Prepared in cooperation with the California State Water Resources Control Board

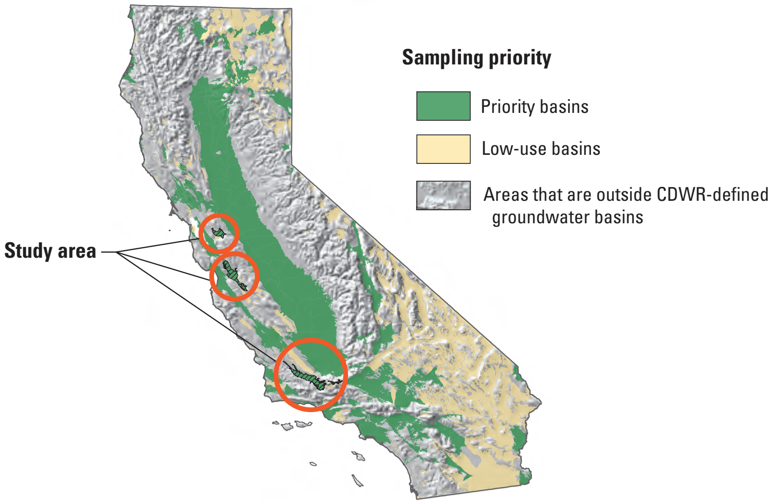
A product of the California Groundwater Ambient Monitoring and Assessment (GAMA) Program

Status and Understanding of Groundwater Quality in the South Coast Interior Groundwater Basins, 2008: California GAMA Priority Basin Project

Scientific Investigations Report 2014–5023

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 (CDWR, 2003).



Cover photographs:

Front cover: Farm in Gilroy, California. (Photograph taken by Michael Land, U.S. Geological Survey.)

Back cover: Golf course irrigation well, Pleasanton, California. (Photograph taken by Tracy Davis, U.S. Geological Survey.)

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By Mary C. Parsons, Justin T. Kulongoski, and Kenneth Belitz

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

U.S. Department of the Interior
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Conversion Factors, Datums, and Abbreviations and Acronyms

Inch/foot/mile to International System of Units (SI)

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C=(°F–32)/1.8.

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). One milligram per liter is equivalent to 1 part per million (ppm); 1 microgram per liter is equivalent to 1 part per billion (ppb).

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 1983 (NAD 83).

Abbreviations and Acronyms

AL-US	U.S. Environmental Protection Agency action level
CUY	Cuyama study area
GAMA	Groundwater Ambient Monitoring and Assessment Program
GIL	Gilroy study area
HAL-US	U.S. Environmental Protection Agency lifetime health advisory level
HBSL	health-based screening level
LIV	Livermore study area
LSD	land-surface datum
LUFT	leaking underground fuel tank
MCL-CA	California Department of Public Health maximum contaminant level
MCL-US	U.S. Environmental Protection Agency maximum contaminant level
NL-CA	California Department of Public Health notification level
pmc	percent modern carbon
RSD5-US	U.S. Environmental Protection Agency risk-specific dose at a risk factor of 10^{-5}
SCI	South Coast Interior Basins study unit
SMCL-CA	California Department of Public Health secondary maximum contaminant level
SMCL-US	U.S. Environmental Protection Agency secondary maximum contaminant level
TT-US	U.S. Environmental Protection Agency treatment technique levels
TU	tritium unit

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
NAWQA	National Water-Quality Assessment Program (USGS)
SWRCB	State Water Resources Control Board (California)
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Selected chemical names

DO	dissolved oxygen
MTBE	methyl *tert*-butyl ether
NDMA	*N*-nitrosodimethylamine
PCE	tetrachloroethene
TDS	total dissolved solids
THM	trihalomethane
VOC	volatile organic compound

Units of Measure

δ	delta notation; the ratio of a heavier isotope to the more common lighter isotope of an element, relative to a standard reference material, expressed as per mil
>	greater than
<	less than
%	percent

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Status and Understanding of Groundwater Quality in the South Coast Interior Groundwater Basins, 2008: California GAMA Priority Basin Project

By Mary C. Parsons, Justin T. Kulongoski, and Kenneth Belitz

Abstract

Groundwater quality in the approximately 653-square-mile (1,691-square-kilometer) South Coast Interior Basins (SCI) study unit was investigated as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The South Coast Interior Basins study unit contains eight priority groundwater basins grouped into three study areas, Livermore, Gilroy, and Cuyama, in the Southern Coast Ranges hydrogeologic province. The GAMA Priority Basin Project is being conducted by the California State Water Resources Control Board in collaboration with the U.S. Geological Survey (USGS) and the Lawrence Livermore National Laboratory.

The GAMA South Coast Interior Basins study was designed to provide a spatially unbiased assessment of untreated (raw) groundwater quality within the primary aquifer system, as well as a statistically consistent basis for comparing water quality between basins. The assessment was based on water-quality and ancillary data collected by the USGS from 50 wells in 2008 and on water-quality data from the California Department of Public Health (CDPH) database. The primary aquifer system was defined by the depth intervals of the wells listed in the CDPH database for the SCI study unit. The quality of groundwater in the primary aquifer system may be different from that in the shallower or deeper water-bearing zones; shallow groundwater may be more vulnerable to surficial contamination.

The first component of this study, the status of the current quality of the groundwater resource, was assessed by using data from samples analyzed for volatile organic compounds (VOCs), pesticides, and naturally occurring inorganic constituents, such as trace elements and minor ions. This *status assessment* is intended to characterize the quality of groundwater resources within the primary aquifer system of the SCI study unit, not the treated drinking water delivered to consumers by water purveyors.

Relative-concentrations (sample concentration divided by the health- or aesthetic-based benchmark concentration) 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, and a relative-concentration less than or equal to 1.0 indicates a concentration equal to or less than a benchmark. Relative-concentrations of organic constituents and special-interest constituents were classified as “high” (relative-concentration greater than 1.0), “moderate” (relative-concentration greater than 0.1 and less than or equal to 1.0), or “low” (relative-concentration less than or equal to 0.1). Relative-concentrations of inorganic constituents were classified as “high” (relative-concentration greater than 1.0), “moderate” (relative-concentration greater than 0.5 and less than or equal to 1.0), or “low” (relative-concentration less than or equal to 0.5).

Aquifer-scale proportion was used as the primary metric 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 aquifer system with 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 areal percentage of the primary aquifer system with moderate and low relative-concentrations, respectively. Two statistical approaches—grid-based and spatially weighted—were used to evaluate aquifer-scale proportions for individual constituents and classes of constituents. Grid-based and spatially weighted estimates were comparable in the SCI study unit (within 90-percent confidence intervals).

Inorganic constituents (one or more) with health-based benchmarks were detected at high relative-concentrations in 29 percent of the primary aquifer system, at moderate relative-concentrations in 37 percent, and at low relative-concentrations in 34 percent. High aquifer-scale proportions of inorganic constituents primarily reflected high aquifer-scale proportions of nitrate (14 percent), boron (8.6 percent), molybdenum (8.6 percent), and arsenic (5.7 percent). In contrast, the relative-concentrations of organic constituents (one or more) were high in 1.6 percent, moderate in

2.0 percent, and low or not detected in 96 percent of the primary aquifer system. Of the 207 organic and special-interest constituents analyzed for, 15 constituents were detected. Perchlorate was found at moderate relative-concentrations in 34 percent of the aquifer. Two organic constituents were frequently detected (in greater than 10 percent of samples): the trihalomethane chloroform and the herbicide simazine.

The second component of this study, the *understanding assessment*, identified natural and human factors that may have affected groundwater quality by evaluating land use, physical characteristics of the wells, and geochemical conditions of the aquifer. This evaluation was done by using statistical tests of correlations between these potential explanatory factors and water-quality data. Concentrations of arsenic, molybdenum, and manganese were generally greater in anoxic and pre-modern groundwater than other groundwater. In contrast, concentrations of nitrate and perchlorate were significantly higher in oxic and modern groundwater. Concentrations of simazine were greater in modern than pre-modern groundwater. Chloroform detections were positively correlated with greater urban land use. Boron concentrations and chloroform detections were higher in the Livermore study area than in the other study areas of the SCI; total dissolved solids and sulfate concentrations were greater in the Cuyama study area.

Introduction

To assess the quality of ambient groundwater in aquifers used for drinking-water supply and to establish a baseline groundwater-quality monitoring program, the California 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 State Water Resources Control Board, 2013, website at http://www.waterboards.ca.gov/gama). The statewide GAMA Program currently consists of four projects: (1) the GAMA Priority Basin Project, conducted by the USGS (U.S. Geological Survey, 2013, website at http://ca.water.usgs.gov/gama/); (2) the GAMA Domestic Well Project, conducted by the SWRCB; (3) the GAMA Special Studies, conducted by LLNL; and (4) the online database GeoTracker GAMA, conducted by the SWRCB. On a statewide basis, the GAMA Priority Basin Project focused on the primary aquifer systems, typically the deep portion of the groundwater resource, and the SWRCB Domestic Well Project generally focused on the shallow aquifer systems. The deeper aquifers may be at less risk of contamination than the shallow wells, such as private domestic or environmental monitoring wells, which are closer to surficial sources of contamination. As a result, concentrations of contaminants, such as volatile organic compounds (VOCs) and nitrate, in wells screened in the deep aquifers may be lower than concentrations of constituents in shallow wells (Kulongoski and others, 2010; Landon and others, 2010).

The SWRCB initiated the GAMA Program in 2000 in response to Legislative mandates (California State Water Resources Control Board, 1999; State of California, 2001a). The GAMA Priority Basin Project was initiated in response to the Groundwater Quality Monitoring Act of 2001 to assess and monitor the quality of groundwater in California (State of California, 2001b). 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 GAMA Priority Basin Project, the USGS, in collaboration with the SWRCB, developed a monitoring plan to assess groundwater basins through direct sampling of groundwater and other statistically reliable sampling approaches (Belitz and others, 2003; California 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 (Kulongoski and Belitz, 2004).

The range of hydrologic, geologic, and climatic conditions in California were considered in this statewide 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). These hydrogeologic provinces include groundwater basins and subbasins designated by the CDWR (California Department of Water Resources, 2003). Groundwater basins generally consist of relatively permeable, unconsolidated deposits of alluvial origin. Eighty percent of California's approximately 16,000 public-supply wells are in designated groundwater basins. Groundwater basins and subbasins were prioritized for sampling on the basis of the number of public-supply wells, with secondary consideration given to municipal groundwater use, agricultural pumping, the number of historically leaking underground fuel tanks, and the number of square-mile sections having registered pesticide applications (Belitz, and others, 2003). The 116 priority basins, a subset of the approximately 350 lower-priority basins, and additional areas outside defined groundwater basins, were grouped into 35 study units, which include approximately 95 percent of public-supply wells in California's groundwater basins. The South Coast Interior Basins study unit (hereinafter referred to as the SCI study unit) contains eight priority groundwater basins grouped into three study areas, Livermore, Gilroy, and Cuyama, in the Southern Coast Ranges hydrogeologic province.

Shaded relief derived from U.S. Geological Survey
National Elevation Dataset, 2006.
Albers Equal Area Conic Projection

Provinces from Belitz and others, 2003.

Figure 1. Location of the South Coast Interior Basins study unit, California GAMA Priority Basin Project, and the California hydrogeologic provinces.

Purpose and Scope

The purposes of this report are to provide (1) a *study unit description*: description of the hydrogeologic setting of the SCI study unit (fig. 1); (2) a *status assessment*: assessment of the status of the current quality of groundwater in the primary aquifer system in the SCI study unit; and (3) an *understanding assessment*: identification of the natural and human factors affecting groundwater quality.

Water-quality data for samples collected by the USGS-GAMA Program in the SCI study unit and details of sample collection, analysis, and quality-assurance procedures for the SCI study unit are reported by Mathany and others (2009). Using 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 datasets, 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 35 wells selected by the USGS for spatial coverage of one well per grid cell (hereinafter referred to as USGS-grid wells) across the SCI study unit. Most of the USGS-grid wells were public-supply wells, but a few other types of wells with perforation depth intervals similar to the public-supply wells also were sampled. Samples were collected for analysis of anthropogenic constituents, including volatile organic compounds (VOCs) and pesticides, and naturally occurring inorganic constituents, such as trace and minor elements. Water-quality data from the California Department of Public Health (CDPH) database also were used to supplement data collected by the 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 system in the SCI study unit; the primary aquifer system is defined by the depth of the screened/perforated intervals of the wells listed in the CDPH database for the SCI study unit. GAMA status assessments were designed to provide a statistically robust characterization of groundwater quality in the primary aquifer system at the basin-scale (Belitz and others, 2003). The statistically robust design also allows basins to be compared and results to be synthesized regionally and statewide.

To provide context, the water-quality data discussed in this report are compared to California and Federal regulatory and non-regulatory benchmarks for drinking water. The assessments in this report are intended to characterize the quality of untreated groundwater resources in the primary aquifer system within the study unit, not the drinking water delivered to consumers by water purveyors. This study does not attempt to evaluate the quality of water delivered to consumers; 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 drinking water that is delivered to the consumer, not to untreated groundwater.

The understanding assessment included data from 15 wells sampled by the USGS (hereinafter referred to as USGS-understanding wells) in addition to the 35 USGS-grid wells sampled for the status assessment to identify the natural and human factors affecting groundwater quality, and to explain the relations between water quality and selected potential explanatory factors. Potential explanatory factors examined included land use, well depth, indicators of groundwater age, and geochemical conditions of the waters.

Hydrogeologic Setting of the South Coast Interior Basins Study Unit

The SCI GAMA study unit covers approximately 653 square miles (mi^2) in Alameda, Contra Costa, Santa Clara, San Benito, San Luis Obispo, Santa Barbara, Ventura, Kern, and Los Angeles Counties. The SCI study unit lies in the Southern Coast Ranges hydrogeologic province (fig. 1) and contains eight groundwater basins: Livermore, Gilroy–Hollister (subbasins: Llagas, Bolsa Area, Hollister Area, and San Juan Bautista Area), Cuyama Valley, Castac Lake Valley, Cuddy Canyon Valley, Cuddy Ranch Area, Cuddy Valley, and Mil Potrero. For the purpose of this study, these eight groundwater basins were grouped into three study areas: Livermore, Gilroy, and Cuyama (figs. 2*A–C*). As part of the Priority Basin Project, untreated groundwater samples were collected from 50 wells that were considered representative of the primary aquifer systems in the SCI study unit from August 11 to November 17, 2008 (Mathany and others, 2009). Samples collected from four additional monitoring wells in the Livermore basin were not included in this report because the monitoring wells were screened at much shallower depths than the primary aquifer system and were therefore not considered representative of the primary aquifer system (table B2).

The climate of the SCI study unit is characterized by hot, dry summers and cold winters. Average annual precipitation in the SCI study unit varies slightly among the three study areas. In the Livermore study area, values range from more than 20 inches along the southeast and northwest study area margins to 16 inches on the valley floor, occurring as rain during the winter (California Department of Water Resources, 2006). In the Gilroy study area, average annual precipitation ranges from 17 inches in the northern reaches of the study area to 13 inches in the south, occurring as rain in the winter and early spring (California Department of Water Resources, 2004a, b, c, d). In the Cuyama study area, precipitation ranges from less than 8 inches in the Cuyama Valley up to 17 inches in the surrounding mountains, occurring as rainfall in the winter and early spring (PRISM Climate Group, Oregon State University, 2010).

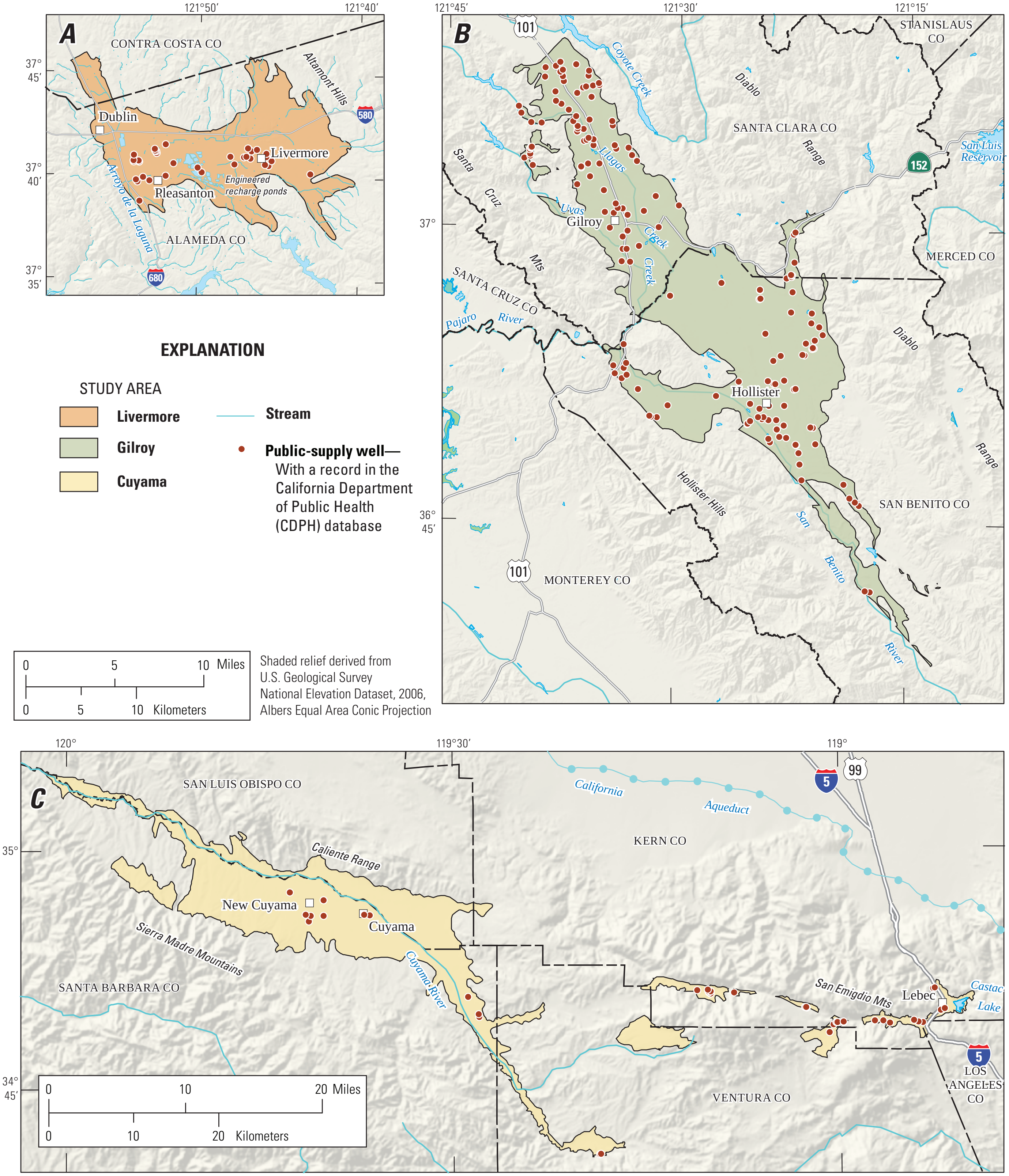


Figure 2*A,B,C*. Geographic features and study areas of the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Livermore Study Area

The Livermore (LIV) study area is approximately 109 mi^2 in area and lies about 40 miles (mi) east of San Francisco within a structural trough of the Diablo Range. The LIV study area is located within the Livermore Valley Groundwater Basin (California Department of Water Resources, 2006) and was defined by the extent of alluvium of Quaternary age within the groundwater basin (fig. 3*A*). The parts of the groundwater basin having surficial geology consisting of sediments of Plio-Pleistocene age were not included in the study area. Elevations within LIV range from about 280 feet (ft) above land-surface datum (LSD) in the southwest, where Arroyo de la Laguna exits the study area, to about 600 ft above LSD in the east, near the Altamont Hills (fig. 2*A*).

The main surface drainage features of the LIV study area are creeks and human-made canals that drain into the Arroyo de la Laguna on west side of the basin (fig. 2*A*). Groundwater recharge in the LIV study area occurs from infiltration of precipitation and irrigation waters, engineered recharge (percolation ponds and lakes), and interbasin lateral flow (California Department of Water Resources, 2006). Groundwater discharge occurs as pumping for municipal and irrigation supply and as evaporation (California Department of Water Resources, 2006).

Primary water-bearing formations in the LIV study area include valley-fill materials of Quaternary age, the Livermore Formation of Plio-Pleistocene age in the south and southwest, and the Tassajara Formation of Pliocene age in the northern region of LIV (California Department of Water Resources, 2006). The LIV study area has three major fault zones (the Pleasanton and Parks faults and the Livermore fault zone), each inhibiting the lateral movement of groundwater (California Department of Water Resources, 2006) (fig. 3*A*).

Gilroy Study Area

The Gilroy (GIL) study area is approximately 287 mi^2 in area and lies within the Gilroy–Hollister groundwater basin, which contains four CDWR-defined subbasins: Llagas, Bolsa Area, Hollister Area, and San Juan Bautista Area (California Department of Water Resources, 2004a, b, c, d). The study area was defined by the extent of alluvium of Quaternary age within these defined groundwater basins (fig. 3*B*). The parts of the groundwater basin having surficial geology consisting of sediments of Plio-Pleistocene age were not included in the study area. Elevations within the study area range from about 140 ft above LSD in the center of the basin, along the Santa Clara County and San Benito County border, to approximately 800 ft above LSD in the south tip of the study area.

The Pájaro River and its major tributaries drain the northern portion of the GIL study area to the Pacific Ocean through Monterey Bay. The southern portion of the GIL study area is drained by the San Benito River and its tributaries (fig. 2*B*). Groundwater recharge in the GIL study area occurs from a variety of sources: stream losses along the Pájaro and San Benito Rivers and their tributaries; areal recharge of precipitation and irrigation waters; seepage along canals; and interbasin lateral flow. A number of engineered-recharge facilities (percolation ponds and channels) enhance ambient recharge in the northern portion of the GIL study area. In the southern region of the GIL study area, engineered recharge occurs from the San Benito River as a result of river regulation at the Hernandez Reservoir, which is located approximately 20 mi southeast of the study area boundary (California Department of Water Resources, 2004a, b, c, d). Groundwater discharge occurs primarily as pumping for municipal and irrigation supply (Kilburn, 1973; California Department of Water Resources, 2004a, b, c, d).

The primary water-bearing formation in GIL is a sedimentary sequence consisting mainly of clays, silts, sands, and gravels ranging in age from Tertiary to Holocene (California Department of Water Resources, 2004a, b, c, d). The major faults that bound the GIL study area (Calaveras, San Andreas, and Sargent) are relatively impermeable barriers to groundwater flow (fig. 3*B*). An unnamed clay confining layer in the Llagas Subbasin restricts vertical groundwater flow in the northern region of GIL (California Department of Water Resources, 2004a).

Cuyama Study Area

The Cuyama (CUY) study area is approximately 257 mi^2 in area, is composed largely of the Cuyama Valley groundwater basin (230 mi^2), and also includes five small CDWR-defined groundwater basins [Castac Lake Valley (6 mi^2), Cuddy Canyon Valley (5 mi^2), Cuddy Ranch Area (7 mi^2), Cuddy Valley (5 mi^2), and Mil Potrero (4 mi^2)] (California Department of Water Resources, 2004e, f, g, h, i, j). The study area was defined by the extent of alluvium of Quaternary age within the groundwater basin (fig. 3*C*). The parts of the groundwater basin having surficial geology consisting of sediments of Plio-Pleistocene age were not included in the study area. Elevations within CUY range from about 1,400 ft above LSD in the west, where the Cuyama River exits the CUY study area, to about 5,000 ft above LSD in the east, in the small alluvial valleys in the San Emigdio Mountains (fig. 2*C*).

The CUY study area is drained by the Cuyama River and its major tributaries) (fig. 2*C*). Groundwater recharge in the CUY study area occurs almost exclusively from seepage from the Cuyama River, which is fed by runoff from the Sierra Madre Mountains (Singer and Swarzenski, 1970; Everett and others, 2013). Groundwater recharge in the five small CDWR-defined groundwater basins in the CUY study area occurs from the percolation of precipitation, spring flows, and septic tank effluent (California Department of Water Resources, 2004f, g, h, i, j). Groundwater discharge in the CUY study area occurs as pumping for irrigation and municipal supply, discharge to rivers and streams, and evapotranspiration (Upson and Worts, 1951).

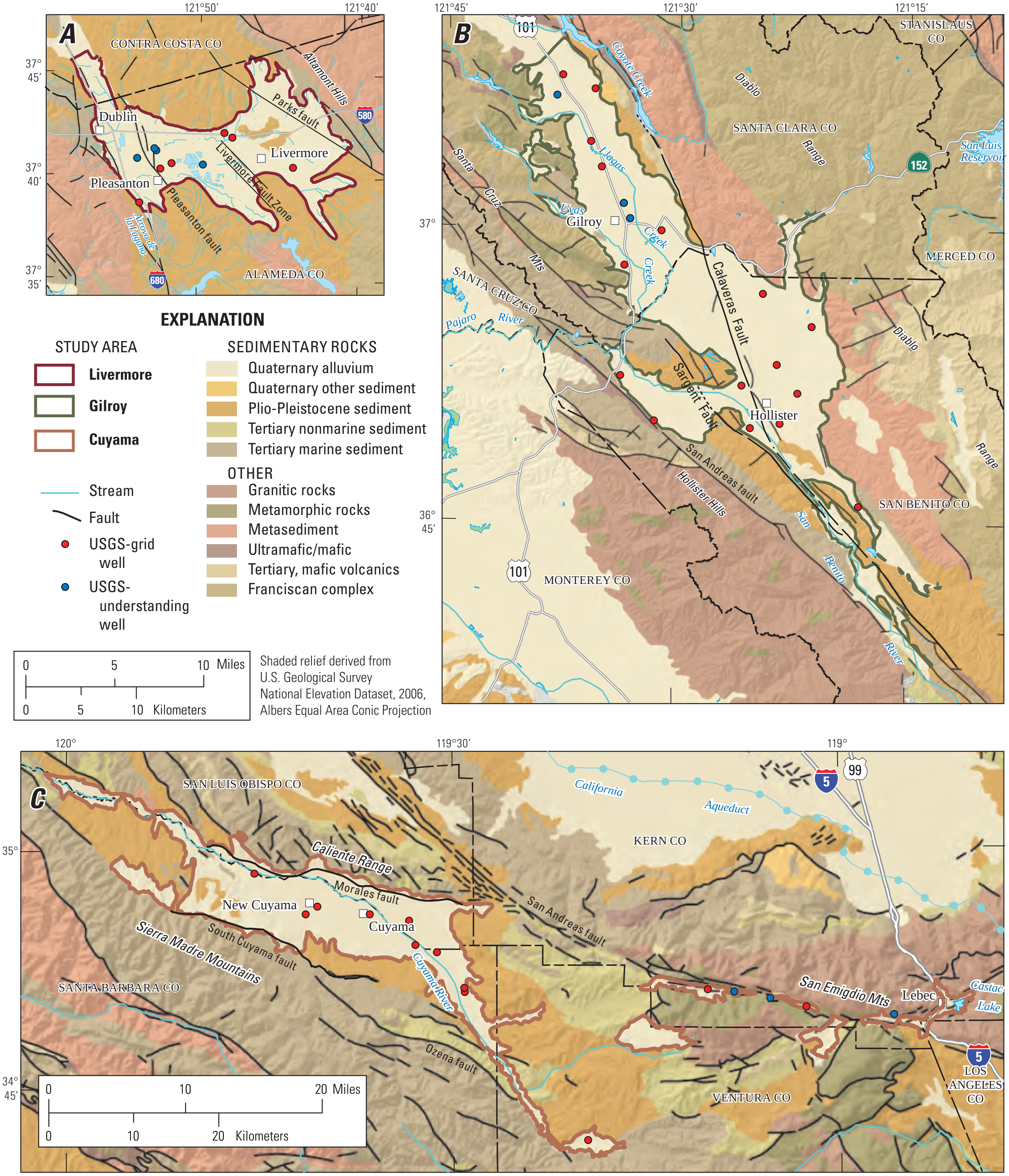


Figure 3*A,B,C*. Geologic formations and areal distribution of USGS-grid and understanding wells sampled in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

The Cuyama Valley consists of a downfaulted block or graben between faults (Singer and Swarzenski, 1970). The Cuyama Valley is bordered on the north by the Morales Fault, and on the south by the Ozena and South Cuyama faults (fig. 3*C*). The eastern part of the Cuyama Valley is underlain by a large syncline, the axis of which strikes roughly parallel to the elongation of the valley and dips towards the northwest (Singer and Swarzenski, 1970; Sweetkind and others, 2013). The Cuyama Valley has sedimentary deposits 3,000–4,000 ft in thickness, which range in age from Cretaceous to Holocene (Singer and Swarzenski, 1970). The basement complex and all sedimentary deposits older than the Morales Formation (clay, silt, sand, and gravel deposits of Pliocene age) are considered non-water-bearing. The Morales Formation, up to 10,000 ft thick along the northern margin, is overlain by alluvium of Pleistocene and Holocene age (Singer and Swarzenski, 1970).

