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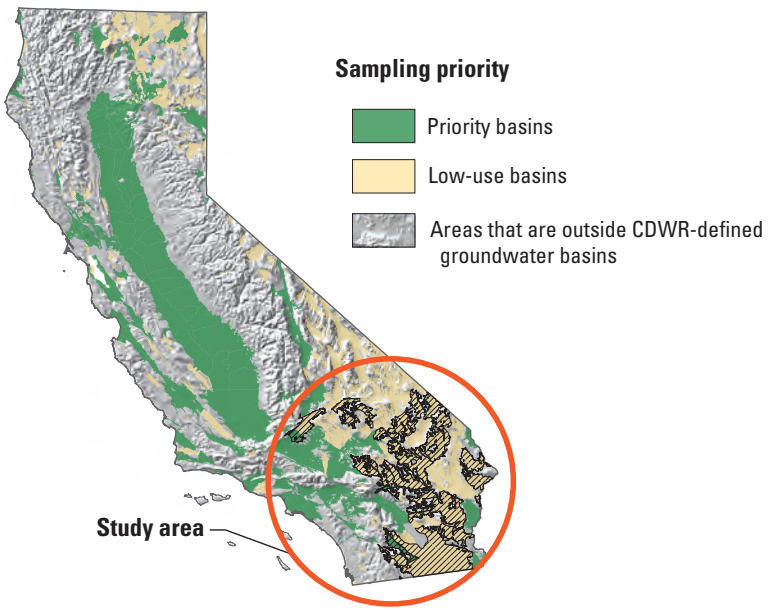
Status of Groundwater Quality in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts Study Unit, 2008–2010: California GAMA Priority Basin Project

Scientific Investigations Report 2014–5001

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: Joshua Tree and public supply well, Yucca Valley, California. (Photograph taken by Dara Goldrath, U.S. Geological Survey)

Back cover: Borrego Valley at sunset, California. (Photograph taken by Michael Solt, U.S. Geological Survey)

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

U.S. Department of the Interior
SALLY JEWELL, Secretary

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Conversion Factors, Datums, and Abbreviations and Acronyms

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
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 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). Concentrations or activities for radioactive constituents in water are given in picocuries per liter (pCi/L), percent modern carbon (pmc), or tritium units (TU).

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
BV	Borrego Valley study area
CD	Central Desert study area
CLUB	Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit
GAMA	Groundwater Ambient Monitoring and Assessment Program

Abbreviations and Acronyms—Continued

HAL-US	U.S. Environmental Protection Agency lifetime health advisory level
HBSL	Health-based screening level
LSD	land-surface datum
LUB	Low-Use Basins study area
MCL	maximum contaminant level
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}
SC	specific conductance
SMCL	secondary maximum contaminant level
SMCL-CA	California Department of Public Health secondary maximum contaminant level
SMCL-US	U.S. Environmental Protection Agency secondary maximum contaminant level
TEAP	Terminal Electron Acceptor Processes
TT-US	U.S. Environmental Protection Agency treatment technique
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
SWRCB	State Water Resources Control Board (California)
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Selected Chemical Names

NDMA	*N*-nitrosodimethylamine
TDS	total dissolved solids
THM	trihalomethane
VOC	volatile organic compound

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Abstract

Groundwater quality in the approximately 963-square-mile Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit was investigated as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The study unit is located in southern California in San Bernardino, Riverside, San Diego, and Imperial Counties. The GAMA Priority Basin Project is being conducted by the California State Water Resources Control Board in collaboration with the U.S. Geological Survey and the Lawrence Livermore National Laboratory.

The GAMA Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study was designed to provide a spatially unbiased assessment of the quality of untreated (raw) groundwater in the primary aquifer system. The assessment is based on water-quality and ancillary data collected by the U.S. Geological Survey from 52 wells (49 grid wells and 3 understanding wells) and on water-quality data from the California Department of Public Health database. The primary aquifer system was defined by the depth intervals of the wells listed in the California Department of Public Health database for the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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.

This study assesses the status of the current quality of the groundwater resource by using data from samples analyzed for volatile organic compounds (VOCs), pesticides, and naturally occurring inorganic constituents, such as major ions and trace elements. This *status assessment* is intended to characterize the quality of groundwater resources in the primary aquifer system of the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 [perchlorate and *N*-nitrosodimethylamine (NDMA)] 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 high relative-concentration for a particular constituent or class of constituents; this percentage is based on an areal rather than a volumetric basis. Moderate and low aquifer-scale proportions were defined as the percentages of the primary aquifer system with moderate and low relative-concentrations, respectively, of a constituent or class of constituents. 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 to each other (within 90-percent confidence intervals) in the study unit.

Inorganic constituents (one or more) with health-based benchmarks were detected at high relative-concentrations in 48 percent of the primary aquifer system and at moderate relative-concentrations in 26 percent of the primary aquifer system. The high aquifer-scale proportion of inorganic constituents primarily reflected high aquifer-scale proportions

of fluoride (27 percent), arsenic (18 percent), molybdenum (16 percent), boron (10 percent), uranium (5.6 percent), gross alpha radioactivity (9.7 percent), and nitrate (2.7 percent). The inorganic constituents with secondary maximum contaminant levels (SMCLs) were detected at high relative-concentrations in 13 percent of the primary aquifer system and at moderate relative-concentrations in 39 percent. The high aquifer-scale proportion for SMCL constituents reflected high aquifer-scale proportions of total dissolved solids (TDS, 11 percent), manganese (2.8 percent), and chloride (2.8 percent).

Organic constituents were not detected at high relative-concentrations in the primary aquifer system, and were present at moderate relative-concentrations in 5.0 percent, and at low relative-concentrations or were not detected in 95 percent of the primary aquifer system. Of the 148 organic constituents analyzed, 12 constituents were detected. Two organic constituents, chloroform and tetrachloroethene (PCE), were detected in more than 10 percent of samples, but were detected mostly at low relative-concentrations.

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: the (1) 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 Priority Basin Project focused primarily on the portion of the groundwater resource represented by the depth intervals of wells listed in the California Department of Public Health database (the primary aquifer system), and the SWRCB Domestic Well Project generally focused on the shallow aquifer systems. The primary aquifer system may be at less risk of contamination than the shallow wells, such as private domestic and 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, may be lower in wells screened in the primary aquifer system than in shallower wells (Kulongoski and others, 2010; Landon and others, 2010).

The SWRCB initiated the GAMA Program in 2000 in response to legislative mandates (State of California, 1999, 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 improve understanding and identification of risks to groundwater resources and to increase the availability of information about groundwater quality to the public. For the Priority Basin Project, the USGS, in collaboration with the SWRCB, developed 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 designated by the CDWR (California Department of Water Resources, 2003a). 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 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 1-square-mile sections having registered pesticide applications (Belitz and others, 2003). Of the 472 basins designated by the CDWR, 116 priority basins, containing approximately 95 percent of the CDPH wells located in basins, were identified. The 116 priority basins, a subset of the remaining 356 low-use 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. The Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit contains 4 priority groundwater basins and 43 low-use basins in the Desert hydrogeologic province.

Figure 1. Location of the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, and the California hydrogeologic provinces.

Purpose and Scope

The purposes of this report are to provide a (1) *study unit description*: description of the hydrogeologic setting of the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit (fig. 1), hereinafter referred to as the CLUB study unit, (2) *status assessment*: assessment of the status of the current quality of groundwater in the primary aquifer system in the CLUB study unit, and (3) *compilation of ancillary data*: compilation of data for selected potential explanatory factors that may be useful for understanding relations between water quality and the human and natural factors that may affect water quality.

Water-quality data for samples collected by the USGS-GAMA Program in the CLUB study unit and details of sample collection, analysis, and quality-assurance procedures for the CLUB study unit are reported by Mathany and others (2012). Utilizing those same data, this report describes methods used in designing the sampling network, identifying CDPH data for use in the *status assessment*, estimating aquifer-scale proportions for categories 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 52 wells, 49 of which were selected for spatial coverage of 1 well per grid cell (hereinafter referred to as USGS-grid wells) across the CLUB study unit. All of the USGS-grid wells were production wells. Samples were collected for analysis of anthropogenic constituents, such as VOCs and pesticides, and naturally occurring inorganic constituents, such as major ions and trace elements. Water-quality data from the CDPH database also were used to supplement data collected by USGS for the GAMA Program. The resulting set of water-quality data from USGS-grid wells and selected CDPH wells was considered to be representative of the primary aquifer system in the CLUB study unit; the primary aquifer system is defined by the depth intervals of the wells listed in the CDPH database for the CLUB study unit. GAMA *status assessments* are 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 on regional and statewide scales.

To provide context, the water-quality data discussed in this report were 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.

Hydrogeologic Setting of the CLUB Study Unit

The CLUB study unit covers approximately 963 square miles (mi^2) in San Bernardino, Riverside, San Diego, and Imperial Counties in southern California. The study unit lies within the Desert hydrogeologic province (fig. 1) (Belitz and others, 2003) and contains 47 groundwater basins. The groundwater basins cover approximately 12,103 mi^2, although wells are not found in much of this area. For the purpose of this study, these 47 groundwater basins and subbasins were grouped into 3 study areas based primarily on location: the Borrego Valley study area located within the Borrego and Lower Borrego Valleys, the Central Desert study area located within the Southern California high desert, and the Low-Use Basins of the Mojave and Sonoran Deserts study area (fig. 2*A*). As part of the Priority Basin Project, untreated groundwater samples were collected from 52 wells (49 grid wells and 3 understanding wells) in the CLUB study unit from December 2, 2008, to March 4, 2010 (Mathany and others, 2012).

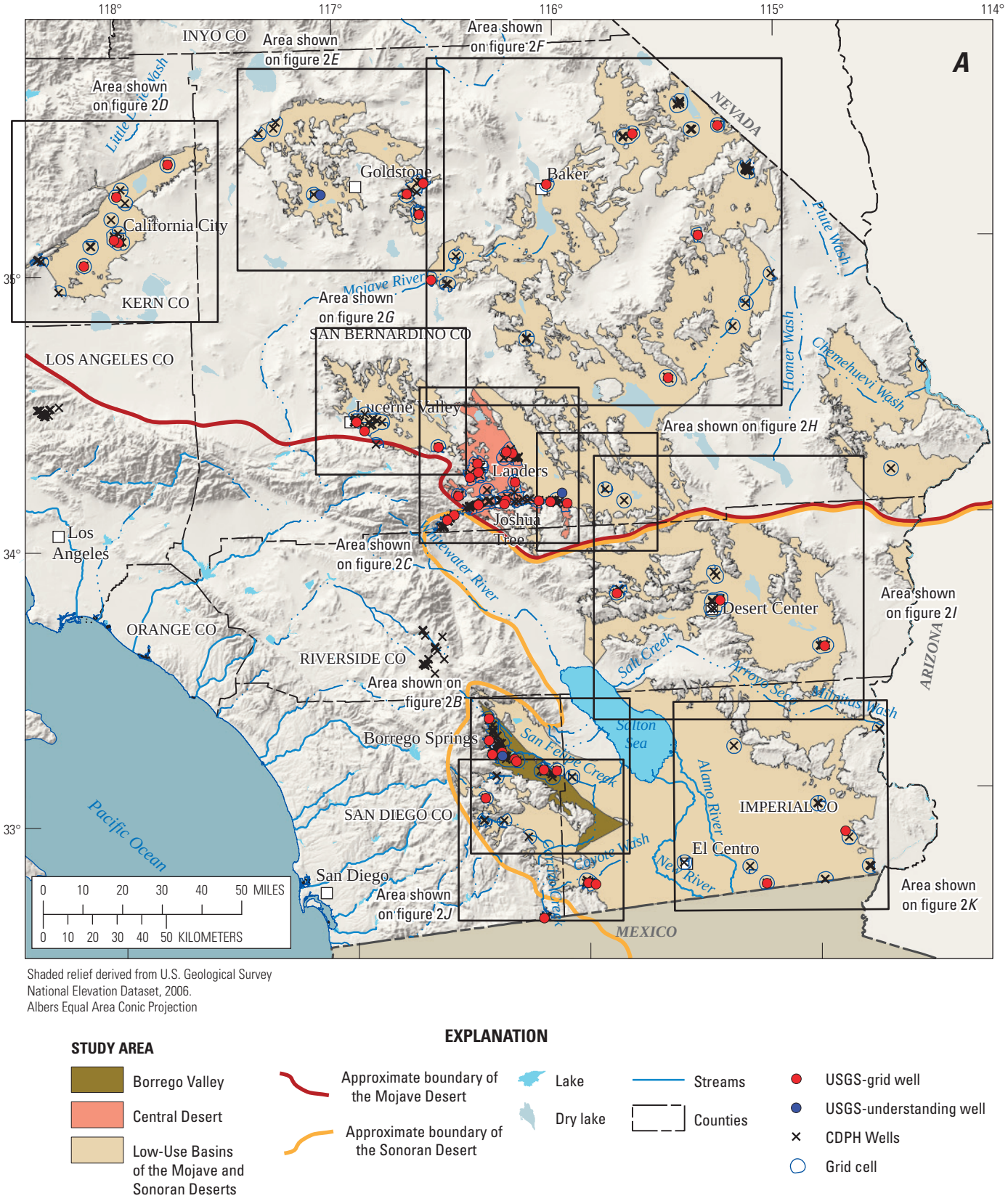
The primary aquifer system in the study unit consists of Quaternary alluvium of Pleistocene to Holocene age, and to a lesser extent, Tertiary alluvium primarily found underlying the Quaternary-age alluvial deposits (fig. 3). These alluvial deposits are composed largely of unconsolidated to semi-consolidated gravels, sands, silts, and clays. The thickness of water-bearing formations in the central and northern parts of the study unit averages 2,000 feet (ft) (California Department

of Water Resources, 2004c, 2004g–r, 2004u–bb); whereas, in the southern portion of the study area, the thickness averages about 850 ft (California Department of Water Resources, 2004s, 2004t, 2004cc–ss).

Water resources for public drinking-water supply include groundwater from local public-supply wells, in addition to delivered water from neighboring basins. The All American and Coachella Canals deliver Colorado River water to the Imperial Valley for use in irrigation. The primary aquifer system targeted by this study includes groundwater-bearing zones in which public-supply wells (CDPH database) are completed. These wells vary in depth from 36 to 1,950 ft below land-surface datum (LSD), depending on their location and depth of the alluvium. Groundwater in the alluvium flows under a natural hydraulic gradient that generally conforms to the surface topography.

