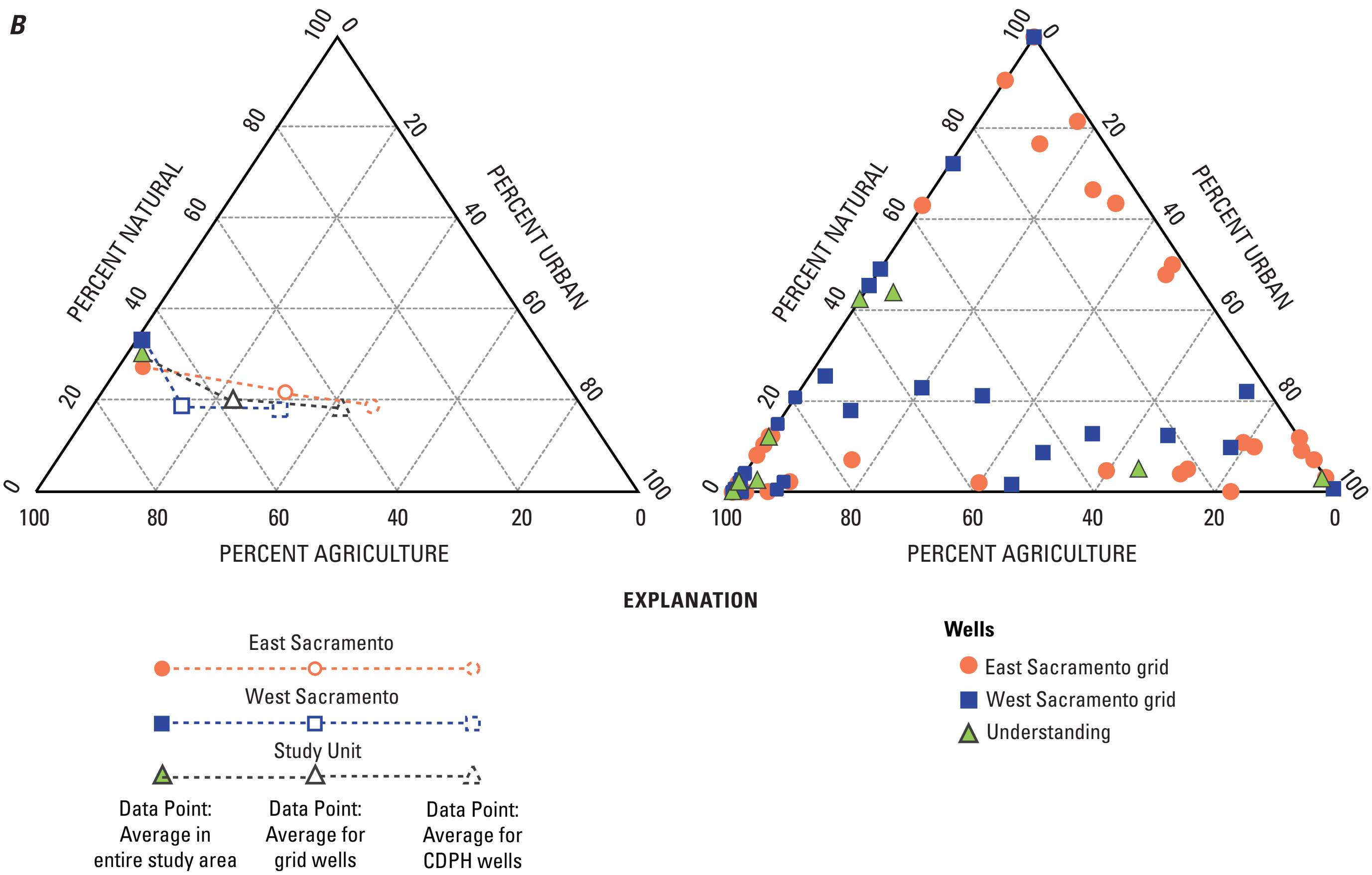

Figure E2.—Continued.

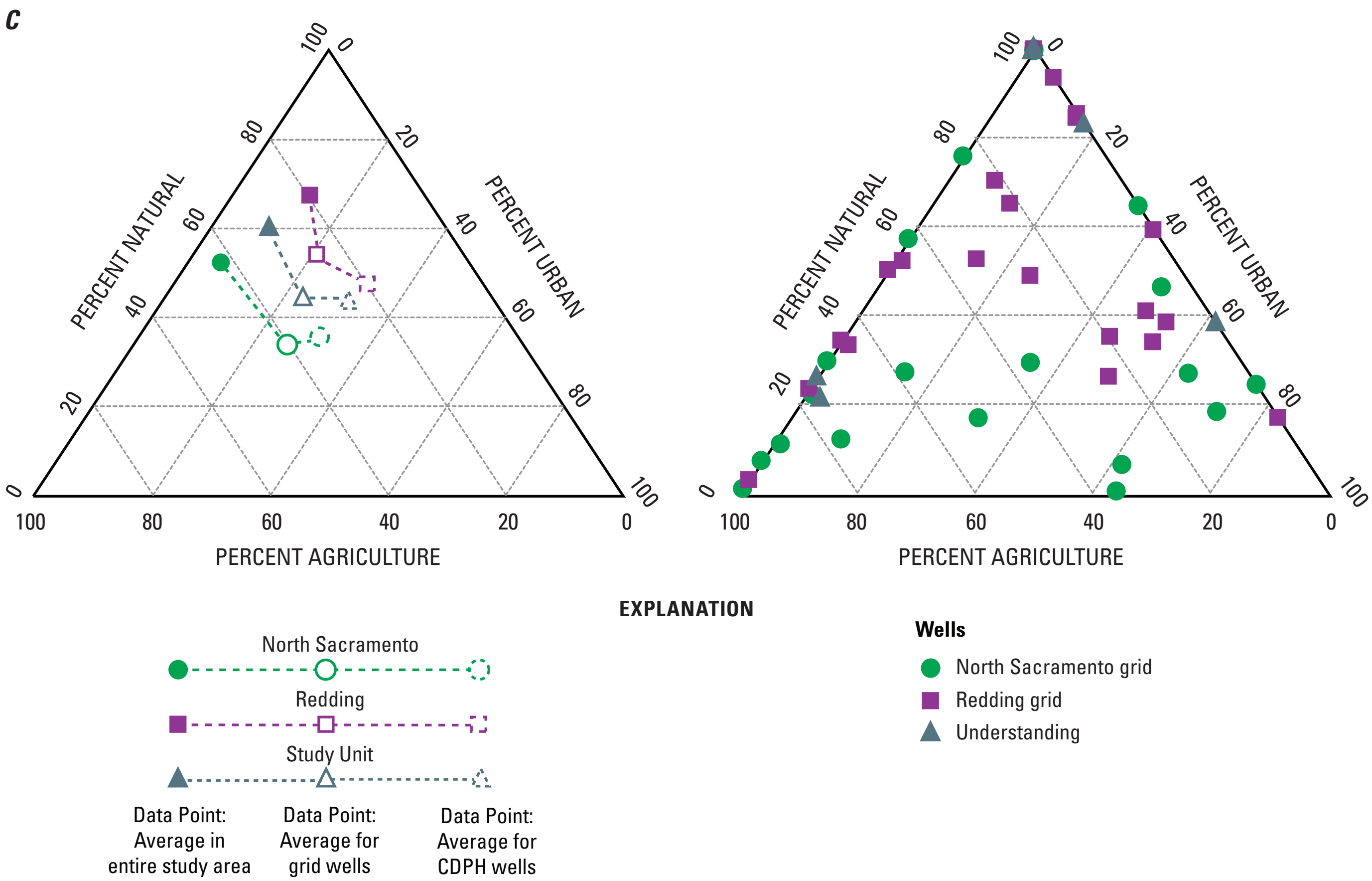

Figure E2.—Continued.

Table E1. Land-use classification for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Ground-Water Ambient Monitoring and Assessment (GAMA) study units, California.

[Land-use classification based on 500-meter buffer (Johnson and Belitz, 2009). na, not available]

USGS-GAMA well No.	Land-use classification: Land use within 500 meters of the well, percent		
	Agricultural	Natural	Urban
Southern Sacramento Valley grid wells			
NAM-01	15	2.5	83
NAM-02	0	14	86
NAM-03	4.4	26	70
NAM-04	0	2.2	98
NAM-05	0.7	63	36
NAM-06	93	2.5	4.1
NAM-07	69	31	0
NAM-08	27	73	0
NAM-09	98	1.9	0
NAM-10	81	16	2.4
NAM-11	100	0	0
SAM-01	0	0	100
SAM-02	0	7.2	93
SAM-03	16	44	40
SAM-04	20	66	14
SAM-05	1.6	30	68
SAM-06	0	14	86
SAM-07	0	0.7	99
SAM-08	0	10	90
SAM-09	6	30	65
SAM-10	0	0	100
SAM-11	0	17	83
SAM-12	0	2.6	97
SOL-01	21	55	23
SOL-02	10	4.9	85
SOL-03	3.4	11	85
SOL-04	22	72	6.4
SOL-05	34	29	37
SOL-06	60	11	29
SOL-07	61	23	16
SOL-08	16	55	29
SOL-09	42	56	1.8
SOL-10	100	0	0
Southern Sacramento Valley grid wells—Continued			
SOL-11	100	0	0
SOL-12	98	1.5	0
SOL-13	17	83	0
SSV-QPC-01	4.7	81	14
SSV-QPC-02	0	1	99
SSV-QPC-03	19	81	0
SSV-QPC-04	0	2.3	98
SSV-QPC-05	0	0.7	99
SSV-QPC-06	6.3	6.1	88
SSV-QPC-07	0	3	97
SSV-QPC-08	3.1	43	54
SSV-QPC-09	0	91	8.7
SSV-QPC-10	0	13	86
SSV-QPC-11	0	100	0
SUI-01	84	16	0
SUI-02	21	74	4.7
SUI-03	0	93	7.1
SUI-04	100	0	0
SUI-05	5.5	84	10
YOL-01	0	10	90
YOL-02	69	0	31
YOL-03	18	17	66
YOL-04	48	11	41
YOL-05	39	55	6.3
YOL-06	33	41	26
YOL-07	89	6.3	4.5
YOL-08	1.3	17	81
YOL-09	75	25	0
YOL-10	97	2.5	0
YOL-11	100	0	0
YOL-12	14	86	0
YOL-13	100	0	0
YOL-14	36	27	37
YOL-15	100	0	0

Table E1. Land-use classification for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Ground-Water Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Land-use classification based on 500-meter buffer (Johnson and Belitz, 2009). na, not available]

USGS-GAMA well No.	Land-use classification: Land use within 500 meters of the well, percent		
	Agricultural	Natural	Urban
Southern Sacramento Valley understanding wells			
NAMFP-05	86	5.0	8.6
NAMFP-06	85	4.9	10
NAMFP-07	85	4.9	10
NAMFP-08	85	4.9	10
NAMFP-09	93	2.5	4.1
NAMFP-10	93	2.5	4.1
NAMFP-11	0	0	100
NAMFP-16	2.9	60	37
SSV-QPCFP-01	0.9	52	47
SSV-QPCFP-02	0.9	52	47
SSV-QPCFP-03	1.3	52	47
SSV-QPCFP-04	1.3	52	47
YOLFP-12	70	25	4.9
YOLFP-13	51	1.1	48
YOLFP-14	51	4.2	45
YOLFP-15	20	61	19
Southern Sacramento Valley additional CDPH grid wells			
NAM-DPH-03	12	21	67
NAM-DPH-09	30	55	15
NAM-DPH-12	70	30	0
NAM-DPH-13	14	15	71
NAM-DPH-14	0	91	9.1
SAM-DPH-09	11	76	13
SAM-DPH-13	50	33	18
SAM-DPH-14	53	25	22
SOL-DPH-10	13	87	0
SOL-DPH-11	78	12	11
SOL-DPH-13	48	16	37
SOL-DPH-14	100	0	0
SOL-DPH-15	52	28	20
SSV-QPC-DPH-04	0	4.9	95
SSV-QPC-DPH-12	4.7	59	36
SUI-DPH-02	0	96	3.4
SUI-DPH-06	58	40	2.3
YOL-DPH-02	84	4.0	12
YOL-DPH-11	71	10	19
YOL-DPH-13	69	5.4	25
Middle Sacramento Valley grid wells			
ESAC-01	94	0	5.8
ESAC-02	99	0	0.6
ESAC-03	0	7.1	93
ESAC-04	58	2.1	40
ESAC-05	17	0	83
ESAC-06	2.1	81	16
ESAC-07	11	77	13
ESAC-08	99	0.5	0
ESAC-09	100	0	0
ESAC-10	7.0	66	27
ESAC-11	0	100	0
ESAC-12	98	1.9	0
ESAC-13	88	12	0
ESAC-14	98	0	2.2
ESAC-15	0	3	97
ESAC-16	4.7	63	32
ESAC-17	24	4.0	72
ESAC-18	1.0	9.2	90
ESAC-19	89	2.3	8.4
ESAC-20	37	63	0
ESAC-21	10	90	0
ESAC-22	36	4.7	60
ESAC-23	77	7.1	16
ESAC-24	22	5.0	73
ESAC-25	2.1	50	48
ESAC-26	92	8.1	0
ESAC-27	4.2	48	48
ESAC-28	8.5	10	82
ESAC-29	87	12	0
ESAC-30	90	10	0
ESAC-31	99	0.7	0
ESAC-32	10	11	79
ESAC-33	0	12	88
ESAC-34	100	0	0
ESAC-35	100	0	0
WSAC-01	0	100	0
WSAC-02	96	4.0	0
WSAC-03	12	10	78

Table E1. Land-use classification for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Ground-Water Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Land-use classification based on 500-meter buffer (Johnson and Belitz, 2009). na, not available]