The primary water-bearing formations in the CUY study area are mainly unconfined and are composed of younger (Holocene-age) and older (Pleistocene-age) alluvium (consisting of alternating layers of sands, gravels, boulders, silts, and clays) (Singer and Swarzenski, 1970). Under natural conditions, groundwater flow in the Cuyama Valley groundwater basin is northwestward, down the valley (Singer and Swarzenski, 1970; Everett and others, 2013). It is postulated that there are also additional faults that do not intersect land surface, yet compartmentalize the basin and create water-level offsets as much as 110 ft (Singer and Swarzenski, 1970).

Five small CDWR-defined groundwater basins (Castac Lake Valley, Cuddy Canyon Valley, Cuddy Ranch Area, Cuddy Valley, and Mil Potrero) located east of the Cuyama Valley groundwater basin were included in the CUY study area to gain information on the quality of groundwater in the San Andreas fault zone (fig. 3*C*). These groundwater basins lie adjacent to the San Emigdio Mountains, contain alluvial fill material of Tertiary, Pleistocene, or Quaternary age, and are drained by a series of streams and creeks. Only the parts of the basins containing alluvium of Quaternary age were included in the CUY study area.

Methods

The status assessment provides a spatially unbiased assessment of groundwater quality in the primary aquifer system, and the understanding assessment was designed to evaluate the natural and human factors that may affect groundwater quality of the SCI study unit. This section describes the methods used for (1) defining groundwater quality, (2) assembling the datasets used for the status assessment, (3) determining which constituents warranted additional evaluation, (4) calculating aquifer-scale proportions, and (5) analyzing explanatory factors and water-quality datasets as part of the understanding assessment. Methods used for compilation of data on potential explanatory factors are described in appendix B.

The primary metric for defining groundwater quality is *relative-concentration*, which references concentrations of constituents measured in groundwater to regulatory and non-regulatory benchmarks used to evaluate drinking-water quality. Some benchmarks are established for protection of human health, and others are established for aesthetic properties, such as taste and odor. Constituents were selected for additional evaluation in the assessment on the basis of objective criteria by using these relative-concentrations. Groundwater-quality data collected by the U.S. Geological Survey for the GAMA Priority Basin Project (USGS-GAMA) and data compiled in the CDPH database were used in the status assessment. Two statistical approaches based on spatially unbiased equal-area grids were used to calculate aquifer-scale proportions of low, moderate, or high relative-concentrations: (1) the "grid-based" approach uses one value per grid cell to represent groundwater quality, and (2) the "spatially weighted" approach uses many values per grid cell (Belitz and others, 2010).

The CDPH database contains historical records from more than 25,000 wells, necessitating targeted retrievals to effectively access relevant water-quality data. For example, for the area representing the SCI study unit, the historical CDPH database contains more than 240,000 records from 330 wells. The CDPH data were used in three ways in the status assessment: (1) to supplement the USGS data for the grid-based calculations of aquifer-scale proportions, (2) to select constituents for additional evaluation in the assessment, and (3) to provide the majority of the data used in the spatially weighted calculations of aquifer-scale proportions.

Relative-Concentrations and Water-Quality Benchmarks

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

$$Relative\text{-}concentraton = \frac{Sample\ concentration}{Benchmark\ concentration}$$

Regulatory and non-regulatory benchmarks apply to treated water that is served to the consumer, not to untreated groundwater. However, to provide some context for the water-quality data collected for this study, concentrations of constituents measured in the untreated groundwater were compared with benchmarks established by the U.S. Environmental Protection Agency (USEPA) and CDPH (U.S. Environmental Protection Agency, 1999, 2009, 2012; California Department of Public Health, 2010, 2012). 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 also permits comparison of constituents present at a wide range of concentrations on a single scale. Relative-concentrations can only be computed for constituents with water-quality benchmarks; therefore, constituents without water-quality benchmarks were not included in the status assessment.

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), action levels (AL-US), and treatment technique levels (TT-US).
2. Non-regulatory, aesthetic-based CDPH and USEPA secondary maximum contaminant levels (SMCL-CA and SMCL-US). For constituents with 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 risk-specific dose at a risk factor of 10^{-5} (1 in 100,000 lifetime risk of cancer, RSD5-US).

Note that 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 are provided by Mathany and others (2009).

Toccalino and others (2004), Toccalino and Norman (2006), and Rowe and others (2007) previously used the ratio of the measured sample concentration to the benchmark concentration [either USEPA MCLs or health-based screening levels (HBSLs)] and defined this ratio as the benchmark quotient. HBSLs were not used in this report because they are not currently used as benchmarks by California drinking-water regulatory agencies. Because different water-quality benchmarks may be used to calculate relative-concentrations and benchmark quotients, the values of these ratios may not be the same for all constituents (for example, Fram and Belitz, 2012).

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

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

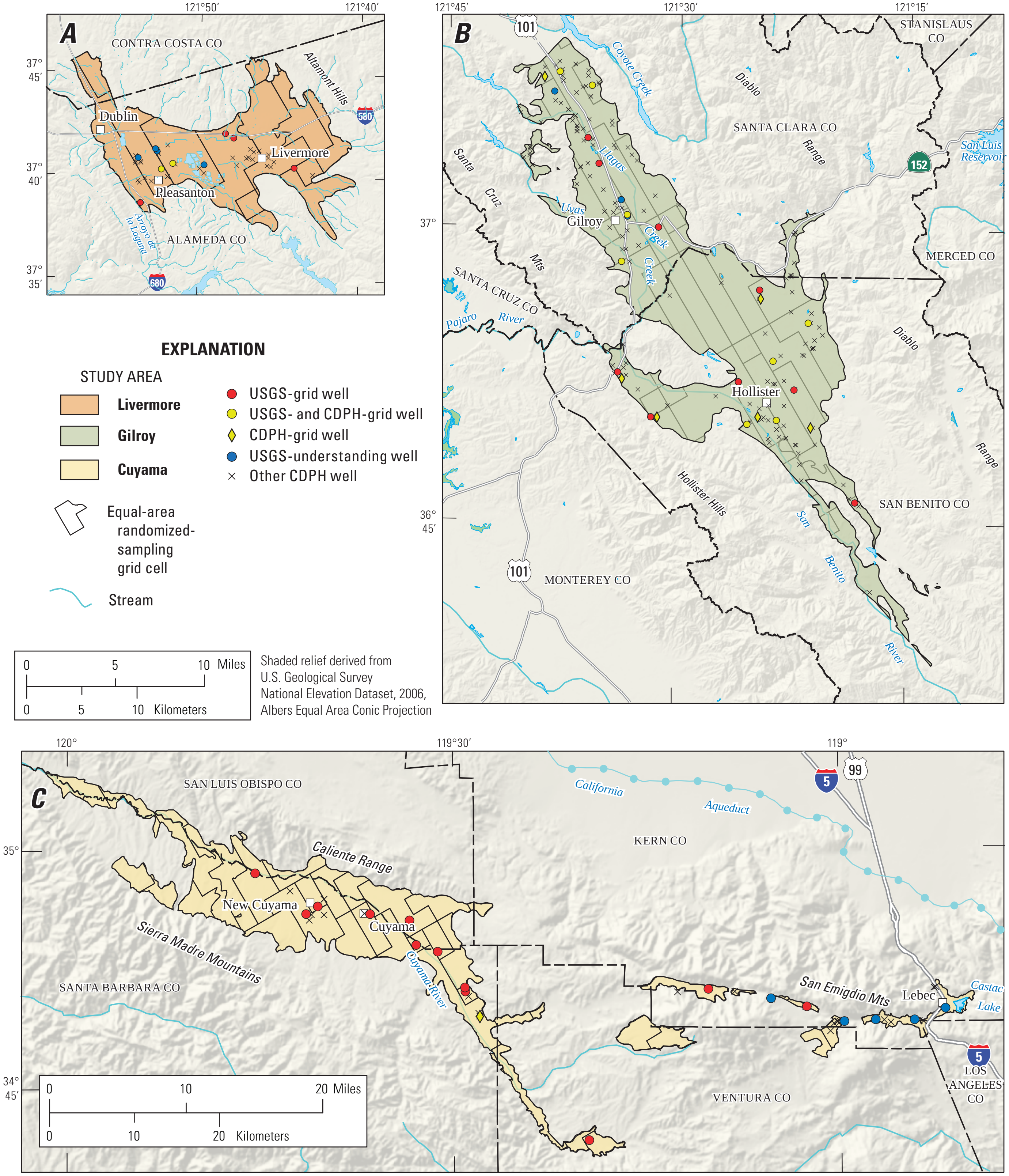
The boundary between “moderate” and “low” relative-concentrations was set at 0.1 for organic and special-interest constituents for consistency with other studies and reporting requirements (U.S. Environmental Protection Agency, 1998; Toccalino and others, 2004). For inorganic constituents, the boundary between “moderate” and “low” relative-concentrations was set at 0.5. The primary reason for using a higher threshold was to focus attention on the inorganic constituents of most immediate concern (Fram and Belitz, 2012). Most inorganic constituents are naturally occurring and tend to be more prevalent than organic constituents in groundwater. Although more complex classifications could be devised based upon the properties and sources of individual constituents, use of a single moderate/low boundary value for each of the two major groups of constituents provided a consistent objective criterion for distinguishing constituents occurring at moderate rather than low concentrations.

Datasets for Status Assessment

The wells selected for sampling by the USGS in the SCI study provide a statistically unbiased, spatially distributed set of wells for the assessment of the quality of groundwater in the primary aquifer system (USGS-grid wells). Water-quality data from the USGS-grid wells were supplemented with data from selected wells in the CDPH database (CDPH-grid wells; see the “California Department of Public Health Grid Data” section) to obtain more complete spatial coverage and to include constituents that were not analyzed for in every USGS-grid well. These data were used to assess proportions of the primary aquifer system with high, moderate, and low relative-concentrations.

U.S. Geological Survey Grid Data

The primary data used for the grid-based calculations of aquifer-scale proportions of relative-concentrations were data from wells sampled by USGS for the GAMA Priority Basin Project (USGS-GAMA). Detailed descriptions of the methods used to identify wells for sampling are given in Mathany and others (2009). Briefly, each study area was divided into 10-mi^2 (~26-square-kilometer) equal-area grid cells (figs. 4*A–C*), and in each cell, one well was randomly selected to represent the cell (Scott, 1990). Wells were selected from the population of wells in a Statewide database maintained by the CDPH. If a cell had no accessible wells listed in the CDPH database, then appropriate wells were selected from the statewide National Water Information System (NWIS) database maintained by the USGS or information from other sources. The SCI study unit contained 44 grid cells, and the USGS sampled wells in 35 of those cells (USGS grid wells); the USGS did not sample a well in the remaining 9 cells (Mathany and others, 2009). The range of groundwater types sampled by the USGS-grid wells was comparable to the range of groundwater types represented in the larger number of wells with data in the CDPH database (appendix C). USGS-grid wells were named with an alphanumeric GAMA ID consisting of a prefix identifying the study area and a number indicating the order of sample collection within each study area (figs. A1*A–C*; table A1). The following prefixes were used to identify the study area: CUY, Cuyama study area; GIL, Gilroy study area; and LIV, Livermore study area.



Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006, Albers Equal Area Conic Projection

Figure 4*A,B,C*. Locations of study area grid cells, U.S. Geological Survey (USGS) grid and understanding wells, and California Department of Public Health (CDPH) wells, South Coast Interior Basins study unit, California GAMA Priority Basin Project, August–December 2008.

Samples collected from USGS-grid wells were analyzed for 205 to 269 constituents, depending on the sampling schedule (table 1). Water-quality indicators (field parameters), volatile organic compounds, pesticides, perchlorate, nutrients, major and minor ions, trace elements, noble gases, and selected isotopes used as hydrologic tracers were analyzed in samples from all wells. Polar pesticides and metabolites, redox species, radiochemical constituents, and *N*-nitrosodimethylamine (NDMA) were analyzed in samples from 11 wells. The collection, analysis, and quality-control data for the analytes listed in table 1 are described by Mathany and others (2009). Water-quality data collected by USGS-GAMA are tabulated in Mathany and others (2009) and also are available from the SWRCB's database GeoTracker GAMA (website at http://www.waterboards.ca.gov/gama/geotracker_gama.shtml).

California Department of Public Health Grid Data

The 3 study areas were divided into 44 grid cells; of these, 9 cells did not have a USGS-grid well, 28 cells had a USGS-grid well but no USGS data for radiochemical constituents, and 7 cells had a USGS-grid well with data for all of the inorganic constituents evaluated. The CDPH database was queried to provide the missing inorganic data for these cells. CDPH wells with data for the most recent 3 years available at the time of sampling (August 11, 2005–August 10, 2008) were considered. If a well had more than one analysis for a constituent in the 3-year interval, the most recent data were selected.

For 10 of the 28 cells with a USGS-grid well but no USGS data for radiochemical constituents, the USGS-grid well was a well in the CDPH database with data for radiochemical constituents, and these data were selected to represent the cell (figs. 4*A*,*B*; USGS- and CDPH-grid wells). For another 6 of the 28 cells, the USGS-grid well was not a well in the CDPH database with data for radiochemical constituents, but at least one other well in the cell had data for radiochemical constituents (figs. 4*B*,*C*; CDPH-grid wells). The procedures used to select one of those wells and all of the radiochemical data selected from the CDPH database to complete the grid dataset are described in appendix A. The CDPH database generally did not contain data for all missing radiochemical constituents at every CDPH grid well; therefore, the number of wells used for the grid-based assessment differed for various radiochemical constituents (table 2A). The 9 cells without USGS-grid wells also did not contain CDPH wells; thus, no data for inorganic constituents were selected to represent those cells. Although other organizations also collect water-quality data, the CDPH database is the only statewide database of groundwater-chemistry data available for comprehensive analysis.

Table 1. Number of wells sampled by the U.S. Geological Survey for the fast and slow sampling schedules and number of constituents sampled in each constituent class for the South Coast Interior Basins study unit, California GAMA Priority Basin Project, August–December 2008.

[NDMA, *N*-nitrosodimethylamine; TDS, total dissolved solids; ns, not sampled]

	Schedule	
	Fast	**Slow**
Total number of wells	43	11
Number of grid wells sampled	28	7
Number of understanding wells sampled	15	4
Constituent Class	**Number of constituents**	
Inorganic constituents		
Specific conductance	1	1
Nutrients	5	5
Major ions, alkalinity, and TDS	11	11
Trace elements	23	23
Uranium and radioactive constituents		
Uranium	1	1
Radon-222[1]	ns	1
Gross alpha/beta[2]	ns	2
Organic constituents[3]		
Volatile organic compounds[4]	85	85
Pesticides and degradates	63	63
Polar pesticides and metabolites[5]	ns	57
Special-interest constituents		
Perchlorate	1	1
NDMA	ns	1
Geochemical and age-dating tracers		
Dissolved oxygen, pH, and temperature	3	3
Ar, Fe, Cr redox species ratios	ns	3
Carbon-14 and $\delta^{13}C$ of dissolved carbonates	2	2
Tritium[6]	1	1
Noble gases (He, Ne, Ar, Kr, Xe), $^{3}He/^{4}He$, and tritium[7]	7	7
$\delta^{2}H$ and $\delta^{18}O$ of water	2	2
Total	205	269

[1] Radon-222 collected at five fast wells in the Gilroy study area as part of a special study.

[2] Both gross alpha and gross beta activities were measured after 72-hour and 30-day holding times; the 72-hour results are used in this report.

[3] Fourteen pharmaceutical compounds were analyzed at slow wells and results are discussed in Fram and Belitz (2011).

[4] Includes nine constituents classified as fumigants or fumigant synthesis byproducts.

[5] Does not include three constituents in common with pesticides and degradates.

[6] Analyzed at USGS Stable Isotope and Tritium Laboratory, Menlo Park, California.

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

Table 2A. Benchmark type and value for constituents, and number of grid cells with U.S. Geological Survey-GAMA data and California Department of Public Health data, for each constituent, South Coast Interior Basins study unit, California Priority Basin Project.

[**Benchmark type**: Regulatory, health-based benchmarks: MCL-US, USEPA maximum contaminant level; Prop MCL-US, proposed USEPA maximum contaminant level; AL-US, USEPA action level; MCL-CA, CDPH maximum contaminant level. Non-regulatory, health-based benchmarks: HAL-US, USEPA lifetime health advisory level; NL-CA, CDPH notification level. Non-regulatory, aesthetic/technical-based benchmarks: SMCL-CA, CDPH secondary maximum contaminant level. Benchmark types and values as of October 2013. **Benchmark units**: µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; pCi/L, picocuries per liter. **Other Abbreviations**: USGS, U.S. Geological Survey; GAMA, Groundwater Ambient Monitoring and Assessment Program; USEPA, U.S. Environmental Protection Agency; CDPH, California Department of Public Health]

Constituent	Benchmark type[1]	Benchmark value	Benchmark units	Number of grid cells with USGS-GAMA data	Number of grid cells with CDPH data
Trace and minor elements with health-based benchmarks					
Aluminum	MCL-CA	1,000	µg/L	35	0
Antimony	MCL-US	6	µg/L	35	0
Arsenic	MCL-US	10	µg/L	35	0
Barium	MCL-CA	1,000	µg/L	35	0
Beryllium	MCL-US	4	µg/L	35	0
Boron	NL-CA	1,000	µg/L	35	0
Cadmium	MCL-US	5	µg/L	35	0
Chromium	MCL-CA	50	µg/L	35	0
Copper	AL-US	1,300	µg/L	35	0
Fluoride	MCL-CA	2	mg/L	35	0
Lead	AL-US	15	µg/L	35	0
Molybdenum	HAL-US	40	µg/L	35	0
Nickel	MCL-CA	100	µg/L	35	0
Selenium	MCL-US	50	µg/L	35	0
Strontium	HAL-US	4,000	µg/L	35	0
Thallium	MCL-US	2	µg/L	35	0
Vanadium	NL-CA	50	µg/L	35	0
Uranium and radioactive constituents					
Uranium	MCL-US	30	µg/L	35	0
Radon-222	Prop. MCL-US	4,000	pCi/L	1	2
Gross alpha particle activity	MCL-US	15	pCi/L	7	15
Gross beta particle activity	MCL-CA	50	pCi/L	7	2
Nutrients					
Ammonia, as nitrogen	HAL-US	[2] 24.7	mg/L	35	0
Nitrite, as nitrogen	MCL-US	1	mg/L	35	0
Nitrate, as nitrogen[3]	MCL-US	10	mg/L	35	0
Trace and minor elements with aesthetic benchmarks					
Chloride	SMCL-CA	500	mg/L	35	0
Iron	SMCL-CA	300	µg/L	35	0
Manganese	SMCL-CA	50	µg/L	35	0
Silver	SMCL-CA	100	µg/L	35	0
Specific Conductance	SMCL-CA	1,600	µS/cm	35	0
Sulfate	SMCL-CA	500	mg/L	35	0
Total dissolved solids (TDS)	SMCL-CA	1,000	mg/L	35	0
Zinc	SMCL-US	5,000	µg/L	35	0

[1] Maximum contaminant level benchmarks are listed as MCL-US when the MCL-US and MCL-CA are identical, and as MCL-CA when the MCL-CA is lower than the MCL-US or no MCL-US exists.

[2] HAL-US benchmark is 30 mg/L for ammonia, as ammonia.

[3] Concentrations of nitrate, as nitrate reported in the CDPH database are converted to concentrations of nitrate, as nitrogen, for comparison with USGS-GAMA data.

Table 2B. Benchmark type and value for organic and special-interest constituents selected for additional evaluation in the status assessment of groundwater quality in the South Coast Interior Basins study unit, California Priority Basin Project.

[**Benchmark type**: MCL-US, USEPA maximum contaminant level; MCL-CA, CDPH maximum contaminant level. Benchmark types and values as of October 2013. **Benchmark units**: µg/L, micrograms per liter. **Other abbreviations**: USGS, U.S. Geological Survey; GAMA, Groundwater Ambient Monitoring and Assessment Program; USEPA, U.S. Environmental Protection Agency; CDPH, California Department of Public Health]

Constituent	Benchmark type	Benchmark value	Benchmark units	Number of grid cells with USGS-GAMA data
Bromoform	MCL-US	[1] 80	µg/L	35
Chloroform	MCL-US	[1] 80	µg/L	35
Tetrachloroethene (PCE)	MCL-US	5	µg/L	35
Simazine	MCL-US	4	µg/L	35
Perchlorate	MCL-CA	6	µg/L	35

[1] The MCL-US threshold for trihalomethanes is for the sum of chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

CDPH data were not used to supplement USGS-grid well data for VOCs, pesticides, or perchlorate because 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 85 VOCs plus 63 pesticides and pesticide degradates at every well in the SCI study unit, plus an additional 57 polar pesticides and degradates analyzed at 7 grid wells (table 1). In addition, method detection limits for USGS-GAMA analyses of organic constituents were typically one to two orders of magnitude lower than the reporting limits for analyses compiled by the CDPH (Fram and Belitz, 2012).

Data Used for Spatially Weighted Calculations

The spatially weighted calculations of aquifer-scale proportions of relative-concentrations were made using data from the USGS-grid wells, from selected additional wells sampled by USGS-GAMA, and from 171 other wells in the CDPH database with water-quality data during the 3-year interval August 11, 2005, to August 10, 2008. For wells with both USGS and CDPH data for the same constituents, only the USGS data were used. Water-quality data collected by the CDPH are available from the SWRCB's internet database GeoTracker GAMA (website at http://www.waterboards.ca.gov/gama/geotracker_gama.shtml).

Nineteen additional wells (12 production wells and 7 monitor wells) were sampled by the USGS to increase the sampling density in the SCI study unit to better understand specific groundwater-quality issues. These "USGS-understanding" wells were numbered with prefixes modified from those used for the USGS grid wells (GILU, LIVU, or CUYU) (fig. A1; table A1). With the exception of four monitoring wells in the LIV study area, these USGS-understanding wells were screened or open at similar depths to the grid wells (tables B1 and B2) and were included in the dataset for the spatially weighted calculations. The four LIV monitoring wells were not included in the calculations of aquifer-scale proportions for the status assessment or in statistical tests of correlations for the understanding assessment.

Selection of Constituents for Additional Evaluation

As many as 133 constituents with benchmarks were analyzed in samples from SCI study unit wells; however, only a subset of these constituents is identified for additional evaluation in this report based on the following criteria:

1. Constituents present at high relative-concentrations in the CDPH database within the 3-year interval (August 11, 2005–August 10, 2008);
2. Constituents present at high or moderate relative-concentrations in the USGS-grid wells; or
3. Organic constituents with detection frequencies of greater than 10 percent in the USGS-grid well dataset for the study unit.

Constituents discussed in the understanding assessment had high relative-concentrations in greater than 2 percent of the primary aquifer system, or were organic constituents detected in greater than 10 percent of the USGS-grid well dataset. A complete list of the constituents investigated by USGS-GAMA in the SCI study unit may be found in the related SCI USGS Data Series Report (Mathany and others, 2009).

The CDPH database also was used to identify constituents with historically high (but not currently high) relative-concentrations. The historical period was defined as the earliest record maintained in the CDPH database to August 10, 2005 (January 8, 1980–August 10, 2005).

Constituent concentrations may be historically high, but not currently high, because of changes in groundwater quality with time or abandonment of wells with high concentrations. Historically high concentrations of constituents that do not otherwise meet the criteria for additional evaluation are not considered representative of potential groundwater-quality concerns in the study unit from 2005 to 2008. For the SCI study unit, 15 constituents were measured at high relative-concentrations prior to August 11, 2005 (table 3). Two-thirds of the constituents reported at high concentrations during the historical period were reported at high concentrations in only one well.

Table 3. Constituents reported at concentrations greater than benchmark values in the California Department of Public Health (CDPH) database between January 8, 1980, and August 10, 2005, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[High concentrations are concentrations greater than the benchmark value. **Benchmark type**: MCL-US, USEPA maximum contaminant level; Prop MCL-US, proposed USEPA maximum contaminant level; MCL-CA, CDPH maximum contaminant level; SMCL-CA, CDPH secondary maximum contaminant level. Benchmark types and values as of October 2013. **Benchmark units**: µg/L, micrograms per liter; pCi/L, picocuries per liter. **Other abbreviations**: USEPA, U.S. Environmental Protection Agency; CDPH, California Department of Public Health]

Constituent	Benchmark type	Benchmark value	Benchmark units	Number of wells with analysis	Number of wells with a high concentration	Date of most recent high value (mm/dd/yyyy)
Trace elements						
Aluminum	MCL-CA	1,000	µg/L	254	6	7/6/2005
Barium	MCL-CA	1,000	µg/L	259	1	7/20/2000
Cadmium	MCL-US	5	µg/L	258	4	1/17/2002
Mercury	MCL-US	2	µg/L	256	1	4/22/1988
Nickel	MCL-CA	50	µg/L	230	2	10/18/2001
Thallium	MCL-US	2	µg/L	330	1	3/29/1994
Zinc	SMCL-CA	5,000	µg/L	262	2	5/4/1998
Solvents						
Carbon tetrachloride	MCL-CA	0.5	µg/L	267	1	9/24/1992
1,1,2-Trichloroethane	MCL-US	5	µg/L	267	1	9/24/1992
Fumigants						
1,2-Dibromoethane (EDB)	MCL-US	0.05	µg/L	28	1	8/18/1992
Other VOCs						
Benzene	MCL-CA	1	µg/L	267	1	12/26/1989
Methyl *tert*-butyl ether (MTBE)	MCL-CA	13	µg/L	226	1	12/13/2004
Uranium and radioactive constituents						
Uranium	MCL-CA	20	pCi/L	54	2	4/2/1991
Radon-222	Prop. MCL-US	4,000	pCi/L	28	1	8/18/1992
Radium-228	MCL-US	[1] 5	pCi/L	50	1	7/7/2004

[1] The MCL-US benchmark for radium is for the sum of radium-226 and radium-228.

Calculation of Aquifer-Scale Proportions

Aquifer-scale proportions are defined as the percentage of the area (rather than the volume) of the primary aquifer system with concentrations greater than or less than specified thresholds relative to regulatory or aesthetic water-quality benchmarks. Two statistical approaches were used to evaluate the proportions of the primary aquifer system (Belitz and others, 2010) in the SCI study unit with high, moderate, or low relative-concentrations of constituents relative to benchmarks.

- Grid-based: One value per grid cell from either USGS-grid or CDPH-grid wells was used to represent the primary aquifer system. The proportion of the primary aquifer system with high relative-concentrations was calculated by dividing the number of grid cells represented by a high relative-concentration for a particular constituent by the total number of grid cells with data for that constituent. Proportions of moderate and low relative-concentrations were calculated similarly. The grid-based estimate is spatially unbiased. However, the grid-based estimate may not identify constituents that are present at high relative-concentrations in small proportions of the primary aquifer system. Confidence intervals for grid-based detection frequencies of high concentrations were computed by using the Jeffreys interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010). The confidence intervals provide a range that is likely (with 90-percent confidence) to bracket the true high aquifer-scale proportion.

- Spatially weighted: All available data from the following sources were used to calculate the aquifer-scale proportions—all CDPH wells in the study unit (most recent analysis from each well with data for that constituent during the current period August 11, 2005–August 10, 2008); USGS-grid wells; and

USGS-understanding wells with perforation depth intervals representative of the primary aquifer system. The proportion of high relative-concentrations for each constituent for the primary aquifer system was computed by (1) calculating the proportion of wells with high relative-concentrations in each grid cell and (2) averaging together the grid-cell proportions computed in step 1 (Isaaks and Srivastava, 1989; Belitz and others, 2010). Similar procedures were used to calculate the proportions of moderate and low relative-concentrations of constituents. The resulting proportions are spatially unbiased (Isaaks and Srivastava, 1989). Confidence intervals for spatially weighted estimates of aquifer-scale proportion are not described in this report.