Faults are abundant throughout the study unit and may act as hydrologic barriers to groundwater flow (Mendez and Christensen, 1997; California Department of Water Resources, 2004s, 2004t, 2004cc–ss). Many faults in the study unit and throughout the Low-Use Basins of the Mojave and Sonoran Deserts study area are part of the larger San Jacinto and San Andreas Fault Zones (fig. 3), which are among the most seismically active zones in California. The northern border of the study unit is bounded by the Garlock Fault Zone. In the Borrego Valley study area, the eastern boundary of the study area is defined by the Coyote Creek and Superstition Mountain Faults (fig. 2*B*), which are part of the larger San Jacinto Fault Zone. The Central Desert (CD) study area contains the Emerson Fault, Surprise Spring Fault, and Johnson Valley Fault Zone (fig. 2*C*).

Human activity on land surface and in the subsurface can affect groundwater quality. Land-use data commonly are used to identify potential effects of such activity because each type of land use typically is associated with specific activities and certain changes in water quality. Land use in the study unit is 92 percent natural, 2.7 percent agricultural, and 5.7 percent urban, according to classifications from USGS National Land Cover Data (Vogelmann and others, 2001; Price and others, 2003) (figs. 4*A*, 5; appendix A). Most of the agricultural and urban land is in the valleys. Natural lands are mostly shrubland and bare rock or sediment, with a small percentage of grassland and forest. Agricultural land is used primarily for pasture and for cultivation of hay and small grains, with a small percentage for vineyards. Urban areas are mostly residential and include the towns of Baker, Borrego Springs, California City, Desert Center, El Centro, Joshua Tree, and Landers, and the Twentynine Palms and Fort Irwin military bases (fig. 2*A*). The percentages of land in selected land-use categories were calculated for the CLUB study unit, for each study area, and for the cumulative area within a 1,640-ft [500-meter (m)] radius around each well (fig. 4). Figure 5 shows the CLUB study unit USGS-grid wells displayed on a land-use classification map that is based on satellite imagery (see appendix A for details).



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

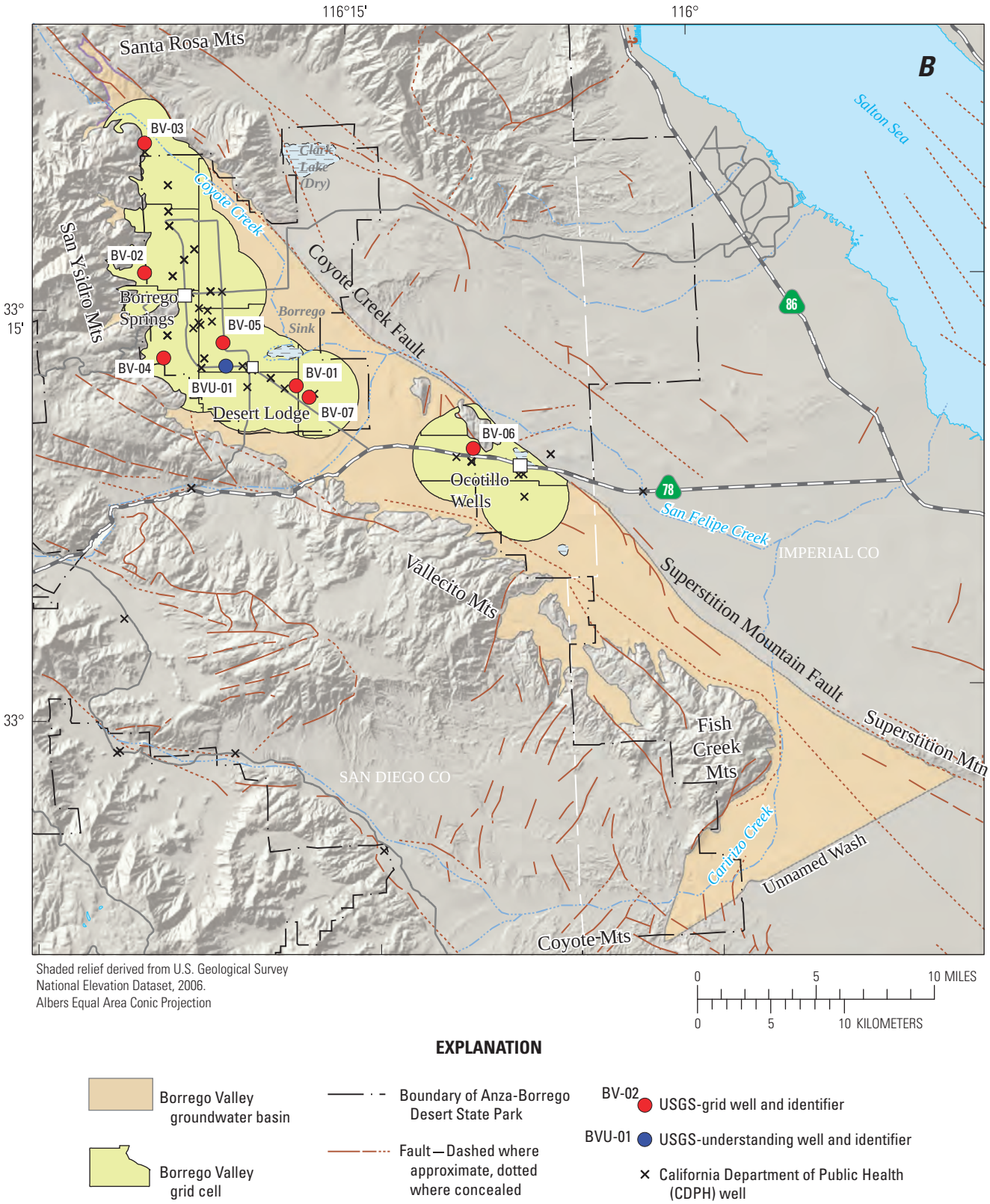
EXPLANATION

STUDY AREA

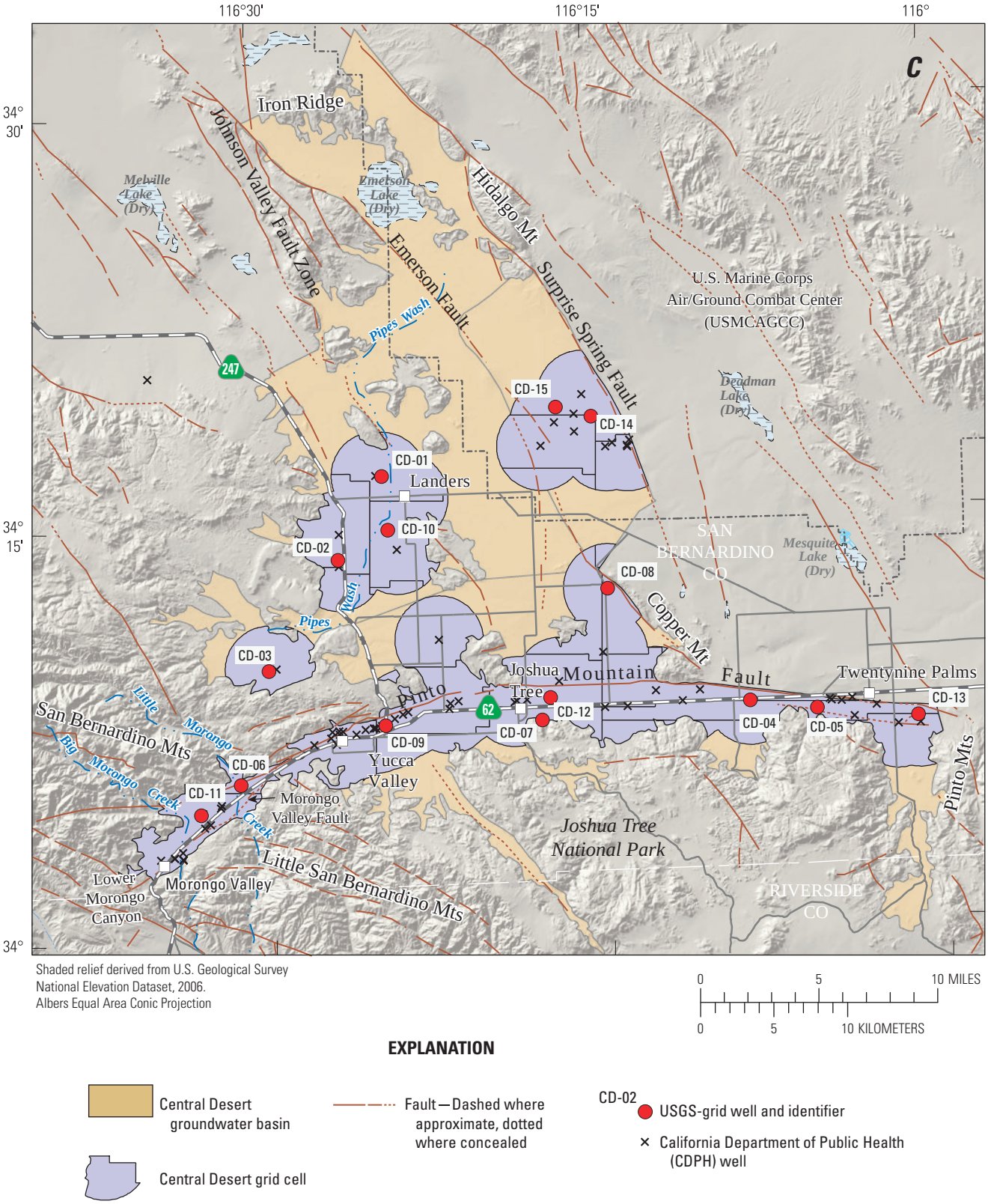
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Approximate boundary of the Mojave Desert
- Approximate boundary of the Sonoran Desert
- Lake
- Dry lake
- Streams
- Counties
- USGS-grid well
- USGS-understanding well
- CDPH Wells
- Grid cell

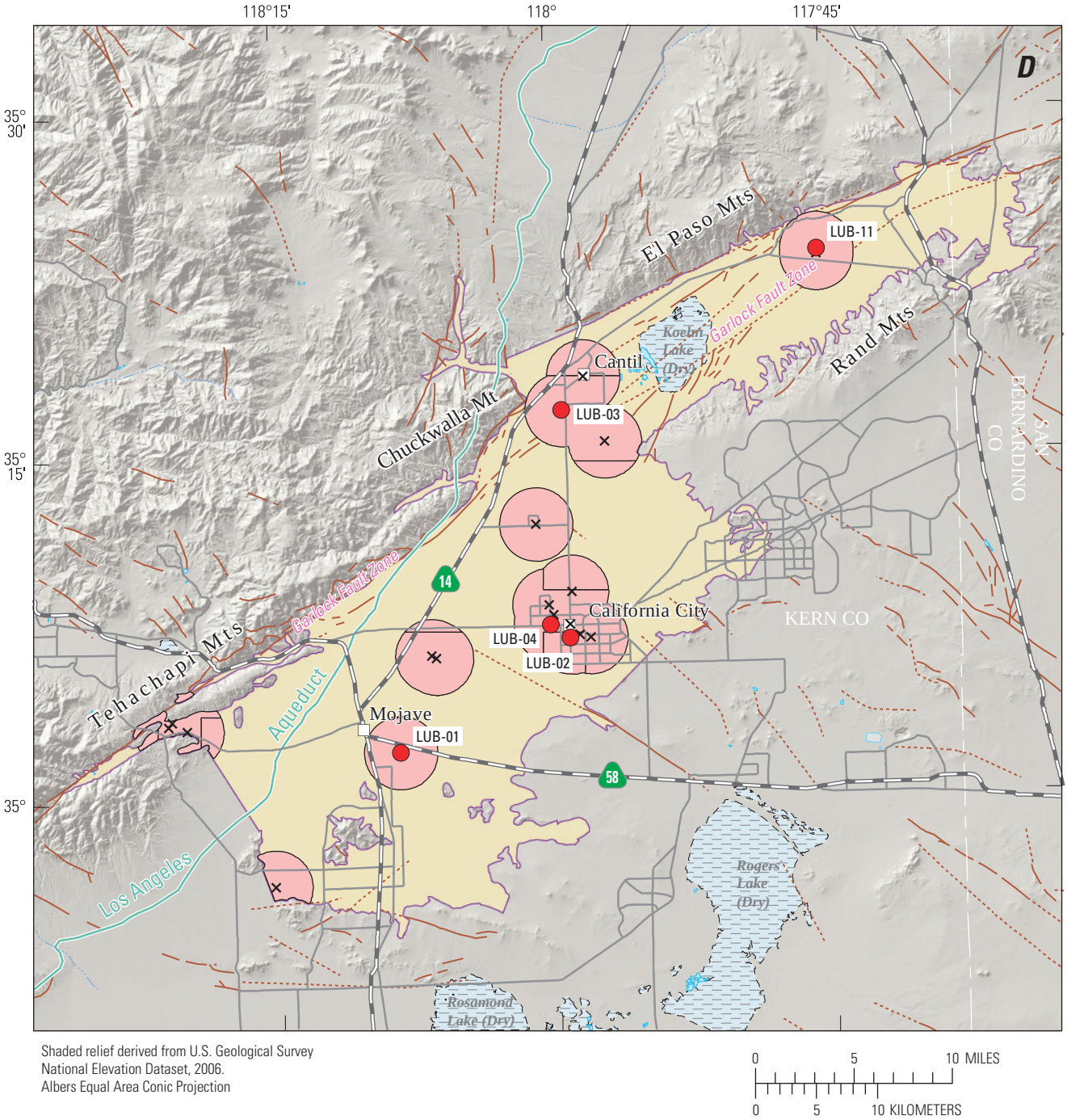
Figures 2*A*–*K*. Geographic features and locations of study area grid cells, U.S. Geological Survey (USGS) grid and understanding wells, and California Department of Public Health (CDPH) wells, Borrego, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008–March 2010.



Figures 2*A*–*K*. —Continued.



Figures 2*A*–*K*. —Continued.