USGS-GAMA well No.	Land-use classification: Land use within 500 meters of the well, percent		
	Agricultural	Natural	Urban
Middle Sacramento Valley grid wells—Continued			
WSAC-04	0	100	0
WSAC-05	27	72	0
WSAC-06	0	100	0
WSAC-07	34	13	53
WSAC-08	0	0.8	99
WSAC-09	72	26	2.6
WSAC-10	99	0.8	0
WSAC-11	53	1.7	45
WSAC-12	57	23	20
WSAC-13	92	0.6	7
WSAC-14	96	4.2	0
WSAC-15	99	0.8	0
WSAC-16	44	8.7	47
WSAC-17	85	15	0
WSAC-18	3.7	22	74
WSAC-19	100	0	0
WSAC-20	100	0	0
WSAC-21	98	2.2	0
WSAC-22	48	21	31
WSAC-23	98	0	2
WSAC-24	71	18	11
WSAC-25	100	0	0
WSAC-26	51	49	0
WSAC-27	100	0	0
WSAC-28	55	45	0
WSAC-29	22	12	66
WSAC-30	99	0.7	0
WSAC-31	79	21	0
WSAC-32	99	0	0.9
WSAC-33	90	2.3	7.3
WSAC-34	100	0	0
WSAC-35	97	2.9	0
WSAC-36	100	0	0
Middle Sacramento Valley understanding wells			
ESAC-FP-01	95	2.5	2.9
ESAC-FP-02	0.8	2.9	96
ESAC-FP-03	58	42	0
Middle Sacramento Valley understanding wells—Continued			
ESAC-FP-04	58	42	0
ESAC-FP-05	100	0	0
ESAC-FP-06	100	0.1	0
ESAC-FP-07	100	0	0
WSAC-FP-01	88	12	0
WSAC-FP-02	51	44	4.8
WSAC-FP-03	51	44	4.8
WSAC-FP-04	98	2.2	0
WSAC-FP-05	30	5.0	65
WSAC-FP-06	98	2.2	0
WSAC-FP-07	100	0	0
WSAC-FP-08	100	0	0
Middle Sacramento Valley additional CDPH grid wells			
ESAC-DPH-08	38	48	14
ESAC-DPH-11	0	100	0
ESAC-DPH-12	80	18	2.4
ESAC-DPH-13	77	0	22
ESAC-DPH-23	77	7.1	16
ESAC-DPH-31	100	0	0
ESAC-DPH-36	0	100	0
ESAC-DPH-37	71	0	29
ESAC-DPH-38	88	3.7	8.0
ESAC-DPH-39	93	7.1	0
WSAC-DPH-13	48	4.1	48
WSAC-DPH-17	83	17	0
WSAC-DPH-20	68	11	20
WSAC-DPH-21	100	0	0
WSAC-DPH-27	76	17	7.3
WSAC-DPH-32	98	0.7	1.5
WSAC-DPH-33	95	0	5.0
WSAC-DPH-37	86	8.7	5.7
WSAC-DPH-38	45	8	47
WSAC-DPH-39	33	66	0
WSAC-DPH-40	69	0	31
WSAC-DPH-41	58	42	0
WSAC-DPH-42	48	7.8	44

Table E1. Land-use classification for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Ground-Water Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Land-use classification based on 500-meter buffer (Johnson and Belitz, 2009). na, not available]

USGS-GAMA well No.	Land-use classification		
	Land use within 500 meters of the well, percent		
	Agricultural	Natural	Urban
Northern Sacramento Valley grid wells			
NSAC-01	77	22	1.3
NSAC-02	88	11	1.4
NSAC-03	0	100	0
NSAC-04	10	27	63
NSAC-05	58	27	15
NSAC-06	77	12	11
NSAC-07	5.2	46	48
NSAC-08	0	65	35
NSAC-09	0	24	76
NSAC-10	10	18	72
NSAC-11	51	17	32
NSAC-12	36	29	35
NSAC-13	93	7.2	0
NSAC-14	36	0	64
NSAC-15	99	0.9	0
NSAC-16	32	6.4	62
NSAC-17	70	30	0
NSAC-18	0	100	0
NSAC-19	24	76	0
NSAC-20	43	57	0
RED-01	0	100	0
RED-02	0	100	0
RED-03	0	17	83
RED-04	8.2	38	53
RED-05	13	34	53
RED-06	24	26	50
RED-07	33	53	14
RED-08	0	59	41
RED-09	46	52	1.5
RED-10	0	85	15
RED-11	10	41	49
RED-12	19	35	45
RED-13	26	49	25
RED-14	97	3.0	0
RED-15	0	100	0
RED-16	0.6	85	15
RED-17	66	34	0
Northern Sacramento Valley grid wells—Continued			
RED-18	22	65	13
RED-19	22	70	8.1
RED-20	0	94	6.4
RED-21	77	23	0
RED-22	65	33	1.7
RED-23	50	50	0
Northern Sacramento Valley understanding wells			
NSAC-U-01	0.6	99	0
NSAC-U-02	0	100	0
NSAC-U-03	82	10	7.7
NSAC-U-04	17	83	0
NSAC-U-05	0	83	17
NSAC-U-06	0	74	26
NSAC-U-07	3.2	97	0
NSAC-U-08	25	75	0
RED-U-01	0.6	99	0
RED-U-02	0	100	0
NSAC-MW-01	0	83	17
NSAC-MW-02	74	26	0
NSAC-MW-03	74	26	0
NSAC-MW-04	76	21	3.0
NSAC-MW-05	76	21	3.0
NSAC-MW-06	76	21	3.0
RED-MW-01	0	83	17
RED-MW-02	74	26	0
RED-MW-03	74	26	0
RED-MW-04	76	21	3.0
RED-MW-05	76	21	3.0
RED-MW-06	76	21	3.0
RED-MW-07	0	38	62
Northern Sacramento Valley additional CDPH grid wells			
NSAC-DPH-13	89	11	0
NSAC-DPH-15	59	38	2.5
RED-DPH-15	0	34	66
RED-DPH-17	12	80	8.1
RED-DPH-20	0	100	0

Well-Construction Information

Well construction data primarily were determined from drillers' logs. More rarely, well construction data were obtained from ancillary records of well owners or the USGS National Water Information System database. Well identification verification procedures are described by Dawson and others (2008), Schmitt and others (2008), and Bennett and others (2009). Well depths and depths to the tops and bottoms of the perforated intervals for USGS-grid wells, USGS-understanding wells, and CDPH-grid wells are listed in table E2. Wells were classified as production or monitoring wells (table E2). Production wells have pumps that pump the groundwater from the aquifer to a distribution system. Monitoring wells include short-screened wells installed specifically as monitoring wells and wells that were once production wells but no longer have pumps.

Well depths for grid wells, which primarily are used for public supply, ranged from 84 to 1,780 ft in SSACV, 56 to 880 ft in MSACV, and 30 to 530 ft in NSACV with median well depths of 301, 263, and 295 ft, respectively (fig. E3*A*). Perforation lengths throughout the three study units ranged from 2 to 660 ft with a median length of 120 ft.

USGS-understanding wells in SSACV and MSACV generally were deeper than selected grid wells, with understanding well depths ranging from 200 to 1,080 ft and 100 to 750 ft, respectively, with median depths of 470 ft and 490 ft, respectively (fig. E3*B*). The difference in well depths is because monitoring wells (MWs) typically are deeper than other understanding wells. Of the 55 additional understanding wells sampled throughout all study units, 30 were MWs. Of *understanding* wells sampled in the three study units, the highest proportion of MWs sampled was in the MSACV (13 of 15). One-half of the understanding wells sampled in SSACV (8 of 17) were MWs and 13 of 23 understanding wells in NSACV were MWs. Monitoring wells generally are perforated over shorter intervals than public-supply wells, which can be seen in the boxplots of perforation length for the understanding wells in figure E3*B*.

Groundwater Age Classification

Groundwater dating techniques provide a measure of the time since the groundwater was last in contact with the atmosphere. Techniques aimed at estimating groundwater residence times or 'age' include those based on tritium (^3H) (for example, Tolstikhin and Kamenskiy, 1969; Torgersen and others, 1979) and ^3H in combination with its decay product helium-3 (^3He) (Takaoka and Mizutani, 1987; Poreda and others, 1988), carbon-14 activities (for example, Vogel and Ehhalt, 1963; Plummer and others, 1993), and dissolved noble gases, particularly helium-4 (^4He) accumulation (for example, Davis and DeWiest, 1966; Andrews and Lee, 1979; Kulongoski and others, 2008). Calculated groundwater recharge temperatures and noble gas data are listed in table E3. Groundwater age-dating data, specifically, tritium activity, tritium-helium age, uncorrected carbon-14 age, percent of terrigenic helium, and age classification are listed in table E4.

^3H is a short-lived radioactive isotope of hydrogen with a half-life of 12.32 years (Lucas and Unterweger, 2000). ^3H is produced naturally in the atmosphere from the interaction of cosmogenic radiation with nitrogen (Craig and Lal, 1961), by above-ground nuclear explosions, and by the operation of nuclear reactors. ^3H enters the hydrological cycle following oxidation to tritiated water. Consequently, the presence of ^3H in groundwater may be used to identify water that has exchanged with the atmosphere in the past 50 years. By determining the ratio of ^3H to ^3He, resulting from the radioactive decay of ^3H, the time that the water has resided in the aquifer can be calculated more precisely than by using ^3H alone for water (Takaoka and Mizutani, 1987; Poreda and others, 1988).

Carbon-14 (^{14}C) is a widely used chronometer that relies on evaluation of the radiocarbon content of dissolved inorganic carbonate species in groundwater. ^{14}C is formed in the atmosphere by the interaction of cosmic-ray neutrons with nitrogen, and to a lesser degree oxygen and carbon. ^{14}C is incorporated into carbon dioxide and mixed throughout the atmosphere, dissolving in precipitation and entering the hydrologic cycle. ^{14}C activity in groundwater, expressed as percent modern carbon (pmc), reflects exposure to the atmospheric ^{14}C source, and is governed by the decay constant of ^{14}C (with a half-life of 5,730 yrs). ^{14}C can be used to estimate groundwater ages ranging from 1,000 to less than 30,000 years before present because of its half-life. Calculated ^{14}C ages in this study are referred to as "uncorrected" because they have not been adjusted to consider exchanges with sedimentary sources of carbon (Fontes and Garnier, 1979). The ^{14}C age (residence time) is calculated based on the decrease in ^{14}C activity as a result of radioactive decay with time since groundwater recharge, relative to an assumed initial ^{14}C concentration (Clarke and Fritz, 1997). A mean initial ^{14}C activity of 99 pmc is assumed for this study, with estimated errors on calculated groundwater ages of up to ±20%. Calculated groundwater ages of less than 1,000 years (corresponding to ^{14}C activities greater than 88 pmc) are reported as less than 1,000 years; no attempt is made to refine ^{14}C ages less than 1,000 years. Measured values of percent modern carbon can be greater than 100 pmc because the definition of the ^{14}C activity in "modern" carbon does not include the excess ^{14}C produced in the atmosphere by above-ground nuclear weapons testing.

Table E2. Well construction information for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Elevation of land-surface datum, in feet above North American Vertical Datum of 1988 (NAVD 88). na, not available; LSD, land-surface datum]

Well identification No.	Elevation of land-surface datum	Well type	Well construction information, in feet below land-surface datum		
			Well depth	Top perforation	Bottom perforation
Southern Sacramento Valley grid wells					
NAM-01	19	Production	470	120	250
NAM-02	25	Production	375	112	328
NAM-03	87	Production	660	185	655
NAM-04	61	Production	220	na	na
NAM-05	67	Production	520	445	na
NAM-06	29	Monitoring	500	470	490
NAM-07	96	Production	140	100	135
NAM-08	77	Production	550	na	na
NAM-09	55	Production	120	na	na
NAM-10	27	Production	84	na	na
NAM-11	27	Production	540	210	520
SAM-01	22	Production	201	91	na
SAM-02	44	Production	512	135	na
SAM-03	18	Production	220	140	220
SAM-04	18	Production	340	260	340
SAM-05	49	Production	264	200	260
SAM-06	83	Production	448	240	428
SAM-07	59	Production	308	180	302
SAM-08	49	Production	298	220	na
SAM-09	71	Production	na	na	na
SAM-10	29	Production	278	156	162
SAM-11	37	Production	270	146	268
SAM-12	23	Production	na	na	na
SOL-01	105	Production	800	230	780
SOL-02	68	Production	540	235	520
SOL-03	108	Production	940	420	900
SOL-04	27	Production	416	303	416
SOL-05	12	Production	104	na	na
SOL-06	6	Production	244	228	240
SOL-07	4	Production	335	95	na
SOL-08	108	Production	1,780	1,100	1,760
SOL-09	47	Production	112	80	112
SOL-10	97	Production	600	120	600
SOL-11	38	Production	na	na	na
SOL-12	29	Production	230	128	226
SOL-13	46	Production	180	100	180
SSV-QPC-01	124	Production	225	180	225
SSV-QPC-02	238	Production	208	na	na
SSV-QPC-03	131	Production	na	na	na
Southern Sacramento Valley grid wells—Continued					
SSV-QPC-04	104	Production	503	na	na
SSV-QPC-05	82	Production	297	252	297
SSV-QPC-06	123	Production	540	260	530
SSV-QPC-07	158	Production	303	175	303
SSV-QPC-08	123	Production	156	na	na
SSV-QPC-09	16	Production	296	240	285
SSV-QPC-10	119	Production	499	246	499
SSV-QPC-11	313	Production	285	197	269
SUI-01	153	Production	na	na	na
SUI-02	23	Production	na	na	na
SUI-03	88	Production	225	60	220
SUI-04	83	Production	390	145	370
SUI-05	93	Production	na	na	na
YOL-01	59	Production	470	210	460
YOL-02	53	Production	110	na	na
YOL-03	56	Production	1,450	1,264	1,432
YOL-04	103	Production	270	160	270
YOL-05	93	Production	na	na	na
YOL-06	136	Production	395	175	395
YOL-07	56	Production	157	134	157
YOL-08	8	Production	393	375	385
YOL-09	26	Production	na	na	na
YOL-10	65	Production	na	na	na
YOL-11	95	Production	349	321	349
YOL-12	27	Production	280	260	270
YOL-13	188	Production	188	na	na
YOL-14	13	Production	1,350	530	797
YOL-15	173	Production	230	150	230
Southern Sacramento Valley understanding wells					
NAMFP-05	16	Monitoring	1,080	1,060	1,070
NAMFP-06	16	Monitoring	815	795	805
NAMFP-07	16	Monitoring	410	380	400
NAMFP-08	16	Monitoring	200	170	190
NAMFP-09	29	Monitoring	995	745	985
NAMFP-10	29	Monitoring	220	190	210
NAMFP-11	82	Production	264	241	na
NAMFP-16	31	Production	635	222	625
SSV-QPCFP-01	148	Monitoring	470	370	460
SSV-QPCFP-02	148	Monitoring	470	274	310

Table E2. Well construction information for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Elevation of land-surface datum, in feet above North American Vertical Datum of 1988 (NAVD 88). na, not available; LSD, land-surface datum]