Grid-based and spatially weighted aquifer-scale proportions for constituent classes were calculated by using the maximum relative-concentration for any constituent in the class to represent the relative-concentration for the cell (grid-based) or for each well (spatially weighted).

In addition, for each constituent, the raw detection frequencies of high and moderate relative-concentrations for individual constituents were calculated by using the same dataset as used for the spatially weighted calculations. However, these raw detection frequencies are not spatially unbiased because the wells in the CDPH database are not uniformly distributed throughout the SCI study unit (figs. 2*A–C*). For example, if a constituent was present at high relative-concentrations in a small region of the aquifer that had a high density of wells, the 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 characterize the groundwater resource.

Aquifer-scale proportions discussed in this report primarily were estimated by using the grid-based approach, and secondarily by using the spatially weighted approach. The grid-based high aquifer-scale proportions were used unless the spatially weighted proportions were significantly different from the grid-based values. Significantly different results were defined as follows:

1. If the grid-based high aquifer-scale proportion was zero and the spatially weighted proportion was non-zero, then the spatially weighted result was used. This situation can happen when the concentration of a constituent is high in a small fraction of the primary aquifer system.

2. If the grid-based high aquifer-scale proportion was non-zero and the spatially weighted proportion was outside the 90-percent confidence interval (based on the Jeffreys interval for the binomial distribution, Brown and others, 2001), then the spatially weighted proportion was used.

The grid-based moderate and low proportions were used in most cases because the reporting levels for many organic constituents and some inorganic constituents in the CDPH database were higher than the threshold between moderate and low categories. However, if the grid-based moderate proportion was zero and the spatially weighted proportion non-zero, then the spatially weighted value was used as a minimum estimate for the moderate proportion.

Aquifer-scale proportions of high relative-concentrations also were determined for classes of constituents. The classes of organic constituents for which aquifer-scale proportions were calculated were trihalomethanes, solvents, and herbicides. The classes of inorganic constituents with health-based benchmarks for which aquifer-scale proportions were calculated were trace and minor elements, radioactive constituents, and nutrients.

Understanding-Assessment Methods

The potential explanatory factors—land use, well depth, depth to the top-of-perforations of the well, groundwater-age class, and geochemical conditions (appendix B)—were analyzed in relation to constituents of interest for the understanding assessment to establish context for physical and chemical processes within the groundwater system. In addition, comparisons of groundwater quality between study areas are discussed in this report. Statistical tests were used to identify significant correlations between the constituents of interest and potential explanatory factors.

The data selected for the understanding assessment varied by whether the variables tested were expected to be primarily areally distributed (land use and study area) or vertically distributed (depth, groundwater age, geochemical conditions). Correlations between explanatory factors and groundwater constituents were tested using data from the USGS- and CDPH-grid wells only, or the USGS- and CDPH-grid wells plus USGS-understanding wells. Data from CDPH-other wells were not used in the understanding assessment because some geochemical and age-dating tracers and well-construction data were not available. Because the USGS-understanding wells were not randomly selected on a spatially distributed grid, these wells were excluded from analysis of relations between water-quality constituents and areally distributed explanatory variables to avoid areal-clustering bias. For variables expected to be primarily vertically distributed, data from 15 understanding wells that were representative of the primary aquifer system (production wells or monitor wells that had similar well construction characteristics as the grid wells) were included to provide more detailed vertical information on water quality across a wider range of depth, age, and geochemical conditions in the portions of the aquifer used for public supply than were present using the grid data alone.

Statistical Analysis

Nonparametric statistical methods were used to test the significance of correlations between water-quality variables and potential explanatory factors. Nonparametric statistics are robust techniques that are generally not affected by outliers and do not require that the data follow any particular distribution (Helsel and Hirsch, 2002). The significance level (*p*) used to test hypotheses for this study was compared to a threshold value (α) of 5 percent ($\alpha = 0.05$) to evaluate whether the relation was statistically significant ($p < \alpha$). Throughout this report, the term "correlated" is used to indicate that the relation was statistically significant.

Two different statistical tests were used because the set of potential explanatory factors included both categorical and continuous variables. Groundwater age class and oxidation-reduction class were treated as categorical variables because there were a finite number of values a well could be assigned: for example, groundwater ages were classified as modern, pre-modern, or mixed. Land use, well depth, depth to top-of-perforations, dissolved oxygen, and pH were treated as continuous variables because there were an infinite number of values a well could be assigned: for example, land use was represented by percentages of land-use types. Concentrations of water-quality constituents were treated as continuous variables.

Relations between potential explanatory factors, and between potential explanatory factors and water-quality constituents, were tested for significance. Correlations between continuous variables were evaluated using the Spearman's rho test to calculate the rank-order coefficient (ρ, rho) and the significance level of the correlation (*p*). Relations between categorical variables and continuous variables were evaluated using the Wilcoxon rank-sum test. The test was applied pair-wise to the groups to determine which pairs had significantly different median values of the continuous variable. For example, the relation between well depth and groundwater age was evaluated by testing for differences in median value of well depth between each of the three pairs of groundwater age classes: modern and mixed, modern and pre-modern, and mixed and pre-modern.

Potential Explanatory Factors

Brief descriptions of potential explanatory factors, including land use, physical characteristics of the wells, indicators of groundwater age, and geochemical conditions of the aquifer, are given in this section. Data sources and methodology used for assigning values for potential explanatory factors are described in appendix B. Apparent correlations between an explanatory factor and a water-quality constituent could actually reflect correlations between two or more explanatory factors. Therefore, it is important to identify statistically significant correlations between explanatory factors (tables 4A,B). Implications of correlations between explanatory variables are discussed later in the report as part of the analysis of factors affecting individual constituents. Values of potential explanatory factors for the four monitoring wells not used in the assessments are listed in the tables in appendix B, but these wells are not included in the descriptions in this section.

Land Use

Land use was described by three land-use types: urban, agricultural, and natural (appendix B). Land classified as agricultural made up the greatest percentage (45 percent) of the total land area in the study unit, while natural land use was 42 percent of the area, and urban land use was 13 percent of the area (fig. 5*A*).

Land use around grid wells (radius of 1,640 ft [500 meters]) in the SCI study unit was different in the three study areas (fig. 5*A*). A 500-meter (m) buffer centered on the well has been shown to be effective at correlating urban land use with VOC occurrence for the purposes of statistical characterization (Johnson and Belitz, 2009). In the Livermore study area, average land use around grid wells was 63 percent urban, 24 percent agricultural, and 13 percent natural (figs. 5*A*,*B*, 6*A*). In the Gilroy study area, average land use around grid wells was 64 percent agricultural, 23 percent urban, and 13 percent natural (figs. 5*A*,*B*, 6*B*). In the Cuyama study area, average land use around grid wells was 54 percent natural, 35 percent agricultural, and 11 percent urban (figs. 5*A*,*B*, 6*C*). In the SCI study unit, average land use around grid wells was 44 percent agricultural, 29 percent urban, and 27 percent natural land use (figs. 5*A*,*B*). The higher percentage of urbanized land surrounding the grid wells (29 percent)—compared to the land in the entire study unit (13 percent)—reflects the association of public-supply wells with population density. Agricultural lands are mostly orchards, vineyards, or pastures. The largest urban areas are the cities of Livermore and Gilroy.

Well Depth and Depth to Top-of-Perforations

Well construction information was available for 24 of the 35 grid wells sampled in the SCI study unit. Grid wells had depths ranging from 93 to 800 ft below LSD; the median was 455 ft below LSD (fig. 7; table B2). Depths to the tops of the perforated interval ranged from 37 to 640 ft below LSD, with a median of 200 ft below LSD. The perforation length was up to 501 ft with a median of 220 ft. The median depth to the tops of the perforated intervals and median perforation lengths of the USGS-understanding wells used in the understanding assessment are similar to those of the USGS-grid wells (fig. 7).

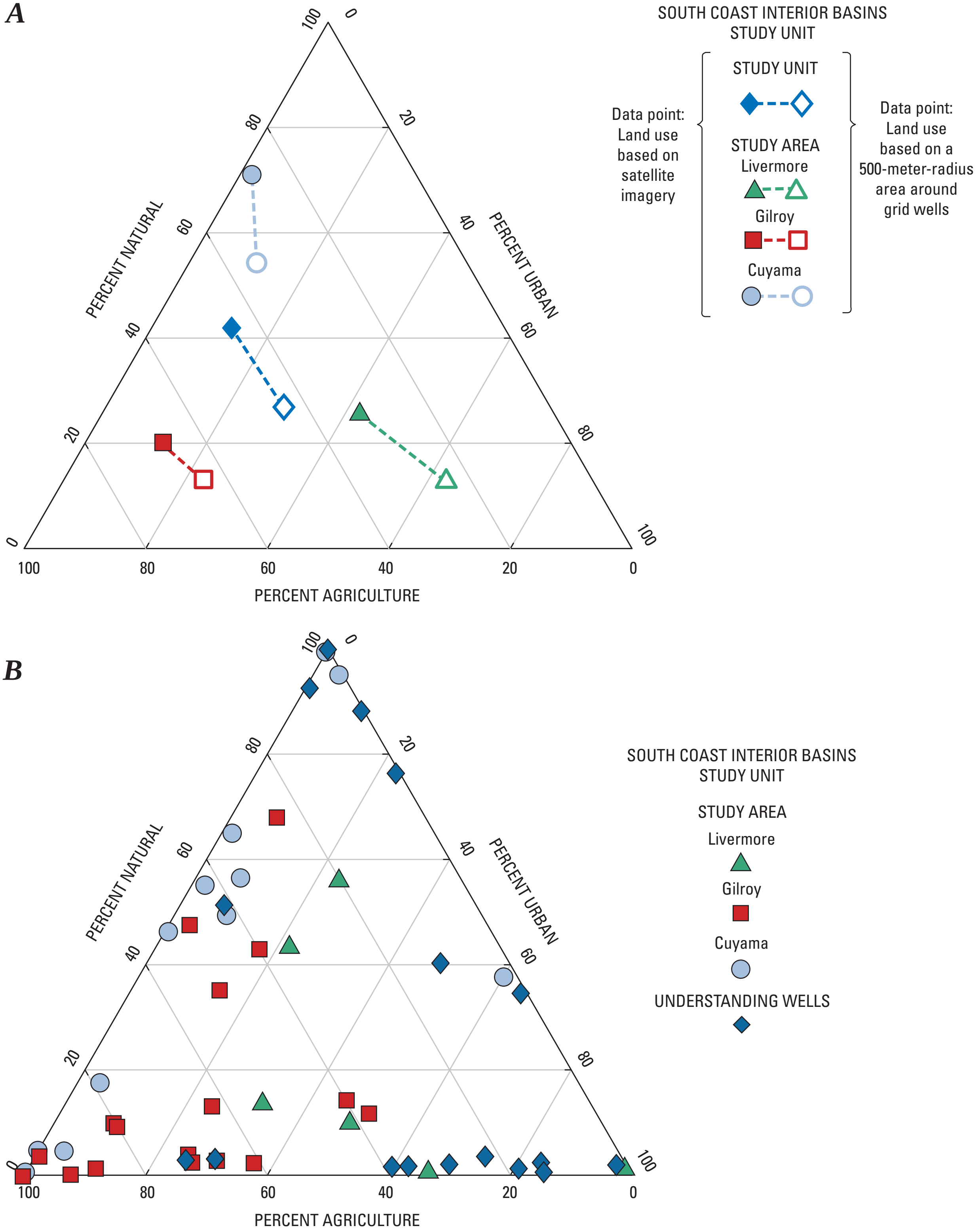
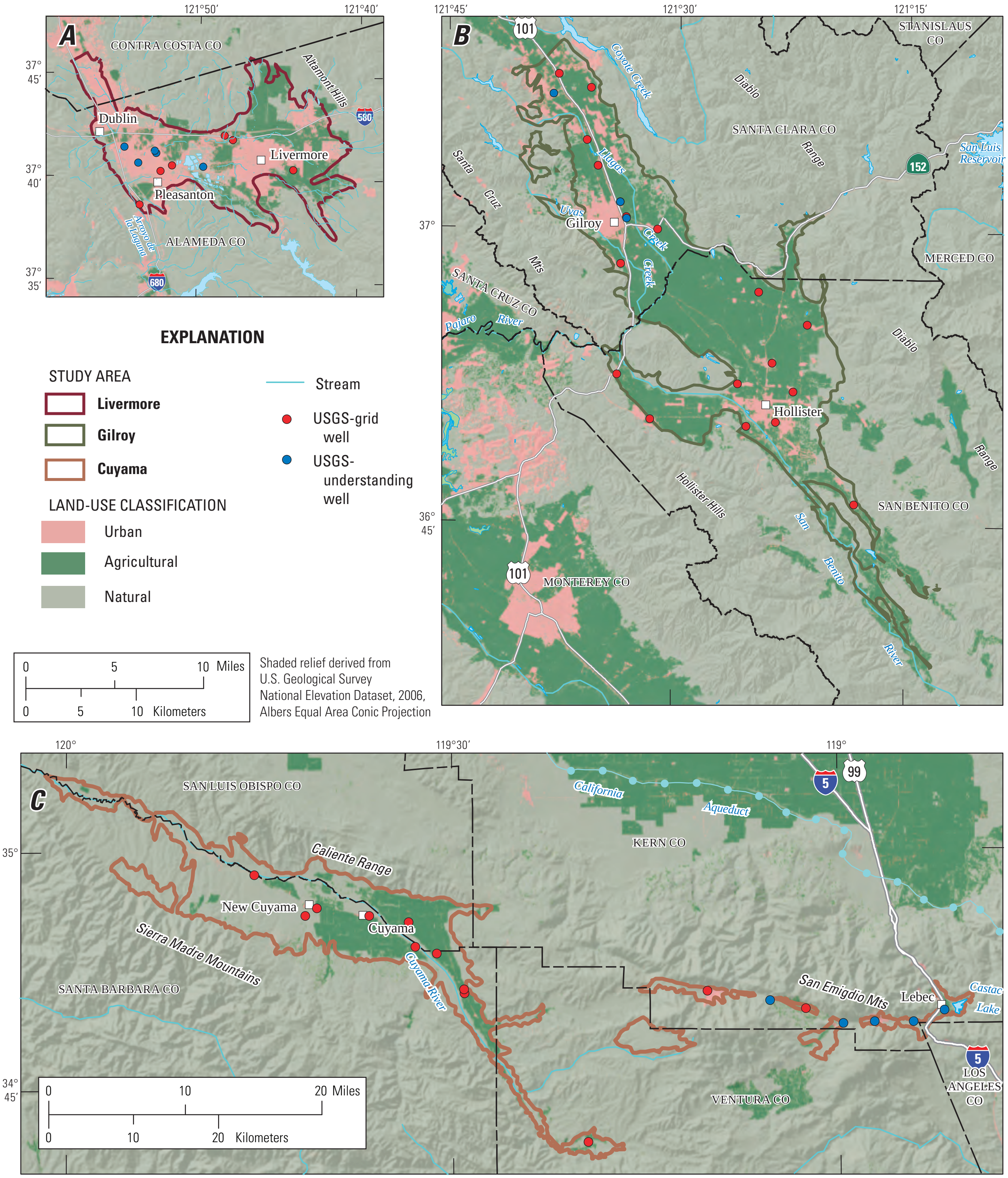


Figure 5. Percentage of urban, agricultural, and natural land use in (*A*) the study unit and study areas, and (*B*) the area surrounding each grid and understanding well in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.



Shaded relief derived from
U.S. Geological Survey
National Elevation Dataset, 2006,
Albers Equal Area Conic Projection

Figure 6*A,B,C*. Land use in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

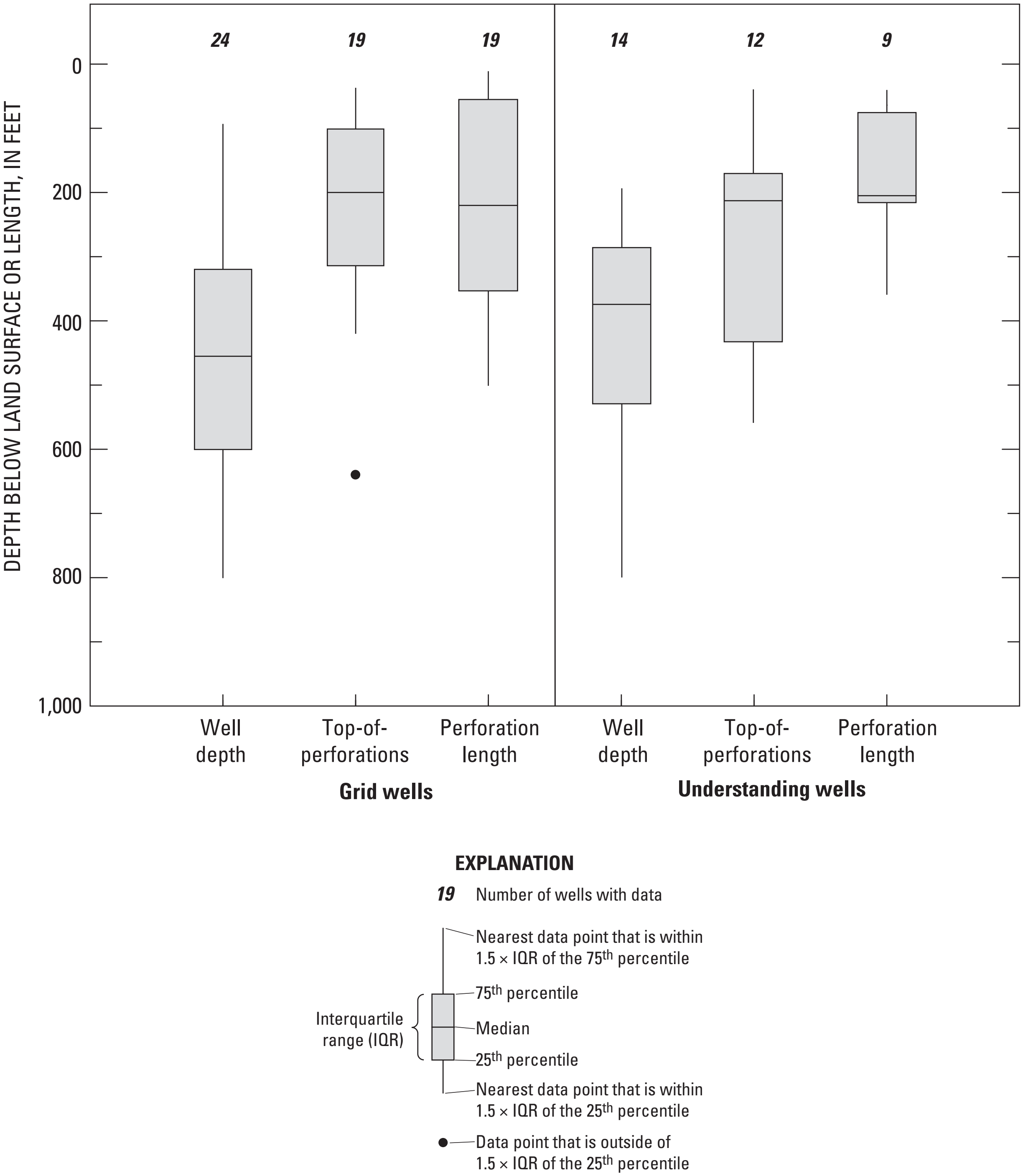


Figure 7. Well depths, depths to top-of-perforations, and perforation lengths for grid and understanding wells, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Groundwater Age

Groundwater samples were assigned age classifications based on the tritium and carbon-14 content of the samples (appendix B). Age classifications were assigned to the 50 USGS-grid and understanding well groundwater samples; 26 were classified as modern (recharged after 1952), 12 were mixed (having a component of both modern and pre-modern waters), 1 was modern or mixed, and 11 were pre-modern (recharged before 1952) (table B3).

Classified groundwater ages were used to create a 3-factor classification system for well depth. Wells of depth less than a critical depth were defined as shallow; wells with depth to top-of-perforations beginning above the critical depth and ending below the critical depth were defined as mixed; and wells with depth of perforations entirely below the critical depth were defined as deep. The critical depth of 250 ft below LSD was selected by optimizing the segregation of modern-age groundwater into shallow wells, mixed-age groundwater into mixed-depth wells, and pre-modern-age groundwater into deep wells (fig. 8).

Geochemical Conditions

An abridged classification of oxidation-reduction (redox) conditions adapted from the framework presented by McMahon and Chapelle (2008) was used to classify redox conditions for the 50 USGS-grid and understanding well samples (table B4). Groundwater samples were classified as oxic, anoxic, or mixed (anoxic/oxic) (Jurgens and others, 2009). Groundwater was oxic in 80 percent of the wells, anoxic in 16 percent of the wells, and mixed in 4 percent of the wells. Dissolved oxygen (DO) concentrations were significantly greater in mixed-age or modern-age groundwater compared with premodern-age groundwater (table 4B). DO concentrations were also significantly greater in the CUY study area than in the GIL study area.

The pH values ranged from 6.7 to 7.9 in the USGS-grid wells and USGS-understanding wells (table B4) and were significantly greater in pre-modern-age groundwater compared with mixed-age or modern-age groundwater (table 4B). Values of pH were not significantly different between wells with modern-age groundwater and mixed-age groundwater. pH showed a negative correlation with DO (table 4A).

Table 4A. Results of non-parametric (Spearman's *rho* method) analysis of correlations in grid and understanding wells between selected potential explanatory factors, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[Spearman's correlation statistic (ρ) shown for correlations determined to be significant on the basis of p-values (not shown) less than threshold value (α) of 0.05. nc, no significant correlation]

Explanatory factor	Depth to top of perforations	Depth of well	Dissolved oxygen concentration	pH
Grid wells				
Percent urban land use	nc	nc	nc	nc
Percent agricultural land use	nc	nc	nc	nc
Percent natural land use	nc	nc	nc	0.43
Grid and understanding wells				
Depth to top of perforations		0.51	nc	nc
Depth of well			nc	nc
Dissolved oxygen concentration				–0.31
pH				

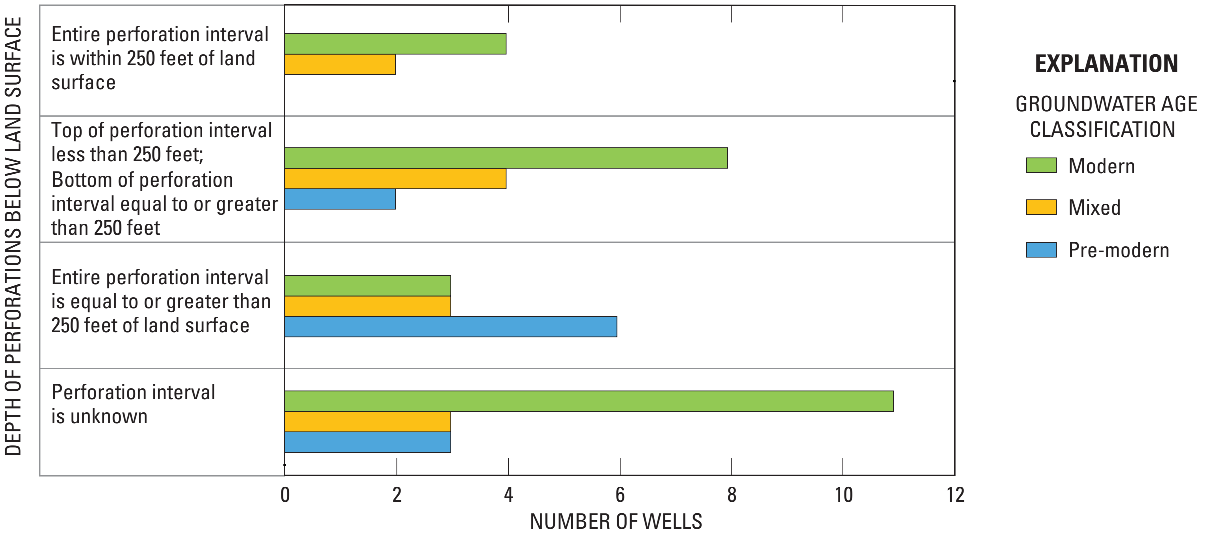


Figure 8. Age classification in relation to the depth of well perforations, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Table 4B. Results of Wilcoxon rank-sum tests for differences in values of selected potential explanatory factors between samples classified by groundwater age, geochemical condition, study area, and well depth, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[Wilcoxon rank-sum test statistic (Z) values shown for differences determined to be significant on the basis of p-values (not shown) less than threshold value (α) of 0.05. Positive values of Z indicate that the median value for the factor in samples classified in the first group is significantly greater than the median concentration of the constituent in samples classified in the second group, and negative values of Z indicate that the median concentration of the constituent in samples classified in the first group is significantly less than the median concentration of the constituent in samples classified in the second group. **Well depth classification**: shallow, well depth < 250 ft; overlapping, top-of-perforations < 250 ft and well depth > 250 ft; deep, well depth > 250 ft and top-of-perforations > 250 ft. **Groundwater age classification**: modern, sample with water recharged after 1952; pre-modern, sample with water recharged before 1952; mixed age, sample with modern and pre-modern components. **Other abbreviations**: nd, no significant difference (p-value > 0.05); ≤, less than or equal to; >, greater than; <, less than]

Selected water-quality constituents	Potential explanatory factors											
	Groundwater age classification			Geochemical conditions classification			Study area			Well depth classification		
	Modern age compared with mixed age	Mixed age compared with pre-modern age	Modern age compared with pre-modern age	Oxic compared with mixed	Mixed compared with anoxic	Oxic compared with anoxic	Cuyama compared with Gilroy	Cuyama compared with Livermore	Gilroy compared with Livermore	Shallow compared with overlapping	Shallow compared with deep	Overlapping compared with deep
	Z: Test statistic for Wilcoxon test											
Percent urban land use	nd	nd	nd	nd	nd	nd	–2.71	–2.96	–2.28	nd	nd	nd
Percent agricultural land use	nd	nd	nd	nd	nd	nd	nd	nd	2.70	nd	nd	nd
Percent natural land use	nd	nd	nd	nd	nd	nd	2.46	nd	nd	nd	nd	nd
Depth to top-of-perforations	nd	nd	nd	nd	nd	nd	nd	nd	nd	–2.65	–2.84	nd
Depth of well	nd	nd	–2.29	nd	nd	nd	nd	nd	nd	–3.23	–3.11	–1.98
Dissolved oxygen	nd	2.61	3.24	1.98	2.10	3.14	2.04	nd	nd	nd	nd	nd
pH	nd	–2.64	–3.24	nd	nd	nd	nd	nd	nd	nd	nd	nd

Status and Understanding of Water Quality

The *status assessment* was designed to identify the constituents or classes of constituents most likely to be of water-quality concern because of their high relative-concentrations or their prevalence. USGS sample analyses, plus additional data from the CDPH database, were included in the assessment of groundwater quality for the SCI study unit. The spatially distributed, randomized approach to grid-well selection and data analysis yields a view of groundwater quality in which all areas of the primary aquifer system are weighted equally; regions with a high density of groundwater use or with high density of potential contaminants were not preferentially sampled or represented (Belitz and others, 2010). The *understanding assessment* identifies the natural and human factors that may affect water quality in the SCI study unit and focuses on the constituents selected for additional evaluation in the status assessment.

The following discussion of the status and understanding assessment results is divided into inorganic, organic, and special-interest constituents. The status assessment begins with a survey of how many constituents were detected at any concentration compared to the number analyzed, and with a graphical summary of the relative-concentrations of constituents detected in the grid wells. Results are presented for the subset of constituents that met criteria for selection for additional evaluation based on concentration, or for organic constituents, prevalence (see Selection of Constituents for Additional Evaluation).

The aquifer-scale proportions calculated by using the spatially weighted approach were within the 90-percent confidence intervals for their respective grid-based aquifer high proportions for all of the constituents selected for additional evaluation in the status assessment, providing evidence that the grid-based and spatially weighted approaches yield statistically equivalent results.