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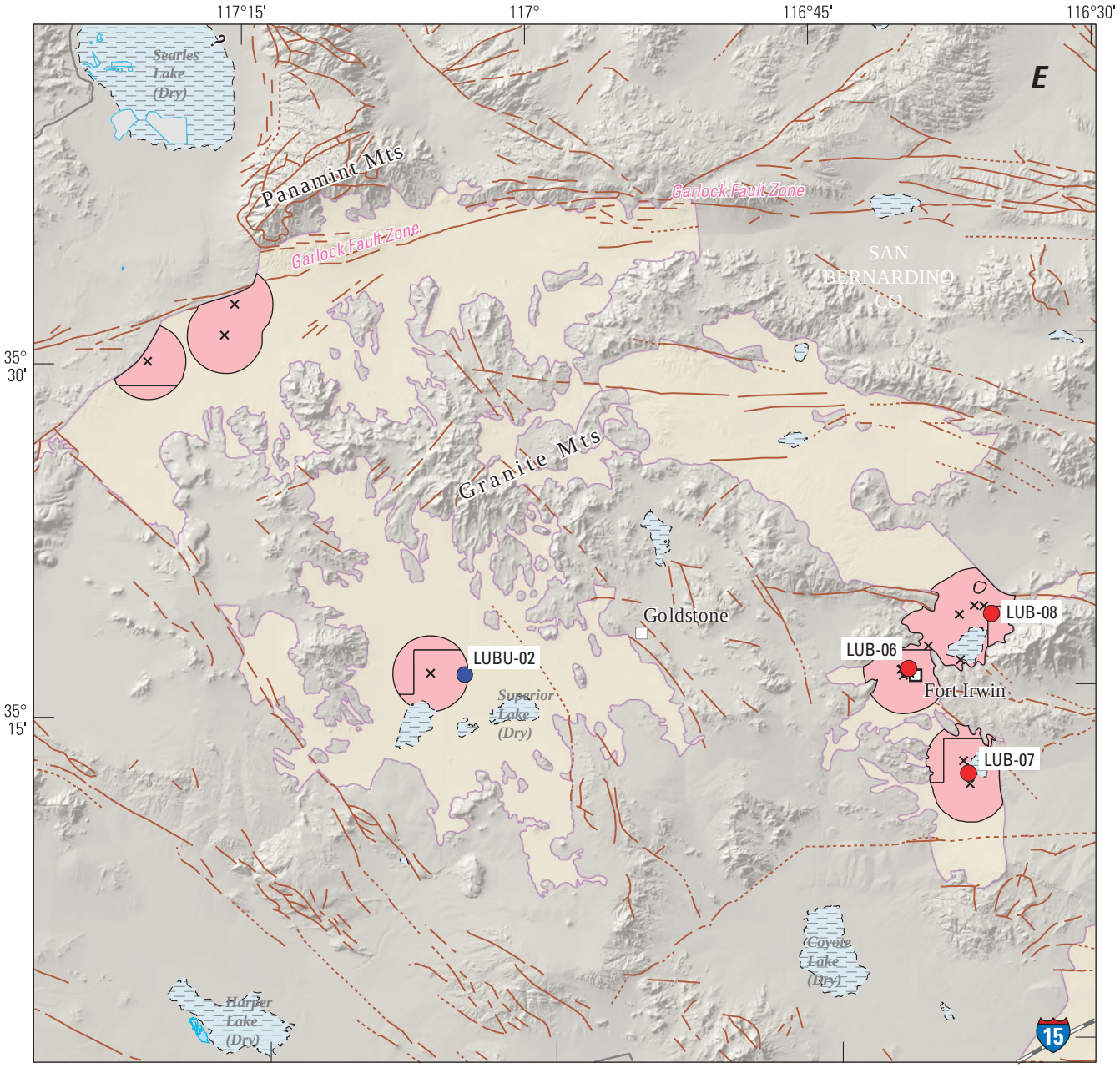

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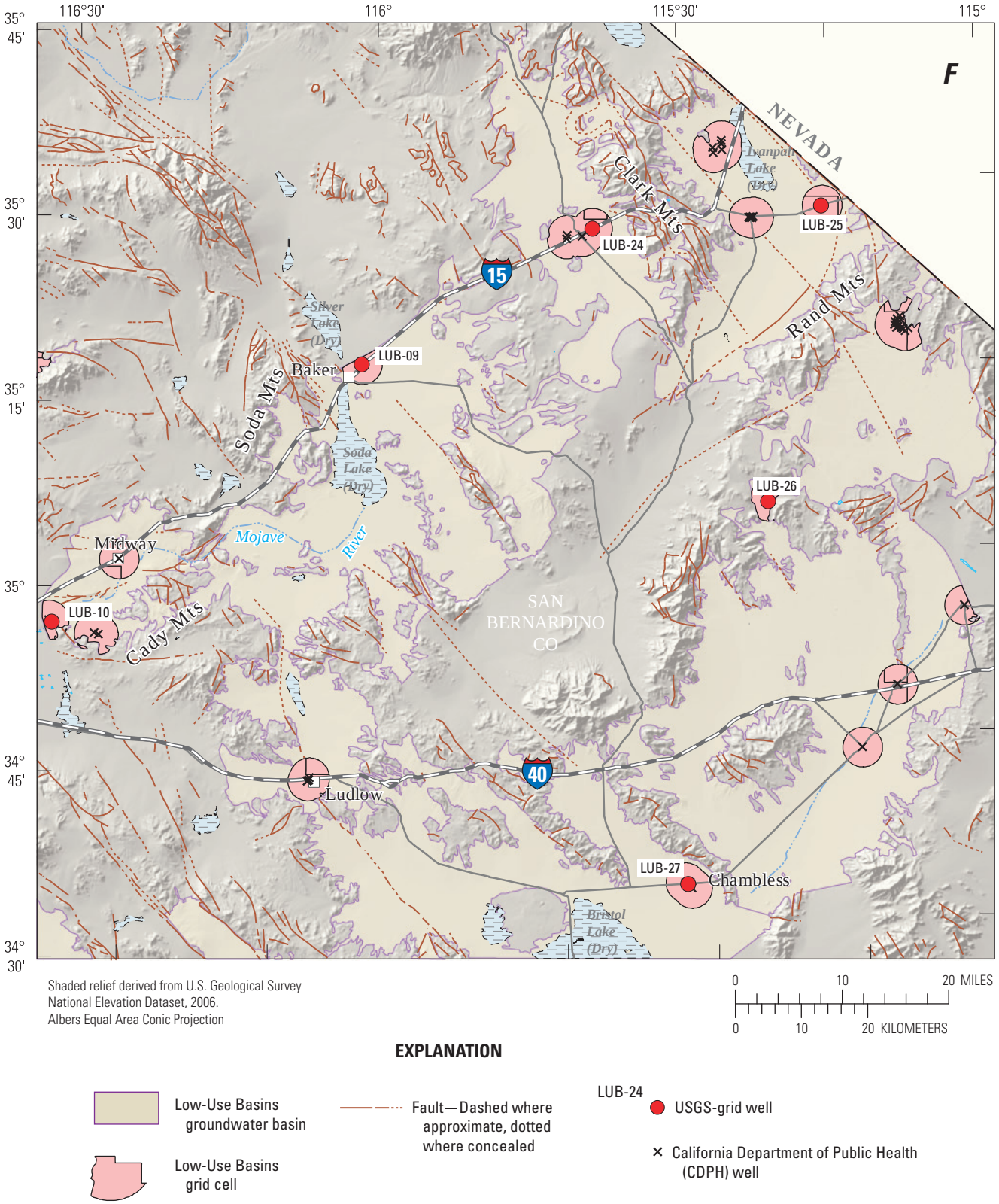

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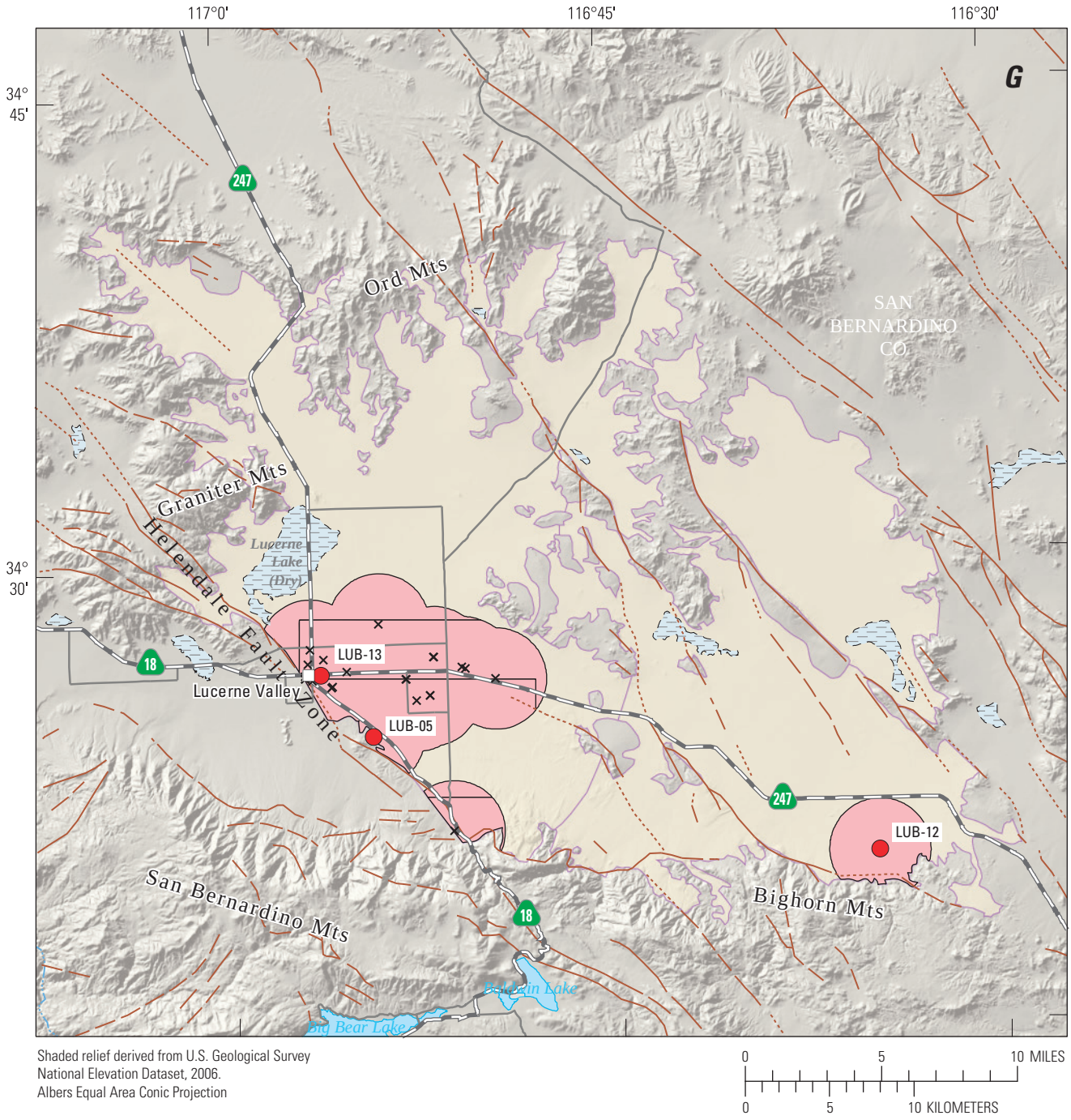

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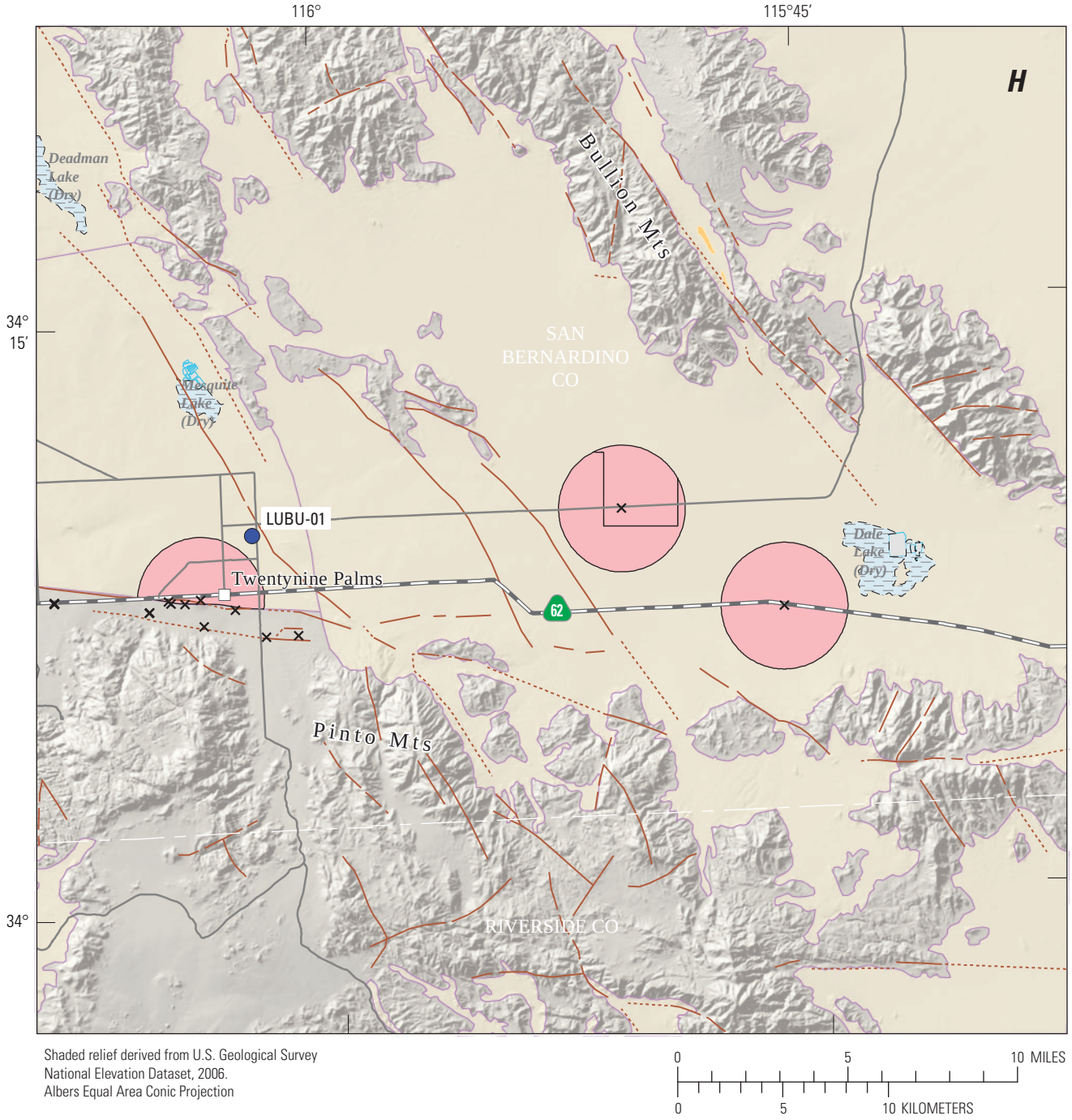