Well identification No.	Elevation of land-surface datum	Well type	Well construction information, in feet below land-surface datum		
			Well depth	Top perforation	Bottom perforation
Southern Sacramento Valley understanding wells—Continued					
SSV-QPCFP-03	148	Production	572	365	560
SSV-QPCFP-04	148	Production	332	240	320
YOLFP-12	73	Production	857	740	842
YOLFP-13	58	Production	456	258	446
YOLFP-14	148	Production	320	204	298
YOLFP-15	145	Production	480	190	470
Southern Sacramento Valley additional CDPH grid wells					
NAM-DPH-03	na	Production	na	na	na
NAM-DPH-09	na	Production	na	na	na
NAM-DPH-12	na	Production	na	na	na
NAM-DPH-13	na	Production	na	na	na
NAM-DPH-14	na	Production	na	na	na
SAM-DPH-09	na	Production	na	na	na
SAM-DPH-13	na	Production	na	na	na
SAM-DPH-14	na	Production	na	na	na
SOL-DPH-10	na	Production	na	na	na
SOL-DPH-11	na	Production	na	na	na
SOL-DPH-13	na	Production	na	na	na
SOL-DPH-14	na	Production	na	na	na
SOL-DPH-15	na	Production	na	na	na
SSV-QPC-DPH-04	na	Production	na	na	na
SSV-QPC-DPH-12	na	Production	na	na	na
SUI-DPH-02	na	Production	na	na	na
SUI-DPH-06	na	Production	na	na	na
YOL-DPH-02	na	Production	na	na	na
YOL-DPH-11	na	Production	na	na	na
YOL-DPH-13	na	Production	na	na	na
Middle Sacramento Valley grid wells					
ESAC-01	76	Production	278	150	252
ESAC-02	38	Production	160	140	160
ESAC-03	176	Production	272	110	150
ESAC-04	154	Production	200	140	200
ESAC-05	77	Production	410	207	395
ESAC-06	182	Production	260	148	260
ESAC-07	153	Production	220	80	220
ESAC-08	89	Production	108	68	108
ESAC-09	129	Production	554	140	554
Middle Sacramento Valley grid wells—Continued					
ESAC-10	60	Production	316	96	303
ESAC-11	68	Production	520	220	510
ESAC-12	107	Production	375	0	370
ESAC-13	207	Production	355	na	na
ESAC-14	47	Production	280	140	280
ESAC-15	195	Production	500	200	480
ESAC-16	275	Production	560	240	540
ESAC-17	50	Production	120	105	na
ESAC-18	218	Production	560	240	540
ESAC-19	47	Production	265	185	265
ESAC-20	83	Production	356	212	356
ESAC-21	52	Production	na	na	na
ESAC-22	105	Production	90	na	na
ESAC-23	93	Production	72	72	na
ESAC-24	92	Production	327	84	318
ESAC-25	262	Production	570	290	550
ESAC-26	35	Production	200	160	200
ESAC-27	54	Production	135	65	125
ESAC-28	92	Production	360	102	360
ESAC-29	31	Production	215	199	215
ESAC-30	36	Production	168	na	na
ESAC-31	62	Production	235	48	235
ESAC-32	66	Production	140	64	124
ESAC-33	212	Production	335	60	na
ESAC-34	100	Production	60	60	na
ESAC-35	112	Production	558	74	558
WSAC-01	446	Production	na	na	na
WSAC-02	179	Production	na	na	na
WSAC-03	274	Production	na	116	253
WSAC-04	452	Production	880	320	880
WSAC-05	367	Production	236	136	236
WSAC-06	485	Production	na	na	na
WSAC-07	150	Production	200	71	200
WSAC-08	246	Production	180	56	170
WSAC-09	220	Production	na	na	na
WSAC-10	185	Production	225	145	225
WSAC-11	140	Production	570	240	561
WSAC-12	50	Production	456	254	444
WSAC-13	84	Production	na	na	na

Table E2. Well construction information for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Elevation of land-surface datum, in feet above North American Vertical Datum of 1988 (NAVD 88). na, not available; LSD, land-surface datum]

Well identification No.	Elevation of land-surface datum	Well type	Well construction information, in feet below land-surface datum		
			Well depth	Top perforation	Bottom perforation
Middle Sacramento Valley grid wells—Continued					
WSAC-14	60	Production	159	157	159
WSAC-15	144	Production	59	19	59
WSAC-16	30	Production	332	313	na
WSAC-17	32	Production	260	230	260
WSAC-18	85	Production	402	160	380
WSAC-19	37	Production	364	348	356
WSAC-20	81	Production	340	253	340
WSAC-21	168	Production	258	208	248
WSAC-22	355	Production	870	408	870
WSAC-23	182	Production	56	31	56
WSAC-24	73	Production	185	165	185
WSAC-25	39	Production	na	na	na
WSAC-26	410	Production	330	110	330
WSAC-27	63	Production	300	140	300
WSAC-28	289	Production	165	145	165
WSAC-29	142	Production	759	173	651
WSAC-30	120	Production	na	na	na
WSAC-31	60	Production	245	145	245
WSAC-32	89	Production	180	110	180
WSAC-33	86	Production	205	na	na
WSAC-34	142	Production	180	60	180
WSAC-35	141	Production	410	100	410
WSAC-36	80	Production	260	160	260
Middle Sacramento Valley understanding wells					
ESAC-FP-01	51	Production	750	580	720
ESAC-FP-02	178	Monitoring	650	460	640
ESAC-FP-03	105	Monitoring	130	99	109
ESAC-FP-04	105	Monitoring	583	509	562
ESAC-FP-05	85	Monitoring	100	80	90
ESAC-FP-06	85	Monitoring	380	340	350
ESAC-FP-07	85	Monitoring	555	520	530
WSAC-FP-01	312	Monitoring	580	490	550
WSAC-FP-02	255	Monitoring	421	390	400
WSAC-FP-03	255	Monitoring	310	270	290
WSAC-FP-04	130	Monitoring	200	135	180
WSAC-FP-05	88	Production	625	540	625
WSAC-FP-06	130	Monitoring	545	445	525
WSAC-FP-07	99	Monitoring	490	415	470
WSAC-FP-08	99	Monitoring	280	190	260
Middle Sacramento Valley additional CDPH grid wells					
ESAC-DPH-08	na	Production	na	na	na
ESAC-DPH-11	na	Production	na	na	na
ESAC-DPH-12	na	Production	na	na	na
ESAC-DPH-13	na	Production	na	na	na
ESAC-DPH-23	na	Production	na	na	na
ESAC-DPH-31	na	Production	na	na	na
ESAC-DPH-36	na	Production	na	na	na
ESAC-DPH-37	na	Production	na	na	na
ESAC-DPH-38	na	Production	na	na	na
ESAC-DPH-39	na	Production	na	na	na
WSAC-DPH-13	na	Production	na	na	na
WSAC-DPH-17	na	Production	na	na	na
WSAC-DPH-20	na	Production	na	na	na
WSAC-DPH-21	na	Production	na	na	na
WSAC-DPH-27	na	Production	na	na	na
WSAC-DPH-32	na	Production	na	na	na
WSAC-DPH-33	na	Production	na	na	na
WSAC-DPH-37	na	Production	na	na	na
WSAC-DPH-38	na	Production	na	na	na
WSAC-DPH-39	na	Production	na	na	na
WSAC-DPH-40	na	Production	na	na	na
WSAC-DPH-41	na	Production	na	na	na
WSAC-DPH-42	na	Production	na	na	na
Northern Sacramento Valley grid wells					
NSAC-01	252	Production	185	30	175
NSAC-02	238	Production	85	na	na
NSAC-03	515	Production	na	na	na
NSAC-04	294	Production	212	100	211
NSAC-05	256	Production	na	na	na
NSAC-06	284	Production	158	118	158
NSAC-07	482	Production	450	na	na
NSAC-08	420	Production	290	280	290
NSAC-09	316	Production	510	230	500
NSAC-10	287	Production	300	na	na
NSAC-11	267	Production	80	na	na
NSAC-12	251	Production	240	na	na
NSAC-13	207	Production	220	100	220
NSAC-14	226	Production	430	140	420
NSAC-15	237	Production	260	130	200

Table E2. Well construction information for wells sampled by the U.S. Geological Survey or selected from the California Department of Public Health (CDPH) database for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Elevation of land-surface datum, in feet above North American Vertical Datum of 1988 (NAVD 88). na, not available; LSD, land-surface datum]

Well identification No.	Elevation of land-surface datum	Well type	Well construction information, in feet below land-surface datum		
			Well depth	Top perforation	Bottom perforation
Northern Sacramento Valley grid wells—Continued					
NSAC-16	222	Production	307	90	307
NSAC-17	594	Production	na	na	na
NSAC-18	488	Production	240	na	na
NSAC-19	433	Production	339	117	156
NSAC-20	310	Production	202	na	na
RED-01	707	Production	418	308	398
RED-02	544	Production	475	245	405
RED-03	529	Production	510	244	460
RED-04	492	Production	395	150	390
RED-05	479	Production	492	192	448
RED-06	459	Production	30	na	na
RED-07	476	Production	201	95	195
RED-08	572	Production	232	194	232
RED-09	504	Production	199	124	196
RED-10	631	Production	530	na	na
RED-11	478	Production	355	144	349
RED-12	457	Production	360	160	360
RED-13	476	Production	431	80	410
RED-14	521	Production	450	216	444
RED-15	756	Production	367	307	367
RED-16	519	Production	104	na	na
RED-17	378	Production	160	140	160
RED-18	465	Production	na	na	na
RED-19	422	Production	300	100	300
RED-20	577	Production	353	na	na
RED-21	424	Production	na	na	na
RED-22	410	Production	120	118	120
RED-23	466	Production	135	100	135

Well identification No.	Elevation of land-surface datum	Well type	Well construction information, in feet below land-surface datum		
			Well depth	Top perforation	Bottom perforation
Northern Sacramento Valley understanding wells					
NSAC-U-01	559	Production	227	224	227
NSAC-U-02	606	Production	124	119	124
NSAC-U-03	349	Production	na	na	na
NSAC-U-04	510	Production	198	na	na
NSAC-U-05	357	Production	140	100	140
NSAC-U-06	306	Production	136	na	na
NSAC-U-07	447	Production	214	na	na
NSAC-U-08	302	Production	na	na	na
RED-U-01	640	Production	339	335	339
RED-U-02	682	Production	263	261	263
NSAC-MW-01	357	Monitoring	415	160	395
NSAC-MW-02	232	Monitoring	369	164	359
NSAC-MW-03	227	Monitoring	871	760	850
NSAC-MW-04	248	Monitoring	200	150	180
NSAC-MW-05	248	Monitoring	780	680	750
NSAC-MW-06	248	Monitoring	980	940	960
RED-MW-01	445	Monitoring	540	480	520
RED-MW-02	442	Monitoring	110	70	110
RED-MW-03	442	Monitoring	200	170	200
RED-MW-04	454	Monitoring	865	755	855
RED-MW-05	454	Monitoring	194	154	189
RED-MW-06	454	Monitoring	440	360	430
RED-MW-07	454	Monitoring	65	50	60
Northern Sacramento Valley additional CDPH grid wells					
NSAC-DPH-13	na	Production	na	na	na
NSAC-DPH-15	na	Production	na	na	na
RED-DPH-15	na	Production	na	na	na
RED-DPH-17	na	Production	na	na	na
RED-DPH-20	na	Production	na	na	na

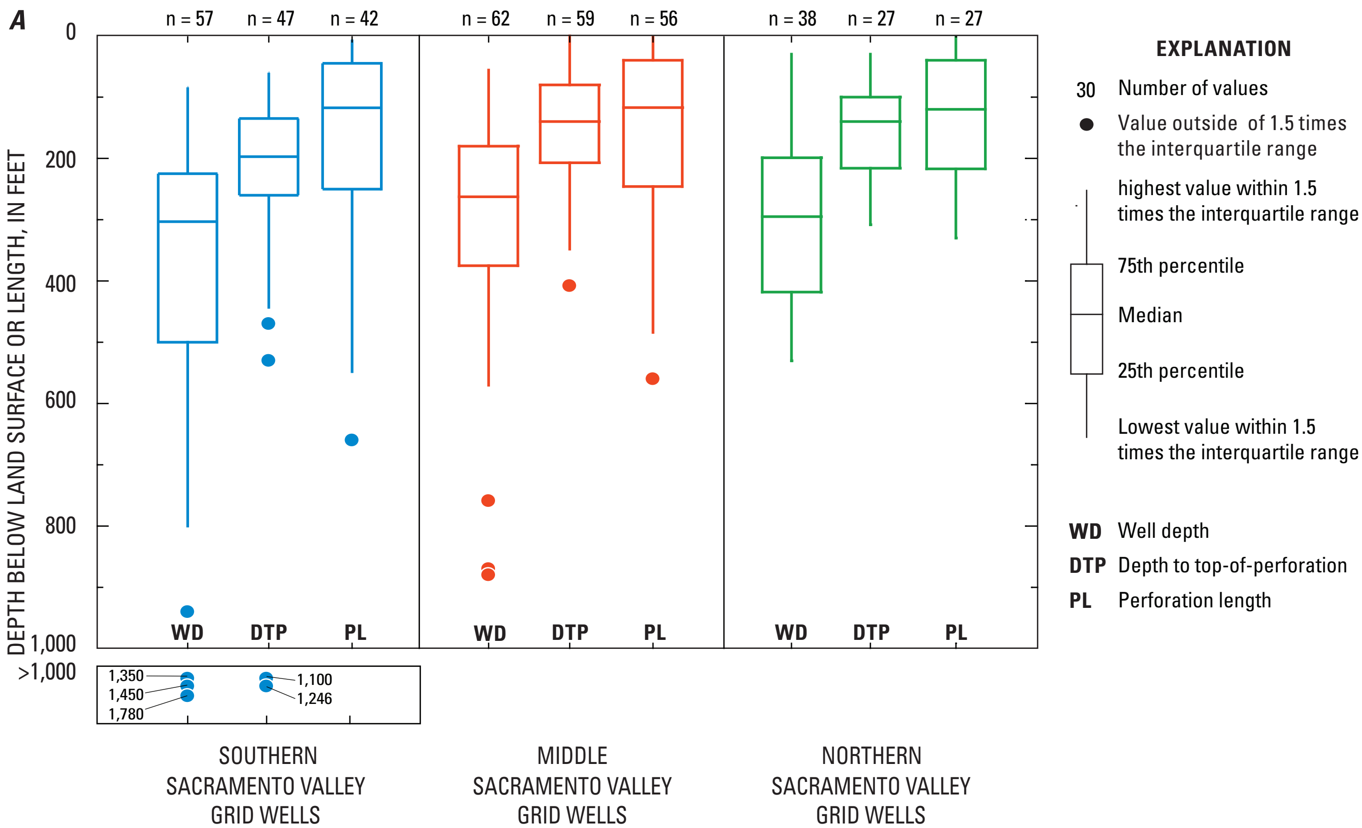

Figure E3. Boxplots showing well depth, depth to top-of-perforations, and perforation lengths for (*A*) grid wells and (*B*) USGS-understanding wells in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