Inorganic Constituents

Inorganic constituents generally occur naturally in groundwater, although their concentrations may be affected by human factors. All but 1 of the 44 inorganic constituents analyzed by the USGS-GAMA Priority Basin Project were detected in the SCI study unit; 32 of the 44 had health-based or aesthetic-based benchmarks (table 5). Nine inorganic constituents with health-based benchmarks (the trace and minor elements arsenic, boron, chromium, fluoride, molybdenum, strontium, and selenium, the radioactive constituent gross alpha particle activity, and the nutrient nitrate) and five inorganic constituents with aesthetic-based benchmarks (the trace metals iron and manganese and the salinity indicators chloride, sulfate, and TDS) met the selection criterion of having maximum relative-concentrations greater than 0.5 (moderate or high) in the grid wells (figs. 9, 10; table 6). Inorganic constituents with health-based benchmarks, as a group, had high relative-concentrations in 29 percent of the primary aquifer system, moderate relative-concentrations in 37 percent, and low relative-concentrations in 34 percent (table 7A). Inorganic constituents with aesthetic-based benchmarks, as a group, had high relative-concentrations in 49 percent of the primary aquifer system, moderate relative-concentrations in 31 percent, and low relative-concentrations in 20 percent.

Table 5. Number of constituents analyzed and detected by the U.S. Geological Survey by constituent class and benchmark type, South Coast Interior Basins study unit, California GAMA Priority Basin Project, August–December 2008.

Benchmark type	Number of Constituents	
	Analyzed	Detected
Volatile organic compounds		
Regulatory health-based	33	7
Non-regulatory health-based	25	1
No benchmark	27	0
Total:	85	8
Pesticides		
Regulatory health-based	11	3
Non-regulatory health-based	28	2
No benchmark	81	1
Total:	120	6
Special interest		
Regulatory health-based	1	1
Non-regulatory health-based	1	0
No benchmark	0	0
Total:	2	1
Inorganic		
Regulatory health-based	19	18
Non-regulatory health-based	5	5
Non-regulatory aesthetic-based	8	8
No benchmark	12	12
Total:	44	43
Geochemical and age-dating tracers		
Regulatory	2	2
Non-regulatory	0	0
No benchmark	16	16
Total:	18	18
All constituents		
Regulatory health-based	66	31
Non-regulatory health-based	59	8
Non-regulatory aesthetic-based	8	8
No benchmark	136	29
Total:	269	76

Table 6. Aquifer-scale proportions from grid-based and spatially weighted approaches for constituents with (1) high relative-concentrations during August 11, 2005, to August 10, 2008, from the California Department of Public Health (CDPH) database, (2) moderate or high relative-concentrations in samples collected from USGS-grid wells (August–December 2008), or (3) detection frequencies of organic constituents greater than 10 percent in USGS-grid wells, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**Relative-concentration categories**: high; concentrations of inorganic or organic or special-interest constituents greater than water-quality benchmark; moderate, concentrations of inorganic constituents greater than or equal to 0.5 of benchmark but less than benchmark or concentrations of organic or special-interest constituents greater than or equal to 0.1 of benchmark but less than benchmark; low, concentrations of inorganic constituents less than 0.5 of benchmark or concentrations of organic or special-interest constituents less than 0.1 of benchmark or not detected. Benchmark types and values for constituents listed in tables 2A,B]

Constituent	Raw detection frequency[1]			Spatially weighted aquifer-scale proportion[1]			Grid-based aquifer-scale proportion			90% confidence interval for grid-based high proportion[2]	
	Number of wells	Moderate values (percent)	High values (percent)	Number of cells	Moderate values (percent)	High values (percent)	Number of wells	Moderate values (percent)	High values (percent)	Lower limit (percent)	Upper limit (percent)
Inorganic constituents with health-based benchmarks											
Trace and minor elements											
Arsenic	137	4.4	3.6	35	3.3	5.3	35	8.6	5.7	1.7	15
Boron	63	16	11	35	14	9.2	35	11	8.6	3.2	19
Chromium	135	1.5	0.7	35	0.8	1.0	35	2.9	0	0	5.3
Fluoride	144	7.6	1.4	35	3.2	0.4	35	5.7	0	0	5.3
Molybdenum	55	5.5	5.5	35	1.7	8.6	35	0	8.6	3.2	19
Selenium	136	0.7	0	35	0.6	0	35	2.9	0	0	5.3
Strontium	50	6.0	0	35	8.6	0	35	8.6	0	0	5.3
Uranium and radioactive onstituents											
Gross alpha[3]	107	10	4.7	24	12	1.2	22	18	0	0	8.3
Nutrients											
Nitrate	191	21	7.9	35	14	16	35	14	14	6.8	26
Inorganic constituents with aesthetic-based benchmarks											
Chloride	130	2.3	0	35	2.6	0	35	2.9	0	0	5.3
Sulfate	128	9.4	7.8	35	14	23	35	8.6	26	15	39
TDS	131	33	12	35	42	27	35	43	29	18	42
Iron	132	3.8	6.1	35	6.5	4.8	35	5.7	0	0	5.3
Manganese	132	3.8	16	35	3.9	18	35	5.7	23	13	36

Table 6. Aquifer-scale proportions from grid-based and spatially weighted approaches for constituents with (1) high relative-concentrations during August 11, 2005, to August 10, 2008, from the California Department of Public Health (CDPH) database, (2) moderate or high relative-concentrations in samples collected from USGS-grid wells (August–December 2008), or (3) detection frequencies of organic constituents greater than 10 percent in USGS-grid wells, South Coast Interior Basins study unit, California GAMA Priority Basin Project.—Continued

[**Relative-concentration categories**: high; concentrations of inorganic or organic or special-interest constituents greater than water-quality benchmark; moderate, concentrations of inorganic constituents greater than or equal to 0.5 of benchmark but less than benchmark or concentrations of organic or special-interest constituents greater than or equal to 0.1 of benchmark but less than benchmark; low, concentrations of inorganic constituents less than 0.5 of benchmark or concentrations of organic or special-interest constituents less than 0.1 of benchmark or not detected. Benchmark types and values for constituents listed in tables 2A,B]

Constituent	Raw detection frequency[1]			Spatially weighted aquifer-scale proportion[1]			Grid-based aquifer-scale proportion			90% confidence interval for grid-based high proportion[2]	
	Number of wells	Moderate values (percent)	High values (percent)	Number of cells	Moderate values (percent)	High values (percent)	Number of wells	Moderate values (percent)	High values (percent)	Lower limit (percent)	Upper limit (percent)
Organic constituents											
Trihalomethanes											
Bromoform	126	0.8	0.8	35	0.3	0.7	35	0	0	0	5.3
Chloroform	123	0	0	35	0.0	0.0	34	0	0	0	5.5
Solvents											
Tetrachloroethene (PCE)	126	4.0	1.6	35	2.0	0.9	35	0	0	0	5.3
Herbicides											
Simazine	112	0	0	35	0	0	35	0	0	0	5.3
Special-interest constituents											
Perchlorate	84	19	1.2	35	24	0.3	35	34	0	0	5.3

[1] Based on most recent analysis for each CDPH well between August 11, 2005, and August 10, 2008, combined with USGS-GAMA grid-based data.

[2] Based on the Jeffreys interval for the binomial distribution (Brown and others, 2001).

[3] Gross alpha activities were not adjusted for uranium activity. The MCL-US for gross alpha activity applies to adjusted gross alpha activity.

Table 7A. Aquifer-scale proportions for inorganic constituent classes, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**Relative-concentration categories**: high, concentrations of constituents greater than water-quality benchmark; moderate, concentrations of constituents greater than or equal to 0.5 of benchmark but less than benchmark; low, concentrations of constituents less than 0.5 of benchmark. Values are grid-based except where footnoted]

Constituent class	Aquifer-scale proportion		
	Low relative-concentration (percent)	Moderate relative-concentration (percent)	High relative-concentration (percent)
Inorganics with health-based benchmarks			
Trace and minor elements	57	23	20
Uranium and radioactive constituents[1]	82	18	0
Nutrients	71	14	14
Any inorganic with health-based benchmarks[1]	34	37	29
Inorganics with aesthetic-based benchmarks			
Salinity indicators[2]	29	40	31
Manganese and (or) iron	71	5.7	23
Any inorganic with aesthetic-based benchmarks	20	31	49

[1] Aquifer-scale proportions for the classes uranium and radioactive constituents and all inorganic constituents with health-based benchmarks were calculated using unadjusted gross alpha activity.

[2] Salinity indicators are chloride, sulfate, and total dissolved solids.

Table 7B. Aquifer-scale proportions for organic constituent classes, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**Relative-concentration categories**: high, concentrations of constituents greater than water-quality benchmark; moderate, concentrations of constituents greater than or equal to 0.1 of benchmark but less than benchmark; low, concentrations of constituents less than 0.1 of benchmark. Values are grid-based except where footnoted]

Constituent class	Low relative-concentration (percent)		Moderate relative-concentration (percent)	High relative-concentration (percent)
	Not detected	Detected low		
Trihalomethanes	88	11	0	[1] 0.7
Solvents	89	8.3	[1] 2.0	[1] 0.9
Herbicides	80	20	0	0
Any organic with health-based benchmarks	65	31	[1] 2.0	[1] 1.6

[1] Spatially weighted value. All other values are grid-based.

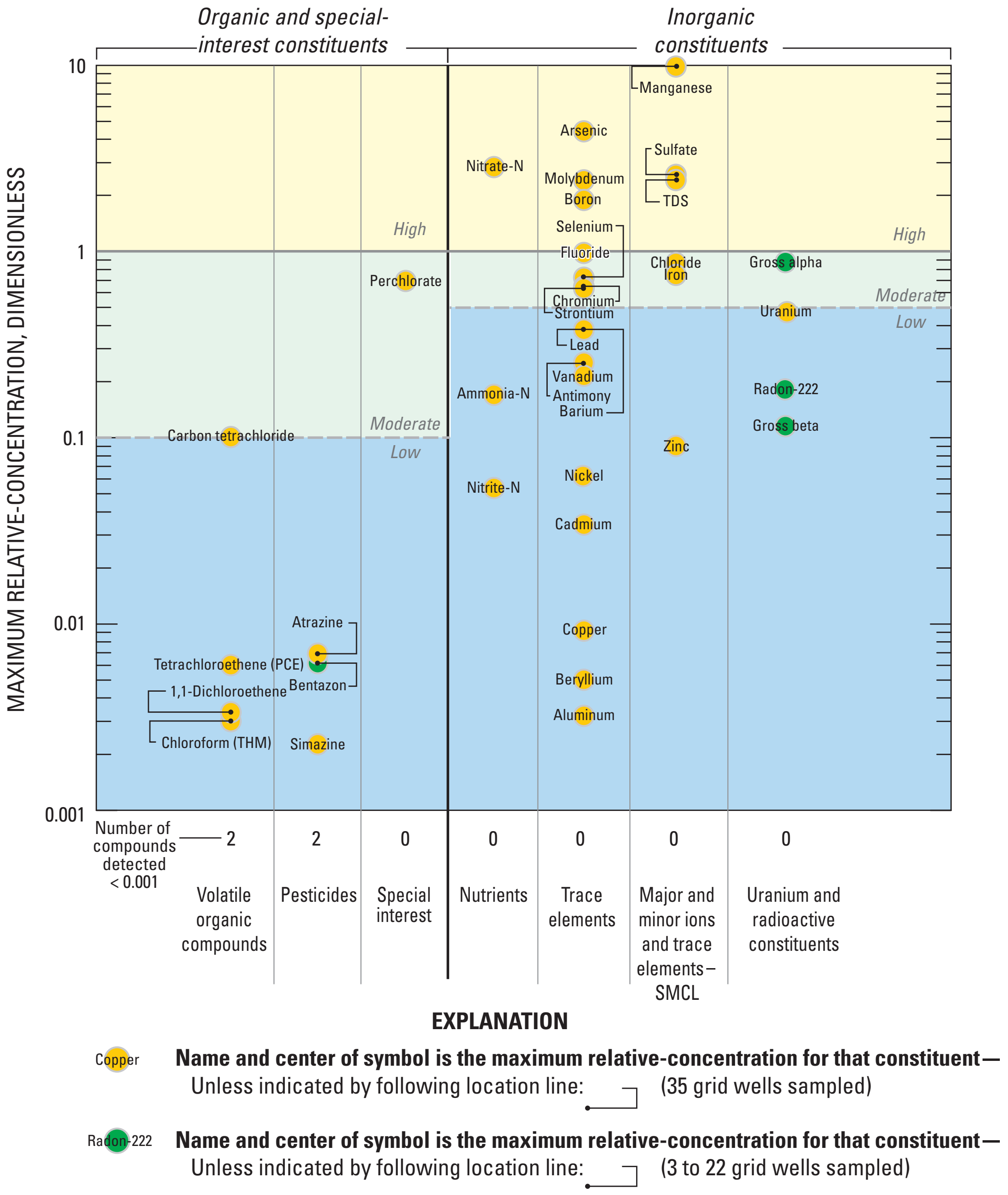


Figure 9. Maximum relative-concentration of constituents detected in grid wells, by constituent class, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

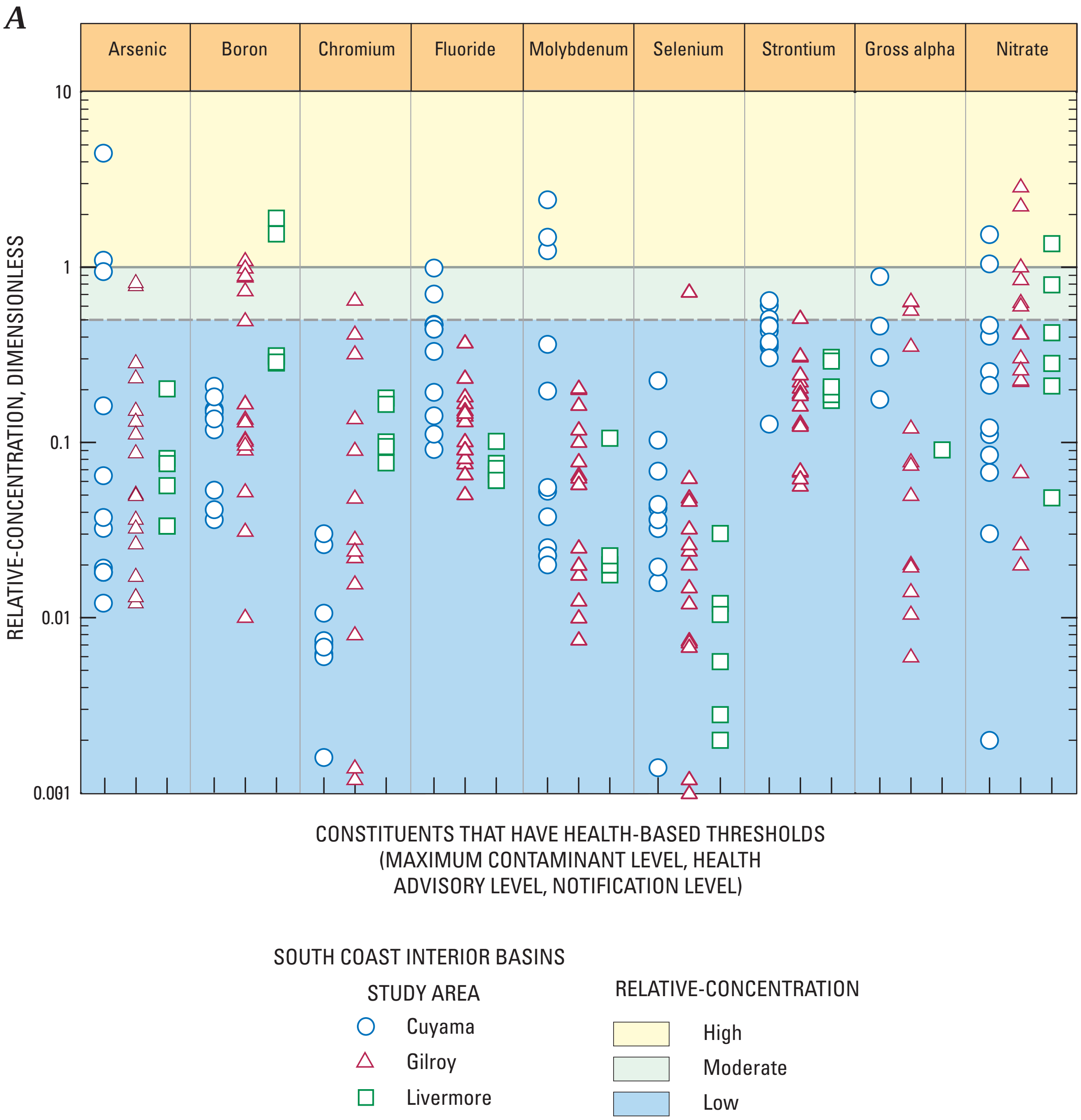


Figure 10. Relative-concentrations of (*A*) arsenic, boron, chromium, fluoride, molybdenum, selenium, strontium, gross alpha radioactivity, and nitrate with health-based benchmarks, and (*B*) total dissolved solids, chloride, iron, manganese, and sulfate with aesthetic benchmarks in USGS- and CDPH-grid wells, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

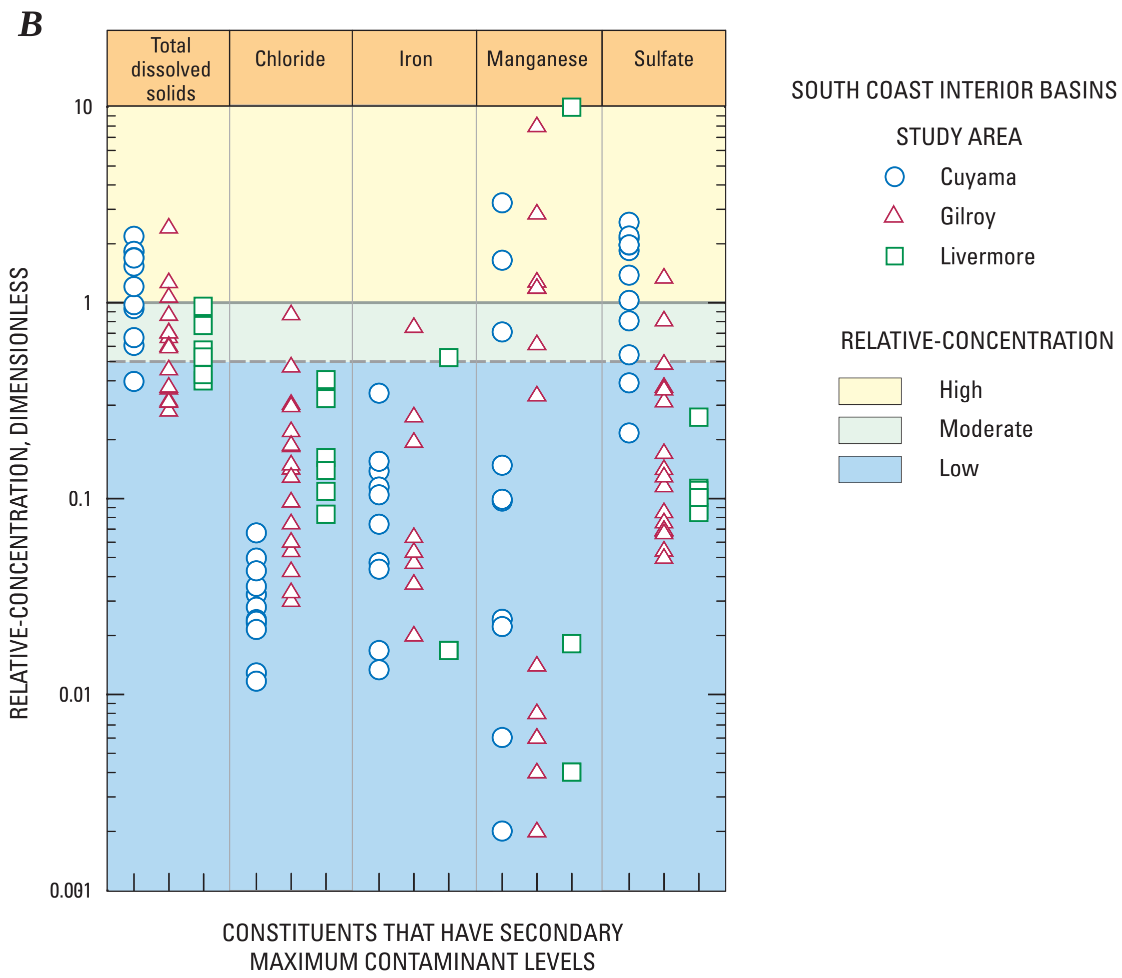


Figure 10. —Continued

Trace Elements

Trace elements, as a class, were detected at high relative-concentrations (for one or more constituents) in 20 percent of the primary aquifer system, moderate values in 23 percent, and low values in 57 percent (table 7A). Arsenic, boron, and molybdenum were detected at high relative-concentrations in more than 2 percent of the primary aquifer system, and chromium and fluoride were detected at high relative concentrations in less than or equal to 1 percent (spatially weighted) of the primary aquifer system (table 6).

Relative-concentrations for some trace elements—aluminum, barium, cadmium, mercury, nickel, thallium, and zinc—were high in at least one well as reported in the CDPH database before August 11, 2005, but not during the current period of study (August 11, 2005–August 10, 2008) (table 3); these high values represent historical values rather than current values.

Understanding Assessment for Arsenic

Arsenic is a naturally occurring semi-metallic trace element. Potential sources of arsenic to groundwater are both natural and anthropogenic. Natural sources include the dissolution of arsenic-rich minerals such as arsenopyrite (FeAsS), a common constituent of shales, and apatite, a common constituent of phosphorites. Arsenic also can be used as a wood preservative, in glass production, in paints, dyes, metals, drugs, soaps, and semi-conductors, and in the mining of copper and gold (Welch and others, 2000). Arsenic solubility increases with increasing water temperature, such that hydrothermal fluids often exhibit higher arsenic concentrations (Ballantyne and Moore, 1988; Webster and Nordstrom, 2003), as do older groundwaters that have had extended exposure to arsenic-bearing minerals. Previous investigations and literature reviews of arsenic have indicated two mechanisms for elevated arsenic concentrations in

Table 8A. Results of non-parametric (Spearman's *rho* method) analysis for correlations between selected water-quality constituents and potential explanatory factors, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[Spearman's correlation statistic (ρ) shown for correlations determined to be significant on the basis of p-values (not shown) less than threshold value (α) of 0.05. nc, no significant correlation]

Selected water-quality constituent	Potential explanatory factors: Grid and understanding wells combined: Well depth	Depth to top-of-perforations	pH	Dissolved oxygen	Grid wells: Percent urban land use[1]	Percent agricultural land use[1]	Percent natural land use[1]
	ρ: Spearman's correlation statistic						
Inorganic constituents							
Arsenic	nc	nc	0.32	–0.40	nc	–0.34	nc
Boron	nc	nc	nc	nc	nc	nc	nc
Molybdenum	nc	nc	0.43	–0.28	nc	nc	0.46
Nitrate	nc	nc	–0.32	0.52	nc	nc	–0.53
Total dissolved solids (TDS)	nc	nc	nc	nc	–0.39	nc	nc
Sulfate	nc	nc	nc	nc	–0.46	nc	0.41
Manganese	nc	nc	nc	–0.52	nc	nc	nc
Organic constituents							
Chloroform	nc	–0.28	nc	nc	0.52	–0.36	nc
Simazine	nc	nc	–0.35	nc	nc	nc	nc
Special-interest constituent							
Perchlorate	nc	nc	–0.29	0.46	nc	nc	–0.53

[1] Land-use percentages are within a radius of 500 meters centered around each well included in analysis.

groundwater: the release of arsenic resulting from reductive dissolution of iron or manganese oxyhydroxides under anoxic conditions and the desorption of arsenic from these oxyhydroxides under high-pH, oxic conditions (for example, Welch and others, 2000; Smedley and Kinniburgh, 2002; Belitz and others, 2003; Stollenwerk, 2003).

Arsenic has an MCL-US of 10 micrograms per liter (µg/L) and was detected at high relative-concentrations in 5.7 percent of the primary aquifer system and at moderate relative-concentrations in 8.6 percent (table 6). High and moderate relative-concentrations occurred in the CUY and GIL study areas (fig. 11).

Arsenic concentrations were negatively correlated to DO (table 8A), and concentrations were significantly lower in samples having a redox classification of oxic than in those samples classified as mixed (table 8B). Arsenic concentrations were positively correlated with manganese concentrations (Spearman's test, p=0.003, ρ=0.40), but were not correlated with iron concentrations (Spearman's test, p=0.129). These relations are consistent with release of arsenic by reductive dissolution of manganese oxyhydroxides. Arsenic concentrations in samples having a groundwater age classified as pre-modern were significantly higher than in samples classified as having modern or mixed ages (table 8B). Arsenic concentrations were not correlated to well depth, despite the significantly greater well depths and lower DO concentrations in wells with pre-modern groundwater compared to wells with modern groundwater (table 4B).