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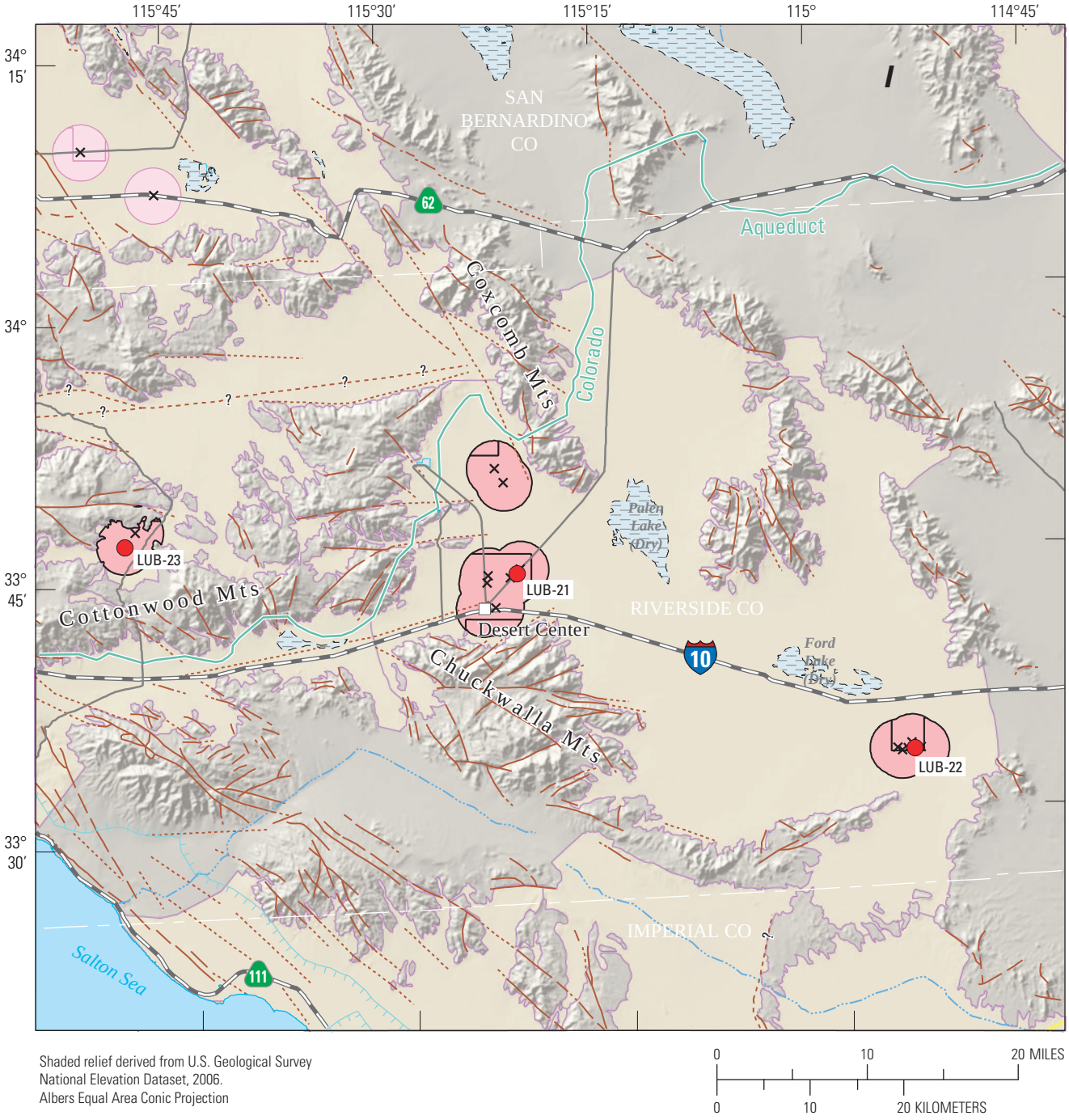

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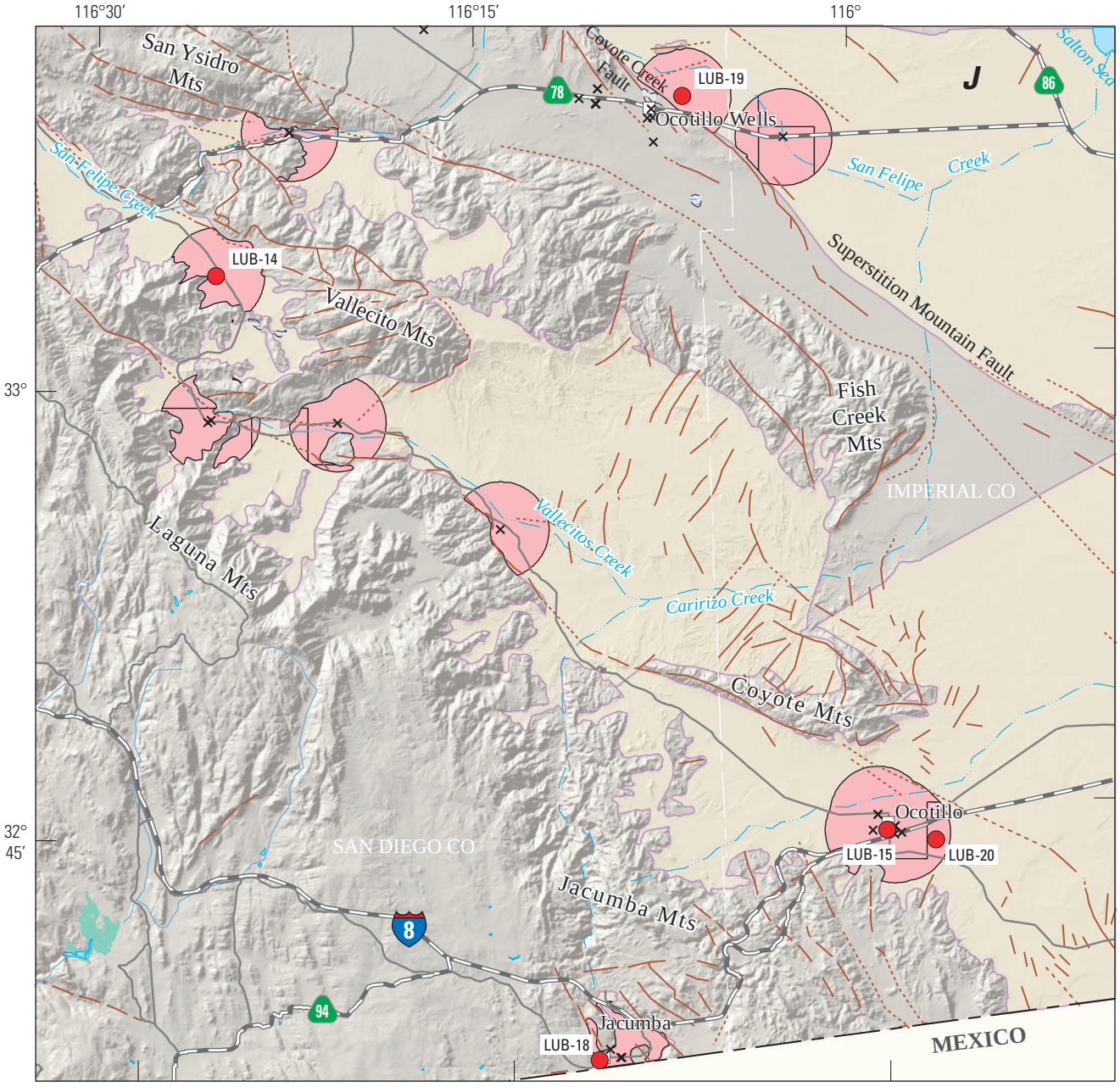

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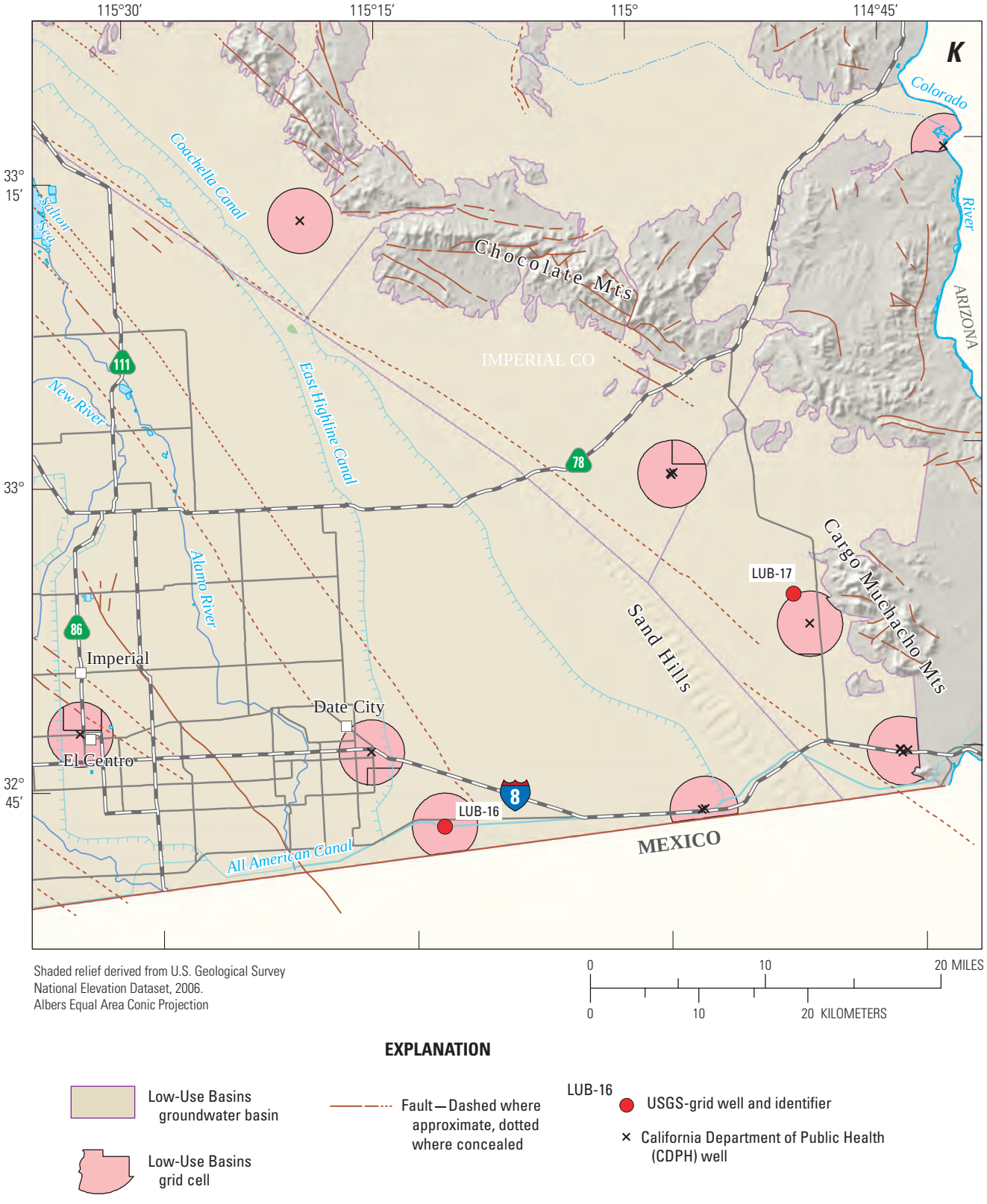

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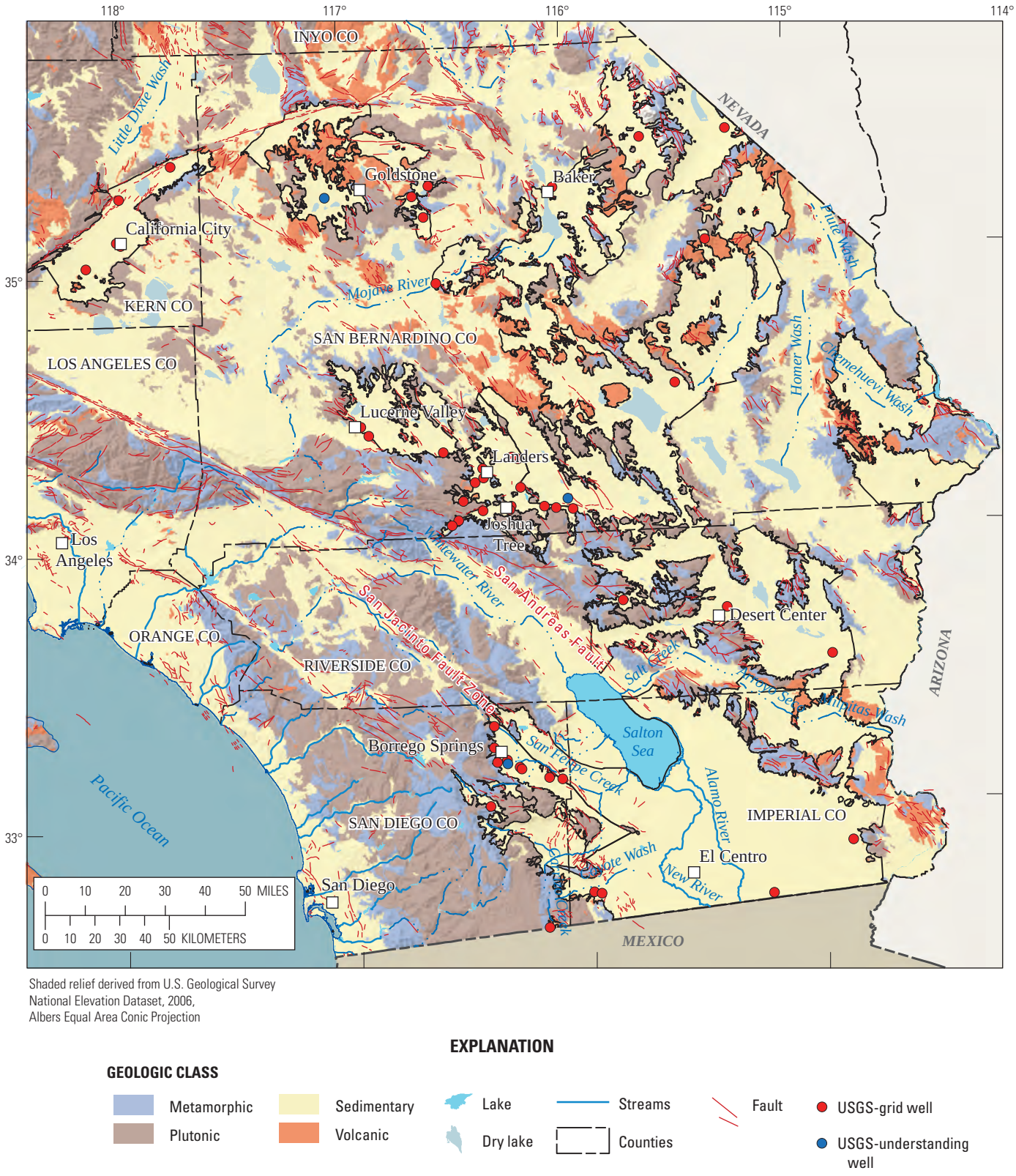