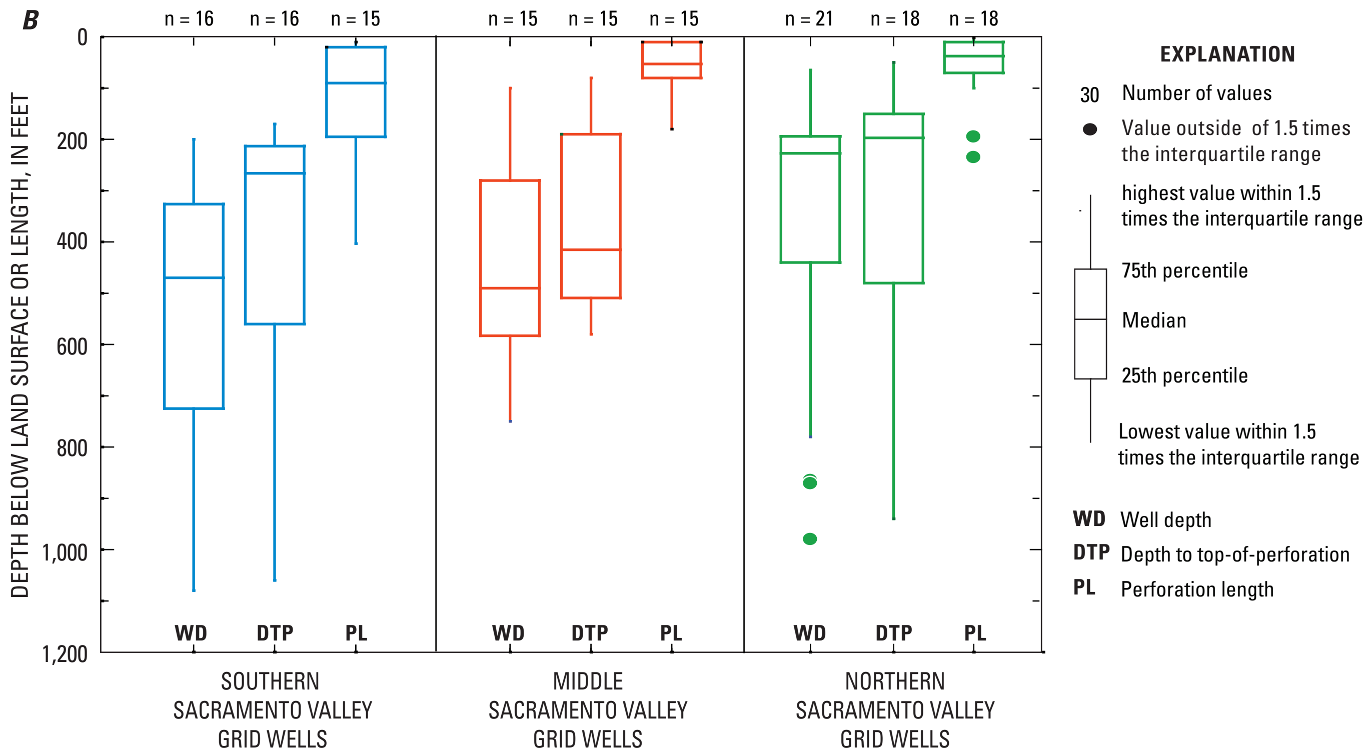

Figure E3.—Continued.

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

USGS-GAMA identification No.	Sample collection data	Calculated recharge temperature (degrees Celsius)	Helium-3/ Helium-4 (atom ratio) (61040)	Helium-4 (cm^3STP/gH_2O) (85561)	Neon (cm^3STP/gH_2O) (61046)	Argon (cm^3STP/gH_2O) (85563)	Krypton (cm^3STP/gH_2O) (85565)	Xenon (cm^3STP/gH_2O) (85567)
Southern Sacramento Valley grid wells								
NAM-01	03/28/05	15.0	5.48	6.17	2.56	3.92	8.63	1.16
NAM-02	03/29/05	19.8	16.43	0.71	2.83	3.83	8.08	1.04
NAM-03	04/10/08	na	4.44	21.20	2.14	3.13	6.75	0.92
NAM-05	04/07/05	18.9	4.98	18.45	1.94	3.19	7.11	1.00
NAM-06	04/14/05	13.4	6.89	17.57	2.26	3.72	8.40	1.20
NAM-08	05/04/05	16.3	12.64	0.99	3.10	4.08	8.78	1.15
SAM-02	03/15/05	15.4	12.74	0.77	2.74	4.04	8.75	1.16
SAM-03	03/22/05	12.9	20.45	0.46	1.93	3.62	8.59	1.18
SAM-07	04/05/05	17.7	20.82	0.62	2.26	3.49	7.73	1.01
SAM-11	04/21/05	18.3	7.93	4.36	2.09	3.30	7.35	1.03
SOL-01	03/16/05	11.2	4.41	4.93	4.80	5.21	10.35	1.40
SOL-03	03/23/05	15.2	12.72	0.80	2.99	4.22	9.12	1.19
SOL-06	03/30/05	16.3	18.24	0.90	2.03	3.39	7.91	1.06
SOL-08	04/08/08	na	11.21	0.80	2.66	3.51	7.52	0.97
SSV-QPC-02	03/16/05	18.5	2.49	13.31	2.48	3.46	7.57	1.03
SSV-QPC-05	03/22/05	13.8	11.22	2.77	2.22	3.68	8.40	1.16
SSV-QPC-06	03/22/05	19.5	13.01	0.48	1.91	3.14	7.15	0.96
SSV-QPC-07	04/04/05	18.8	2.44	20.32	1.91	3.18	7.21	0.98
SSV-QPC-08	04/06/05	20.2	1.45	103.23	1.96	3.15	6.91	0.95
SSV-QPC-09	04/07/05	21.6	9.52	1.20	2.37	3.41	7.38	0.95
SUI-01	03/31/05	17.0	13.59	0.59	2.39	3.80	8.64	1.10
SUI-02	04/20/05	na	na	na	na	na	na	na
SUI-03	04/09/08	na	12.23	0.60	2.35	3.41	7.41	0.96
YOL-01	04/07/08	na	17.29	0.65	2.68	3.65	7.91	1.02
YOL-02	04/18/05	16.8	14.33	0.79	3.22	4.32	9.11	1.15
YOL-03	04/19/05	15.8	10.17	1.08	3.36	4.27	9.16	1.17
YOL-04	04/26/05	15.1	14.52	0.84	3.47	4.24	9.01	1.16
YOL-06	04/27/05	15.1	11.35	0.81	2.69	3.78	8.41	1.14
YOL-08	05/10/05	10.5	3.83	5.29	2.91	4.27	9.55	1.33
YOL-09	05/17/05	11.8	15.78	0.53	2.27	3.86	8.90	1.24
YOL-13	05/24/05	22.1	16.84	0.65	2.73	3.63	7.80	0.95
Southern Sacramento Valley understanding wells								
NAMFP-05	04/05/05	na	na	na	na	na	na	na
NAMFP-06	04/06/05	14.0	3.98	53.68	2.63	4.04	9.04	1.21
NAMFP-07	04/07/05	14.2	2.20	9.31	2.81	4.05	8.89	1.20
NAMFP-08	04/07/05	15.4	3.17	10.23	2.59	3.88	8.49	1.15
NAMFP-09	04/13/05	13.5	5.01	162.46	5.94	6.45	12.09	1.47

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

USGS-GAMA identification No.	Sample collection data	Calculated recharge temperature (degrees Celsius)	Helium-3/ Helium-4 (atom ratio) (61040)	Helium-4 (cm^3STP/gH_2O) (85561)	Neon (cm^3STP/gH_2O (61046)	Argon (cm^3STP/gH_2O (85563)	Krypton (cm^3STP/gH_2O) (85565)	Xenon (cm^3STP/gH_2O) (85567)
Southern Sacramento Valley understanding wells—Continued								
NAMFP-10	04/18/05	15.0	6.47	19.02	2.25	3.61	8.14	1.12
NAMFP-16	06/15/05	16.7	5.49	3.60	2.11	3.45	7.64	1.06
SSV-QPCFP-01	03/29/05	17.3	4.29	11.62	2.20	3.44	7.81	1.02
SSV-QPCFP-02	03/30/05	19.4	5.23	3.23	2.09	3.26	7.22	0.97
SSV-QPCFP-03	04/01/05	17.0	4.09	15.24	2.07	3.40	7.78	1.02
SSV-QPCFP-04	04/01/05	18.2	4.55	5.06	2.10	3.33	7.45	1.00
YOLFP-12	04/20/05	15.3	9.46	1.13	2.97	4.21	9.07	1.17
YOLFP-13	04/21/05	15.0	17.18	0.76	3.18	4.08	8.89	1.15
YOLFP-14	04/27/05	16.9	16.74	0.71	3.04	4.11	9.03	1.13
YOLFP-15	04/28/05	17.3	14.88	0.73	3.12	4.05	8.68	1.11
Middle Sacramento Valley grid wells								
ESAC-01	06/29/06	16.9	2.02	19.21	2.47	3.57	7.92	1.08
ESAC-02	06/29/06	17.5	10.27	8.54	2.63	4.41	7.81	1.06
ESAC-03	07/10/06	15.4	5.90	14.67	22.98	9.29	21.62	2.07
ESAC-04	07/10/06	19.5	15.93	0.67	2.79	3.72	7.85	1.02
ESAC-05	07/10/06	18.0	17.13	0.76	2.30	3.48	7.73	1.00
ESAC-06	07/12/06	20.5	12.83	0.70	1.94	3.10	7.02	0.93
ESAC-07	07/12/06	19.8	5.48	1.55	2.12	3.30	7.00	0.97
ESAC-08	07/12/06	na	na	na	na	na	na	na
ESAC-09	07/13/06	21.2	13.06	0.98	2.22	3.36	7.34	0.95
ESAC-10	07/13/06	21.4	4.26	2.34	4.37	4.96	9.29	1.12
ESAC-11	07/13/06	18.1	10.51	10.22	20.12	9.20	19.76	1.84
ESAC-12	07/17/06	na	7.17	9.84	15.88	7.60	11.04	1.27
ESAC-13	07/17/06	18.1	16.35	0.49	2.14	3.44	7.55	1.03
ESAC-14	07/17/06	19.0	17.94	0.58	2.47	3.52	7.45	1.00
ESAC-15	07/20/06	19.4	16.24	0.55	2.48	3.60	7.83	1.01
ESAC-16	07/20/06	19.4	15.52	0.50	1.95	3.13	6.99	0.99
ESAC-17	07/20/06	19.6	9.83	10.45	2.23	8.42	6.96	1.01
ESAC-18	07/20/06	17.6	14.56	0.49	2.07	3.38	7.33	1.03
ESAC-19	07/20/06	20.3	19.68	0.89	2.36	3.46	7.44	0.99
ESAC-20	07/25/06	na	na	na	na	na	na	na
ESAC-21	07/25/06	na	9.80	na	na	na	na	na
ESAC-22	07/26/06	17.6	13.85	0.64	2.58	3.85	8.33	1.08
ESAC-23	07/26/06	16.5	14.72	0.51	2.23	3.56	7.86	1.08
ESAC-24	07/26/06	19.1	7.54	3.35	2.15	3.42	7.46	1.00
ESAC-25	07/27/06	21.3	9.60	0.86	1.79	2.99	6.73	0.92
ESAC-26	07/31/06	13.2	14.43	0.43	1.95	3.54	8.23	1.21
ESAC-27	08/02/06	19.7	16.30	0.57	3.02	3.46	7.66	1.02

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

USGS-GAMA identification No.	Sample collection data	Calculated recharge temperature (degrees Celsius)	Helium-3/ Helium-4 (atom ratio) (61040)	Helium-4 (cm^3STP/gH_2O) (85561)	Neon (cm^3STP/gH_2O (61046)	Argon (cm^3STP/gH_2O (85563)	Krypton (cm^3STP/gH_2O) (85565)	Xenon (cm^3STP/gH_2O) (85567)
Middle Sacramento Valley grid wells—Continued								
ESAC-28	08/03/06	19.4	16.68	0.77	2.58	3.39	7.42	1.05
ESAC-29	08/03/06	18.2	16.04	0.64	3.20	3.73	8.28	1.10
ESAC-30	08/07/06	14.0	7.94	1.05	2.49	3.48	8.17	1.21
ESAC-31	08/07/06	18.9	7.24	4.22	2.57	3.47	7.61	1.03
ESAC-32	08/17/06	16.3	15.08	0.60	2.42	3.59	8.04	1.09
ESAC-33	08/17/06	18.4	5.02	2.02	2.25	3.40	7.36	1.01
ESAC-34	08/17/06	19.5	31.71	0.54	2.61	3.51	7.43	1.01
WSAC-01	07/10/06	16.8	0.77	9.26	1.92	3.46	7.33	0.99
WSAC-02	07/11/06	18.0	14.54	0.94	3.79	4.38	8.75	1.12
WSAC-03	07/11/06	13.7	13.49	5.81	22.16	10.81	20.86	2.11
WSAC-04	07/11/06	20.1	12.85	0.72	1.99	3.15	7.04	0.93
WSAC-05	07/12/06	17.6	13.48	0.56	2.06	3.68	7.57	1.00
WSAC-06	07/12/06	17.5	10.51	0.77	2.23	3.97	9.04	1.14
WSAC-07	07/18/06	18.6	19.31	0.58	2.46	3.54	7.48	1.01
WSAC-08	07/18/06	20.4	19.37	0.56	2.32	3.32	7.10	0.95
WSAC-09	07/18/06	18.1	14.82	0.63	2.65	3.82	7.88	1.07
WSAC-10	07/18/06	19.9	17.38	0.61	2.54	3.47	7.29	0.99
WSAC-11	07/19/06	19.9	13.51	0.76	3.04	4.07	8.39	1.05
WSAC-12	07/19/06	15.1	2.87	5.09	2.60	3.91	8.39	1.15
WSAC-13	07/24/06	19.9	8.83	1.11	2.18	3.30	7.20	0.95
WSAC-14	07/24/06	17.2	10.71	0.71	2.27	3.51	7.78	1.02
WSAC-15	07/31/06	18.8	13.95	0.61	2.58	3.50	7.38	1.04
WSAC-16	07/31/06	17.8	15.06	0.58	2.32	3.48	7.47	1.04
WSAC-17	08/01/06	15.6	14.72	0.47	2.10	3.45	7.86	1.12
WSAC-18	08/01/06	19.7	4.26	2.07	2.68	3.44	7.55	1.02
WSAC-19	08/01/06	19.5	14.20	0.61	2.43	3.44	7.37	0.99
WSAC-20	08/02/06	18.7	14.53	1.13	4.22	4.31	8.74	1.10
WSAC-21	08/02/06	na	14.92	5.91	7.72	5.21	6.80	0.58
WSAC-22	08/08/06	18.3	15.08	0.90	3.96	4.22	8.80	1.07
WSAC-23	08/08/06	na	14.67	0.11	3.75	2.07	2.25	0.21
WSAC-24	08/09/06	19.9	14.34	0.79	3.50	4.01	8.17	1.01
WSAC-25	08/09/06	18.7	12.98	0.62	2.56	3.48	7.71	1.03
WSAC-26	08/14/06	22.0	13.82	1.10	4.50	5.41	9.87	1.15
WSAC-27	08/15/06	18.4	19.82	0.61	2.52	3.56	7.69	1.01
WSAC-28	08/15/06	20.4	22.48	0.60	2.63	3.41	7.29	0.99
WSAC-29	08/16/06	19.8	5.64	1.64	2.40	3.53	7.62	0.99
WSAC-30	08/16/06	19.4	12.74	1.37	2.27	3.34	7.28	0.98