Table 8B. Results of Wilcoxon rank-sum tests to determine significant differences between selected water-quality constituents grouped by explanatory factor classifications, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[Wilcoxon rank-sum test statistic (Z) values shown for differences determined to be significant on the basis of p-values (not shown) less than threshold value (α) of 0.05. Positive values of Z indicate that the median concentration of the constituent in samples classified in the first group is significantly greater than the median concentration of the constituent in samples classified in the second group, and negative values of Z indicate that the median concentration of the constituent in samples classified in the first group is significantly less than the median concentration of the constituent in samples classified in the second group. **Well depth classification**: shallow, well depth < 250 ft; overlapping, top-of-perforations < 250 ft and well depth > 250 ft; deep, well depth > 250 ft and top-of-perforations > 250 ft. **Groundwater age classification**: modern, sample with water recharged after 1952; pre-modern, sample with water recharged before 1952; mixed age, sample with modern and pre-modern components. **Other abbreviations**: nd, no significant difference (p-value > 0.05); ≤, less than or equal to; >, greater than; <, less than]

Selected water-quality constituent	Potential explanatory factors											
	Groundwater age classification			Geochemical conditions classification			Study area			Well depth classification		
	Modern compared with mixed	Mixed compared with pre-modern	Modern compared with pre-modern	Oxic compared with mixed	Mixed compared with anoxic	Oxic compared with anoxic	Cuyama compared with Gilroy	Cuyama compared with Livermore	Gilroy compared with Livermore	Shallow compared with overlapping	Shallow compared with deep	Overlapping compared with deep
	Z: Test statistic for Wilcoxon test											
Arsenic	nd	–2.17	–2.78	–2.22	nd	–2.26	nd	nd	nd	nd	nd	nd
Boron	nd	nd	nd	1.98	nd	nd	nd	–3.32	nd	nd	nd	nd
Molybdenum	nd	–2.18	–3.16	nd	nd	–2.59	nd	2.36	nd	nd	nd	nd
Nitrate	nd	nd	2.66	nd	nd	2.82	nd	nd	nd	nd	nd	nd
Total dissolved solids	nd	nd	nd	nd	nd	nd	2.75	2.29	nd	2.36	nd	–2.03
Sulfate	nd	nd	nd	nd	nd	nd	3.87	3.23	nd	nd	nd	nd
Manganese	nd	nd	–2.49	–2.36	nd	–3.18	nd	nd	nd	nd	nd	nd
Chloroform	nd	nd	nd	nd	nd	nd	nd	–2.06	–2.99	nd	nd	nd
Simazine	nd	nd	2.01	nd	nd	nd	nd	–2.52	nd	nd	nd	nd
Perchlorate	nd	nd	2.87	nd	nd	3.18	nd	nd	nd	nd	nd	nd

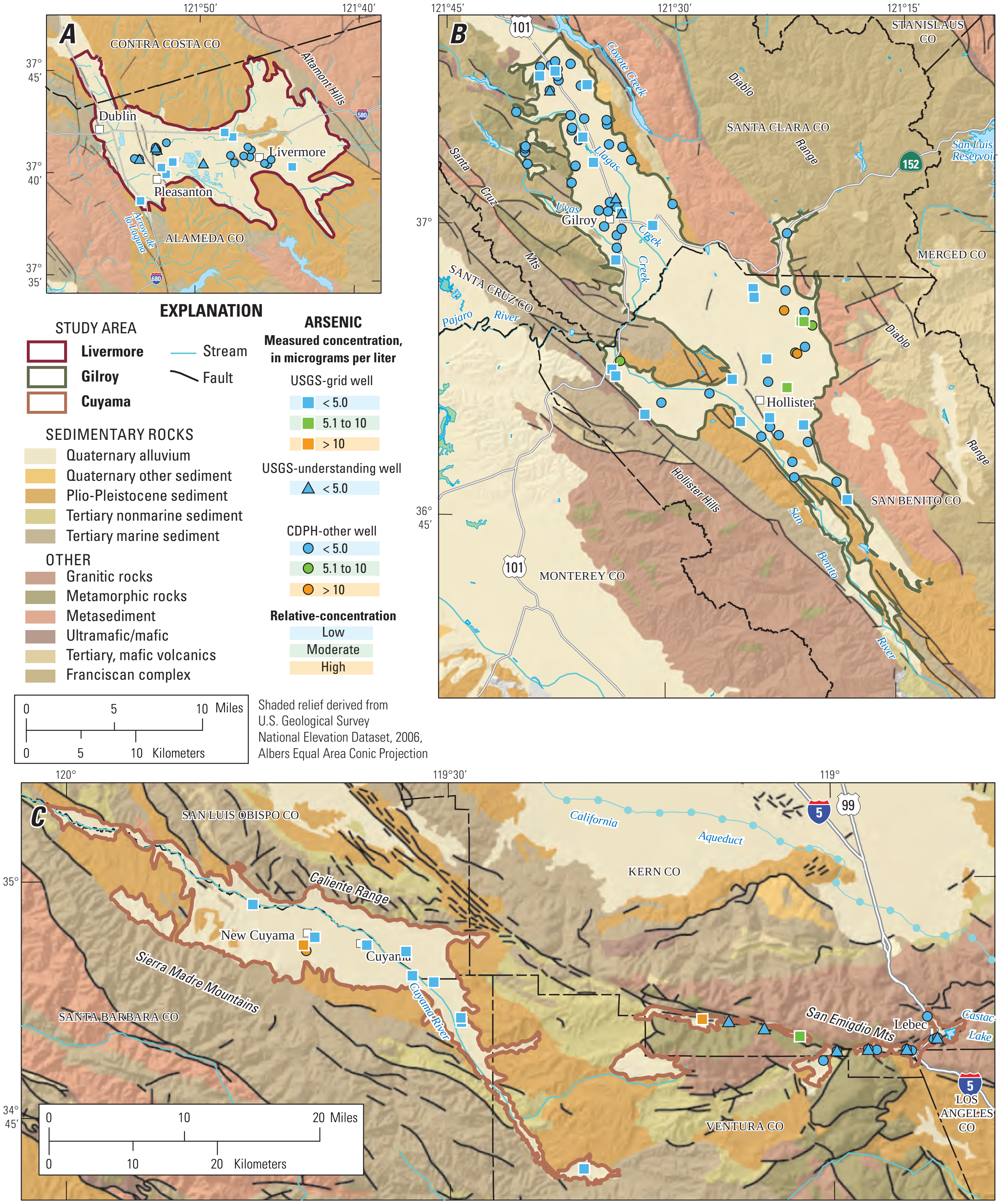


Figure 11. Relative-concentrations of arsenic for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Understanding Assessment for Boron

Boron is a naturally occurring semi-metallic element that occurs in many minerals. Natural sources of boron include igneous rocks such as granite and pegmatite (as the mineral tourmaline), and evaporite minerals such as borax, kernite and colemanite (Hem, 1985; Reimann and de Caritat, 1998). Borax, a boron-containing evaporate mineral that is mined in California, is used as a cleaning agent and therefore may be present in sewage and industrial wastes. Seawater contains 4.5 milligrams per liter (mg/L) of boron (Summerhayes and Thorpe, 1996), and boron also is associated with thermal springs (Hem, 1985; Kulongoski and others, 2010). Boron also is used to produce semiconductors, insecticides, preservatives, and chemical reagents. Boron is highly mobile because no mineral has a low enough solubility to provide an upper limit to its concentration range.

Boron has an NL-CA of 1,000 µg/L and was detected at high relative-concentrations in 8.6 percent of the primary aquifer system and at moderate relative-concentrations in 11 percent (table 6). High and moderate relative-concentrations occurred in all three study areas (fig. 12). Boron concentrations were significantly greater in the LIV study area than in the CUY study area (table 8B). Boron concentrations are known to be elevated in the LIV study area due to marine sediments neighboring the groundwater basin (California Department of Water Resources, 2006). Boron concentrations were greater in oxic groundwater compared with mixed groundwater (table 8B).

Understanding Assessment for Molybdenum

Molybdenum is a trace element that is found in the major ore mineral molybdenite, and to a lesser extent, in the mineral wulfenite (Evans and Barabash, 2010). High concentrations of molybdenum also are found in shales and phosphate deposits formed in strongly reducing marine environments (for example, Krauskopf, 1955). Industrial uses of molybdenum include steel and iron alloys, electrodes, and catalysts. Molybdenum commonly is present in biosolids, such as sewage sludges, and can accumulate in vegetation and forage crops (particularly legumes) grown on lands fertilized with these materials (Evans and Barabash, 2010).

Molybdenum has a HAL-US of 40 µg/L and was detected at high relative-concentrations in 8.6 percent of the primary aquifer system and at moderate relative-concentrations in 1.7 percent (spatially weighted) (table 6). High and moderate relative-concentrations occurred only in the western and eastern parts of the CUY study area, respectively (fig. 13). Molybdenum concentrations were significantly greater in pre-modern-age groundwater compared to modern or mixed-age groundwater, and greater in anoxic groundwater compared to oxic groundwater (table 8B). Similarly, molybdenum was negatively correlated with dissolved oxygen (table 8A). Molybdenum was positively correlated with pH and percentage of natural land use; the CUY study area has the greatest percentage of natural land.

Uranium and Radioactive Constituents

All concentrations of radioactive constituents in samples from grid wells were below health-based benchmarks (table 7A). Moderate relative-concentrations of gross alpha were detected in 18 percent of the primary aquifer system (table 6). None of the wells with moderate relative-concentrations of gross alpha had moderate relative-concentrations of uranium or radon-222.

The radioactive constituents radon-222, radium-228, and uranium had high relative-concentrations in at least one well reported in the CDPH database before August 11, 2005, but not during the current period of study (table 3).

Nutrients

Nutrients, as a class, were detected at high relative-concentrations in 14 percent of the primary aquifer system and at moderate relative-concentrations in 14 percent (table 6). High and moderate relative-concentrations of nitrate occurred in all three study areas (figs. 10*A*, 14).

Understanding Assessment for Nitrate

Nitrate has both natural and anthropogenic sources to groundwater; however, concentrations greater than 2 mg/L (as nitrogen) (relative-concentration of 0.2) generally are considered to indicate presence of nitrate from anthropogenic sources (Mueller and Helsel, 1996). Potential anthropogenic sources of nitrate include use of fertilizers in agricultural and urban areas, nitrate in water used for engineered recharge, seepage from septic and sewage systems, and animal and human wastes.

Nitrate concentrations were significantly higher in modern groundwater than in pre-modern groundwater and in oxic groundwater than in anoxic groundwater (table 8B). Nitrate was also positively correlated with dissolved oxygen and negatively correlated with pH and percentage of natural land use (table 8A). Some of the explanatory variables related to nitrate, such as dissolved oxygen and groundwater age, are generally related to each other (table 4A).

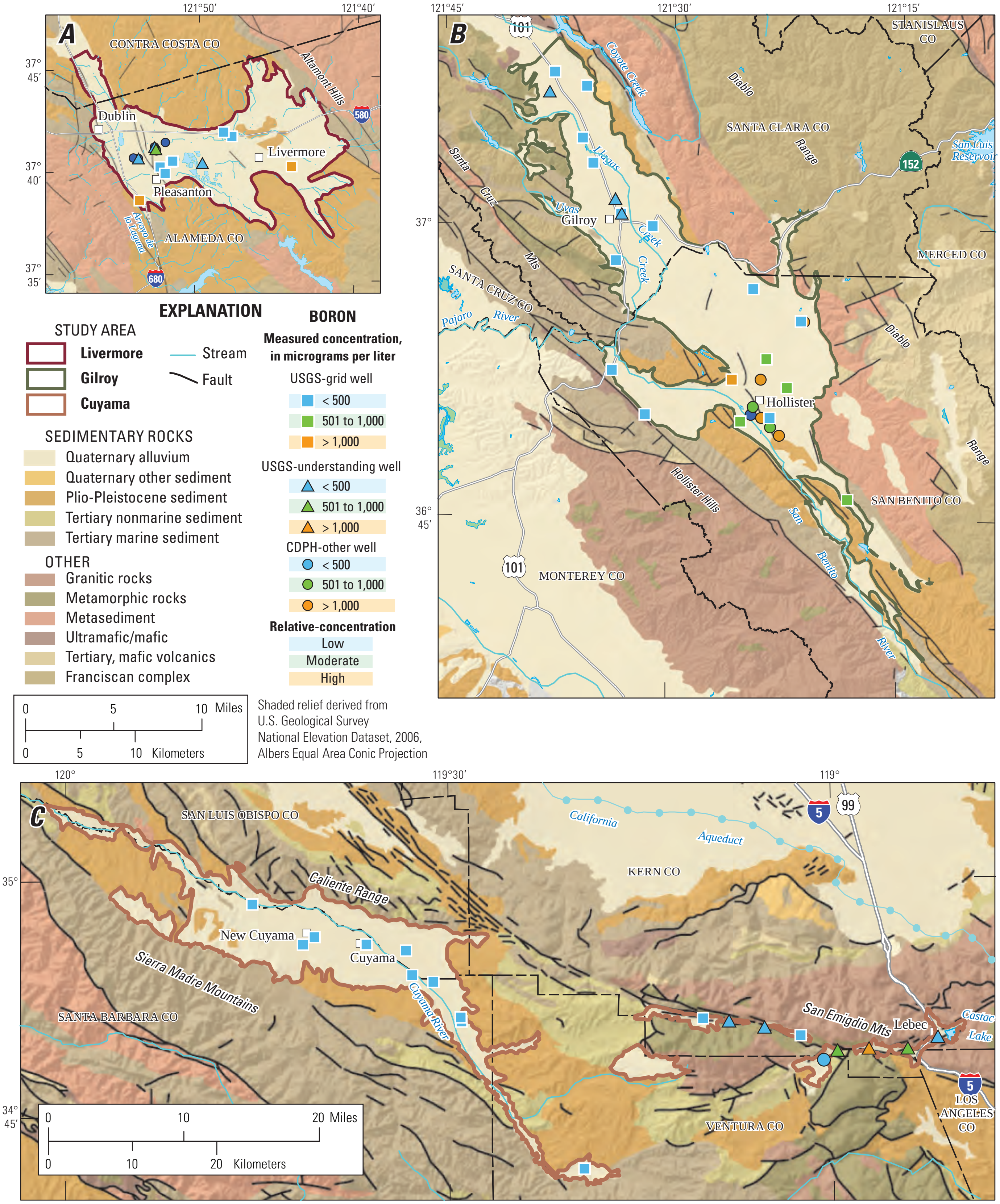


Figure 12. Relative-concentrations of boron for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

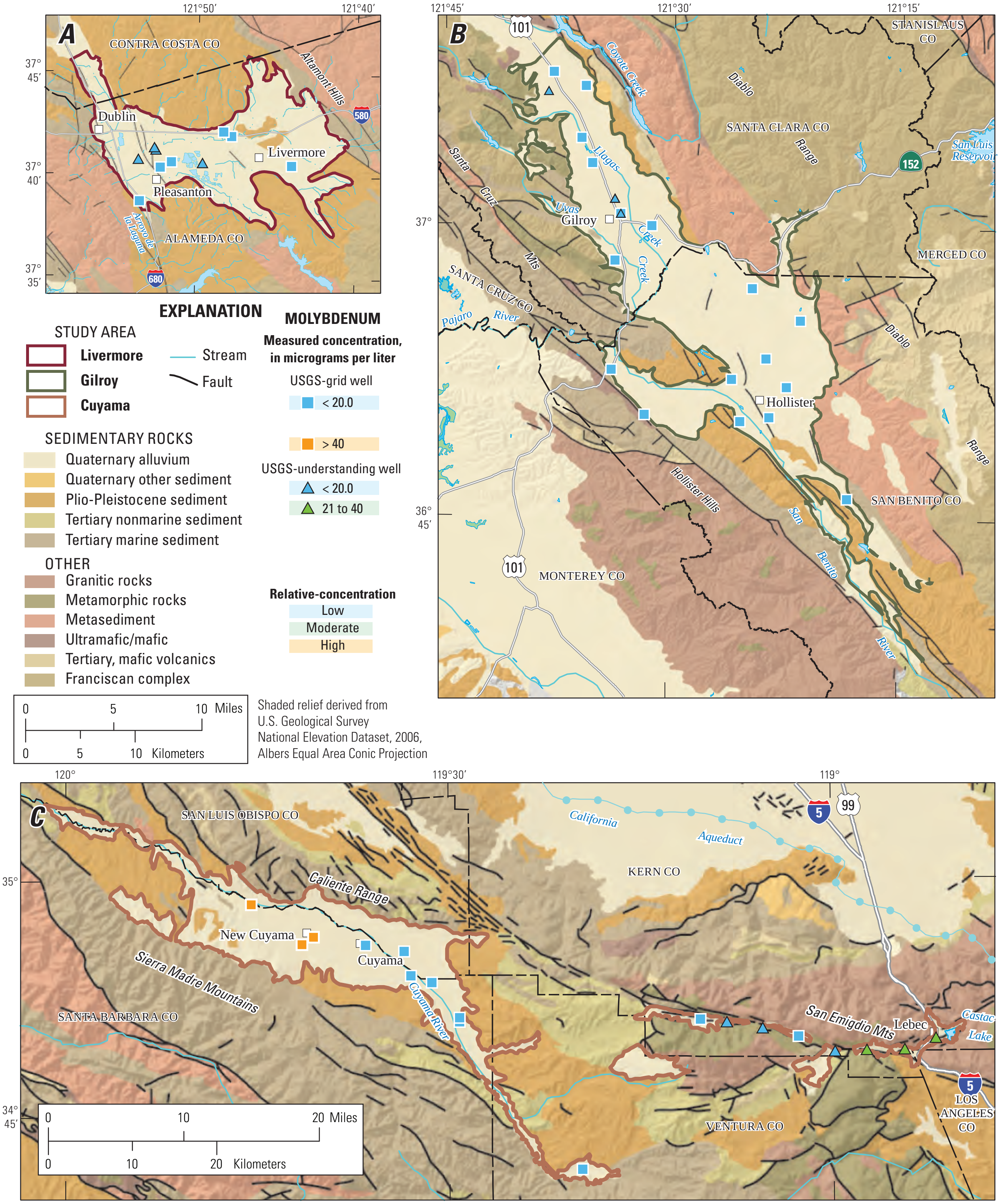


Figure 13. Relative-concentrations of molybdenum for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

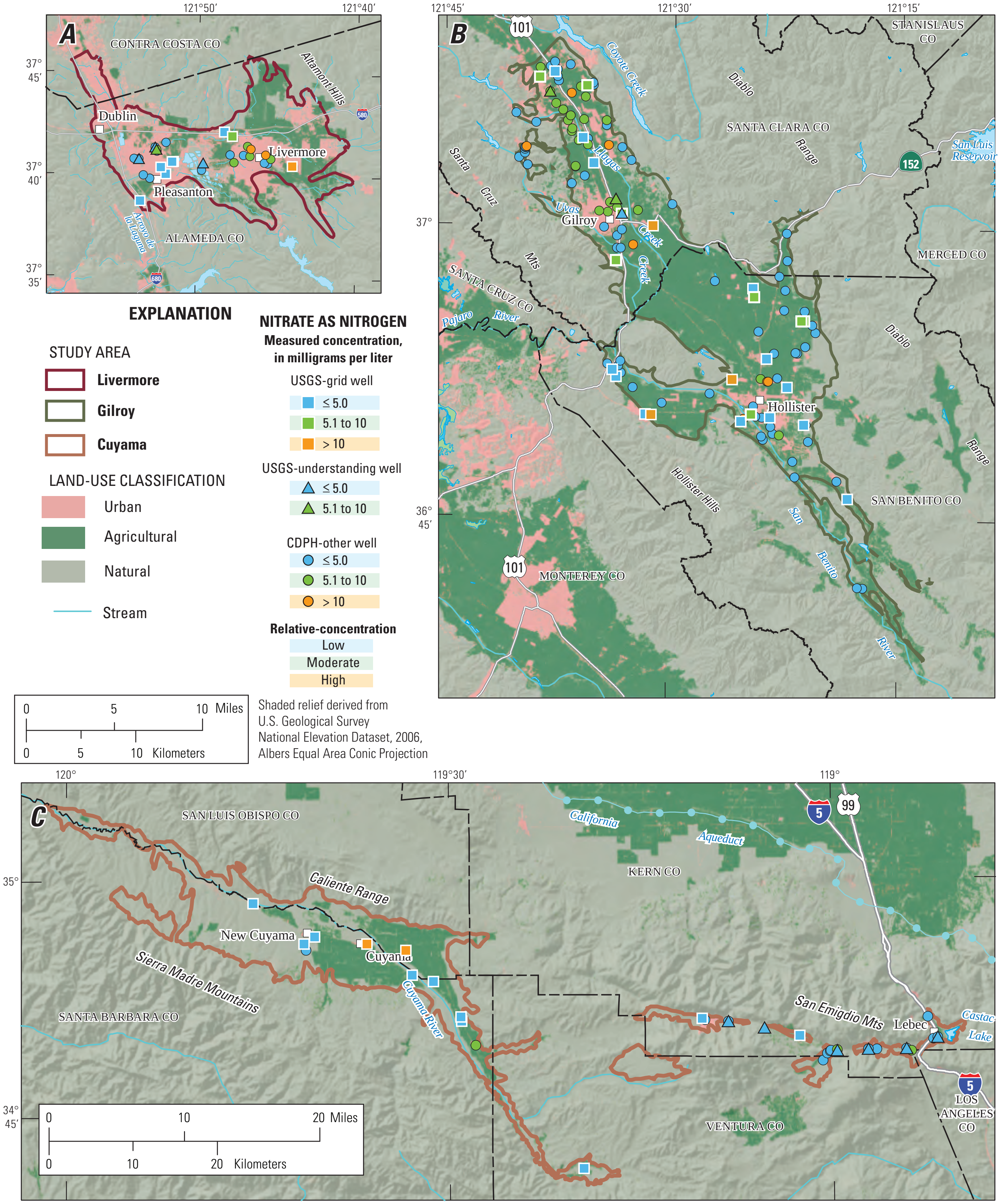


Figure 14. Relative-concentrations of nitrate for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Inorganic Constituents with Aesthetic Benchmarks

One or more inorganic constituents with aesthetic-based benchmarks were detected at high relative-concentrations in 49 percent of the primary aquifer system and at moderate relative-concentrations in 31 percent (table 7A). The constituents most commonly detected at high relative-concentrations were TDS, sulfate, and manganese (table 6).

Understanding Assessment for Total Dissolved Solids (TDS)

Natural sources of TDS include mixing of groundwater with deep saline groundwater (connate water) that is influenced by interactions with deep marine or lacustrine sediments, concentration of salts by evaporation in discharge areas, and (or) water-rock interactions. Potential anthropogenic sources of TDS to groundwater in the SCI study unit include agricultural and urban irrigation, increased evaporation from irrigation water, disposal of wastewater and industrial effluent, and leaking water and sewer pipes.

TDS has an SMCL-CA of 1,000 mg/L and was detected at high relative-concentrations in 29 percent of the primary aquifer system and at moderate relative-concentrations in 43 percent (table 6). TDS concentrations were negatively correlated with percentage of urban land use (table 8A). High relative-concentrations of TDS were measured in wells representative of the primary aquifer system in the GIL and CUY study areas, and moderate relative-concentrations were detected in all three study areas (fig. 15). TDS concentrations were significantly greater in the CUY study area than in the GIL or LIV study areas, and were significantly greater in shallow and deep wells than in wells perforated in both the shallow and deep depth intervals (“overlapping” wells) (table 8B). These relations in part reflect the distribution of well types among the study areas: the percentage of wells classified as overlapping was lowest in CUY.

Understanding Assessment for Sulfate

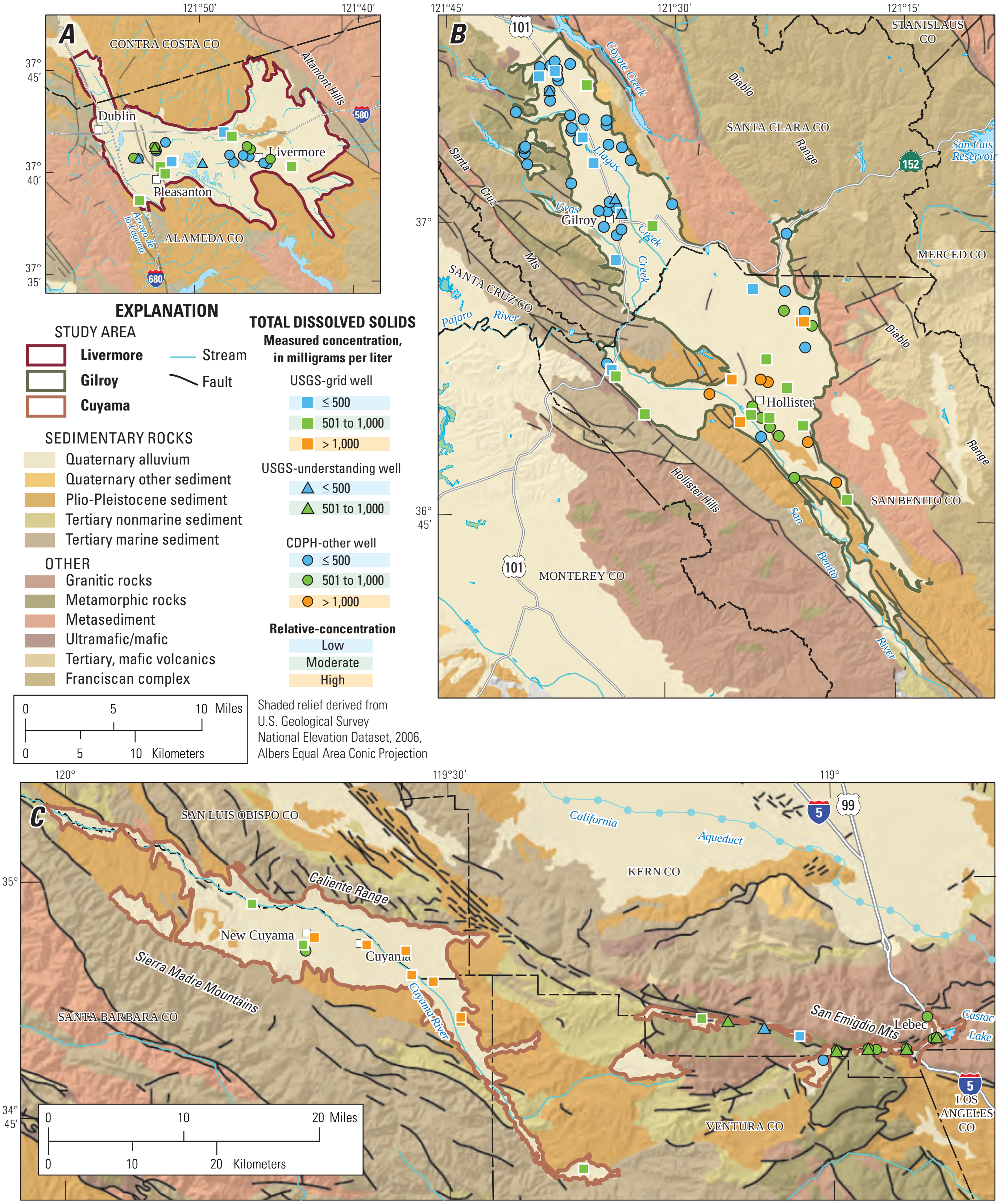
Natural sources of sulfate include the dissolution of natural sulfur and its oxidation to the anion sulfate, or the biochemical oxidation of sulfide minerals or species. Sulfate occurs in evaporite sediments as gypsum or anhydrite and in soils in arid and semi-arid environments as gypsum, and commonly exceeds 1 mg/L in rainfall (Hem, 1985). Anthropogenic sources include sulfuric acid used in some agriculture to lower the pH of irrigation water and assist with nutrient uptake.

Sulfate has an SMCL-CA of 500 mg/L and was detected at high relative-concentrations in 26 percent of the primary aquifer system and at moderate relative-concentrations in 8.6 percent (table 6). Similar to TDS concentrations, sulfate concentrations were significantly greater in the CUY study area than in the GIL or LIV study areas (fig. 16; table 8B). Sulfate concentrations were correlated with TDS concentrations, and all samples with high or moderate relative-concentrations of sulfate also had high or moderate relative-concentrations of TDS. Sulfate was negatively correlated with percentage of urban land use and positively correlated with percentage of natural land use (table 8A).

Understanding Assessment for Manganese

Potential natural sources of manganese to groundwater include the dissolution of manganese oxyhydroxide minerals present in many sediments and rocks and of primary manganese-bearing silicate minerals found in igneous and metamorphic rocks (Hem, 1985). Potential anthropogenic sources of manganese to groundwater include effluents associated with the steel and mining industries (Reimann and de Caritat, 1998) and soil amendments, in the form of manganese sulfates, that are added to deficient soils in order to stimulate crop growth. Concentrations of manganese are strongly influenced by redox conditions in the aquifer. In sediments, the manganese oxyhydroxide minerals are common as suspended particles and as coatings on mineral surfaces (Sparks, 1995). These minerals are stable in oxygenated systems at neutral pH. However, under anoxic conditions, the process of reductive dissolution can mobilize these minerals from oxyhydroxides, increasing their concentrations in groundwater (Sparks, 1995).

Manganese has an SMCL-CA of 50 µg/L and was detected at high relative-concentrations in 23 percent of the primary aquifer system and at moderate relative-concentrations in 5.7 percent (table 6). High relative-concentrations of manganese were observed in all three study areas (figs. 10*B*, 17). Manganese concentrations were significantly greater in pre-modern-age groundwater compared with modern-age groundwater (table 8B). Manganese concentrations were significantly less in oxic groundwater compared with mixed or anoxic groundwater. Manganese was also negatively correlated to dissolved oxygen (table 8A).



Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006, Albers Equal Area Conic Projection

Figure 15. Relative-concentrations of total dissolved solids for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

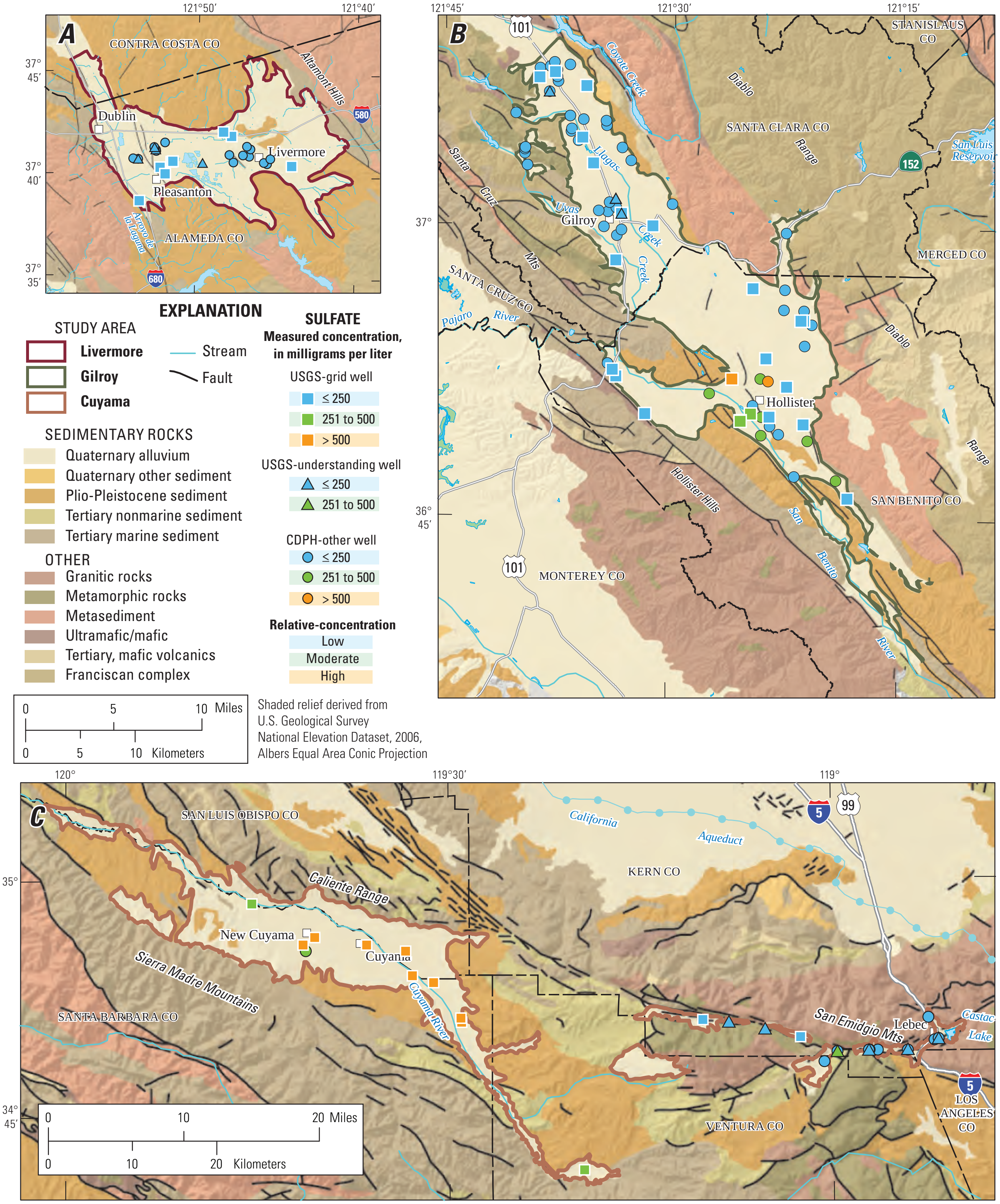


Figure 16. Relative-concentrations of sulfate for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

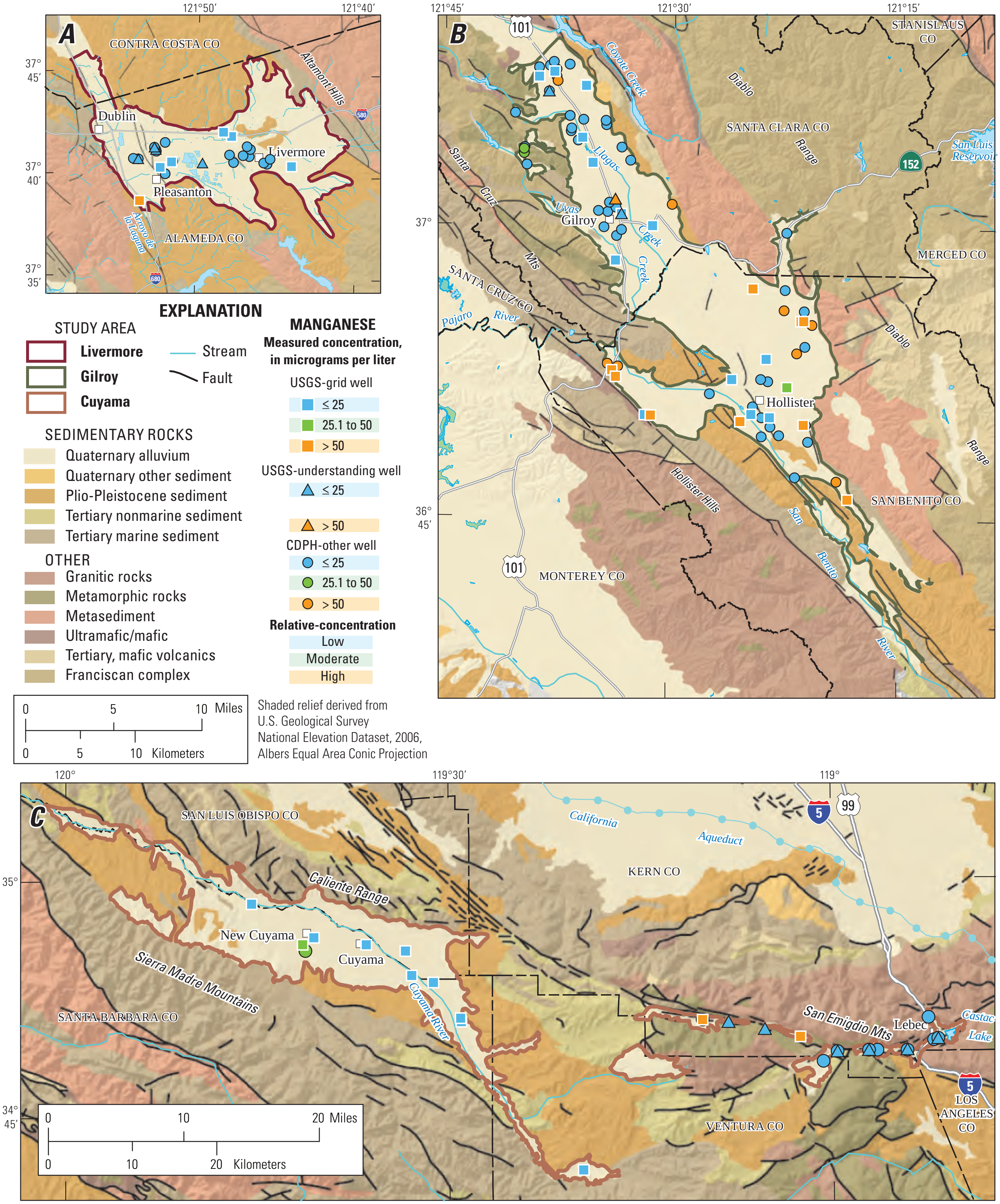


Figure 17. Relative-concentrations of manganese for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Organic Constituents

The organic compounds are organized by constituent class, including volatile organic compounds (VOCs) and pesticides. VOCs are characterized by their tendency to evaporate and are present in paints, solvents, fuels, fuel additives, refrigerants, fumigants, and disinfected water. VOCs typically persist longer in groundwater than in surface water because groundwater is isolated from the atmosphere. Pesticides are used to control weeds, fungi, or insects in agricultural and urban settings.

Organic constituents, as a class, were detected at high relative-concentrations in 1.6 percent of the primary aquifer system and at moderate relative-concentrations in 2.0 percent (both values based on the spatially weighted approach) (table 7B). The constituents detected at high relative-concentrations were the solvent tetrachloroethene (PCE) and the trihalomethane bromoform. The trihalomethane chloroform and the herbicide simazine were detected (at low relative-concentrations only) in more than 10 percent of the primary aquifer system (figs. 18, 19). Of the 205 organic constituents analyzed for in the SCI study unit, 14 were detected, of which 13 had health-based benchmarks (table 5). Ten organic constituents with health-based benchmarks were detected in grid wells (fig. 18).

Solvents are used for various industrial, commercial, and domestic purposes. Solvents had a high spatially weighted proportion of 0.9 percent, reflecting a high relative-concentration of PCE in two wells in the LIV study area reported in the CDPH database during the current period of study (August 11, 2005–August 10, 2008). The proportions of the aquifer having moderate or low (or not detected) relative-concentrations of solvents were 2 percent and 97 percent, respectively (table 7B). PCE was detected in one USGS-grid well at low relative-concentration (fig. 19). Historically high relative-concentrations for the solvent carbon tetrachloride and 1,1,2-trichloroethane were recorded in the CDPH database for the period before August 11, 2005, but not during the current period of study (table 3).

Understanding Assessment for Trihalomethanes

Trihalomethanes (THMs) may form during disinfection of water supplies and may enter groundwater by infiltration of landscape irrigation water. THMs, as a class, were detected at high relative-concentrations in 0.7 percent (spatially weighted approach) of the primary aquifer system and at low relative-concentrations (or not detected) in 99 percent of the primary aquifer system (table 7B). The THM chloroform was detected in 11 percent of the 35 grid wells in the study unit (figs. 18, 19). Chloroform was only detected at low relative-concentrations in the primary aquifer system (table 6). Chloroform also was the most frequently detected VOC in groundwater according to the USGS National Water-Quality Assessment (NAWQA) Program (Zogorski and others, 2006). Most detections of chloroform were in the LIV study area (fig. 20).

The THM bromoform was detected at high relative-concentrations in one well reported in the CDPH database during the current period of study (August 11, 2005–August 10, 2008), resulting in a spatially weighted high relative-concentration of 0.7 percent in the primary aquifer system (table 6). Bromoform was not detected in the 35 USGS-grid wells. The spatially weighted approach includes data from a larger number of wells than the grid-based approach and therefore is more likely to include constituents that are detected at high relative-concentrations in small proportions of the primary aquifer system.

Chloroform concentrations were positively correlated with percentage of urban land use and negatively correlated with percentage of agricultural land use (table 8B). Nationally, THM concentrations have been positively correlated with percentage of urban land use (Zogorski and others, 2006). Potential urban sources of THMs include recharge from landscape irrigation that uses disinfected water and leakage from distribution lines or sewer systems, as well as industrial and commercial sources (Ivahnenko and Barbash, 2004). The LIV study area has the highest percentage of urban land (fig. 5*A*), consistent with the higher concentrations of chloroform than the CUY or GIL study areas (table 8B; fig. 20). Chloroform concentrations were negatively correlated with depth to top-of-perforations, indicating that concentrations decrease with depth in the primary aquifer system.

Understanding Assessment for Herbicides

Herbicides are applied to crops, gardens, lawns, around buildings, and along roads to control weeds. As a class, herbicides were detected at low relative-concentrations in 20 percent of the primary aquifer system (table 7B), reflecting low relative-concentrations of simazine (figs. 9, 18, 21). Simazine also was among the most commonly detected herbicides in groundwater in major aquifers across the United States (Gilliom and others, 2006) and was the most frequently detected herbicide in groundwater in California (Troiano and others, 2001). No herbicides were detected in grid wells from the CUY study area (fig. 21).

Simazine was detected in seven grid wells in the GIL and LIV study areas (fig. 21), three of which had construction information available and had depth to top-of-perforations of less than 250 ft. Simazine was negatively correlated with pH (table 8A) as a result of other explanatory factors correlating to each other. Because there were no detections of simazine in USGS-grid wells in the CUY study area, pH and simazine concentrations present a negative correlation. Simazine concentrations were significantly greater in modern-age groundwater compared with pre-modern-age groundwater (table 8B).

Simazine concentrations were not significantly correlated with percent agricultural or percent urban land use in the SCI study unit. Nationally, simazine has been used in agricultural applications on citrus and vineyards and in urban settings for weed control (Gilliom and others, 2006).

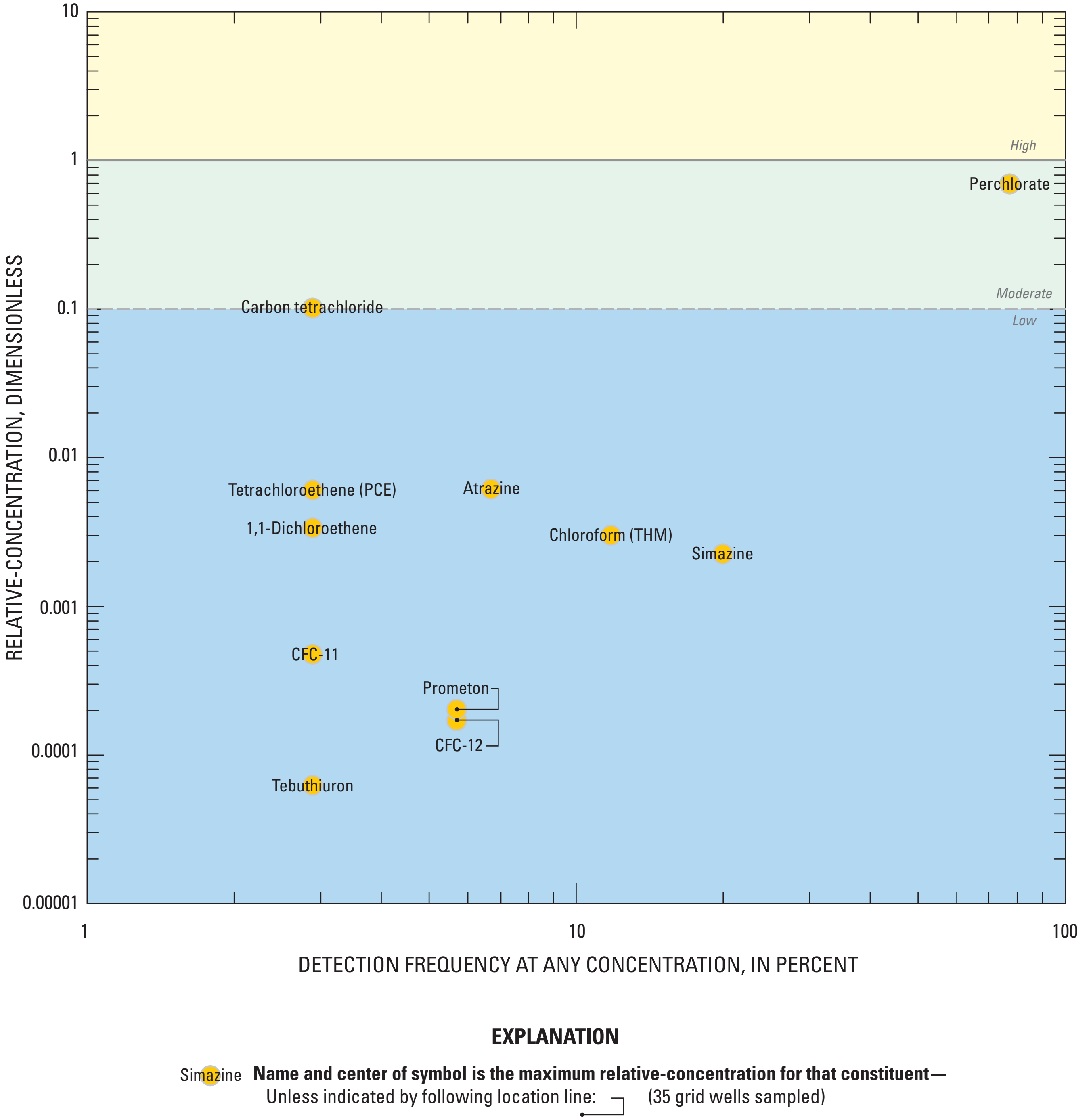


Figure 18. Detection frequency and maximum relative-concentrations of organic and special-interest constituents detected in USGS-grid wells in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

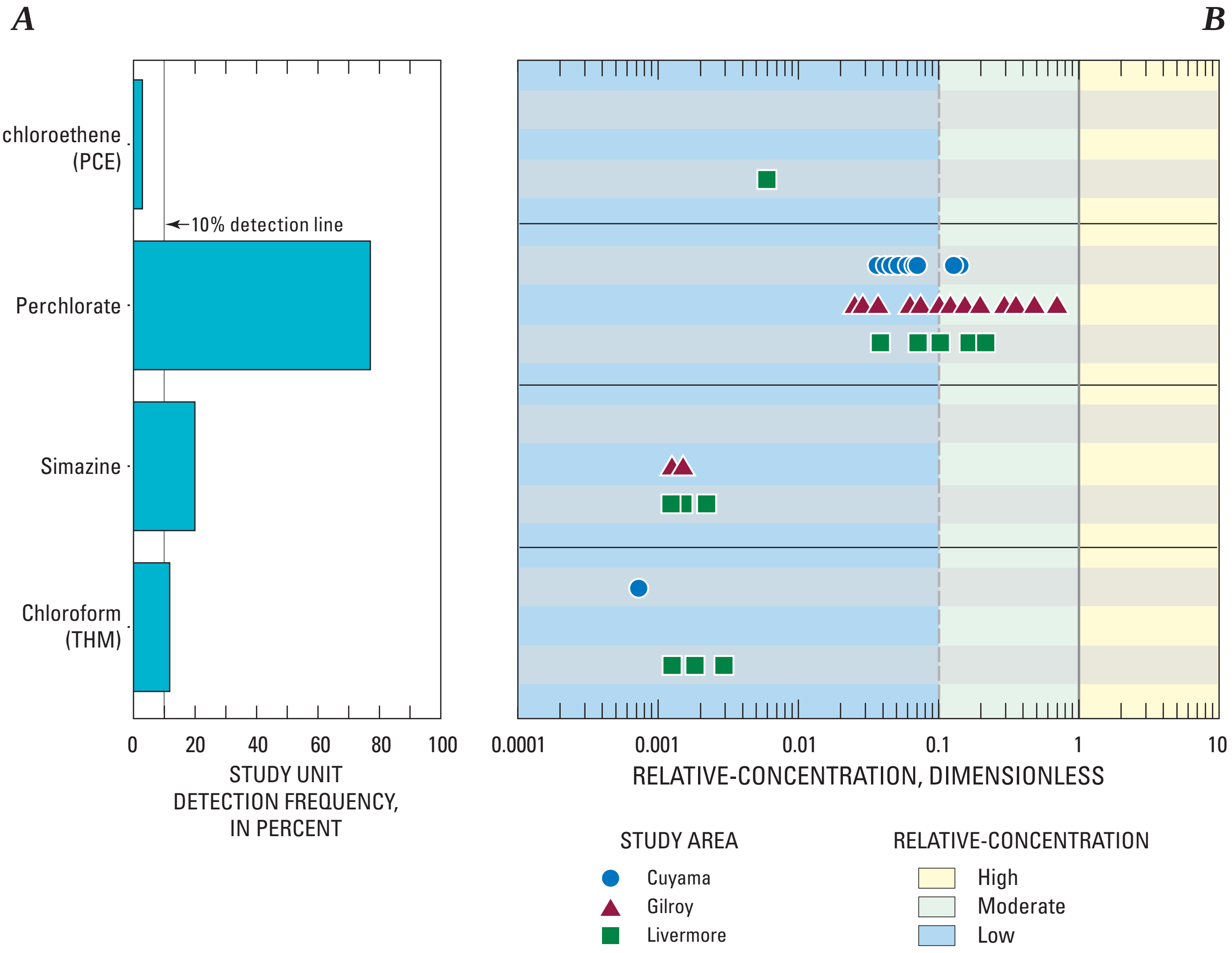


Figure 19. (*A*) Detection frequency and (*B*) relative-concentrations of selected organic and special-interest constituents in USGS-grid wells in the South Coast Interior Basins study unit, California GAMA Priority Basin Project, August–December 2008.

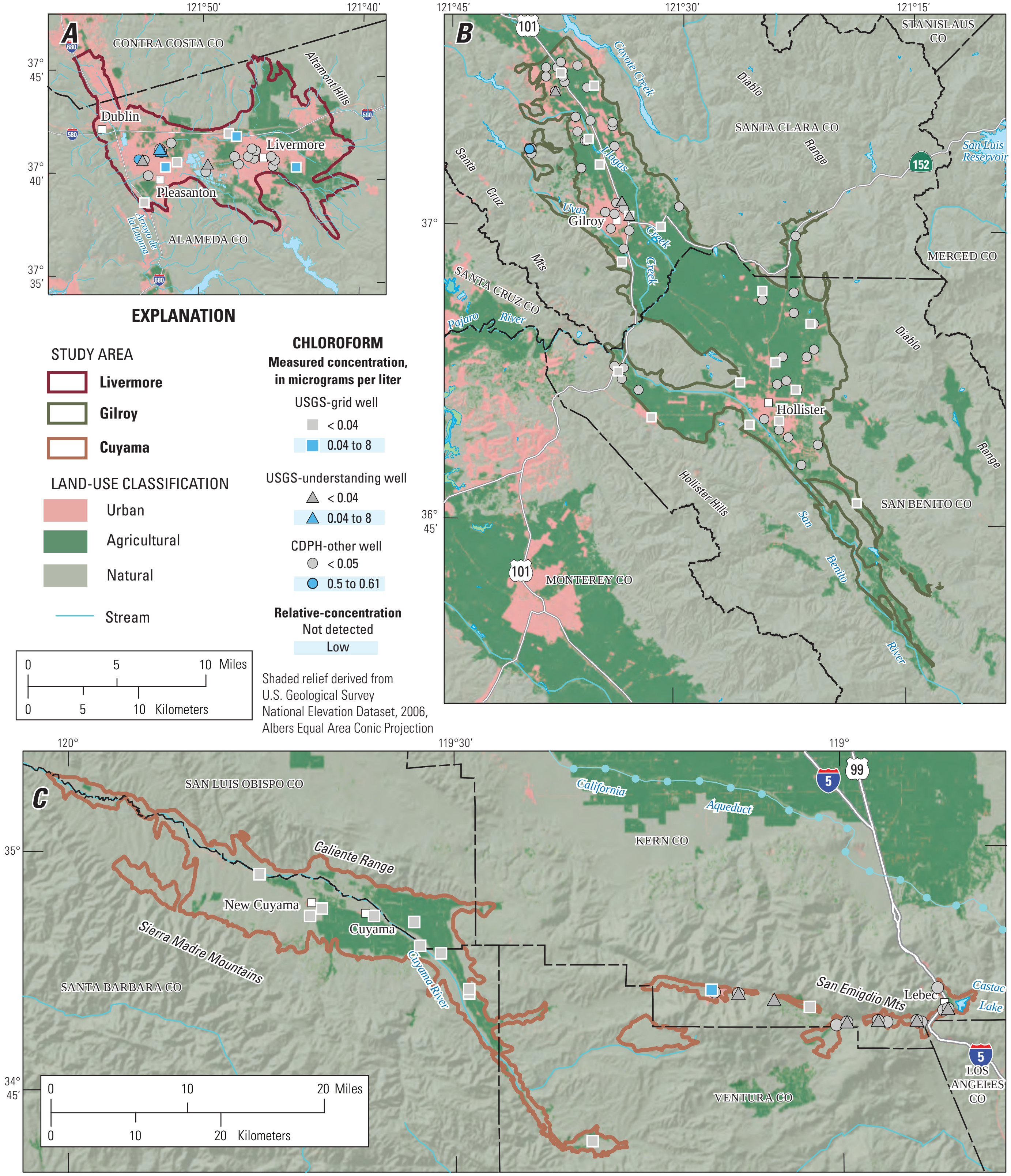


Figure 20. Relative-concentrations of chloroform for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

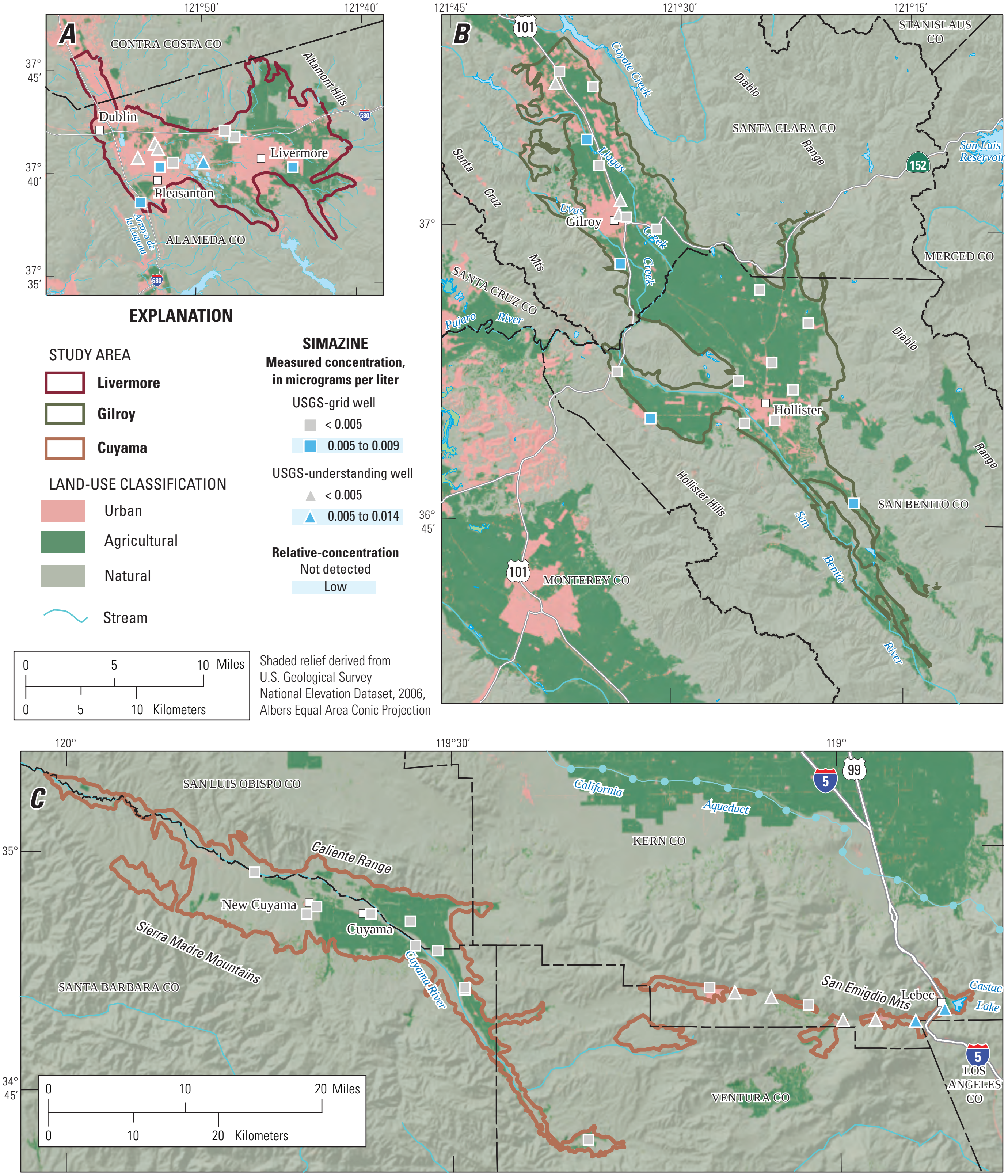


Figure 21. Relative-concentrations of simazine for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Special-Interest Constituents

Constituents of special interest analyzed for in the SCI study unit were perchlorate and *N*-nitrosodimethylamine (NDMA). These constituents were of special interest at the inception of the GAMA Priority Basin Project in 2001 because they recently had been observed in, or were considered to have the potential to reach, drinking-water supplies (California Department of Public Health, 2008a, b). An MCL-CA for perchlorate was established in 2007. Perchlorate was analyzed for in samples from all grid wells (table 1). Perchlorate had a high spatially weighted proportion of 0.3 percent and was detected at moderate relative-concentrations in 34 percent of the primary aquifer system (table 6). Perchlorate was not detected at high relative-concentrations in the USGS-grid wells (table 6). Perchlorate was detected, at any concentration, in 75 percent of grid wells. NDMA, a semi-volatile organic chemical, was not detected in the seven grid wells sampled in the SCI study unit (Mathany and others, 2009).

Understanding Assessment for Perchlorate

Perchlorate has natural and anthropogenic sources to groundwater. Perchlorate forms naturally in the atmosphere and is present dissolved in precipitation and deposited in unsaturated zones (Rajagopalan and others, 2006, 2009). Perchlorate can be present at low concentrations in groundwater under natural conditions (Fram and Belitz, 2011). Potential anthropogenic sources of perchlorate include industrial, manufacturing, or commercial uses such as rocket fuel, explosives, road flares, automobile air-bag systems, and other products, and nitrate fertilizers mined from the Atacama Desert of Chile that have been used historically on some orchard crops (U.S. Environmental Protection Agency, 2005; Dasgupta and others, 2006; Böhlke and others, 2009).

Perchlorate concentrations were negatively correlated with percentage of natural land use (table 8A). Concentrations of perchlorate were significantly higher in modern waters than in pre-modern-age waters (table 8B). Perchlorate concentrations were negatively correlated with pH and positively correlated with DO concentrations (table 8A). Concentrations of perchlorate were significantly higher in oxic waters compared with anoxic waters (table 8B). Although perchlorate biodegrades under anoxic conditions in some aquifers (Sturchio and others, 2007), the occurrence of perchlorate in oxic groundwater in the study unit may result from relations of both DO and perchlorate with modern-age groundwater.