Shaded relief derived from U.S. Geological Survey National Elevation Dataset, 2006, Albers Equal Area Conic Projection

EXPLANATION

GEOLOGIC CLASS

- Metamorphic
- Plutonic
- Sedimentary
- Volcanic
- Lake
- Dry lake
- Streams
- Counties
- Fault
- USGS-grid well
- USGS-understanding well

Figure 3. Geologic map of the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

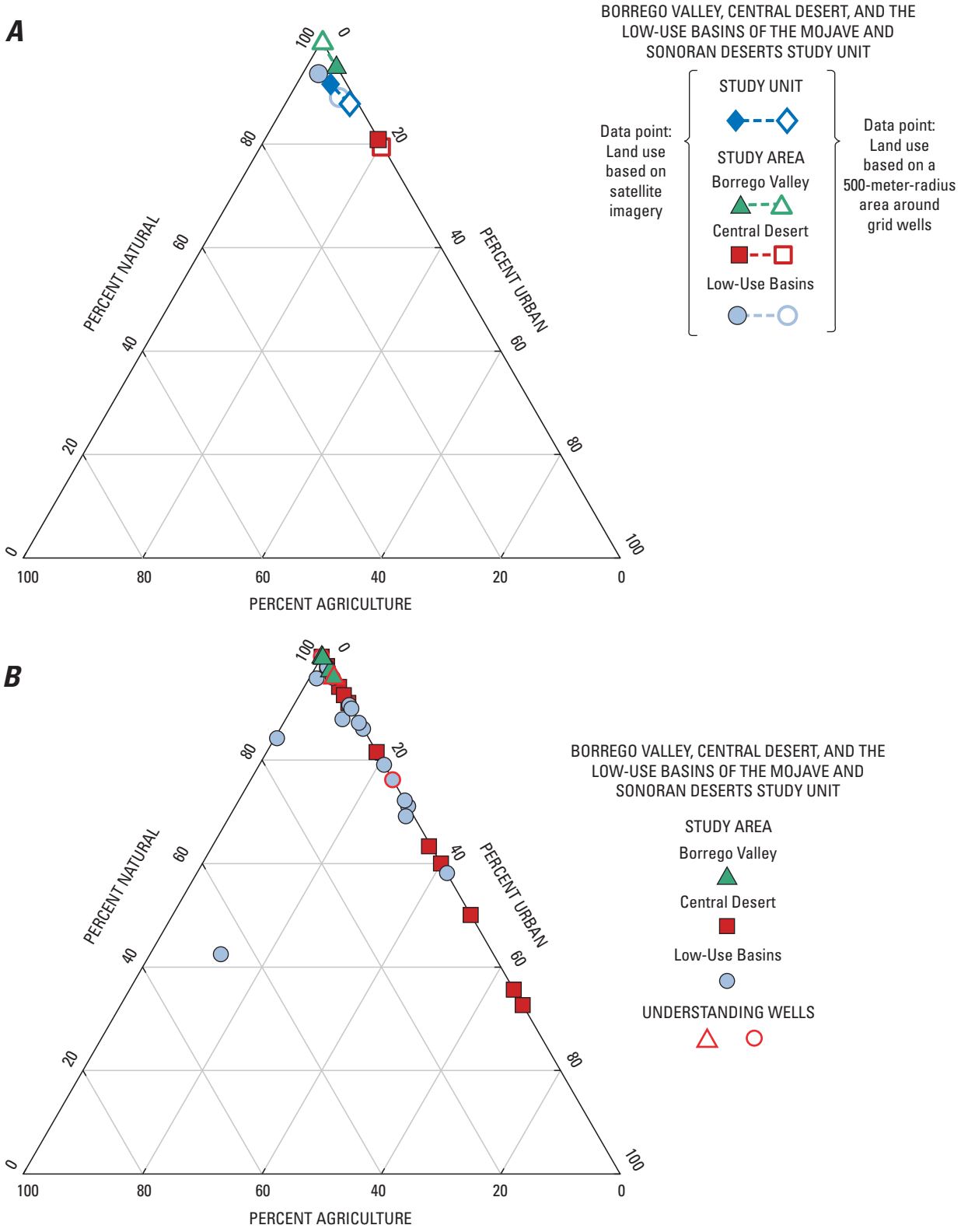
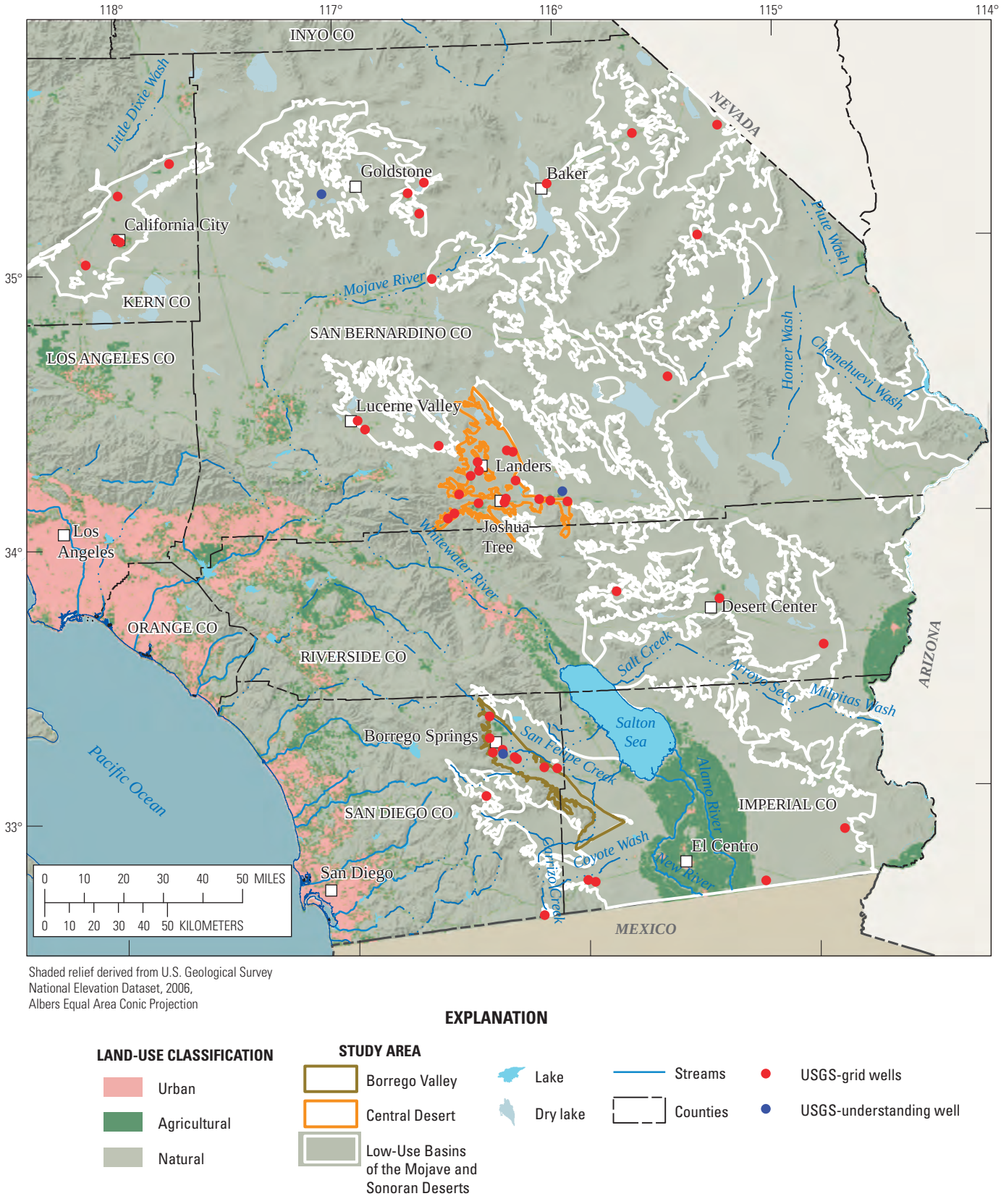


Figure 4. Percentages of urban, agricultural, and natural land use in (*A*) the study unit and study areas, and (*B*) the 500-meter radius surrounding each USGS-grid well in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.



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

EXPLANATION

LAND-USE CLASSIFICATION
- Urban
- Agricultural
- Natural

STUDY AREA
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties
- USGS-grid wells
- USGS-understanding well

Figure 5. Land use and the locations of USGS-grid and understanding wells in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

Borrego Valley Study Area

The Borrego Valley (hereinafter referred to as BV) study area is located in San Diego County about 80 miles (mi) east of San Diego (fig. 2*A*). The BV study area covers approximately 87 mi^2 and consists of the Borrego Valley and Lower Borrego Valley groundwater basins. Land cover in the BV study area is mostly natural and is composed of shrubland and bare rock or sediment with some forest (fig. 5). There are some small residential communities in the towns of Borrego Springs, Desert Lodge, and Ocotillo Wells (fig. 2*B*).

The study area is bounded to the west by the San Ysidro, Vallecito, Fish Creek, and Coyote Mountains; to the north by the Santa Rosa Mountains; to the east by the Coyote Creek and Superstition Mountain Faults, which are part of the larger San Jacinto Fault Zone; and to the south by a large unnamed wash that stretches from the Coyote Mountains northeast to Superstition Mountain (fig. 2*B*). Altitudes in the BV study area range from approximately 30 ft below LSD in the lower Borrego Valley to over 4,500 ft above LSD in the San Ysidro Mountains, located just southwest of the town of Borrego Springs.

The climate in the BV study area is classified as arid desert, with hot, dry summers and cool winters (PRISM Climate Group, Oregon State University, 2010; U.S. Department of Commerce, 2010). Average annual precipitation in the BV study area is less than 7 in. and is fairly evenly distributed throughout the year (U.S. Department of Commerce, 2010). The BV study area is drained by Coyote and San Felipe Creeks and by the Borrego Sink, which is a large surface drainage feature in the northern part of the BV study area and is a major collection point for surficial runoff in the study area (fig. 2*B*). Sources of groundwater recharge include percolation of rainfall and river and stream infiltration.

The primary aquifer in the BV study area is the upper aquifer of a three-tiered, alluvium-filled aquifer system that is underlain by crystalline bedrock. The upper aquifer is composed of alluvial, playa, eolian, and fan deposits of Pleistocene to Holocene age. The middle and lower aquifers consist of continental deposits of moderately consolidated gravel, sand, and boulders of Pleistocene age (California Department of Water Resources, 2004a).

Infiltration of surface runoff from the surrounding mountains into Coyote Creek, San Felipe Creek, and Borrego Sink is the primary source of recharge. Seepage from small, intermittent streams and washes originating from the mountains west and north of the study area is a secondary source of recharge (California Department of Water Resources, 2004a). The general groundwater-flow direction in the BV study area is southeast from the western and northern sides of the study area toward the center, then southward, following the topography of the Borrego and Lower Borrego Valleys. The San Jacinto Fault Zone, containing the two major northwest-trending faults (Superstition Mountain and Coyote Creek), acts as barrier to groundwater flow (California Department of Water Resources, 2004a) (fig. 2*B*).

Central Desert Study Area

The Central Desert study area (hereinafter referred to as CD) is located in San Bernardino County about 30 mi north of Palm Springs, within the Southern California high desert (fig. 2*A*). The CD study area covers 156 mi^2 and consists of six CDWR-defined basins and subbasins. Land cover in the CD study area is mostly natural and is composed of shrubland and bare rock or sediment with some forest. Small residential communities are located in the towns of Landers, Morongo Valley, and Yucca Valley and the Joshua Tree National Park and Twentynine Palms military base (fig. 2*C*).

The CD study area is bounded to the west by the uplands of the San Bernardino Mountains; to the north by the Emerson Fault, Johnson Valley Fault Zone, and Iron Ridge; to the east by the Surprise Spring Fault and the Hidalgo, Copper, and Pinto Mountains; and to the south by Lower Morongo Canyon, the Little San Bernardino Mountains, and the uplands areas of the Joshua Tree National Park (fig. 2*C*). Elevations in the CD study area range from approximately 2,300 ft above LSD near the often dry bed of Emerson Lake, to over 5,000 ft above LSD in the Little San Bernardino Mountains, located south of the town of Yucca Valley. The southernmost reaches of the study area are drained by the Big and Little Morongo Creeks. A large surface drainage feature named Pipes Wash drains the northern and western portions of the CD study area to Emerson Lake. Ephemeral streams drain the eastern parts of the CD study area towards Emerson and Deadman Lakes, which are often dry beds (California Department of Water Resources, 2003b, 2004b–f).

The climate in the CD study area is classified as arid desert, with hot, dry summers and cool winters (PRISM Climate Group, 2010; U.S. Department of Commerce, 2010). Average annual precipitation in the CD study area ranges from 6 in. around the Yucca Valley to 10 in. in the Morongo Valley, and precipitation is fairly evenly distributed throughout the year (U.S. Department of Commerce, 2010). Groundwater recharge comes from infiltration of runoff from surrounding mountains and hills into Little and Big Morongo Creeks, Pipes Wash, and Emerson Lake; seepage from ephemeral streams; infiltration and percolation of precipitation; and infiltration and percolation from percolation ponds and septic tanks (U.S. Geological Survey, 2009).

The primary aquifer system in the CD study area consists of unconsolidated to partly consolidated continental deposits of Miocene to Quaternary age. These unconfined water-bearing formations consist of interbedded conglomerates, gravels, sands, and silts deposited into alluvial fan systems. To a lesser extent, groundwater in the CD study area is found in deposits of clays, sandy clays, distal silts, and dune sand (California Department of Water Resources, 2003b, 2004b–f).

Groundwater flows from the southern, western, and eastern parts of the study area, towards the center, then northward to the Emerson Lake area. In the southwestern-most part of the CD study area, groundwater flows through Lower Morongo Canyon, and then exits the study area. The east-west–trending Pinto Mountain fault is the most influential hydrologic barrier to groundwater flow in the study area, with water-table differences up to 125 ft across the fault. Additionally, the Emerson, Surprise Spring, and Morongo Valley Faults and the Johnson Valley Fault Zone act as hydrologic barriers to groundwater flow (Mendez and Christensen, 1997; California Department of Water Resources, 2003b, 2004b–f; U.S. Geological Survey, 2009; fig. 2*C*).