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

USGS-GAMA identification No.	Sample collection data	Calculated recharge temperature (degrees Celsius)	Helium-3/ Helium-4 (atom ratio) (61040)	Helium-4 (cm^3STP/gH_2O) (85561)	Neon (cm^3STP/gH_2O (61046)	Argon (cm^3STP/gH_2O (85563)	Krypton (cm^3STP/gH_2O) (85565)	Xenon (cm^3STP/gH_2O) (85567)
Middle Sacramento Valley grid wells—Continued								
WSAC-31	08/21/06	20.5	10.22	0.87	2.19	3.27	7.03	0.95
WSAC-32	08/21/06	19.2	12.70	0.53	2.05	3.22	7.29	0.98
WSAC-33	08/22/06	18.6	15.22	0.57	2.38	3.46	7.35	1.03
WSAC-35	08/23/06	19.8	13.96	0.64	2.33	3.39	7.52	0.94
Middle Sacramento Valley understanding wells								
ESAC-FP-01	07/13/06	20.6	4.55	50.73	2.26	7.69	6.81	0.99
ESAC-FP-02	08/21/06	18.3	18.00	0.48	2.05	3.32	7.40	0.99
ESAC-FP-03	08/23/06	18.0	22.44	0.54	2.32	3.59	7.99	1.04
ESAC-FP-04	08/23/06	21.2	15.21	0.63	2.65	3.61	7.60	0.98
ESAC-FP-05	08/24/06	19.2	15.79	0.79	2.51	3.61	7.93	1.02
ESAC-FP-06	08/24/06	17.7	4.32	11.89	1.98	5.24	7.30	1.03
WSAC-FP-01	08/14/06	21.2	13.45	0.70	2.90	3.58	7.34	0.96
WSAC-FP-02	08/15/06	20.8	13.16	0.52	2.15	3.21	6.89	0.95
WSAC-FP-03	08/15/06	20.1	21.28	0.60	2.48	3.41	7.26	0.97
WSAC-FP-04	08/16/06	22.1	6.00	1.69	2.34	4.54	6.68	0.94
WSAC-FP-05	08/16/06	16.3	0.55	42.51	2.11	3.42	7.79	1.07
WSAC-FP-06	08/16/06	18.9	2.29	3.17	2.04	3.20	7.34	1.00
WSAC-FP-07	08/17/06	19.4	4.63	1.85	2.08	3.21	7.11	1.00
WSAC-FP-08	08/17/06	19.6	25.81	0.53	2.32	3.38	7.38	0.97
Northern Sacramento Valley grid wells								
NSAC-01	10/04/07	na	na	na	na	na	na	na
NSAC-02	10/24/07	18.4	16.68	0.13	2.19	3.43	7.48	1.01
NSAC-03	10/29/07	19.0	16.66	0.12	3.42	3.94	7.70	1.06
NSAC-04	10/30/07	20.3	17.38	0.13	2.14	3.23	6.95	0.95
NSAC-05	10/31/07	21.6	16.54	0.12	2.31	3.28	6.89	0.92
NSAC-06	10/31/07	18.1	20.29	0.15	2.13	3.31	7.35	1.03
NSAC-07	11/01/07	18.8	14.84	0.11	2.32	3.38	7.40	0.99
NSAC-08	11/05/07	20.1	12.71	0.10	2.05	3.15	6.93	0.96
NSAC-09	11/06/07	19.6	13.65	0.10	2.00	3.12	7.04	0.99
NSAC-10	11/06/07	20.0	14.99	0.11	2.14	3.17	7.04	0.99
NSAC-11	11/26/07	14.8	13.32	0.10	2.31	3.62	8.04	1.14
NSAC-12	11/27/07	20.3	13.46	0.10	2.20	3.27	7.03	0.95
NSAC-13	11/27/07	na	na	na	na	na	na	na
NSAC-14	11/28/07	na	na	na	na	na	na	na
NSAC-15	11/28/07	18.3	13.67	0.10	2.36	3.45	7.66	1.00
NSAC-16	12/06/07	19.5	15.85	0.12	1.98	3.19	6.99	0.97
NSAC-17	12/13/07	na	na	na	na	na	na	na
NSAC-18	12/18/07	20.6	13.97	0.10	1.80	2.99	6.91	0.92

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

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Northern Sacramento Valley grid wells—Continued								
NSAC-19	01/08/08	20.5	13.83	0.10	2.17	3.31	7.15	0.95
NSAC-20	01/15/08	na	na	na	na	na	na	na
RED-01	10/01/07	20.9	13.35	0.10	2.00	3.09	6.71	0.92
RED-02	10/01/07	na	na	na	na	na	na	na
RED-03	10/02/07	na	na	na	na	na	na	na
RED-04	10/03/07	na	na	na	na	na	na	na
RED-05	10/03/07	na	na	na	na	na	na	na
RED-06	10/22/07	18.0	14.73	0.11	1.94	3.23	7.26	1.00
RED-07	10/23/07	18.0	18.53	0.14	2.07	3.31	7.36	1.00
RED-08	10/23/07	19.6	15.82	0.12	2.47	3.57	7.65	0.99
RED-09	10/25/07	17.1	20.08	0.15	2.04	3.34	7.33	1.04
RED-10	10/25/07	18.3	7.06	0.05	2.00	3.29	7.06	0.98
RED-11	11/07/07	16.5	16.15	0.12	2.20	3.38	7.55	1.10
RED-12	11/08/07	19.6	9.58	0.07	2.25	3.42	7.35	0.98
RED-13	11/20/07	20.7	14.40	0.11	2.01	3.12	6.82	0.93
RED-14	11/29/07	20.4	8.85	0.07	2.02	3.12	6.92	0.94
RED-15	12/03/07	20.1	15.26	0.11	2.59	3.42	7.26	0.96
RED-16	12/03/07	18.5	17.35	0.13	1.94	3.21	7.24	0.97
RED-17	12/05/07	17.6	11.86	0.09	1.95	3.23	7.46	1.01
RED-18	12/05/07	21.8	18.74	0.14	2.27	3.22	6.73	0.92
RED-19	12/11/07	16.4	17.79	0.13	2.07	3.41	7.58	1.06
RED-20	12/12/07	na	na	na	na	na	na	na
RED-21	12/12/07	na	na	na	na	na	na	na
RED-22	01/15/08	17.9	17.21	0.21	2.24	3.43	7.59	0.99
RED-23	01/16/08	17.5	13.62	0.42	2.17	3.34	7.53	1.03

Table E3. Results for analyses of noble gases in samples from the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[The five-digit number in parentheses below the constituent name is the U.S. Geological Survey parameter code used to uniquely identify a specific constituent or property. **Other abbreviations:** $cm^3STP/g\ H_20$, cubic centimeters at standard temperature and pressure per gram of water; na, not available]

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Northern Sacramento Valley understanding wells								
NSAC-MW-01	01/07/08	na	na	na	na	na	na	na
NSAC-MW-02	01/08/08	17.8	16.74	0.13	2.21	3.39	7.51	1.03
NSAC-MW-03	01/08/08	21.1	14.30	0.11	1.82	3.00	6.83	0.91
NSAC-MW-04	01/09/08	19.3	14.33	0.11	2.32	3.37	7.40	0.98
NSAC-MW-05	01/09/08	16.6	8.70	0.07	2.46	3.63	7.84	1.07
NSAC-MW-06	01/10/08	na	na	na	na	na	na	na
NSAC-U-01	12/04/07	20.8	12.90	0.10	2.15	3.18	6.89	0.93
NSAC-U-02	12/04/07	21.4	16.27	0.12	2.78	3.45	7.20	0.95
NSAC-U-03	12/13/07	18.7	17.71	0.13	2.16	3.32	7.50	0.97
NSAC-U-04	12/18/07	19.9	13.59	0.10	2.24	3.28	7.29	0.94
NSAC-U-05	01/07/08	na	na	na	na	na	na	na
NSAC-U-06	01/07/08	na	na	na	na	na	na	na
NSAC-U-07	01/09/08	21.6	12.12	0.09	2.25	3.30	7.15	0.93
NSAC-U-08	01/14/08	20.9	15.70	0.19	1.98	3.13	6.91	0.91
RED-MW-01	01/15/08	16.3	11.58	0.15	1.99	3.36	7.61	1.05
RED-MW-02	01/15/08	18.5	19.57	0.60	2.63	3.53	7.49	1.04
RED-MW-03	01/15/08	16.1	22.77	0.70	2.67	3.68	8.23	1.09
RED-MW-04	01/16/08	na	na	na	na	na	na	na
RED-MW-05	01/16/08	22.5	13.62	0.42	2.03	2.99	6.89	0.87
RED-MW-06	01/17/08	19.6	13.55	0.42	2.10	3.23	7.28	0.94
RED-MW-07	01/17/08	18.5	15.31	0.47	3.02	3.76	7.79	1.04
RED-U-01	01/08/08	23.6	13.55	0.10	1.89	2.89	6.40	0.84
RED-U-02	01/14/08	22.8	13.88	0.17	3.70	3.87	7.47	0.95

Table E4. Groundwater age-date data and classification for samples for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[Samples classified as "pre-modern" if tritium activity is less than 1 TU, terrigenic helium is greater than 5 percent, and uncorrected carbon-14 age is greater than 1,000 years. Samples classified as "modern" if tritium activity is greater than 1 TU, uncorrected carbon-14 age is less than 1,000 years, and percentage of terrigenic helium is less than 5. Samples with both "pre-modern" and "modern" components are designated as "mixed" age. **Abbreviations:** TU, tritium units; na, not available; nc, not calculable. >, greater than; <, less than]

USGS-GAMA identification No.	Tritium activity (TU)	Tritium-helium age (years)	Uncorrected carbon-14 age (years before present)	Terrigenic helium (percent of total helium)	Groundwater age classification
Southern Sacramento Valley grid wells					
NAM-01	3.4	34	na	90	Mixed
NAM-02	1.6	31	na	0	Modern
NAM-05	0.0	>50	na	97	Pre-Modern
NAM-06	0.1	>50	21,700	97	Pre-Modern
NAM-08	3.9	13	na	18	Mixed
SAM-02	0.7	>50	na	10	Pre-Modern
SAM-03	3.8	26	na	2	Modern
SAM-07	2.8	37	na	9	Mixed
SAM-11	0.2	>50	na	88	Pre-Modern
SOL-01	–0.1	>50	na	74	Pre-Modern
SOL-03	0.2	>50	na	4	Mixed
SOL-06	4.2	39	na	46	Mixed
SSV-QPC-02	0.7	>50	na	95	Pre-Modern
SSV-QPC-05	5.3	45	na	81	Mixed
SSV-QPC-06	0.4	>50	<1,000	3	Mixed
SSV-QPC-07	0.4	>50	2,000	98	Pre-Modern
SSV-QPC-08	0.4	>50	na	100	Pre-Modern
SSV-QPC-09	0.1	>50	na	50	Pre-Modern
SUI-01	0.7	>50	na	0	Mixed
YOL-02	2.3	11	na	0	Modern
YOL-03	0.0	>50	13,600	19	Pre-Modern
YOL-04	3.2	11	<1,000	0	Modern
YOL-06	0.4	>50	na	16	Pre-Modern
YOL-08	–0.1	>50	32,000	86	Pre-Modern
YOL-09	2.8	17	na	0	Modern
YOL-13	3.5	21	na	0	Modern
Southern Sacramento Valley understanding wells					
NAMFP-06	0.0	>50	42,200	99	Pre-Modern
NAMFP-07	0.1	>50	39,100	92	Pre-Modern
NAMFP-08	0.4	>50	6,600	94	Pre-Modern
NAMFP-09	0.1	>50	23,900	99	Pre-Modern
NAMFP-10	–0.1	>50	17,300	97	Pre-Modern
NAMFP-16	0.1	>50	4,400	86	Pre-Modern
SSV-QPCFP-01	0.4	>50	1,900	95	Pre-Modern
SSV-QPCFP-02	0.3	>50	2,400	84	Pre-Modern
SSV-QPCFP-03	0.3	>50	na	97	Pre-Modern
SSV-QPCFP-04	0.2	>50	na	90	Pre-Modern
YOLFP-12	na	>50	12,400	31	Pre-Modern
YOLFP-13	3.0	27	<1,000	0	Modern
YOLFP-14	3.0	24	<1,000	0	Modern
YOLFP-15	0.7	>50	2,200	0	Mixed
Middle Sacramento Valley grid wells					
ESAC-01	0.6	>50	na	97	Pre-Modern
ESAC-02	3.6	>50	na	92	Mixed
ESAC-03	2.5	>50	<1,000	56	Mixed
ESAC-04	0.9	>50	na	0	Mixed
ESAC-05	2.5	37.8	<1,000	24	Mixed
ESAC-06	0.4	>50	<1,000	32	Pre-Modern
ESAC-07	1.3	>50	na	66	Mixed
ESAC-09	1.2	47.2	na	43	Mixed
ESAC-10	0.9	>50	<1,000	50	Pre-Modern
ESAC-11	–0.1	>50	11,000	44	Pre-Modern
ESAC-12	0.3	>50	3,600	55	Pre-Modern
ESAC-13	1.1	31.4	na	0	Modern
ESAC-14	0.8	>50	na	0	Mixed
ESAC-15	0.3	>50	<1,000	0	Mixed
ESAC-16	0.9	>50	<1,000	6	Pre-Modern
ESAC-17	1.1	>50	1,500	95	Mixed
ESAC-18	0.2	>50	<1,000	0	Mixed
ESAC-19	0.0	>50	1,400	33	Pre-Modern
ESAC-22	3.8	1.9	<1,000	0	Modern
ESAC-23	3.2	9.3	na	0	Modern
ESAC-24	0.2	>50	na	84	Pre-Modern
ESAC-25	0.0	>50	na	49	Pre-Modern
ESAC-26	–0.1	>50	5,300	0	Mixed
ESAC-27	2.9	20	<1,000	0	Modern
ESAC-28	2.3	34.6	<1,000	14	Mixed
ESAC-29	0.9	>50	4,900	0	Mixed
ESAC-30	–0.1	>50	4,500	42	Pre-Modern
ESAC-31	2.7	>50	1,500	85	Mixed
ESAC-32	3.0	13.4	<1,000	0	Modern
ESAC-33	3.9	>50	na	72	Mixed
ESAC-34	4.2	41.4	<1,000	0	Modern
WSAC-01	–0.1	>50	na	95	Pre-Modern
WSAC-02	2.0	16.5	na	0	Modern
WSAC-03	2.3	nc	<1,000	0	Modern
WSAC-04	0.1	>50	8,300	32	Pre-Modern
WSAC-05	2.4	11	na	10	Mixed
WSAC-06	na	>50	<1,000	24	Mixed
WSAC-07	4.2	25.2	na	0	Modern
WSAC-08	3.7	26.6	11,700	0	Mixed
WSAC-09	2.1	15.4	na	0	Modern