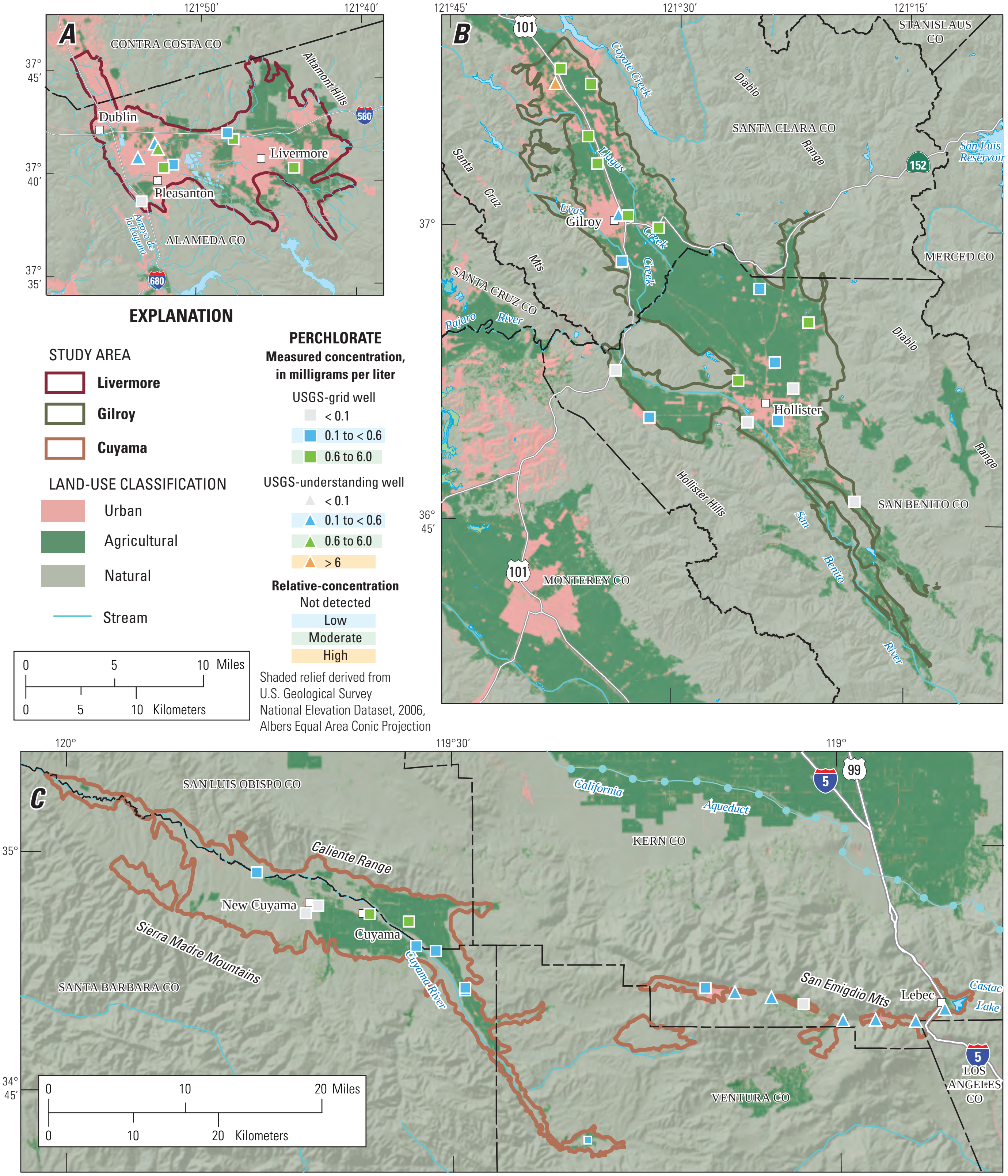


Figure 22. Relative-concentrations of perchlorate for U.S. Geological Survey (USGS)-grid and USGS-understanding wells and for California Department of Public Health (CDPH) wells with data during the time period used for the status assessment for the (*A*) Livermore, (*B*) Gilroy, and (*C*) Cuyama study areas, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

Summary

Groundwater quality in the approximately 653-square-mile South Coast Interior Basins (SCI) study unit was investigated as part of the California State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment (GAMA) Program Priority Basin Project. The GAMA SCI study was designed to provide a spatially unbiased characterization of untreated groundwater quality in the primary aquifer system. The assessment is based on water-quality and ancillary data collected by the U.S. Geological Survey (USGS) from 50 wells in 2008 and water-quality data from the California Department of Public Health (CDPH) database.

The first component of this study, the status of the current quality of the groundwater resource, was assessed on the basis of data from samples analyzed for volatile organic compounds (VOCs), pesticides, and naturally occurring inorganic constituents such as trace and minor elements. The status assessment characterizes the quality of groundwater resources in the primary aquifer system of the SCI study unit, not the treated drinking water delivered to consumers by water purveyors.

Relative-concentrations (sample concentration divided by the benchmark concentration) were used to evaluate groundwater quality for those constituents that have Federal and (or) California regulatory or non-regulatory benchmarks for drinking-water quality. Aquifer-scale proportion was used as the primary metric for evaluating regional-scale groundwater quality. High aquifer-scale proportion is defined as the percentage of the primary aquifer system 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 primary aquifer system 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. Grid-based and spatially weighted estimates were comparable in the SCI study unit (within 90-percent confidence intervals). However, the grid-based estimate may not identify constituents that are present at high relative-concentrations in small proportions of the primary aquifer system.

Inorganic constituents with health-based benchmarks were detected at high relative-concentrations in 29 percent of the primary aquifer system, moderate in 37 percent, and low in 34 percent. The high aquifer-scale proportion of inorganic constituents primarily reflected the high aquifer-scale proportions of nitrate (14 percent), molybdenum (8.6 percent), boron (8.6 percent), and arsenic (5.7 percent). The inorganic constituents with secondary maximum contaminant levels were detected at high relative-concentrations in 49 percent of the primary aquifer system, moderate in 31 percent, and low in 20 percent. The high aquifer-scale proportion primarily reflected the high aquifer-scale proportions of total dissolved solids (29 percent), sulfate (26 percent), and manganese (23 percent).

Relative-concentrations of organic constituents (one or more) were high in 1.6 percent, moderate in 2.0 percent, and low or not detected in the remaining 96 percent of the primary aquifer system. The high aquifer-scale proportion of organic constituents reflected the high spatially weighted aquifer-scale proportions of tetrachloroethene (PCE) (0.9 percent) and bromoform (0.7 percent). Of the 207 organic and special-interest constituents analyzed, 15 constituents were detected. The trihalomethane chloroform and the herbicide simazine were detected in greater than 10 percent of the primary aquifer system, but only at low relative-concentrations.

In the second component of this study, the understanding assessment, some of the primary natural and human factors that affect groundwater quality were identified through evaluation of correlations between land use, physical characteristics of the wells, geochemical conditions of the aquifer, water temperature, and relative-concentrations of constituents. Results from these analyses may be used to explain the occurrence and distribution of constituents in the SCI study unit. Concentrations of arsenic, molybdenum, and manganese were generally greater in anoxic and pre-modern groundwater than other groundwater. In contrast, concentrations of nitrate and perchlorate were significantly higher in oxic and modern groundwater. Concentrations of simazine were significantly greater in modern than pre-modern groundwater. Chloroform detections were positively correlated with greater urban land use. Boron concentrations and chloroform detections were significantly higher in the LIV study area; TDS and sulfate concentrations were significantly greater in the CUY study area.

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Appendix A. Use of Data from the California Department of Public Health (CDPH) Database

The grid-based calculation of aquifer-scale proportion uses one value per grid cell. Where USGS data for inorganic constituents were not available, additional data to represent a cell were selected from the CDPH database. Of the 44 grid cells in the SCI study unit, 7 cells had USGS-grid wells with the full complement of inorganic constituent data collected by USGS-GAMA, 28 cells had USGS-grid wells with the full complement of inorganic constituent data with the exception of gross alpha particle, gross beta particle, and radon-222 activities, and 9 cells did not have USGS-grid wells. The CDPH database was queried to provide these missing data for inorganic constituents. CDPH wells with data for the most recent 3 years available at the time of sampling (August 11, 2005–August 10, 2008) were considered. If a well had more than one analysis for a constituent in the 3-year interval, then the most recent data were selected.

The first choice was to select CDPH data for the grid well sampled by the USGS for other constituents. This approach resulted in the selection of radiochemical data from the CDPH database for 10 USGS-grid wells. To identify the USGS-grid wells that incorporated CDPH radiochemical data, a well ID was created that added “DG” to the GAMA ID for these wells (for example, LIV-01 with CDPH data was assigned the well ID: LIV-DG-01; table A1; figs. A1*A–C*).

If the first step did not yield CDPH radiochemical data for the USGS-grid well, the second step was to assign random rankings to the CDPH wells and find the highest ranked well in each grid cell that had radiochemical data. This step resulted in selecting CDPH radiochemical data from additional CDPH wells that were not USGS-grid wells for six grid cells. To identify these new CDPH grid wells, a well ID was created that added “DPH” after the study unit prefix (for example, CDPH-grid well GIL-DPH-03).

The result of these steps was that for each constituent, data were obtained from 1 grid well per cell from the USGS database or the CDPH database for 35 of the 44 grid cells. Radiochemical data from the CDPH database were used for 15 grid wells (table A2). Data were available from the CDPH database for 2 grid wells for radon-222 and gross beta and for 15 grid wells for gross alpha (table A2). Estimates of aquifer-scale proportion for constituents based on a smaller number of wells are subject to a larger error associated with the 90-percent confidence intervals (on the basis of Jeffreys interval for the binomial distribution) (Brown and others, 2001).

Differences in constituent laboratory reporting levels associated with USGS and CDPH data did not affect analysis of high or moderate relative-concentrations because concentrations greater than one-half of water-quality benchmarks were substantially higher than the reporting levels.

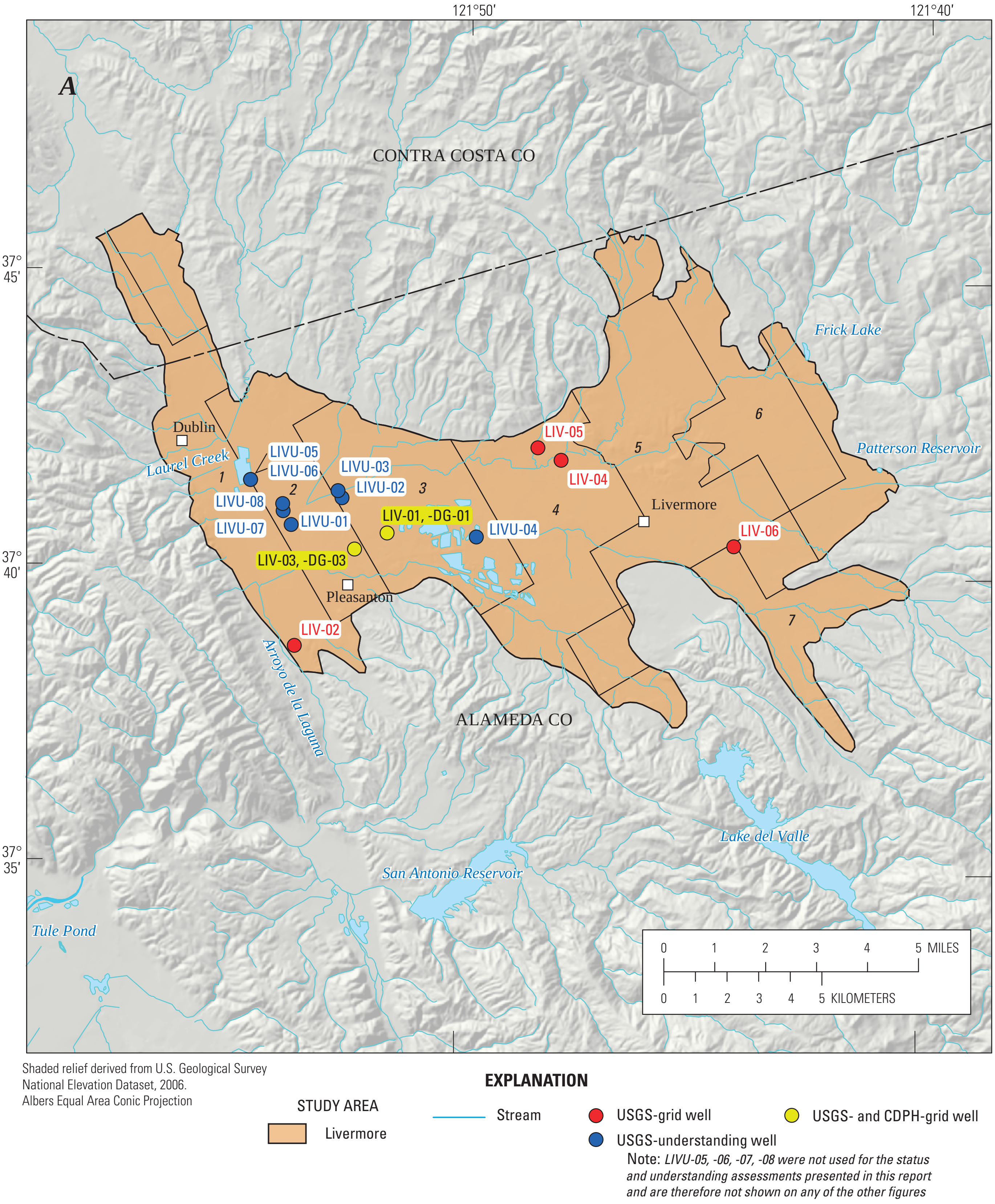
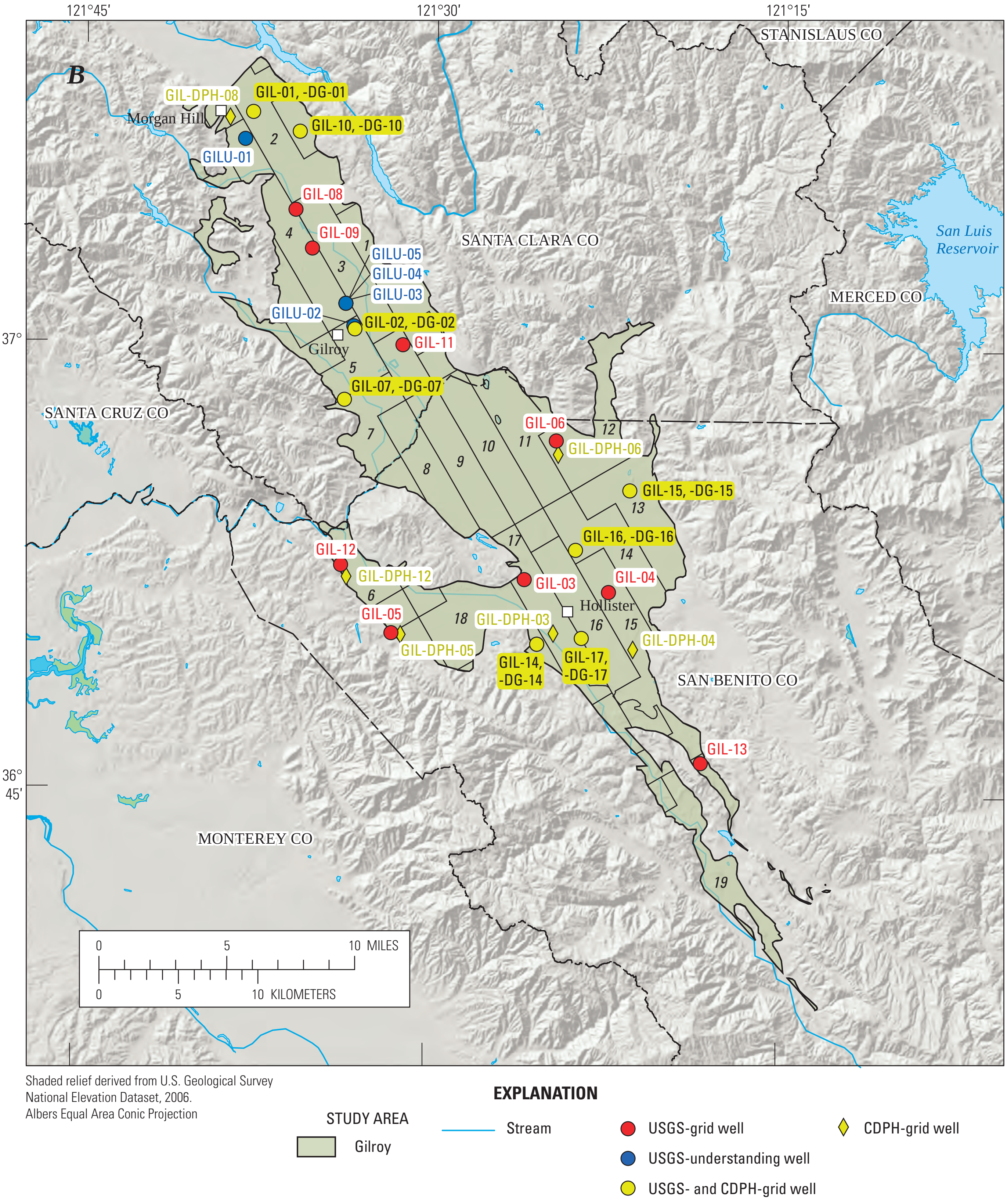


Figure A1. Identifiers and locations of USGS-grid, USGS-understanding, and CDPH-grid wells in the (*A*) Livermore study area, (*B*) Gilroy study area, and (*C*) Cuyama study area of the South Coast Interior Basins study unit, California GAMA Priority Basin Project.



Shaded relief derived from U.S. Geological Survey
National Elevation Dataset, 2006.
Albers Equal Area Conic Projection

Figure A1. —Continued

Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006.
Albers Equal Area Conic Projection

Figure A1. —Continued

Table A1. Cell number and USGS-GAMA well identification numbers for well data used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[A USGS-GAMA well identification number indicates the use of USGS data from the grid well; a CDPH-grid well identification number with “DG” indicates the use of CDPH data from the USGS-grid well; a CDPH-grid well identification number with “DPH” indicates the use of CDPH data from a different well. —, no wells sampled or selected; CUY, Cuyama study area well; GIL, Gilroy study area well; LIV, Livermore study area well; CUYU, GILU, or LIVU, understanding well]

USGS-GAMA well identification number	Grid cell number	Grid supplemented by CDPH data from same well	Grid supplemented by CDPH data from different well
Cuyama study area grid wells			
CUY-01	5	—	—
CUY-02	11	—	—
CUY-03	14	—	—
CUY-04	9	—	—
CUY-05	10	—	—
CUY-06	13	—	—
CUY-07	7	—	—
CUY-08	12	—	—
CUY-09	18	—	—
CUY-10	17	—	—
CUY-11	16	—	—
CUY-12	15	—	—
Gilroy study area grid wells			
GIL-01	2	GIL-DG-01	—
GIL-02	5	GIL-DG-02	—
GIL-03	17	—	GIL-DPH-03
GIL-04	15	—	GIL-DPH-04
GIL-05	19	—	GIL-DPH-05
GIL-06	12	—	GIL-DPH-06
GIL-07	7	GIL-DG-07	—
GIL-08	3	—	GIL-DPH-08
GIL-09	4	—	—
GIL-10	1	GIL-DG-10	—
GIL-11	8	—	—
GIL-12	6	—	GIL-DPH-12
GIL-13	11	—	—
GIL-14	18	GIL-DG-14	—
GIL-15	13	GIL-DG-15	—
GIL-16	14	GIL-DG-16	—
GIL-17	16	GIL-DG-17	—
Livermore study area grid wells			
LIV-01	3	LIV-DG-01	—
LIV-02	1	—	—
LIV-03	2	LIV-DG-03	—
LIV-04 [1]	[2] 5	—	—
LIV-05	4	—	—
LIV-06	7	—	—
USGS-understanding wells			
CUYU-01	18	—	—
CUYU-02	17	—	—
CUYU-03	18	—	—
CUYU-04	17	—	—
CUYU-05	18	—	—
CUYU-06	18	—	—
GILU-01	4	—	—
GILU-02	5	—	—
GILU-03	4	—	—
GILU-04	4	—	—
GILU-05	4	—	—
LIVU-01	2	—	—
LIVU-02	3	—	—
LIVU-03	3	—	—
LIVU-04	3	—	—
LIVU-05 [2]	2	—	—
LIVU-06 [2]	2	—	—
LIVU-07 [2]	2	—	—
LIVU-08 [2]	2	—	—

[1] LIV-04 is located in cell 4 near to the boundary with cell 5. It was used to represent cell 5 because cell 5 contained no accessible wells.

[2] Well not used in calculation of spatially weighted aquifer-scale proportions or in testing of statistical relations among potential explanatory factors or between potential explanatory factors and water-quality constituents.

Table A2. CDPH well identification number and radiochemical data from the CDPH database used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[A CDPH-grid well identification number with "DG" indicates the use of CDPH data from the USGS-grid well; a CDPH-grid well identification number with "DPH" indicates the use of CDPH data from a different well. GIL, Gilroy study area well; LIV, Livermore study area well. pCi/L, picocuries per liter; na, no data available; <, less than]

CDPH well identification number	Gross alpha particle activity (pCi/L)	Gross beta particle activity (pCi/L)	Radon-222 (pCi/L)
GIL-DG-01	0.29	na	na
GIL-DG-02	0.21	na	na
GIL-DPH-03	1.2	na	na
GIL-DPH-04	0.09	na	na
GIL-DPH-05	9.4	na	na
GIL-DPH-06	1.1	na	na
GIL-DG-07	0.30	na	na
GIL-DPH-08	0.20	na	na
GIL-DG-10	0.74	na	na
GIL-DPH-12	9.4	na	na
GIL-DG-14	0.16	na	na
GIL-DG-15	1.8	na	na
GIL-DG-16	5.2	na	na
GIL-DG-17	8.4	na	na
LIV-DG-01	<3.0	<3.0	330
LIV-DG-03	<3.0	<3.0	286

Appendix B. Ancillary Datasets

Land-Use Classification

Land use was classified by using an enhanced version of the satellite-derived [98-ft (30-m) pixel resolution] USGS Enhanced 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 dataset characterizes land cover during the early 1990s. The imagery was classified into 25 land-cover categories (Nakagaki and Wolock, 2005). These 25 land-cover categories were aggregated into 3 principal land-use classes for the purpose of general characterization of land use—urban, agricultural, and natural. Average land use (proportions of urban, agricultural, and natural) for the study unit, for each study area, and for areas within a radius of 1,640 ft (500 m) surrounding each well (table B1) were calculated using ArcGIS (version 9.2) (Johnson and Belitz, 2009).

Septic Systems and LUFTs

Septic tank density was determined from housing characteristics data from the 1990 U.S. Census (U.S. Census Bureau, 1990). The density of septic tanks in each housing census block was calculated from the number of tanks and block area. The density of septic tanks around each well was then calculated from the area-weighted mean of the block densities for blocks within a 500-m buffer around the well location (Tyler Johnson, U.S. Geological Survey, written commun., 2009) (table B1).

The density of leaking or formerly-leaking underground fuel tanks (LUFTs) was determined from the locations of tanks in the SWRCB's GeoTracker database of environmental cleanup sites (California Environmental Protection Agency, 2001). The density of LUFTs was calculated by using Theissen polygons (Tyler Johnson, U.S. Geological Survey, written commun., 2007). The boundaries of the Theissen polygon around a particular LUFT are created by bisecting the linear distances between the LUFT and all the surrounding LUFTs. The density of LUFTs in the polygon is the number of tanks in the polygon (generally one) divided by the area of the polygon in square kilometers. A well is assigned the LUFT density of the Theissen polygon in which it is located.

Well Construction Information and Hydrologic Conditions

Well construction data primarily were obtained from drillers' logs filed with CDWR. Other sources were ancillary records of well owners and the USGS National Water Information System database. Well construction data are not available in the CDPH database. Well identification verification procedures are described by Mathany and others (2009). Well depths, depths to the tops and bottoms of the perforated intervals, and lengths of the perforated intervals for wells are listed in table B2.

The climate at each well site was represented by an aridity index (table B2) (United Nations Educational, Scientific, and Cultural Organization, 1979; United Nations Environment Programme, 1997):

$$aridity\ index = \frac{average\ annual\ precipitation}{average\ annual\ evapotranspiration}$$

Higher values of the index correspond to wetter conditions. Average annual precipitation for each well site was extracted from the PRISM average annual precipitation for 1971–2000 GIS coverage (PRISM Climate Group, Oregon State University, 2010). Average annual potential evapotranspiration for each well site was extracted from a GIS coverage modified from Flint and Flint (2007). The modification consisted of calibrating the potential evapotranspiration values to the California Irrigation Management Information System actual reference evapotranspiration values for well-watered grass (California Irrigation Management Information System, 2005; Alan Flint, U.S. Geological Survey California Water Science Center, oral commun., 2009).

Groundwater Age Classification

Groundwater dating techniques indicate the time since the groundwater was last in contact with the atmosphere. The techniques used in this report to estimate groundwater residence times or 'age' were those based on tritium (for example, Tolstikhin and Kamenskiy, 1969; Torgersen and others, 1979) and carbon-14 activities (for example, Vogel and Ehhalt, 1963; Plummer and others, 1993).

Tritium (^3H) is a short-lived radioactive isotope of hydrogen with a half-life of 12.32 years (Lucas and Unterweger, 2000). Tritium 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. Tritium enters the hydrological cycle following oxidation to tritiated water (^3HOH). Natural background levels of tritium in precipitation are approximately 3 to 15 tritium units (TU) (Craig and Lal, 1961; Clark and Fritz, 1997). Above-ground nuclear explosions resulted in a large increase in tritium values in precipitation, beginning in about 1952 and peaking in 1963 at values over 1,000 TU in the northern hemisphere (Michel, 1989). Radioactive decay over a period of 60 years would decrease tritium values of 10 TU to 0.6 TU.

Previous investigations have used a range of tritium values from 0.3 to 1.0 TU as thresholds for indicating presence of water that has exchanged with the atmosphere since 1952 (Michel, 1989; Plummer and others, 1993; Michel and Schroeder, 1994; Clark and Fritz, 1997; Manning and others, 2005; Kulongoski and others, 2010; Landon and others, 2010). For samples collected for the SCI study unit in 2008, tritium values greater than or equal to a threshold of 0.3 TU were defined as indicating the presence of groundwater recharged since 1952 (Kulongoski and others, 2010; Landon and others, 2010). Water recharged since 1952 is defined as "modern" groundwater.

Carbon-14 (^{14}C) is a widely used chronometer based on the radiocarbon content of organic and inorganic carbon. Dissolved inorganic carbon species, carbonic acid, bicarbonate, and carbonate typically are used for ^{14}C dating of groundwater. ^{14}C is formed in the atmosphere by the interaction of cosmic-ray neutrons with nitrogen and, to a lesser degree, with oxygen and carbon, and by above-ground nuclear explosions. ^{14}C is incorporated into carbon dioxide and mixed throughout the atmosphere. The carbon dioxide enters the hydrologic cycle because it dissolves in precipitation and surface water in contact with the atmosphere. ^{14}C activity in groundwater, expressed as percent modern carbon (pmc), reflects the time since groundwater was last exposed to the atmospheric ^{14}C source. ^{14}C has a half-life of 5,730 years and can be used to estimate groundwater ages ranging from 1,000 to approximately 30,000 years before present.

The ^{14}C age (residence time, presented in years) is calculated on the basis of the decrease in ^{14}C activity as a result of radioactive decay since groundwater recharge, relative to an assumed initial ^{14}C concentration (Clark and Fritz, 1997). An average initial ^{14}C activity of 99 pmc is assumed for this study, with estimated errors on calculated groundwater ages up to ± 20 percent. 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). Groundwater with a ^{14}C activity of >88 pmc is reported as having an age of <1,000 years; no attempt is made to refine ^{14}C ages <1,000 years. Measured values of pmc can be >100 in groundwater samples containing a significant component of water recharged after 1952 because the definition of pmc is based on ^{14}C activity in the absence of ^{14}C contributed by above-ground nuclear explosions (Clark and Fritz, 1997). For the SCI study unit, ^{14}C activity <88 pmc was defined as indicating the presence of groundwater recharged before the modern era (Kulongoski and others, 2010). Water recharged before the modern era is defined as "pre-modern" groundwater.