Low-Use Basins of the Mojave and Sonoran Deserts Study Area

The Low-Use Basins of the Mojave and Sonoran Deserts (hereinafter referred to as Low-Use Basins, or LUB) study area extends over a large area in southeastern California that encompasses parts of Imperial, Kern, Riverside, San Bernadino, and San Diego Counties (fig. 2*A*). The LUB study area covers approximately 720 mi^2 and contains 40 CDWR-defined basins and subbasins (California Department of Water Resources, 2004c, 2004g–ss). Similar to the other study areas, land use in the LUB study area is mostly natural and is composed of shrubland and bare rock or sediment with some grassland and forest (fig. 5). There are some small residential communities in the towns of Baker, California City, Desert Center, El Centro, Ludlow, and Midway and in Twentynine Palms and Fort Irwin military bases.

The LUB study area is bounded to the west by the Laguna, San Bernardino, and Little San Bernardino Mountains; to the north by the Garlock Fault Zone and the Tehachapi and Panamint Mountains; to the east by the State of Nevada and the Colorado River; and to the south by the international border with Mexico (California Department of Water Resources, 2004c, 2004g–ss; figs. 2*D–K*). Elevations in the northern and central parts of the LUB study area range from approximately 600 ft above LSD at Bristol Lake, to over 7,900 ft above LSD in the Clark Mountains located northeast of the city of Baker. Elevations in the southern part of the LUB study area range from approximately 230 ft below LSD in the basins surrounding the Salton Sea to approximately 9,700 ft above LSD in the Santa Rosa Mountains near the Borrego Valley. The major surface drainage features of LUB study area are the Salton Sea, the Mojave and Colorado Rivers, and numerous ephemeral streams, creeks, and washes that flow towards dry lake beds located inside or adjacent to the groundwater basins and (or) subbasins (figs. 2*D–K*). The Salton Sea is fed by the New, Alamo, and Whitewater Rivers, Salt and San Felipe Creeks, and unnamed ephemeral streams.

Most of the LUB study area is in the Mojave Desert; the southern part is in the Sonoran Desert (fig. 2*A*). The climate in the Mojave Desert is classified as high arid desert, with hot, dry summers and cool winters (PRISM Climate Group, Oregon State University, 2010; U.S. Department of Commerce, 2010). Rainfall in the Mojave Desert occurs mainly in winter months from storms originating in the Pacific Ocean, and average annual precipitation is less than 6 in. (PRISM Climate Group, Oregon State University, 2010; Western Regional Climate Center, 2010). The climate in the Sonoran Desert is classified as subtropical desert and is generally hotter than in the Mojave Desert. Average annual precipitation is approximately 3.5 in., and the rainfall pattern is bimodal, with winter rain from storms originating in the Pacific Ocean and summer rain derived from the North American Monsoon, which is drawn northward through Mexico from the Pacific Ocean and (or) the Gulf of Mexico in the months of August through October (Western Regional Climate Center, 2010).

The primary aquifer system in the LUB study area mostly consists of alluvium of Quaternary age and, to a lesser extent, alluvium of Tertiary age that underlies the alluvial deposits of Quaternary age. Both the Quaternary and Tertiary deposits are composed largely of unconsolidated to semi-consolidated gravels, sands, silts, and clays. The thickness of waterbearing formations averages 2,000 ft in the central and northern parts of the study area and averages 850 ft in the southern part of the study area (California Department of Water Resources, 2004s, 2004t, 2004cc–ss).

Groundwater recharge in the region comes from a variety of sources: infiltration of runoff from the surrounding mountains into alluvial fan deposits; direct percolation of precipitation; seepage from ephemeral rivers, streams, washes, and unlined canals; recharge of imported surface water used for agricultural irrigation; and subsurface inflow (from non-alluvial geologic units that bound the alluvial basins) (California Department of Water Resources, 2004s, 2004t, 2004cc–ss).

The general direction of groundwater flow in the LUB study area is from the surrounding mountains and hills towards rivers, creeks, and streams that discharge into lakes, such as the Salton Sea, and to various dry lake beds located inside or adjacent to the basins and (or) subbasins. Nearly every basin and subbasin contains faults. Parts of the San Jacinto and San Andreas Fault Zones in the study area act as hydrologic barriers, although it is unknown whether other faults act as barriers to groundwater flow (California Department of Water Resources, 2004c, 2004g–r, 2004u–bb; fig. 3). To a lesser extent, clay deposits and bedrock act as barriers to groundwater flow. Also, north of the Twentynine Palms military base, an anticline restricts groundwater flow to the south within three groundwater basins and subbasins (California Department of Water Resources, 2004w–y).

Methods

The *status assessment* provides a spatially unbiased assessment of groundwater quality in the primary aquifer system of the CLUB study unit. This section describes the methods used in this study to (1) define groundwater quality, (2) assemble the datasets used for the *status assessment*, (3) determine which constituents warrant additional evaluation, and (4) calculate aquifer-scale proportions. Methods used for compilation of data on potential explanatory factors are described in appendix A.

In this study, groundwater-quality data are presented as *relative-concentrations*, the concentrations of constituents measured in groundwater relative to regulatory and non-regulatory benchmarks used to evaluate drinking-water quality. Constituents were selected for additional evaluation in the assessment based on objective criteria defined in terms of 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 are used in the *status assessment*. Two statistical methods based on spatially unbiased equal-area grids are used to calculate aquifer-scale proportions of low, moderate, or high relative-concentrations: (1) the "grid-based" method uses one value per grid cell to represent groundwater quality, and (2) the "spatially weighted" method 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 CLUB study unit, the historical CDPH database contains more than 103,506 records from 202 wells. The CDPH data were used in three ways in the *status assessment*: (1) to fill in gaps in the USGS data for the grid-based calculations of aquifer-scale proportions, (2) to aid in selecting 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*:

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

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 results, 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, 2006; California Department of Public Health, 2008a,b). Relative-concentrations less than 1 (< 1.0) indicate sample concentrations less than the benchmark, and relative-concentrations greater than 1 (> 1.0) indicate sample concentrations greater than the benchmark. The use of relative-concentrations also permits comparisons on a single scale among constituents that can be present at a wide range of concentrations. Relative-concentrations can only be computed for constituents with water-quality benchmarks; therefore, constituents without water-quality benchmarks are not included in this 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 both recommended and upper SMCL-CA levels, the values for the upper levels were used.

3. Non-regulatory, health-based CDPH notification levels (NL-CA), USEPA lifetime health advisory levels (HAL-US), and USEPA risk-specific doses at a risk factor of 10^{-5} (for a risk of 1:100,000) (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 is provided by Mathany and others (2012).

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 than to calculate benchmark quotients, the values of these ratios may not be the same for all constituents (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 Used for Status Assessment

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-GAMA. Detailed descriptions of the methods used to identify wells for sampling are given in Mathany and others (2012). Briefly, the three study areas each were divided into equal-area grid cells, and the objective was to sample one public-supply well in each cell. CDPH wells were not evenly distributed within the study areas, so to minimize the number of cells without any public-supply wells, only the parts of the study areas near CDPH wells were included in the gridded area. A 1.86-mi [3-kilometer (km)] radius circle was drawn around each CDPH well, and the collective area encompassed by the circles in each study area was divided into grid cells (Scott, 1990). One CDPH well was randomly selected for sampling in each cell, and if a cell had no accessible CDPH wells, then an appropriate well was selected by door-to-door canvassing. The BV study area was divided into nine equal-area grid cells, each approximately 9.7 mi^2, and seven wells were sampled inside this grid network (fig. 2*B*; table A1). The CD study area was divided into 17 equal-area grid cells, each approximately 9.2 mi^2, and 15 wells were sampled inside this grid network (fig. 2*C*; table A1). The LUB study area was divided into 36 equal-area grid cells, each approximately 20 mi^2, and 27 wells were sampled inside this grid network (figs. 2*D–K*; table A1).

The CLUB study unit contained 62 total grid cells, and the USGS sampled wells in 49 of those cells (USGS-grid wells). Of the 49 USGS-grid wells, 40 were listed in the CDPH database. The nine wells that were not listed in the CDPH database are perforated at depths similar to the depths of CDPH wells in their respective cells. 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 (fig. B1*B*; table A1). The following prefixes were used to indicate study areas: BV, Borrego Valley study area; CD, Central Desert study area; and LUB, Low-Use Basins of the Mojave and Sonoran Deserts study area.

Samples collected from USGS-grid wells were analyzed for 165 to 212 constituents (table 1), of which 113 had benchmarks for use in calculating relative-concentrations. Dissolved oxygen, temperature, pH, specific conductance, major ions, VOCs, pesticides, noble gases, and perchlorate were analyzed in samples from all of the USGS wells. Trace elements, nutrients, hexavalent chromium, radioactive constituents, selected isotopes, and *N*-nitrosodimethylamine (NDMA) were analyzed in samples from a subset of the wells. The collection, analysis, and quality-control data for the analyte classes listed in table 1 are described by Mathany and others (2012).

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 Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, December 2008 to March 2010.

[ns, not sampled]

	Sampling schedule	
	Fast	Slow
Well summary	**Number of wells**	
Number of grid wells sampled	26	23
Number of understanding wells sampled	2	1
Constituent classes	**Number of constituents**	
Inorganic constituents		
Specific conductance	1	1
Trace elements	ns [1]	23
Nutrients	ns [1]	5
Major ions, alkalinity, total dissolved solids (TDS)	ns [1]	12
Hexavalent chromium (chromium-VI) [2]	ns	1
Uranium and radioactive constituents		
Uranium	ns [1]	1
Radon-222	ns	1
Radium	ns	1
Gross alpha and gross beta particle activities [3]	ns	2
Organic constituents [4]		
Volatile organic compounds (VOCs) [5]	85	85
Pesticides and pesticide degradates	63	63
Special-interest constituents		
Perchlorate	1	1
N-Nitrosodimethylamine (NDMA)	ns	1
Geochemical and age-dating tracers		
Dissolved oxygen, temperature, and pH	3	3
$\delta^{2}H$ and $\delta^{18}O$ of water	2	2
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
Total	**165**	**212**

[1] These constituents were not analyzed in samples from wells on the fast schedule in the Borrego Valley and Central Desert study areas, but were analyzed in samples from wells on the fast schedule in the Low-Use Basins of the Mojave and Sonoran Deserts study area.

[2] Hexavalent chromium analysis was added to the slow sampling schedule starting October 2009.

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

[4] Fourteen pharmaceutical compounds were analyzed in samples from wells on the slow schedule, and results are discussed in Fram and Belitz (2011).

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

[6] Analyzed at U.S. Geological Survey Tritium Laboratory, Menlo Park, California.

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

California Department of Public Health Grid Data

The three study areas were divided into 62 grid cells, of which 13 cells did not have a USGS-grid well. The CDPH database was queried to provide the missing data for inorganic constituents for these cells. CDPH wells with data for the most recent 3 years available at the time of sampling (December 3, 2005, to December 1, 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 procedures used to identify suitable data from CDPH wells are described in appendix B. Briefly, the first choice was to use CDPH data from the same well sampled by the USGS (USGS-grid well). In this case, "DG" was added to the GAMA ID to signify that the data were from a well sampled by the USGS and that the data were supplemented from the CDPH database (fig. B1*A*; table A1). If the DG well did not have all of the needed data, then a second well in the cell was randomly selected from the subset of CDPH wells with data, and a new identification with "DPH" was assigned to that well (fig. B1*A*; table A1). The combination of the USGS-grid wells and the CDPH-grid wells produced a grid-well network covering 51 of the 62 grid cells in the CLUB study unit (table A1). No accessible wells or data were available for the remaining 11 cells.

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

Table 2. Benchmark type and value for inorganic constituents and number of grid cells with U.S. Geological Survey–GAMA data and California Department of Public Health data for each constituent, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA 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	Units	Number of grid cells with USGS-GAMA data	Number of grid cells with CDPH data	Selected for additional evaluation
Trace and minor elements with health-based benchmarks						
Aluminum	MCL-CA	1,000	µg/L	39	5	no
Antimony	MCL-US	6	µg/L	39	5	no
Arsenic	MCL-US	10	µg/L	39	7	yes
Barium	MCL-CA	1,000	µg/L	39	5	no
Beryllium	MCL-US	4	µg/L	39	5	no
Boron	NL-CA	1,000	µg/L	39	5	yes
Cadmium	MCL-US	5	µg/L	39	5	no
Chromium	MCL-CA	50	µg/L	39	6	yes
Copper	AL-US	1,300	µg/L	39	5	no
Fluoride	MCL-CA	2	mg/L	39	7	yes
Lead	AL-US	15	µg/L	39	5	no
Molybdenum	HAL-US	40	µg/L	39	0	yes
Nickel	MCL-CA	100	µg/L	39	5	no
Selenium	MCL-US	50	µg/L	39	5	no
Strontium	HAL-US	4,000	µg/L	39	0	no
Thallium	MCL-US	2	µg/L	39	5	no
Vanadium	NL-CA	50	µg/L	39	5	yes

Table 2. Benchmark type and value for inorganic constituents and number of grid cells with U.S. Geological Survey–GAMA data and California Department of Public Health data for each constituent, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.—Continued

[**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	Units	Number of grid cells with USGS-GAMA data	Number of grid cells with CDPH data	Selected for additional evaluation
Uranium and radioactive constituents						
Uranium	MCL-US	30	µg/L	39	4	yes
Gross alpha radioactivity	MCL-US	15	pCi/L	23	14	yes
Gross beta radioactivity	MCL-CA	50	pCi/L	23	2	no
Radium	MCL-US	5	pCi/L	23	15	no
Radon-222	Prop. MCL-US	4,000	pCi/L	22	0	no
Nutrients						
Ammonia, as nitrogen	HAL-US	[2] 24.7	mg/L	39	0	no
Nitrate, as nitrogen	MCL-US	10	mg/L	39	9	yes
Nitrite, as nitrogen [3]	MCL-US	1	mg/L	39	6	no
Inorganic constituents with SMCL benchmarks						
Chloride	SMCL-CA	500	mg/L	39	5	yes
Sulfate	SMCL-CA	500	mg/L	39	5	yes
Total dissolved solids (TDS)	SMCL-CA	1,000	mg/L	[4] 48	2	yes
Iron	SMCL-CA	300	µg/L	39	5	yes
Manganese	SMCL-CA	50	µg/L	39	5	yes
Silver	SMCL-CA	100	µg/L	39	5	no
Zinc	SMCL-US	5,000	µg/L	39	5	no

[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.

[4] Total dissolved solids (TDS) were measured directly or calculated from specific conductance (see appendix D).