Table E4. Groundwater age-date data and classification for samples for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Samples classified as "pre-modern" if tritium activity is less than 1 TU, terrigenic helium is greater than 5 percent, and uncorrected carbon-14 age is greater than 1,000 years. Samples classified as "modern" if tritium activity is greater than 1 TU, uncorrected carbon-14 age is less than 1,000 years, and percentage of terrigenic helium is less than 5. Samples with both "pre-modern" and "modern" components are designated as "mixed" age. **Abbreviations:** TU, tritium units; na, not available; nc, not calculable. >, greater than; <, less than]

USGS-GAMA identification No.	Tritium activity (TU)	Tritium-helium age (years)	Uncorrected carbon-14 age (years before present)	Terrigenic helium (percent of total helium)	Groundwater age classification
Middle Sacramento Valley grid wells—Continued					
WSAC-10	2.3	28.4	<1,000	0	Modern
WSAC-11	0.1	>50	3,200	0	Mixed
WSAC-12	na	>50	na	84	Pre-Modern
WSAC-13	na	>50	na	51	Pre-Modern
WSAC-14	0.1	>50	na	21	Pre-Modern
WSAC-15	2.6	4.2	<1,000	0	Modern
WSAC-16	0.8	>50	na	0	Mixed
WSAC-17	2.7	10.2	1,500	0	Mixed
WSAC-18	0.5	>50	8,400	67	Pre-Modern
WSAC-19	0.2	>50	na	0	Mixed
WSAC-20	1.4	22.3	na	0	Modern
WSAC-21	0.6	>50	<1,000	63	Pre-Modern
WSAC-22	1.8	23.2	1,800	0	Mixed
WSAC-23	2.4	4.6	na	0	Modern
WSAC-24	0.4	>50	na	0	Mixed
WSAC-25	0.0	>50	7,500	0	Mixed
WSAC-26	1.2	4	2,300	0	Modern
WSAC-27	2.9	32.3	na	0	Modern
WSAC-28	3.7	34	<1,000	0	Modern
WSAC-29	0.1	>50	6,400	63	Pre-Modern
WSAC-30	4.6	35.6	1,200	58	Mixed
WSAC-31	0.1	>50	7,100	37	Pre-Modern
WSAC-32	2.6	nc	na	5	Modern
WSAC-33	0.2	>50	na	0	Mixed
WSAC-35	2.3	15.8	<1,000	9	Mixed
Middle Sacramento Valley understanding wells					
ESAC-FP-01	–0.1	>50	10,300	99	Pre-Modern
ESAC-FP-02	1.1	38.4	<1,000	0	Modern
ESAC-FP-03	2.0	41.8	<1,000	0	Modern
ESAC-FP-04	0.2	>50	4,200	0	Mixed
ESAC-FP-05	4.0	25.9	<1,000	19	Mixed
ESAC-FP-06	0.1	>50	18,900	96	Pre-Modern
WSAC-FP-01	0.0	>50	6,500	0	Mixed
WSAC-FP-02	–0.2	>50	11,600	0	Mixed
WSAC-FP-03	2.8	35.9	1,200	0	Mixed
WSAC-FP-04	0.4	>50	13,500	65	Pre-Modern
WSAC-FP-05	0.0	>50	15,500	99	Pre-Modern
WSAC-FP-06	0.0	>50	15,100	84	Pre-Modern
WSAC-FP-07	0.1	>50	15,100	72	Pre-Modern
WSAC-FP-08	4.0	35.7	<1,000	0	Modern

USGS-GAMA identification No.	Tritium activity (TU)	Tritium-helium age (years)	Uncorrected carbon-14 age (years before present)	Terrigenic helium (percent of total helium)	Groundwater age classification
Northern Sacramento Valley grid wells					
NSAC-01	3.2	na	<1,000	na	Modern[1]
NSAC-02	3.1	19.3	<1,000	0	Modern
NSAC-03	1.5	32.5	1,200	0	Mixed
NSAC-04	1.8	29.0	<1,000	0	Mixed
NSAC-05	2.8	22.1	1,200	4	Mixed
NSAC-06	2.1	35.7	<1,000	0	Modern
NSAC-07	0.5	>50	3,200	0	Mixed
NSAC-08	0.2	>50	5,300	3	Mixed
NSAC-09	0.6	>50	4,400	3	Mixed
NSAC-10	0.7	>50	2,300	0	Mixed
NSAC-11	2.5	Not datable	<1,000	0	Modern
NSAC-12	0.2	>50	4,900	0	Mixed
NSAC-13	0.1	>50	3,900	na	Pre-Modern
NSAC-14	0.8	>50	2,300	na	Pre-Modern
NSAC-15	2.2	Not datable	<1,000	0	Modern
NSAC-16	0.9	>50	<1,000	43	Pre-Modern
NSAC-17	0.0	>50	28,000	na	Pre-Modern
NSAC-18	0.4	>50	2,500	0	Mixed
NSAC-19	0.3	>50	3,700	1	Mixed
NSAC-20	0.0	>50	3,300	na	Pre-Modern
RED-01	0.2	>50	2,100	0	Mixed
RED-02	0.1	>50	2,100	na	Pre-Modern
RED-03	2.4	na	<1,000	na	Modern
RED-04	3.0	na	<1,000	na	Modern
RED-05	0.1	>50	2,200	na	Pre-Modern
RED-06	2.8	9.5	<1,000	0	Modern
RED-07	2.1	30.9	<1,000	0	Modern
RED-08	1.2	30.2	<1,000	0	Modern
RED-09	3.0	28.8	<1,000	0	Modern
RED-10	0.2	>50	8,500	86	Pre-Modern
RED-11	1.8	24.0	<1,000	0	Modern
RED-12	1.3	36.7	<1,000	70	Mixed
RED-13	0.6	>50	1,300	0	Mixed
RED-14	0.1	>50	4,200	38	Pre-Modern
RED-15	1.2	26.4	<1,000	0	Modern
RED-16	2.2	24.8	<1,000	0	Modern
RED-17	0.0	>50	2,500	37	Pre-Modern
RED-18	3.6	22.4	<1,000	0	Modern
RED-19	2.6	48.0	<1,000	54	Mixed
RED-20	0.1	>50	2,100	na	Pre-Modern
RED-21	4.5	na	<1,000	na	Modern
RED-22	2.9	22.0	<1,000	0	Modern
RED-23	0.8	>50	<1,000	22	Pre-Modern

Table E4. Groundwater age-date data and classification for samples for the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[Samples classified as "pre-modern" if tritium activity is less than 1 TU, terrigenic helium is greater than 5 percent, and uncorrected carbon-14 age is greater than 1,000 years. Samples classified as "modern" if tritium activity is greater than 1 TU, uncorrected carbon-14 age is less than 1,000 years, and percentage of terrigenic helium is less than 5. Samples with both "pre-modern" and "modern" components are designated as "mixed" age. **Abbreviations:** TU, tritium units; na, not available; nc, not calculable. >, greater than; <, less than]

USGS-GAMA identification No.	Tritium activity (TU)	Tritium-helium age (years)	Uncorrected carbon-14 age (years before present)	Terrigenic helium (percent of total helium)	Groundwater age classification
Northern Sacramento Valley understanding wells					
NSAC-MW-01	0.0	>50	6,200	na	Pre-Modern
NSAC-MW-02	1.0	35.3	<1,000	0	Modern
NSAC-MW-03	0.0	>50	3,500	27	Pre-Modern
NSAC-MW-04	0.2	>50	2,600	0	Mixed
NSAC-MW-05	0.0	>50	19,200	33	Pre-Modern
NSAC-MW-06	0.0	>50	24,600	na	Pre-Modern
NSAC-U-01	0.1	>50	7,800	0	Mixed
NSAC-U-02	1.7	26.9	<1,000	0	Modern
NSAC-U-03	3.2	26.4	<1,000	8	Mixed
NSAC-U-04	0.0	>50	3,900	0	Mixed
NSAC-U-05	0.7	>50	1,500	na	Pre-Modern
Northern Sacramento Valley understanding wells—Continued					
NSAC-U-06	1.7	na	<1,000	na	Modern
NSAC-U-07	0.0	>50	11,300	9	Pre-Modern
NSAC-U-08	2.1	18.2	1,700	0	Mixed
RED-MW-01	–0.1	>50	2,200	34	Pre-Modern
RED-MW-02	2.5	33.9	<1,000	0	Modern
RED-MW-03	3.0	37.9	1,800	0	Mixed
RED-MW-04	0.1	>50	6,200	na	Pre-Modern
RED-MW-05	0.2	>50	2,200	0	Mixed
RED-MW-06	0.2	>50	3,000	2	Mixed
RED-MW-07	2.8	16.8	<1,000	0	Modern
RED-U-01	–0.1	>50	5,000	0	Mixed
RED-U-02	–0.1	>50	3,800	0	Mixed

Helium (He) is a naturally occurring inert gas initially present during the accretion of the planet, and later produced by the radioactive decay of lithium, thorium, and uranium in the earth. Measured groundwater He concentrations represent the sum of several He components including air-equilibrated He (He_{eq}), He from dissolved-air bubbles (He_a), terrigenic He (He_{terr}), and tritiogenic ^3He (^3He_t). Helium (^3He and ^4He) concentrations in groundwater often exceed the expected solubility equilibrium values, a function of the temperature of the water, as a result of subsurface production of both isotopes and their subsequent release into the groundwater (for example, Morrison and Pine, 1955; Andrews and Lee, 1979; Torgersen, 1980; Andrews, 1985; Torgersen and Clark, 1985). The presence of He_{terr} in groundwater, from its production in aquifer material or deeper in the crust, is indicative of long groundwater residence times. The amount of He_{terr} is defined as the concentration of the total measured He, minus the fraction as a result of air-equilibration [He_{eq}] and dissolved air-bubbles [He_a]. For this study, percent He_{terr} is used to identify groundwater with residence times greater than 100 years. Percent He_{terr} is defined as the concentration of He_{terr} (as defined previously) divided by the total measured He in the sample (corrected for air-bubble entrainment). Samples with greater than 5 percent He_{terr} represent groundwater with a residence time of more than 100 years.

Recharge temperatures, excess air, and gas fractionation for 166 samples (table E3) were determined from concentrations of dissolved neon, argon, krypton, and xenon. Recharge temperatures were calculated by using methods described in Aeschbach-Hertig and others (1999) and Aeschbach-Hertig and others (2000).

^3H /^3He apparent ages were computed as described in Poreda and others (1988). The $^3He/^4He$ ratio of samples was determined by linear regression of the percent of He_{terr} against the δ^3He [($\delta^3He = R_{meas}/R_{atm}$ -1) × 100] of samples with less than 1 tritium unit (TU). Calculations of the noble gas temperature and $^3He/^4He$ ratios are useful because they provide further constraints for helium-based groundwater ages.

In this study, the age distributions of samples were classified as pre-modern, modern, and mixed. Groundwater with tritium activity less than 1 TU, percent He_{terr} greater than 5%, and ^{14}C less than 90 pmc was designated as pre-modern: defined as having recharged prior to 1950. Groundwater with ^3H activities greater than 1 TU, percent ^3He_t less than 5%, and ^{14}C greater than 90 pmc was designated as modern, and is defined as having recharged during the last 50 years. Samples with both pre-modern and modern components were designated as "mixed" age groundwater, which includes substantial fractions of both old and young waters. In reality, pre-modern groundwater could contain very small fractions of modern water and modern groundwater could contain small fractions of pre-modern water. Previous investigations have used a range of tritium values from 0.3 to 1.0 TU as thresholds for distinguishing pre-1950 from post-1950 water (Michel, 1989; Plummer and others, 1993; Michel and Schroeder, 1994; Clark and Fritz, 1997; Manning and others, 2005). By using a ^{3}H value of 1.0 TU, at the upper end of the range used in the literature, for the threshold in this study, the age classification scheme allows a slightly larger fraction of modern water to be present in a classified pre-modern age distribution than if a lower threshold were used. A lower threshold for ^{3}H would result in fewer wells classified as pre-modern rather than mixed water, when other tracers, such as ^{14}C and He_{terr}, would suggest that they primarily were pre-modern water. This higher threshold was considered more appropriate for this study because many of the wells are long-screened production wells and some mixing of at least some waters of different ages likely occurred.

Because of uncertainties in age distributions, in particular caused by mixing of waters of different ages in wells with long perforation intervals and high withdrawal rates, these age estimates were not specifically used for statistically quantifying the relation between age and water quality in this report. Although more sophisticated lumped parameter models for analyzing age distributions that incorporate mixing are available (for example, Cook and Böhlke, 2000), use of these alternative models to characterize age mixtures was beyond the scope of this report. Rather, classification into modern, mixed, and pre-modern categories was considered sufficient to provide an appropriate and useful characterization for the purposes of examining groundwater quality.