Tritium and ^{14}C data and age classifications are reported in table B3. Because of uncertainties in age distributions, particularly the uncertainties caused by mixing of waters of different ages in wells with long screened or open intervals and high withdrawal rates, the uncorrected ^{14}C ages were not specifically used for quantifying the relation between age and water quality in this report. While more sophisticated lumped parameter models for analyzing age distributions that incorporate mixing are available (Cook and Böhlke, 2000), use of these alternative models to understand age mixtures was not needed for the assessments in this report. Classification into modern, mixed, and pre-modern categories was sufficient to provide an appropriate and useful characterization for the purposes of examining groundwater quality.

For the SCI study unit, groundwater samples were assigned the following age classifications:

Classification	Tritium (TU)	^{14}C (pmc)
Modern	≥0.3	≥88
Modern or Mixed	≥0.3	No data
Mixed	≥0.3	<88
Pre-modern	<0.3	<88

Classification of Geochemical Condition

Geochemical conditions investigated as potential explanatory variables in this report include oxidation-reduction characteristics and pH (table B4). Oxidation-reduction (redox) conditions influence the mobility of many organic and inorganic constituents (McMahon and Chapelle, 2008). Along groundwater flow paths, redox conditions commonly proceed along a well-documented sequence of terminal electron acceptor processes (TEAPs); one TEAP typically dominates at a particular time and aquifer location (Chapelle and others, 1995; Chapelle, 2001). The predominant TEAPs are oxygen-reduction, nitrate-reduction, manganese-reduction, iron-reduction, sulfate-reduction, and methanogenesis. The presence of redox-sensitive chemical species suggesting more than one TEAP may indicate mixed waters from different redox zones upgradient of the well, a well screened across more than one redox zone, or spatial heterogeneity in microbial activity in the aquifer.

Redox conditions were assigned to each sample by using a modified version of the classification scheme of McMahon and Chapelle (2008) and Jurgens and others (2009) (tables B4). Samples with DO > 1.0 mg/L were classified as oxic, and samples with DO ≤ 1.0 mg/L were classified as anoxic. The anoxic samples were further classified according to the TEAPs inferred from data for nitrate, manganese, and iron. Data for these constituents were obtained from USGS-GAMA for all wells.

Table B1. Well type, percent land use by category, land-use classification, septic density, leaking underground fuel tank density, and USGS-GAMA well identification number for GAMA well data and CDPH-grid well data used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**USGS-GAMA well identification number**: CUY, Cuyama study area well; GIL, Gilroy study area well; LIV, Livermore study area well; CUYU, GILU, or LIVU, understanding well; LUFT, Leaking underground fuel tank. **Well types**: PROD, production well; MON, monitor well. **Other abbreviations**: USGS, U.S. Geological Survey; CDPH, California Department of Public Health; LUFT, leaking (or formerly leaking) underground fuel tank; na, not available; tanks/km^2, number of tanks per square kilometer; <, less than]

USGS-GAMA well identification number	Well type	Land use (in percent) [1]			Land-use classification	Septic density (tanks/km^2) [2]	LUFT density (tanks/km^2) [3]
		Agricultural	Natural	Urban			
			Cuyama study area grid wells				
CUY-01	PROD	1	95	4	Natural	0.1	<0.01
CUY-02	PROD	1	99	0	Natural	0.1	<0.01
CUY-03	PROD	78	18	4	Agricultural	0.1	<0.01
CUY-04	PROD	36	57	7	Natural	0.1	<0.01
CUY-05	PROD	42	49	9	Mixed	0.1	<0.01
CUY-06	PROD	95	5	0	Agricultural	0.1	<0.01
CUY-07	PROD	99	1	0	Agricultural	0.1	<0.01
CUY-08	PROD	53	46	1	Agricultural	0.1	<0.01
CUY-09	PROD	42	55	2	Natural	9.6	0.02
CUY-10	PROD	2	38	60	Urban	4.8	<0.01
CUY-11	PROD	33	65	2	Natural	0.1	<0.01
CUY-12	PROD	91	5	4	Agricultural	0.1	<0.01
			Gilroy study area grid wells				
GIL-01	PROD	61	3	37	Agricultural	17.2	0.40
GIL-02	PROD	71	3	26	Agricultural	6.8	0.53
GIL-03	PROD	40	43	17	Mixed	6.5	0.03
GIL-04	PROD	71	4	25	Agricultural	13.4	1.19
GIL-05	PROD	62	13	24	Agricultural	7.0	0.02
GIL-06	PROD	100	0	0	Agricultural	2.1	<0.01
GIL-07	PROD	80	9	11	Agricultural	3.7	0.02
GIL-08	PROD	80	10	10	Agricultural	35.3	0.44
GIL-09	PROD	87	1	11	Agricultural	18.5	0.47
GIL-10	PROD	92	0	8	Agricultural	15.2	0.06
GIL-11	PROD	67	3	30	Agricultural	7.9	0.12
GIL-12	PROD	50	35	15	Agricultural	7.5	0.03
GIL-13	PROD	24	68	8	Natural	1.0	<0.01
GIL-14	PROD	49	48	4	Mixed	10.6	0.01
GIL-15	PROD	95	4	1	Agricultural	2.0	<0.01
GIL-16	PROD	37	12	51	Urban	13.1	0.31
GIL-17	PROD	40	14	46	Mixed	31.2	7.10
			Livermore study area grid wells				
LIV-01	PROD	41	11	48	Mixed	2.9	0.57
LIV-02	PROD	34	44	22	Mixed	0.3	0.31
LIV-03	PROD	0	2	98	Urban	1.3	0.81
LIV-04	PROD	53	14	32	Agricultural	13.3	0.28
LIV-05	PROD	20	57	24	Natural	4.0	0.28
LIV-06	PROD	33	1	66	Urban	8.1	0.28

Table B1. Well type, percent land use by category, land-use classification, septic density, leaking underground fuel tank density, and USGS-GAMA well identification number for GAMA well data and CDPH-grid well data used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.—Continued

[**USGS-GAMA well identification number**: CUY, Cuyama study area well; GIL, Gilroy study area well; LIV, Livermore study area well; CUYU, GILU, or LIVU, understanding well; LUFT, Leaking underground fuel tank. **Well types**: PROD, production well; MON, monitor well. **Other abbreviations**: USGS, U.S. Geological Survey; CDPH, California Department of Public Health; LUFT, leaking (or formerly leaking) underground fuel tank; na, not available; tanks/km^2, number of tanks per square kilometer; <, less than]

USGS-GAMA well identification number	Well type	Land use (in percent) [1]			Land-use classification	Septic density (tanks/km^2) [2]	LUFT density (tanks/km^2) [3]
		Agricultural	Natural	Urban			
			CDPH-grid wells				
CUY-DPH-06	PROD	88	4	8	Agricultural	na	na
GIL-DPH-03	PROD	13	11	76	Urban	na	na
GIL-DPH-04	PROD	41	59	0	Natural	na	na
GIL-DPH-05	PROD	68	8	24	Agricultural	na	na
GIL-DPH-06	PROD	88	6	6	Agricultural	na	na
GIL-DPH-08	PROD	29	7	64	Urban	na	na
GIL-DPH-12	PROD	66	31	2	Agricultural	na	na
			USGS-understanding wells				
CUYU-01	PROD	1	35	64	Urban	123.7	0.01
CUYU-02	PROD	0	88	11	Natural	13.0	<0.01
CUYU-03	PROD	1	76	23	Natural	13.7	0.02
CUYU-04	PROD	7	93	1	Natural	12.4	0.02
CUYU-05	PROD	0	100	0	Natural	4.5	0.01
CUYU-06	PROD	41	51	7	Natural	0.3	0.12
GILU-01	PROD	29	2	69	Urban	18.9	1.88
GILU-02	PROD	72	3	25	Agricultural	6.8	0.53
GILU-03	MON	67	3	30	Agricultural	6.7	0.77
GILU-04	MON	67	3	30	Agricultural	6.7	0.77
GILU-05	MON	67	3	30	Agricultural	6.7	0.77
LIVU-01	PROD	1	2	96	Urban	0.0	0.37
LIVU-02	PROD	18	1	81	Urban	1.3	0.93
LIVU-03	PROD	14	1	85	Urban	0.7	0.93
LIVU-04	PROD	11	40	48	Mixed	1.3	0.35
LIVU-05 [4]	MON	38	2	60	Urban	0	2.10
LIVU-06 [4]	MON	36	2	62	Urban	0	2.10
LIVU-07 [4]	MON	14	3	84	Urban	0	0.91
LIVU-08 [4]	MON	22	4	74	Urban	0	0.91

[1] Land-use percentages within 500-meter radius of well site (Johnson and Belitz, 2009).

[2] Septic tank density within 500-meter radius of well site, based on 1990 U.S. Census data.

[3] LUFT density within 500-meter radius of well site, based on GEIMS LUFT database (California Environmental Protection Agency, 2001).

[4] Well not used in calculation of spatially weighted aquifer-scale proportions or in testing of statistical relations among potential explanatory factors or between potential explanatory factors and water-quality constituents.

Table B2. Well construction information, well depth class, and aridity index for wells used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**USGS-GAMA well identification number**: CUY, Cuyama study area well; GIL, Gilroy study area well; LIV, Livermore study area well; CUYU, GILU, or LIVU, understanding well. **Well depth class**: Shallow, well depth ≤ 250 ft; overlapping, well depth > 250 ft and depth to top of perforations ≤250 ft; deep, well depth > 250 ft and depth to top of perforations > 250 ft. **Other abbreviations**: USGS, U.S. Geological Survey; CDPH, California Department of Public Health; na, not available; ft, feet; LSD, land-surface datum; <, less than; >, greater than; ≤, less than or equal to]

USGS-GAMA well identification number	Construction information				Well depth class	Aridity index (dimensionless)[1]
	Well depth (ft below LSD)	Top of perforations (ft below LSD)	Bottom of perforations (ft below LSD)	Length from top of perforations to bottom of well (ft)		
Cuyama study area grid wells						
CUY-01	188	45	125	80	Shallow	0.17
CUY-02	790	340	790	450	Deep	0.16
CUY-03	na	na	na	na	na	0.17
CUY-04	720	420	720	300	Deep	0.14
CUY-05	na	na	na	na	na	0.15
CUY-06	800	640	800	160	Deep	0.16
CUY-07	750	250	750	500	Deep	0.15
CUY-08	550	na	na	na	Overlapping or Deep	0.16
CUY-09	361	80	361	281	Overlapping	0.41
CUY-10	298	146	288	142	Overlapping	0.32
CUY-11	357	na	na	na	Overlapping or Deep	0.23
CUY-12	93	na	na	na	Shallow	0.16
Gilroy study area grid wells						
GIL-01	484	157	480	323	Overlapping	0.41
GIL-02	470	240	460	220	Overlapping	0.41
GIL-03	na	na	na	na	na	0.29
GIL-04	500	147	500	353	Overlapping	0.31
GIL-05	na	na	na	na	na	0.37
GIL-06	na	na	na	na	na	0.40
GIL-07	na	na	na	na	na	0.41
GIL-08	na	na	na	na	na	0.41
GIL-09	na	na	na	na	na	0.41
GIL-10	378	na	na	na	Overlapping or Deep	0.42
GIL-11	na	na	na	na	na	0.41
GIL-12	700	na	na	na	Overlapping or Deep	0.43
GIL-13	460	100	460	360	Overlapping	0.31
GIL-14	na	na	na	na	na	0.29
GIL-15	382	360	382	22	Deep	0.39
GIL-16	339	282	337	55	Deep	0.33
GIL-17	450	314	325	11	Deep	0.29
Livermore study area grid wells						
LIV-01	500	200	490	290	Overlapping	0.34
LIV-02	113	37	107	70	Shallow	0.41
LIV-03	650	149	650	501	Overlapping	0.36
LIV-04	147	101	146	45	Shallow	0.30
LIV-05	300	270	290	20	Deep	0.31
LIV-06	na	na	na	na	na	0.32

Table B2. Well construction information, well depth class, and aridity index for wells used in the South Coast Interior Basins study unit, California GAMA Priority Basin Project.—Continued

[**USGS-GAMA well identification number**: CUY, Cuyama study area well; GIL, Gilroy study area well; LIV, Livermore study area well; CUYU, GILU, or LIVU, understanding well. **Well depth class**: Shallow, well depth ≤ 250 ft; overlapping, well depth > 250 ft and depth to top of perforations ≤250 ft; deep, well depth > 250 ft and depth to top of perforations > 250 ft. **Other abbreviations**: USGS, U.S. Geological Survey; CDPH, California Department of Public Health; na, not available; ft, feet; LSD, land-surface datum; <, less than; >, greater than; ≤, less than or equal to]

USGS-GAMA well identification number	Construction information				Well depth class	Aridity index (dimensionless)[1]
	Well depth (ft below LSD)	Top of perforations (ft below LSD)	Bottom of perforations (ft below LSD)	Length from top of perforations to bottom of well (ft)		
CDPH-grid wells						
CUY-DPH-06	na	na	na	na	na	na
GIL-DPH-03	590	142	590	448	Overlapping	na
GIL-DPH-04	na	na	na	na	na	na
GIL-DPH-05	na	na	na	na	na	na
GIL-DPH-06	na	na	na	na	na	na
GIL-DPH-08	na	na	na	na	na	na
GIL-DPH-12	na	na	na	na	na	na
USGS-understanding wells						
CUYU-01	193	39	193	154	Shallow	0.37
CUYU-02	270	51	256	205	Overlapping	0.33
CUYU-03	212	na	na	na	Shallow	0.41
CUYU-04	na	na	na	na	na	0.34
CUYU-05	351	191	351	160	Overlapping	0.28
CUYU-06	295	na	na	na	Overlapping or Deep	0.25
GILU-01	420	190	420	230	Overlapping	0.41
GILU-02	800	530	790	260	Deep	0.41
GILU-03	285	225	280	55	Overlapping	0.41
GILU-04	395	350	390	40	Deep	0.41
GILU-05	615	560	610	50	Deep	0.41
LIVU-01	315	235	310	75	Overlapping	0.39
LIVU-02	530	150	510	360	Overlapping	0.37
LIVU-03	745	515	730	215	Deep	0.37
LIVU-04	420	200	410	210	Overlapping	0.30
LIVU-05 [2]	35	20	35	15	Shallow	0.42
LIVU-06 [2]	70	45	65	20	Shallow	0.42
LIVU-07 [2]	52	42	52	10	Shallow	0.40
LIVU-08 [2]	50	30	50	20	Shallow	0.40

[1] Aridity index is average annual precipitation divided by average annual evapotranspiration.

[2] Well not used in calculation of spatially weighted aquifer-scale proportions or in testing of statistical relations among potential explanatory factors or between potential explanatory factors and water-quality constituents.

Table B3. Tritium, percent modern carbon, and age classification of samples, South Coast Interior Basins study unit, California Priority Basin Project.

[na, not available; <, less than; modern, groundwater recharged after 1952; pre-modern, groundwater recharged before 1952; mixed, groundwater with modern and pre-modern components]

USGS GAMA well identification number	Tritium, tritium units	Percent modern carbon (percent)	Uncorrected carbon-14 age (years)	Age classification
Cuyama study area grid wells				
CUY-01	0.9	74	2,350	Mixed
CUY-02	<0.3	2	33,020	Pre-modern
CUY-03	2.3	95	<1,000	Modern
CUY-04	<0.3	66	3,300	Pre-modern
CUY-05	<0.3	4	25,430	Pre-modern
CUY-06	2.1	89	<1,000	Modern
CUY-07	1.3	72	2,530	Mixed
CUY-08	2.8	76	2,160	Mixed
CUY-09	<0.3	50	5,490	Pre-modern
CUY-10	0.9	na	na	Modern or Mixed
CUY-11	0.8	66	3,260	Mixed
CUY-12	2.0	89	<1,000	Modern
Gilroy study area grid wells				
GIL-01	1.2	75	2,230	Mixed
GIL-02	1.8	88	1,000	Modern
GIL-03	1.3	97	<1,000	Modern
GIL-04	<0.3	39	7,470	Pre-modern
GIL-05	2.3	100	<1,000	Modern
GIL-06	2.8	96	<1,000	Modern
GIL-07	2.7	105	<1,000	Modern
GIL-08	2.5	112	<1,000	Modern
GIL-09	2.9	112	<1,000	Modern
GIL-10	1.3	90	<1,000	Modern
GIL-11	3.0	104	<1,000	Modern
GIL-12	<0.3	60	4,040	Pre-modern
GIL-13	1.8	100	<1,000	Modern
GIL-14	<0.3	21	12,590	Pre-modern
GIL-15	<0.3	88	1,000	Pre-modern
GIL-16	<0.3	67	3,120	Pre-modern
GIL-17	<0.3	79	1,870	Pre-modern
Livermore study area grid wells				
LIV-01	3.5	100	<1,000	Modern
LIV-02	2.7	83	1,450	Mixed
LIV-03	4.9	68	3,050	Mixed
LIV-04	6.5	97	<1,000	Modern
LIV-05	0.7	88	<1,000	Modern
LIV-06	6.6	109	<1,000	Modern
USGS-understanding wells				
CUYU-01	2.3	96	<1,000	Modern
CUYU-02	2.6	79	1,820	Mixed
CUYU-03	2.1	100	<1,000	Modern
CUYU-04	1.4	83	1,430	Mixed
CUYU-05	2.3	92	<1,000	Modern
CUYU-06	2.3	98	<1,000	Modern
GILU-01	2.0	88	<1,000	Modern
GILU-02	1.2	49	5,710	Mixed
GILU-03	1.5	101	<1,000	Modern
GILU-04	1.8	89	<1,000	Modern
GILU-05	<0.3	40	7,380	Pre-modern
LIVU-01	0.3	95	<1,000	Modern
LIVU-02	10.3	39	7,550	Mixed
LIVU-03	2.7	2	33,130	Mixed
LIVU-04	3.2	94	<1,000	Modern
LIVU-05 [1]	3.7	78	1,910	Mixed
LIVU-06 [1]	<0.3	45	6,400	Pre-modern
LIVU-07 [1]	2.9	94	<1,000	Modern
LIVU-08 [1]	3.0	99	<1,000	Modern

[1] Well not used in calculation of spatially weighted aquifer-scale proportions or in testing of statistical relations among potential explanatory factors or between potential explanatory factors and water-quality constituents.

Table B4. Dissolved oxygen concentrations, pH values, and oxidation-reduction classifications for samples from the South Coast Interior Basins study unit, California GAMA Priority Basin Project.

[**Redox class**: oxic, DO > 1.0 mg/L and not Mn- or Fe-reducing; anoxic, DO < 1.0 mg/L; mixed, DO > 1.0 mg/L and Mn- or Fe-reducing. Redox process: O_2, oxygen reducing (DO > 1.0 mg/L); suboxic, anoxic and not NO_3-, Mn-, or Fe-reducing; NO_3, anoxic and nitrate reducing (NO_3 < 0.5 mg/L); Mn, manganese reducing (Mn > 50 µg/L); Fe, iron reducing (Fe > 100 µg/L). Nitrate, manganese, and iron concentration data from Mathany and others (2009). **Other abbreviations**: DO, dissolved oxygen; mg/L, milligrams per liter; µg/L; micrograms per liter; <, less than]

	Dissolved oxygen (mg/L)	Redox classification	Redox process	pH (standard units)
		Cuyama study area grid wells		
CUY-01	3.8	Oxic	O_2	7.3
CUY-02	1.3	Oxic	O_2	7.5
CUY-03	8.8	Oxic	O_2	7.2
CUY-04	6.2	Oxic	O_2	7.2
CUY-05	1.8	Oxic	O_2	7.3
CUY-06	5.6	Oxic	O_2	7.2
CUY-07	9.4	Oxic	O_2	7.2
CUY-08	10	Oxic	O_2	7.2
CUY-09	1.4	Mixed	O_2-Mn	7.6
CUY-10	1.9	Mixed	O_2-Mn	7.2
CUY-11	3.4	Oxic	O_2	7.3
CUY-12	6.7	Oxic	O_2	7.2
		Gilroy study area grid wells		
GIL-01	3.7	Oxic	O_2	7.3
GIL-02	4.6	Oxic	O_2	7.3
GIL-03	5.9	Oxic	O_2	7.2
GIL-04	0.7	Anoxic	suboxic	7.8
GIL-05	2.4	Oxic	O_2	7.0
GIL-06	<0.2	Anoxic	NO_3-Mn	7.2
GIL-07	5.6	Oxic	O_2	6.7
GIL-08	2.3	Oxic	O_2	7.1
GIL-09	2.0	Oxic	O_2	7.1
GIL-10	5.8	Oxic	O_2	7.1
GIL-11	5.4	Oxic	O_2	6.9
GIL-12	<0.2	Anoxic	Mn	7.8
GIL-13	0.2	Anoxic	Mn	7.2
GIL-14	<0.2	Anoxic	Fe-Mn	7.8
GIL-15	<0.2	Anoxic	NO_3-Mn	7.0
GIL-16	1.1	Oxic	O_2	7.5
GIL-17	4.7	Oxic	O_2	7.5
		Livermore study area grid wells		
LIV-01	3.5	Oxic	O_2	7.2
LIV-02	0.2	Anoxic	Fe-Mn	6.9
LIV-03	4.0	Oxic	O_2	7.0
LIV-04	4.5	Oxic	O_2	7.4
LIV-05	5.1	Oxic	O_2	7.7
LIV-06	5.3	Oxic	O_2	7.1
		USGS-understanding wells		
CUYU-01	4.5	Oxic	O_2	7.3
CUYU-02	6.4	Oxic	O_2	7.1
CUYU-03	5.2	Oxic	O_2	7.2
CUYU-04	2.5	Oxic	O_2	7.2
CUYU-05	6.3	Oxic	O_2	7.4
CUYU-06	6.3	Oxic	O_2	7.4
GILU-01	5.3	Oxic	O_2	7.0
GILU-02	1.5	Oxic	O_2	7.6
GILU-03	3.4	Oxic	O_2	7.3
GILU-04	4.1	Oxic	O_2	7.4
GILU-05	<0.2	Anoxic	NO_3-Mn	7.9
LIVU-01	5.0	Oxic	O_2	7.2
LIVU-02	3.8	Oxic	O_2	7.2
LIVU-03	3.2	Oxic	O_2	7.4
LIVU-04	5.1	Oxic	O_2	7.2
LIVU-05 [1]	4.7	Mixed	O_2-Mn	6.8
LIVU-06 [1]	0.6	Anoxic	Fe-Mn	6.9
LIVU-07 [1]	0.3	Anoxic	suboxic	6.8
LIVU-08 [1]	0.3	Anoxic	Mn	7.1

[1] Well not used in calculation of spatially weighted aquifer-scale proportions or in testing of statistical relations among potential explanatory factors or between potential explanatory factors and water-quality constituents.

Appendix C. Comparison of California Department of Public Health and U.S. Geological Survey-GAMA Data

Major ion data for grid wells with sufficient data (USGS and CDPH data) were plotted on a trilinear diagram (Piper, 1944) along with all CDPH major ion data to determine whether the groundwater types in grid wells were similar to groundwater types observed historically in the study unit. Trilinear diagrams show the relative abundance of major cations and anions (on a charge equivalent basis) as a percentage of the total ion content of the water (fig. C1). Trilinear diagrams are often used to define groundwater type (Hem, 1985). All samples with major ion data in the CDPH database with a cation/anion imbalance of less than 10 percent were retrieved and plotted on the trilinear diagram for comparison with USGS- and CDPH-grid well data.

The ranges of water types for USGS-grid wells and other wells from the historical CDPH database were similar (fig. C1). In most water samples from wells, no single cation accounted for more than 60 percent of the total cations, and bicarbonate accounted for more than 60 percent of the total anions. Waters in these wells are described as mixed cation–bicarbonate type waters. There were also sodium/potassium-bicarbonate waters, for which sodium plus potassium and bicarbonate account for more than 60 percent of the cations and anions, respectively.

The determination that the range of relative abundance of major cations and anions in grid wells is similar to the range of those in all CDPH wells indicates that the grid wells represent the types of water present within the primary aquifer system in the SCI study unit.

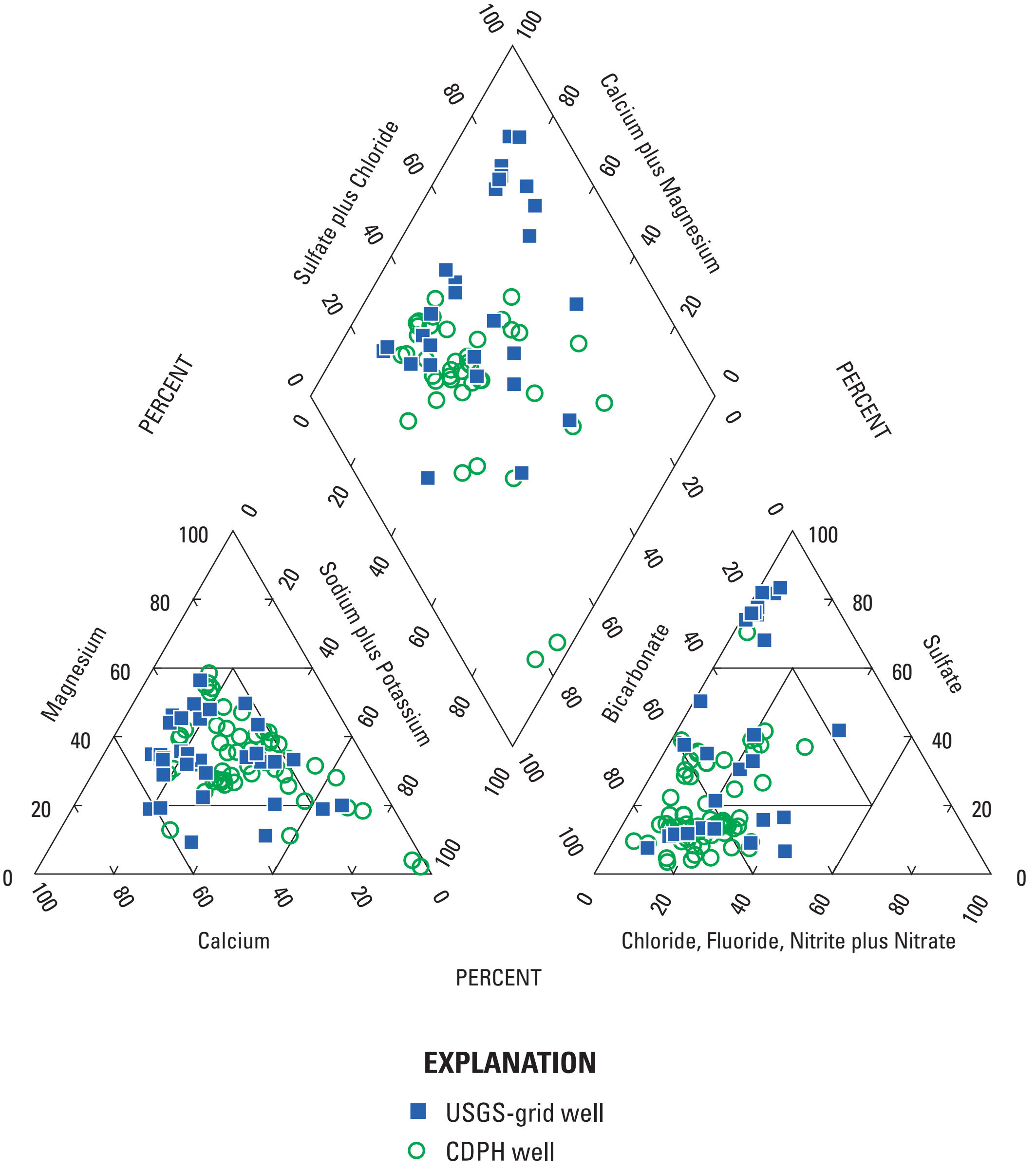


Figure C1. Trilinear diagram of selected inorganic data from the U.S. Geological Survey (USGS)-grid wells and from all wells in the California Department of Public Health (CDPH) database that have a charge imbalance of less than 10 percent, South Coast Interior Basins study unit, California GAMA Priority Basin Project.

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