CDPH data were not used in calculations of grid-based aquifer-scale proportions for VOCs, pesticides, or special-interest constituents because a larger number of VOCs and pesticide compounds are analyzed for by 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 each of the 49 grid wells sampled by the USGS in the CLUB study unit (table 1). In addition, method detection limits for USGS-GAMA analyses typically were one to two orders of magnitude lower than the reporting levels for analyses compiled by the CDPH (Fram and Belitz, 2012).

Additional Data Used for Spatially Weighted Calculation

The spatially weighted aquifer-scale proportions of relative-concentrations were calculated with data from the USGS-grid wells, from additional wells sampled by USGS-GAMA, and from all wells in the CDPH database with water-quality data collected during the 3-year interval December 3, 2005–December 1, 2008. For wells with USGS and CDPH data for inorganic or radioactive constituents, only the USGS data were used.

Three additional, non-randomized wells were sampled by the USGS to increase the sampling density in the BV and LUB study areas to better understand specific groundwater-quality issues. These "USGS-understanding" wells were numbered with prefixes modified from those used for the USGS-grid wells (BVU-01, LUBU-01, and LUBU-02) (fig. B1*B*; table A1).

Selection of Constituents for Additional Evaluation

Of the 113 constituents with benchmarks that were analyzed in samples from CLUB study unit wells, only a subset of these constituents is discussed in this report. Three criteria were used to select constituents for additional evaluation:

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

These criteria identified 7 organic and special-interest constituents and 14 inorganic constituents for additional evaluation in the status assessment (tables 2, 3). An additional 8 organic constituents and 32 inorganic constituents were detected by USGS-GAMA, but were not selected for additional evaluation in the status assessment because either benchmarks were not established, or detection was at low relative-concentrations. A complete list of the constituents investigated by USGS-GAMA in the CLUB study unit can be found in Mathany and others (2012).

Table 3. Benchmark type and value for organic and special-interest constituents selected for additional evaluation, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[**Benchmark type**: MCL-US, USEPA maximum contaminant level; MCL-CA, CDPH maximum contaminant level; RSD5-US, USEPA risk-specific dose at a factor of 10^{-5}. Benchmark types and values as of October 2013. **Benchmark units**: µg/L, micrograms per liter. **Other abbreviations**: GAMA, Groundwater Ambient Monitoring and Assessment Program; USEPA, U.S. Environmental Protection Agency; CDPH, California Department of Public Health]

Constituent and constituent class	Benchmark type [1]	Benchmark value	Units
Volatile organic compounds (VOCs)			
Benzene	MCL-CA	1	µg/L
Tetrachloroethene (PCE)	MCL-US	5	µg/L
Bromoform	MCL-US	[2] 80	µg/L
Chloroform	MCL-US	[2] 80	µg/L
Dibromochloromethane	MCL-US	[2] 80	µg/L
Pesticides			
Dieldrin	RSD5-US	0.02	µg/L
Special interest			
Perchlorate	MCL-CA	6	µg/L

[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] The MCL-US for trihalomethanes applies to the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

The CDPH database also was used to identify constituents with high relative-concentrations historically, but not currently. The historical period was defined as from the earliest record maintained in the CDPH database to December 3, 2005 (February 2, 1980, through December 3, 2005). Constituent concentrations may be historically high, but not currently high, because of improvement of 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 in the status assessment are not considered representative of potential groundwater-quality concerns in the study unit from 2005 to 2008. For the CLUB study unit, 10 constituents had historically high relative-concentrations (table 4). Seven of the constituents reported at high concentrations only during the historical period were reported at high concentrations in only 1 well.

Table 4. Constituents reported at concentrations greater than benchmark values in the California Department of Public Health database between February 2, 1980, and December 3, 2005, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[High concentrations are concentrations greater than the benchmark value. **Benchmark type**: MCL-US, USEPA maximum contaminant level; AL-US, USEPA action level SMCL-CA, CDPH secondary maximum contaminant level; RSD5-US, USEPA risk-specific does at a factor of 10^{-5}. Benchmark types and values as of October 2013. **Benchmark units**: µg/L, micrograms per liter; mg/L, milligrams 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
Inorganic constituents						
Antimony	MCL-US	6	µg/L	151	2	1/14/2005
Lead	AL-US	15	µg/L	165	5	8/16/2005
Selenium	MCL-US	50	µg/L	165	1	3/23/1987
Radium-226	MCL-US	[1] 5	pCi/L	25	1	9/2/1987
Radium-228	MCL-US	[1] 5	pCi/L	40	1	1/22/2003
Sulfate	SMCL-CA	500	mg/L	168	2	4/26/2004
Organic constituents						
Total trihalomethanes	MCL-US	[2] 80	µg/L	170	1	8/18/2005
1,2-Dibromoethane (EDB)	MCL-US	0.05	µg/L	108	1	1/23/1990
Aldicarb sulfone	MCL-US	3	µg/L	54	1	6/4/2003
Aldrin	RSD5-US	0.02	µg/L	81	1	6/4/2003

[1] The MCL-US for radium applies to the sum of the activities of radium-226 and radium-228.

[2] The MCL-US for trihalomethanes applies to the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Calculation of Aquifer-Scale Proportions

The status assessment is intended to characterize the quality of groundwater resources in the primary aquifer system of the CLUB study unit. The primary aquifer system is defined by the depth intervals over which wells listed in the CDPH database are perforated; these wells primarily are classified as municipal and community public-supply wells. The use of the term "primary aquifer system" does not imply that there exists a discrete aquifer unit. In most groundwater basins, municipal and community supply wells generally are perforated at greater depths than are domestic wells. However, to the extent that domestic wells are perforated over the same depth intervals as the CDPH wells, the assessments presented in this report also may be applicable to the portions of the aquifer systems used for domestic drinking-water supplies.

Two statistical approaches, grid-based and spatially weighted, were selected to evaluate the proportions of the primary aquifer system in the CLUB study unit having high, moderate, and low relative-concentrations of constituents (Belitz and others, 2010). For ease of discussion, these proportions are referred to as "high," "moderate," and "low" aquifer-scale proportions. Calculations of aquifer-scale proportions were made for individual constituents meeting the criteria for additional evaluation in the *status assessment*, as well as for classes of constituents. The classes consisted of groups of related individual constituents. For constituents with human-health benchmarks, the classes included trace and minor elements, uranium and radioactive constituents, nutrients, trihalomethanes, and insecticides. For constituents with aesthetic-based benchmarks, the classes included salinity indicators and manganese and (or) iron.

The grid-based calculation uses the grid-well dataset assembled from the USGS-grid and CDPH-grid wells. For each constituent, the high aquifer-scale proportion was calculated by dividing the number of cells with concentrations greater than the benchmark by the total number of grid cells with data for that constituent in each of the study areas. The proportion for each study area is calculated individually because grid-cell sizes are not uniform across the study areas. The proportion for the study unit is then determined by calculating the area-weighted sum. Moderate and low aquifer-scale proportions were calculated similarly. A more detailed discussion of the calculation used for aquifer-scale proportion is located in appendix C. Confidence intervals for the high aquifer-scale proportions were computed using the Jeffreys interval for the binomial distribution (Brown and others, 2001; Belitz and others, 2010). The grid-based estimate is spatially unbiased. However, the grid-based approach may not detect constituents that are present at high concentrations in small proportions of the primary aquifer system. The confidence intervals provide a range that is likely (with 90-percent confidence) to contain the true high aquifer-scale proportion. For calculation of aquifer-scale proportions for classes of

constituents, cells were considered high if values for any of the constituents in that class were high. Cells were considered moderate if values for any of the constituents were moderate, but no values were high.

The spatially weighted calculation uses the dataset assembled from all CDPH and USGS-GAMA wells. For each constituent, the high aquifer-scale proportion was calculated by computing the proportion of wells with high values in each cell and then averaging the proportions for all of the cells (Belitz and others, 2010). As with the grid-based calculation, the spatially weighted calculations were made separately for the three study areas, and then the results were combined on an area-weighted basis. The moderate aquifer-scale proportion was calculated similarly. Confidence intervals for spatially weighted detection frequencies of high concentrations are not presented in this report. For calculation of aquifer-scale proportions for classes of constituents, values for wells were considered high if the values for any of the constituents in that class were high. Values for wells were considered moderate if the values for any of the constituents were moderate, but no values for wells were high.

In addition, for each constituent, the raw detection frequencies of high and moderate values for individual constituents were calculated by using the same dataset as was used for the spatially weighted calculations. However, raw detection frequencies are not spatially unbiased because the wells in the CDPH database are not uniformly distributed throughout the CLUB study unit (fig. 2). For example, if a constituent were present at high concentrations in a small region of the aquifer with a high density of wells, the raw detection frequency of high values would be greater than the true high aquifer-scale proportion. Raw detection frequencies are provided for reference, but were not used to assess aquifer-scale proportions (see appendix C for details of statistical methods). Raw detection frequencies were not area-weighted.

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

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

- If the grid-based high aquifer-scale proportion was greater than zero and the spatially weighted proportion was outside the 90-percent confidence interval (based on the Jeffreys interval for the binomial distribution), 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 (Fram and Belitz, 2012). However, if the grid-based moderate proportion was zero and the spatially weighted proportion was greater than zero, then the spatially weighted value was used as a minimum estimate for the moderate proportion.

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 A.

Land Use

Land use was described by three land-use types: urban, agricultural, and natural (appendix A). Percentages of the three types were calculated for the study unit and study areas, and for areas within a radius of 500 meters (m) (1,640 ft), hereinafter referred to as 500-m buffers, around wells (Johnson and Belitz, 2009). Land classified as natural made up the greatest percentage (92 percent) of the total land area in the study unit (taking into account the entire area of the study unit, and not just the area around grid wells), whereas urban land use was only 5.7 percent of the area, and agricultural land use was 2.7 percent of the study unit area (figs. 4A, 5). Likewise, land use within the 500-m buffers around USGS-grid wells in the CLUB study unit was mostly natural (88 percent), urban land use accounted for 11 percent, and agricultural land use accounted for 1.4 percent (fig. 4*A*). Most of the agricultural land is in the Imperial Valley south of the Salton Sea. Natural lands are mostly shrubland and bare rock or sediment, with a small percentage of grassland and forest. The primary use of agricultural land is for pasture, hay, and small grains, with a small percentage for vineyards. Urban areas are mostly residential and include towns such as Baker, Borrego Springs, California City, Chambless, Desert Lodge, Landers, Ludlow, Midway, Morongo Valley, and Yucca Valley; Joshua Tree and Mojave National Parks; and Twentynine Palms and Fort Irwin military bases (figs. 2*A–K*). The CD study area has more urban land use (19 percent of that study area) than the BV and LUB study areas have (5.0 percent and 2.7 percent, respectively; fig. 4*A*). The CD study area contains the towns and areas with larger populations such as Landers, Morongo Valley, Twentynine Palms, and Yucca Valley and the area of Joshua Tree National Park (fig. 2*C*).

Well Depth and Depth to Top-of-Perforation

Well construction information was available for 42 of the 49 grid wells sampled by the USGS in the CLUB study unit. Depths of grid wells ranged from 36 to 1,200 ft below LSD; the median was 490 ft (fig. 6; table A3). The depths to top-of-perforations ranged from 0 to 690 ft below LSD, with a median of 220 ft. The perforation lengths were as much as 565 ft, with a median of 190 ft. Well construction information also was available for three understanding wells. The understanding wells have ranges in well depth and perforation length and a median value for depth to top-of-perforation (fig. 6; table A3) similar to those of the grid wells. The median well depth was 400 ft, and the median depth to top-of-perforation was 162 ft.

Groundwater Age

Groundwater samples were assigned age classifications on the basis of the tritium and carbon-14 content of the samples (appendix A). Age classifications were assigned to 49 USGS-grid and 3 understanding well samples; 6 were classified as modern (recharged after 1952), 5 were mixed, and 41 were pre-modern (table A4).

Comparisons of well depths and depths to top-of-perforations with groundwater samples classified as modern, mixed, and pre-modern ages did not show significant differences (figs. 7*A*,*B*). However, other GAMA studies with well construction information for wells with groundwater samples classified as modern reported that median groundwater ages increased for deeper top-of-perforations and well depths (Kulongoski and others, 2010).

Geochemical Condition

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 49 wells sampled by the USGS-GAMA Priority Basin Project and is given in appendix A (table A5). Groundwater was oxic in 92 percent of the wells and anoxic in 8 percent of the wells.

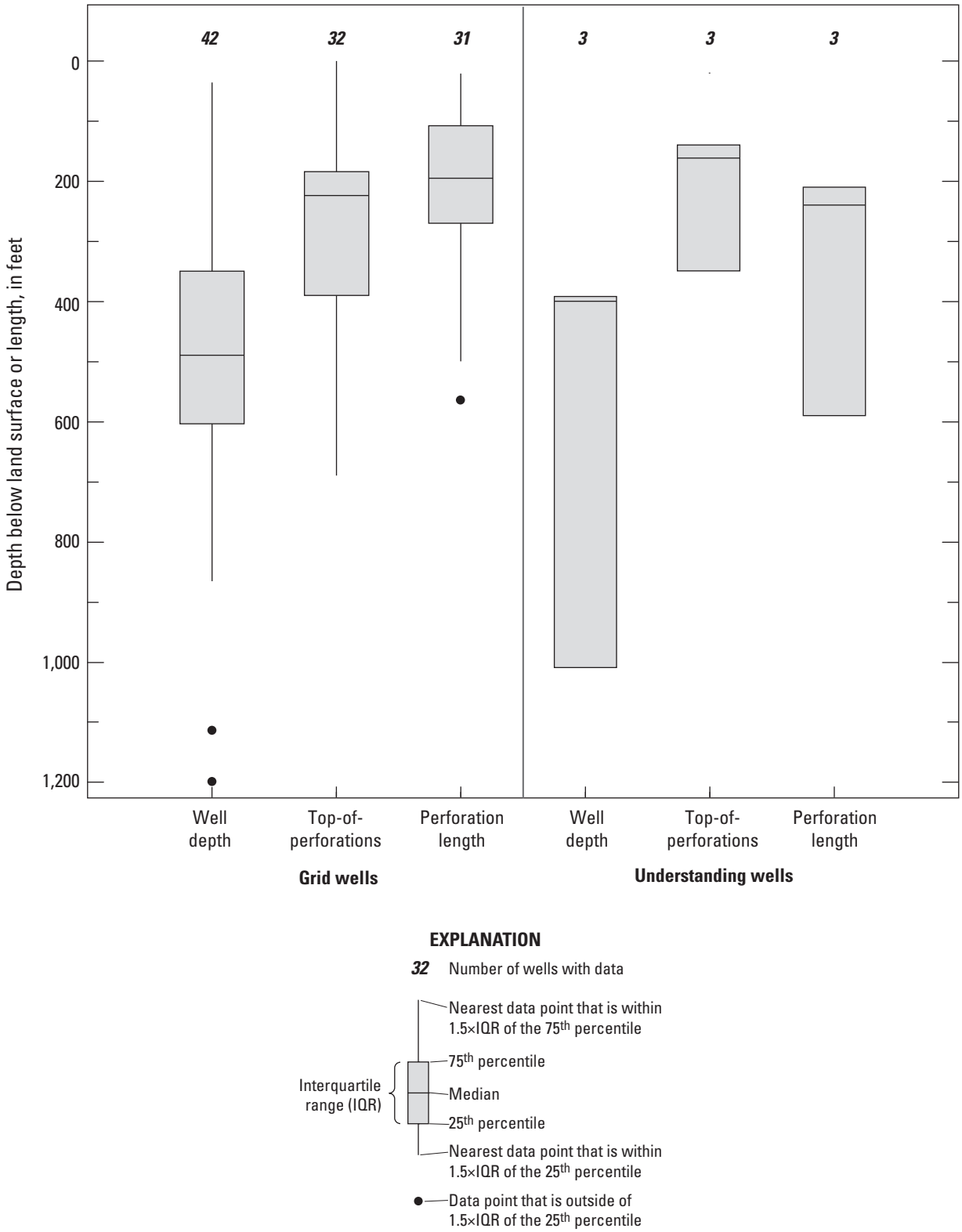


Figure 6. Well depths, depths to top-of-perforations, and perforation lengths for grid and understanding wells, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, December 2008 to March 2010.