Groundwater ages were assigned to 185 wells throughout the three Sacramento Valley study units. Of those 185, 68 were classified as pre-modern, 66 were classified as mixed, and 51 were classified as modern. The distribution of groundwater age classifications was compared with well construction information in figure E4. Construction information was not available for all wells with age classifications; however, construction information was available for enough wells to show a clear increase in groundwater age with increasing depth to top-of-perforation and well depth (figs. E4*A* and E4*B*). Depth categories were selected to maximize the segregation of groundwater samples with "modern" age distributions from those with "pre-modern" age distributions. Most of the wells classified as "shallow" (perforated intervals less than 200 ft deep) yielded groundwater with either modern or mixed age distributions (fig. E4*C*). In contrast, most of the wells classified as "deep" (perforated intervals greater than 200 ft deep) yielded groundwater with mixed or pre-modern age distributions. Most wells classified as "both" (perforated less than and greater than 200 ft deep) yielded groundwater with mixed age distributions. Wells classified as "both" were nearly equally split among the three groundwater age categories; however, the mixed and pre-modern categories occurred more often than modern (fig. E4*C*).

Classification of Geochemical Conditions

Geochemical conditions investigated as potential explanatory variables include oxidation-reduction characteristics (redox) and pH. Redox conditions influence the transport of many organic and inorganic constituents (McMahon and Chapelle, 2008). Redox conditions along groundwater flow paths commonly proceed along a well-documented sequence of Terminal Electron Acceptor Processes (TEAP), in which a single TEAP typically dominates at a particular time and aquifer location (Chapelle and others, 1995; Chapelle, 2001). The predominant TEAPs are oxygen-reducing (oxic), nitrate-reducing, manganese-reducing, iron-reducing, sulfate-reducing, and methanogenic.

Classifications of redox condition were made by using the framework of McMahon and Chapelle (2008) for grid and USGS-understanding wells with available measurements of redox-sensitive constituents. An automated workbook program was used to assign a redox classification to each sample (Jurgens and others, 2009). The program classifies redox conditions according to dissolved oxygen, nitrate, manganese, iron, and sulfate concentrations. However, data for all five constituents were not available for some samples. In particular, dissolved oxygen was not measured at 62 of the 68 wells in the SSACV study unit, and dissolved oxygen data were not available from the CDPH database for any of the "DPH" CDPH-grid wells in the three study units. Because dissolved oxygen data were not available, samples classified as manganese-, iron-, or sulfate-reducing or methanogenic also could have mixed oxic/anoxic conditions, and nitrate-reducing and suboxic conditions could not be distinguished from oxic conditions. In this report, samples missing only dissolved oxygen data were presumed to be oxic, unless their manganese, iron, and sulfate concentrations indicated that manganese-, iron-, or sulfate-reducing or methanogenic conditions were present, in which case, they were classified as anoxic. It was assumed that samples without dissolved oxygen data were either oxic or anoxic; no samples without dissolved oxygen data were classified as mixed. Samples with no data for any of the five constituents used in the classification and samples with data only for nitrate were classified as "indeterminate."

Of the 215 wells with analyses of one or more redox-sensitive constituents, enough information was available for 194 wells to make a classification of redox condition (table E5). Seventy-three percent of the groundwater samples were oxic, 21% were anoxic, and 6% were mixed (table E5). Most of the samples from wells in the NSACV and northern half of the MSACV study units were oxic (fig. E5). Most of the anoxic samples came from wells located in the axis of the Sacramento Valley, along the Sacramento River, in the SSACV and southern half of the MSACV study units (fig E5). Values of pH for the Sacramento Valley (all study units) ranged from 6.3 to 9.2 (table E5).

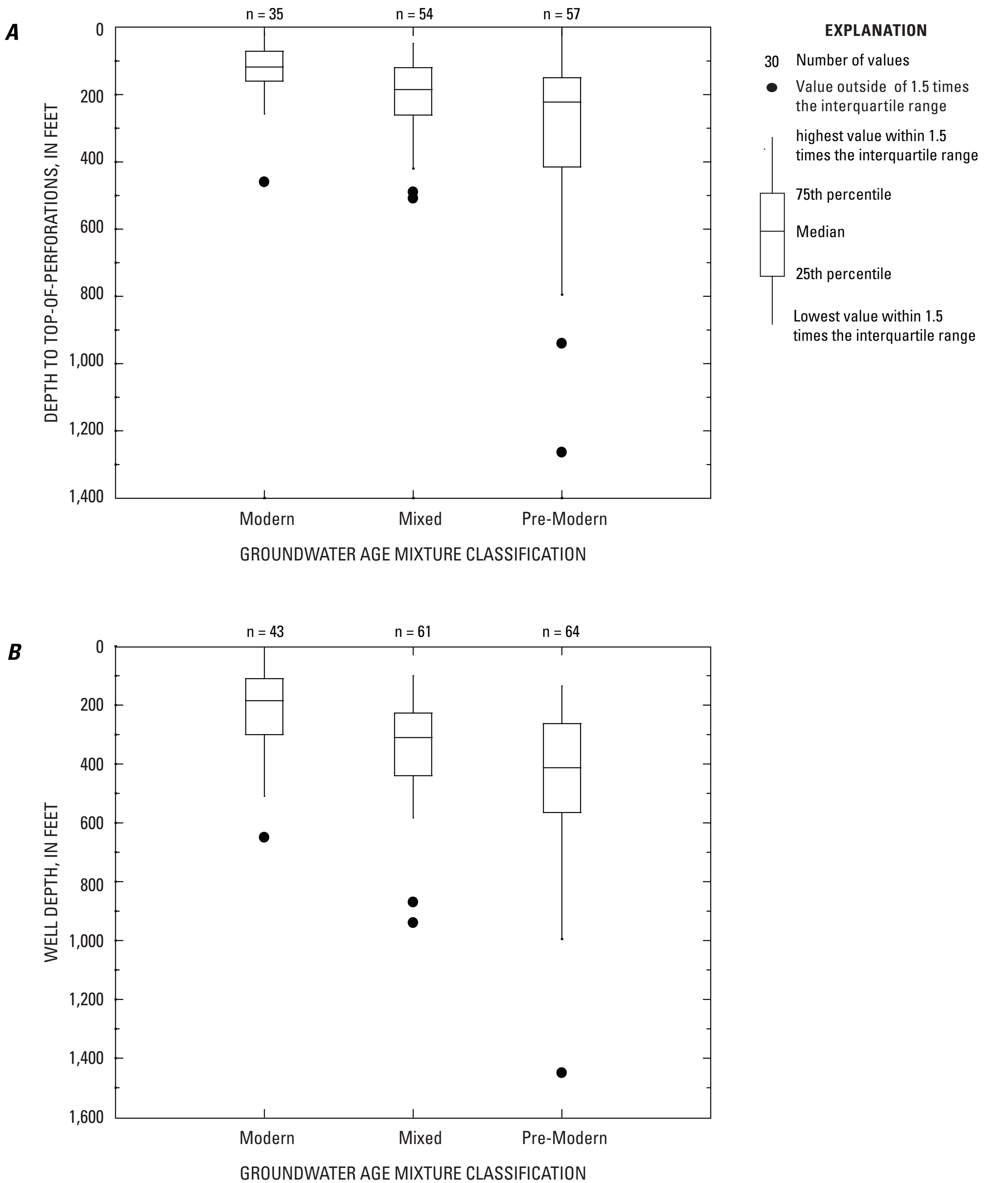

Figure E4. Graphs comparing age classification information in the Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study unit wells to (*A*) depth to top-of-perforation, (*B*) well depth, and (*C*) perforation intervals.

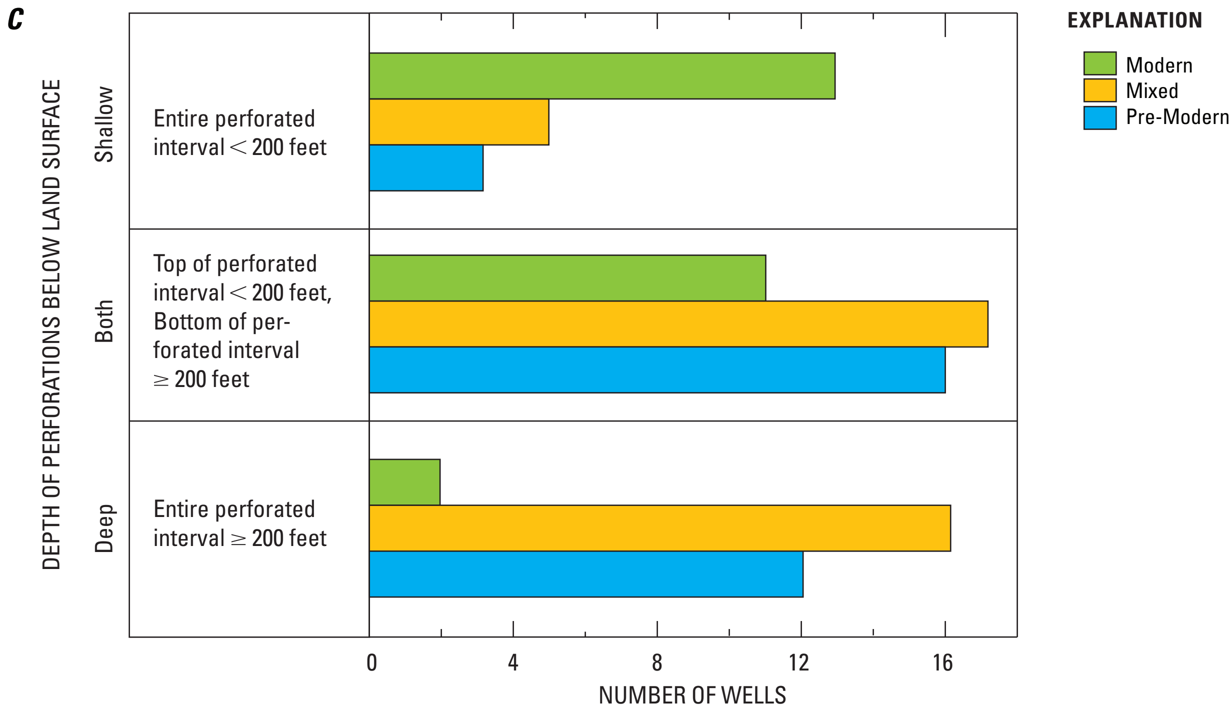

Figure E4.—Continued.

Table E5. pH, dissolved oxygen, and oxidation-reduction classification in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

[CDPH, California Department of Public Health database; E, having a higher degree of uncertainty; mg/L, milligram per liter; <, less than; na, not available]

USGS-GAMA identification No.	Source of inorganic data	pH (standard units)	Dissolved oxygen (mg/L)	Oxidation-reduction classification
Southern Sacramento Valley grid wells				
NAM-01	GAMA	8.0	na	Anoxic
NAM-02	GAMA	7.5	na	Oxic
NAM-03	CDPH	na	na	Oxic
NAM-04	CDPH	7.9	na	Anoxic
NAM-05	GAMA	7.5	na	Oxic
NAM-08	GAMA	7.4	na	Oxic
NAM-09	CDPH	7.5	na	Indeterminate
NAM-10	CDPH	na	na	Indeterminate
NAM-11	CDPH	8.0	na	Indeterminate
SSV-QPC-02	GAMA	7.1	na	Oxic
SSV-QPC-03	CDPH	7.6	na	Oxic
SSV-QPC-04	CDPH	7.8	na	Oxic
SSV-QPC-05	GAMA	7.7	na	Oxic
SSV-QPC-06	GAMA	7.2	8.6	Oxic
SSV-QPC-07	GAMA	7.0	4.7	Oxic
SSV-QPC-08	GAMA	7.2	na	Oxic
SSV-QPC-09	GAMA	7.4	na	Oxic
SSV-QPC-10	CDPH	8.0	na	Anoxic
SSV-QPC-11	CDPH	7.2	na	Indeterminate
SOL-01	GAMA	8.3	na	Oxic
SOL-02	GAMA	7.8	na	Oxic
SOL-03	GAMA	7.6	na	Oxic
SOL-04	CDPH	8.4	na	Oxic
SOL-05	CDPH	7.7	na	Anoxic
SOL-06	GAMA	7.8	na	Anoxic
SOL-07	CDPH	8.2	na	Anoxic
SOL-08	CDPH	8.1	na	Anoxic
SOL-10	CDPH	8.1	na	Anoxic
SOL-11	CDPH	7.8	na	Oxic
SOL-12	CDPH	7.9	na	Oxic
SOL-13	CDPH	7.7	na	Oxic
SAM-01	CDPH	7.4	na	Anoxic
SAM-02	GAMA	7.2	na	Oxic
SAM-03	GAMA	7.9	na	Anoxic
SAM-04	CDPH	na	na	Indeterminate
SAM-05	CDPH	7.6	na	Oxic
SAM-06	CDPH	8.0	na	Oxic
SAM-07	GAMA	7.7	na	Oxic
SAM-08	CDPH	8.0	na	Oxic
SAM-09	CDPH	na	na	Indeterminate
SAM-10	CDPH	7.9	na	Oxic
SAM-11	GAMA	7.6	na	Oxic
SUI-01	GAMA	7.6	na	Oxic
SUI-02	GAMA	8.2	na	Anoxic
SUI-03	CDPH	na	na	Indeterminate
SUI-04	CDPH	7.7	na	Indeterminate
SUI-05	CDPH	na	na	Indeterminate
Southern Sacramento Valley grid wells—Continued				
YOL-01	CDPH	na	na	Oxic
YOL-02	GAMA	7.6	na	Oxic
YOL-03	GAMA	8.2	0.2	Anoxic
YOL-04	GAMA	7.5	4.9	Oxic
YOL-05	CDPH	na	na	Indeterminate
YOL-06	GAMA	8.0	na	Oxic
YOL-07	CDPH	na	na	Indeterminate
YOL-08	GAMA	8.2	0.2	Anoxic
YOL-09	GAMA	8.1	na	Oxic
YOL-13	GAMA	7.5	na	Oxic
YOL-14	GAMA	7.6	<0.2	Anoxic
YOL-17	CDPH	na	na	Oxic
Southern Sacramento Valley additional wells				
NAM-DPH-12	CDPH	8.1	na	Anoxic
NAM-DPH-13	CDPH	7.9	na	Anoxic
NAM-DPH-14	CDPH	na	na	Indeterminate
SAM-DPH-13	CDPH	7.7	na	Indeterminate
SAM-DPH-14	CDPH	na	na	Anoxic
SOL-DPH-14	CDPH	8.0	na	Indeterminate
SOL-DPH-15	CDPH	na	na	Indeterminate
SSV-QPC-DPH-12	CDPH	7.2	na	Oxic
SUI-DPH-06	CDPH	na	na	Indeterminate
Middle Sacramento Valley grid wells				
ESAC-01[1]	CDPH	7.3	2.4	Oxic
ESAC-02[1]	CDPH	na	<0.2	Anoxic
ESAC-03	GAMA	7.8	3.2	Oxic
ESAC-04[1]	CDPH	7.5	6.8	Oxic
ESAC-05	GAMA	7.1	1.6	Oxic
ESAC-06	GAMA	7.1	6.9	Oxic
ESAC-07[1]	CDPH	7.7	4.7	Oxic
ESAC-08[1]	CDPH	7.7	1.9	Oxic
ESAC-09	GAMA	6.3	2.6	Oxic
ESAC-10	GAMA	7.3	0.4	Anoxic
ESAC-11	GAMA	7.4	0.4	Anoxic
ESAC-12	GAMA	na	na	Oxic
ESAC-13[1]	CDPH	na	3.9	Oxic
ESAC-14[1]	CDPH	7.0	2.5	Oxic
ESAC-15	GAMA	7.6	10.1	Oxic
ESAC-16	GAMA	7.5	9.9	Oxic
ESAC-17	GAMA	7.3	<0.2	Anoxic
ESAC-18	GAMA	7.7	8.7	Oxic
ESAC-19	GAMA	7.0	2.3	Oxic
ESAC-20	GAMA	7.5	<0.2	Anoxic
ESAC-21	GAMA	7.6	<0.2	Anoxic
ESAC-22	GAMA	6.5	8.9	Oxic
ESAC-23[1]	CDPH	6.3	3.4	Mixed
ESAC-24	GAMA	7.5	na	Oxic

Table E5. pH, dissolved oxygen, and oxidation-reduction classification in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[CDPH, California Department of Public Health database; E, having a higher degree of uncertainty; mg/L, milligram per liter; <, less than; na, not available]

USGS-GAMA identification No.	Source of inorganic data	pH (standard units)	Dissolved oxygen (mg/L)	Oxidation-reduction classification
Middle Sacramento Valley grid wells—Continued				
ESAC-25	GAMA	7.2	6.9	Oxic
ESAC-26	GAMA	7.9	<0.2	Anoxic
ESAC-27	GAMA	7.1	0.8	Mixed
ESAC-28	GAMA	7.4	2.1	Oxic
ESAC-29	GAMA	na	<0.2	Anoxic
ESAC-30	GAMA	7.8	0.2	Anoxic
ESAC-31	GAMA	7.6	<0.2	Anoxic
ESAC-32	GAMA	7.2	1.0	Oxic
ESAC-33	GAMA	7.0	4.1	Oxic
ESAC-34	GAMA	7.2	2.5	Oxic
ESAC-35	GAMA	7.4	na	Oxic
WSAC-01	GAMA	8.1	2.0	Oxic
WSAC-02	GAMA	7.3	6.3	Oxic
WSAC-03	GAMA	7.3	7.7	Oxic
WSAC-04	GAMA	7.9	0.2	Anoxic
WSAC-05[1]	CDPH	7.9	<0.2	Anoxic
WSAC-06	GAMA	7.0	2.7	Oxic
WSAC-07[1]	CDPH	7.1	7.0	Oxic
WSAC-08	GAMA	7.0	4.1	Oxic
WSAC-09[1]	CDPH	6.9	6.3	Mixed
WSAC-10	GAMA	7.4	6.9	Oxic
WSAC-11	GAMA	7.8	7.1	Oxic
WSAC-12	GAMA	7.6	<0.2	Anoxic
WSAC-13	GAMA	7.1	2.1	Oxic
WSAC-14	GAMA	7.2	na	Mixed
WSAC-15	GAMA	7.1	6.9	Oxic
WSAC-16	GAMA	7.5	<0.2	Anoxic
WSAC-17	GAMA	7.2	1.3	Oxic
WSAC-18	GAMA	7.8	<0.2	Mixed
WSAC-19	GAMA	7.6	0.7	Oxic
WSAC-20	GAMA	7.0	5.9	Oxic
WSAC-21	GAMA	7.0	7.8	Oxic
WSAC-22	GAMA	7.7	5.1	Oxic
WSAC-23	GAMA	7.2	5.4	Oxic
WSAC-24	GAMA	7.2	6.8	Oxic
WSAC-25	GAMA	7.8	0.2	Anoxic
WSAC-26	GAMA	7.6	10.8	Oxic
WSAC-27	GAMA	7.8	0.5	Oxic
WSAC-28	GAMA	7.2	4.8	Oxic
WSAC-29	GAMA	8.0	3.2	Oxic
WSAC-30	GAMA	7.4	2.2	Oxic
WSAC-31	GAMA	8.0	1.8	Oxic
WSAC-32	GAMA	7.8	1.8	Oxic
WSAC-33	GAMA	7.6	5.4	Oxic
WSAC-34	GAMA	7.1	E20.4	Oxic
WSAC-35	GAMA	7.3	13.3	Oxic
WSAC-36	GAMA	7.6	na	Oxic
Middle Sacramento Valley additional wells				
ESAC-DPH-36	CDPH	na	na	Indeterminate
ESAC-DPH-37	CDPH	7.8	na	Anoxic
ESAC-DPH-38	CDPH	na	na	Indeterminate
ESAC-DPH-39	CDPH	8.3	na	Anoxic
WSAC-DPH-37	CDPH	7.7	na	Mixed
WSAC-DPH-38	CDPH	7.3	na	Mixed
WSAC-DPH-39	CDPH	na	na	Indeterminate
WSAC-DPH-40	CDPH	na	na	Indeterminate
WSAC-DPH-41	CDPH	na	na	Indeterminate
WSAC-DPH-42	CDPH	8.2	na	Anoxic
Northern Sacramento Valley grid wells				
NSAC-01	GAMA	7.1	4.7	Oxic
NSAC-02	GAMA	6.9	2.4	Oxic
NSAC-03	GAMA	7.7	0.6	Oxic
NSAC-04	GAMA	7.2	5.8	Oxic
NSAC-05	GAMA	7.7	3.8	Oxic
NSAC-06	GAMA	7.2	3.0	Oxic
NSAC-07	GAMA	7.6	3.3	Oxic
NSAC-08	GAMA	8.3	0.1	Anoxic
NSAC-09	GAMA	8.1	2.2	Oxic
NSAC-10	GAMA	7.7	6.0	Oxic
NSAC-11	GAMA	6.6	2.5	Oxic
NSAC-12	GAMA	8.0	3.5	Oxic
NSAC-13	GAMA	7.9	4.7	Oxic
NSAC-14	GAMA	7.9	4.1	Oxic
NSAC-15	GAMA	6.9	1.3	Oxic
NSAC-16	GAMA	7.8	4.9	Oxic
NSAC-17	GAMA	8.6	0.1	Anoxic
NSAC-18	GAMA	7.7	5.4	Oxic
NSAC-19	GAMA	7.7	3.4	Oxic
NSAC-20	GAMA	7.4	6.1	Oxic
RED-01	GAMA	7.5	6.0	Oxic
RED-02	GAMA	7.6	6.6	Oxic
RED-03	GAMA	6.6	4.5	Oxic
RED-04	GAMA	7.1	0.2	Anoxic
RED-05	GAMA	7.2	4.2	Oxic
RED-06	GAMA	6.4	3.6	Oxic
RED-07	GAMA	7.1	7.5	Oxic
RED-08	GAMA	7.0	6.5	Oxic
RED-09	GAMA	7.1	5.2	Oxic
RED-10	GAMA	8.3	0.6	Oxic
RED-11	GAMA	6.7	5.6	Oxic
RED-12	GAMA	7.6	0.1	Anoxic
RED-13	GAMA	7.1	6.0	Oxic
RED-14	GAMA	7.8	0.1	Anoxic
RED-15	GAMA	6.8	7.0	Oxic

Table E5. pH, dissolved oxygen, and oxidation-reduction classification in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.—Continued

[CDPH, California Department of Public Health database; E, having a higher degree of uncertainty; mg/L, milligram per liter; <, less than; na, not available]

USGS-GAMA identification No.	Source of inorganic data	pH (standard units)	Dissolved oxygen (mg/L)	Oxidation-reduction classification
Northern Sacramento Valley grid wells—Continued				
RED-16	GAMA	6.7	7.0	Oxic
RED-17	GAMA	7.7	3.8	Oxic
RED-18	GAMA	7.2	3.7	Oxic
RED-19	GAMA	6.7	4.7	Oxic
RED-20	GAMA	7.6	5.2	Oxic
RED-21	GAMA	7.4	6.7	Oxic
RED-22	GAMA	7.1	2	Oxic
RED-23	GAMA	7.2	4.9	Oxic
Northern Sacramento Valley understanding wells				
NSAC-MW-01	GAMA	8.4	0.7	Oxic
NSAC-MW-02	GAMA	7.9	1.2	Mixed
NSAC-MW-03	GAMA	9.2	0.6	Mixed
NSAC-MW-04	GAMA	7.7	6.3	Oxic
NSAC-MW-05	GAMA	8.6	0.5	Oxic
NSAC-MW-06	GAMA	8.7	0.3	Anoxic
NSAC-U-01	GAMA	8.0	4.0	Oxic
Northern Sacramento Valley understanding wells—Continued				
NSAC-U-02	GAMA	7.0	7.8	Oxic
NSAC-U-03	GAMA	7.0	3.2	Oxic
NSAC-U-04	GAMA	7.7	6.3	Oxic
NSAC-U-05	GAMA	7.7	3.8	Oxic
NSAC-U-06	GAMA	6.9	4.6	Oxic
NSAC-U-07	GAMA	8.0	0.2	Anoxic
NSAC-U-08	GAMA	7.2	7.6	Oxic
RED-MW-01	GAMA	7.7	1.5	Mixed
RED-MW-02	GAMA	7.2	3.7	Oxic
RED-MW-03	GAMA	7.1	3.7	Oxic
RED-MW-04	GAMA	8.0	0.7	Oxic
RED-MW-05	GAMA	7.1	4.8	Oxic
RED-MW-06	GAMA	8.1	4.8	Oxic
RED-MW-07	GAMA	9.2	2.5	Oxic
RED-U-01	GAMA	8.0	5.8	Oxic
RED-U-02	GAMA	8.1	8.2	Oxic

[1] Values of dissolved oxygen obtained from GAMA, not CDPH.

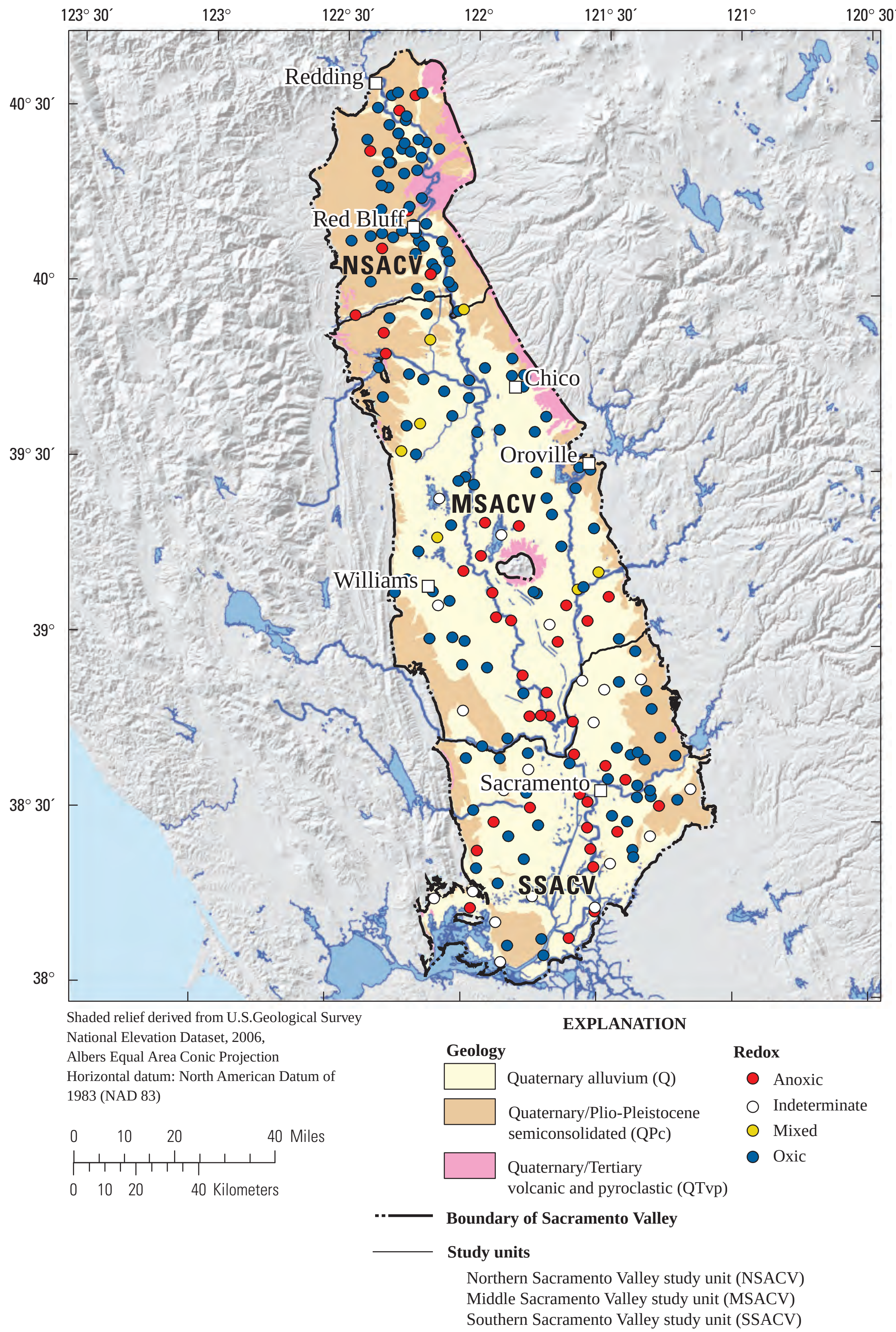

Figure E5. Map showing redox conditions in grid and USGS-understanding wells in the Southern, Middle, and Northern Sacramento Valley Groundwater Ambient Monitoring and Assessment (GAMA) study units, California.

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Bennett and others—**Status of Groundwater Quality in the Southern, Middle, and Northern Sacramento Valley Study Units, 2005–08: California GAMA Priority Basin Project**—SIR 2011–5002

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