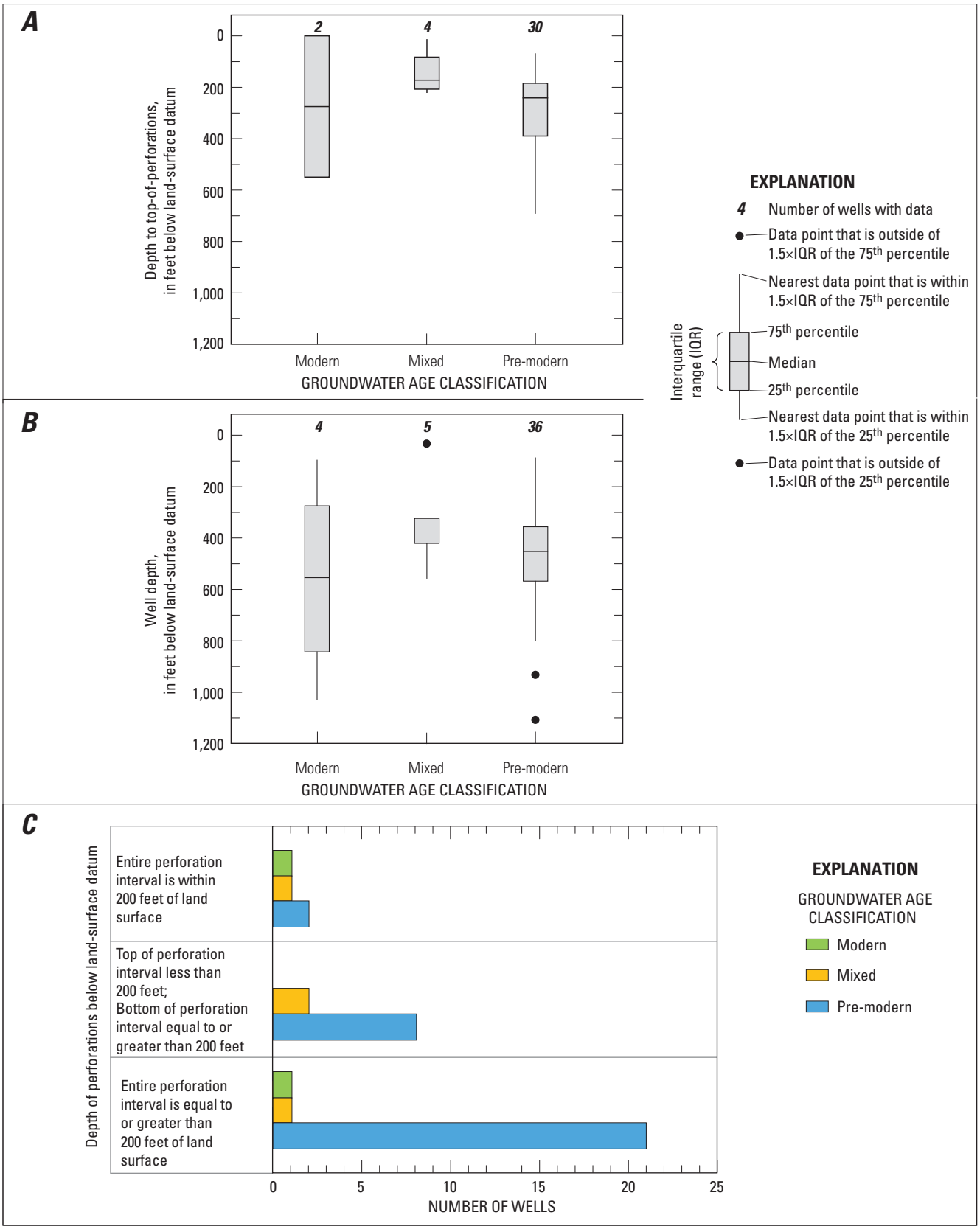


Figure 7. Relation of groundwater age classification to (*A*) depth to top-of-perforations and to (*B*) well depth, and (*C*) age classification in relation to well depth classification for USGS-grid wells and USGS-understanding wells, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, December 2008–March 2010.

Status 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. More than 10,000 individual analytical results were included in the assessment of groundwater quality for the CLUB study unit. The status assessment applies only to constituents with regulatory or non-regulatory health-based or aesthetic/technical-based benchmarks established by the USEPA or the CDPH (as of 2012). 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 following discussion of the status assessment results is divided into inorganic, organic, and special-interest constituents. The assessment begins with a survey of how many constituents were detected compared to the number analyzed and a graphical summary of the relative-concentrations of constituents detected in the grid wells. Results are presented for those constituents that met criteria for selection for additional evaluation based on concentration, or for organic constituents, prevalence.

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 constituents listed in table 5, providing evidence that the grid-based approach yields results that are statistically equivalent to those calculated using the spatially weighted approach.

Inorganic Constituents

Inorganic constituents generally occur naturally in groundwater, although their concentrations may be influenced by human activities as well as by natural factors. All 47 inorganic constituents analyzed by the USGS-GAMA were detected in the CLUB study unit; 26 of the 47 had regulatory or non-regulatory health-based benchmarks, 8 had non-regulatory aesthetic-based benchmarks, and 13 had no established benchmarks (table 6). Twelve inorganic constituents—arsenic, boron, fluoride, molybdenum, vanadium, manganese, chloride, sulfate, TDS, gross alpha radioactivity, uranium, and nitrate—met the selection criterion of having maximum relative-concentrations greater than 0.5 (moderate or high) in the grid-well dataset (fig. 8; table 5). The relative-concentrations of these 12 inorganic constituents detected in grid wells from the 3 study areas are shown in figure 9. Two other constituents, chromium and iron, were detected at high concentrations in CDPH wells between December 3, 2005, and December 1, 2008 (table 5), but not in the grid wells.

Inorganic constituents with health-based benchmarks (trace and minor elements, uranium and radioactive constituents, and nutrients), as a class, had high relative-concentrations in 48 percent of the primary aquifer system and moderate relative concentrations in 26 percent (table 7A). At least one inorganic constituent with a health-based benchmark was detected at a high relative-concentration in each of the study areas. Inorganic constituents with aesthetic-based SMCL benchmarks, as a class, had high relative-concentrations in 13 percent of the primary aquifer system and moderate relative-concentrations in 39 percent (table 7A). The spatial distributions of the eleven inorganic constituents that were present at high relative-concentrations in greater than 2 percent of the primary aquifer system (table 5) are shown in figures 10*A*–*K*. These maps show inorganic constituent data for USGS-grid and USGS-understanding wells from December 2008 to March 2010 and for CDPH-grid wells and other CDPH wells from December 3, 2005, to December 1, 2008.

Table 5. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010), Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency [1]			Spatially weighted aquifer-scale proportion [1]			Grid-based aquifer-scale proportion			90-percent 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)
Trace and minor elements											
Arsenic	110	14	18	46	19	19	46	23	18	8.3	26
Boron	90	10	5.6	44	15	11	44	17	10	4.0	19
Chromium	104	0	1.0	45	0	0.4	45	0	0	0	3.0
Fluoride	111	14	20	46	15	28	46	22	27	15	44
Molybdenum	42	9.5	17	40	8.5	16	40	10	16	7.8	27
Vanadium	87	12	3.4	44	12	2.3	44	13	1.5	0.3	9.9
Radioactive constituents											
Gross alpha activity [3]	90	22	8.9	39	23	8.5	38	24	9.7	4.6	21
Uranium	80	16	6.3	45	6.7	4.4	44	4.3	5.6	2.6	16
Nutrients											
Nitrate	131	4.6	2.3	48	6.5	2.2	48	2.7	2.7	0.4	7.9
Inorganic constituents with SMCLs											
Iron	107	1.9	3.7	45	1.9	2.9	44	0	0	0	3.0
Manganese	107	0	2.8	45	0	3.1	44	0	2.8	0.4	8.5
Chloride	107	1.9	0.9	44	4.2	2.8	44	4.2	2.8	0.4	8.5
Sulfate	107	10	0	44	18	0	44	14	0	0	3.0
Total dissolved solids (TDS)	111	31	4.5	45	37	11.8	49	41	11.0	4.8	19
Volatile organic compounds (VOCs)											
Benzene	94	1.5	0	49	0.9	0	49	0	0	0	2.7
Tetrachloroethene (PCE)	94	1.5	0	49	1.4	0	49	0	0	0	2.7
Bromoform	94	3.0	0	49	1.4	0	49	0	0	0	2.7
Chloroform	94	2.1	0	49	1.2	0	49	0	0	0	2.7
Dibromochloromethane	94	3.0	0	49	1.4	0	49	0	0	0	2.7
Pesticides											
Dieldrin	68	1.5	0	48	1.4	0	47	2.8	0	0	2.8
Special interest											
Perchlorate	145	8.0	0	49	24	0	49	32	0	0	2.7

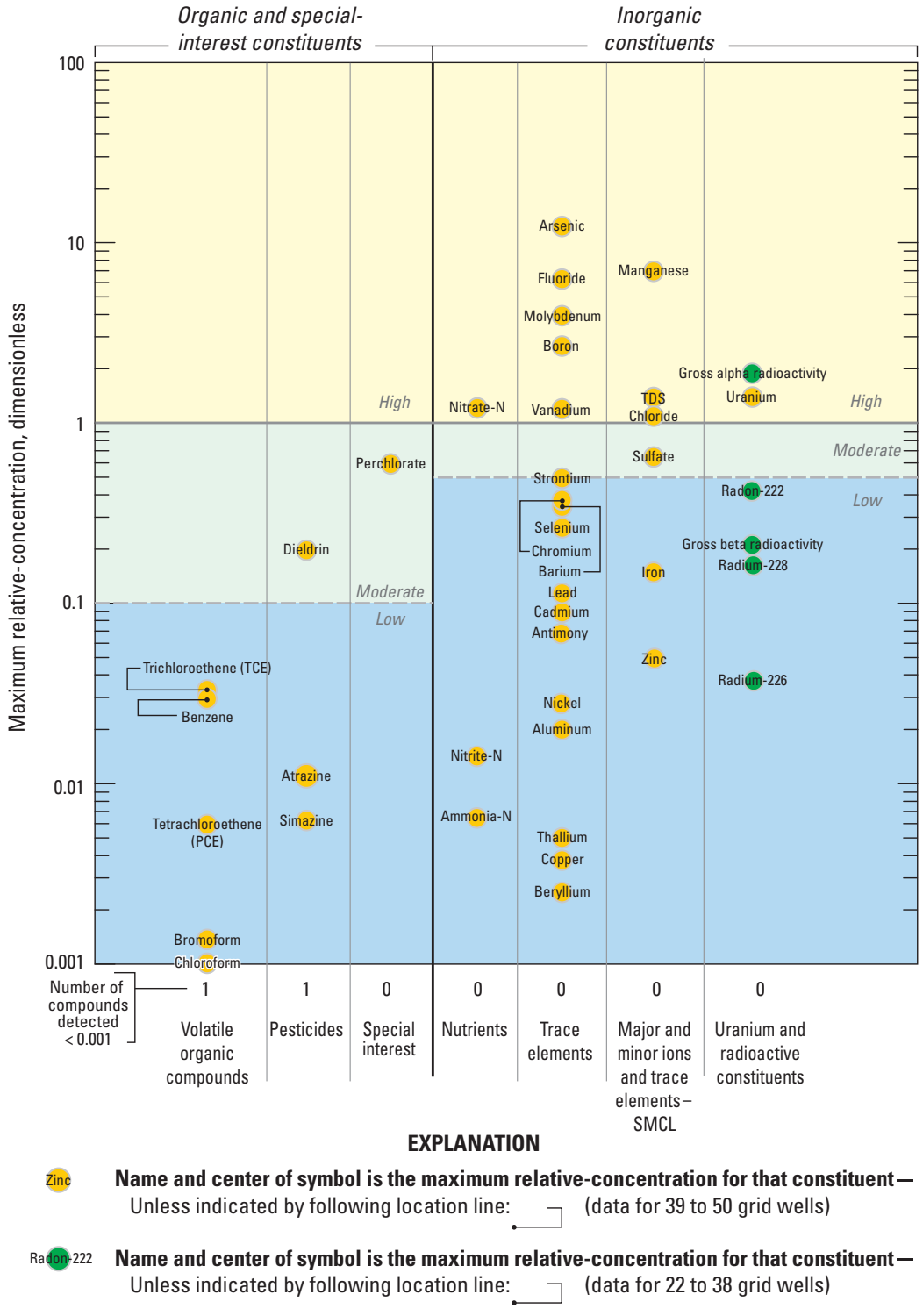
[1] Based on the most recent data for each CDPH well during the period December 3, 2005—December 1, 2008, combined with GAMA grid and understanding well data.

[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 6. Numbers of constituents analyzed and detected by the U.S. Geological Survey by constituent class and benchmark type, Borrego Valley, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008 to March 2010.

Benchmark type	Number of constituents	
	Analyzed	Detected
Volatile organic compounds (VOCs)		
Regulatory health-based	33	6
Non-regulatory health-based	25	0
No benchmark	27	0
Total:	85	6
Pesticides		
Regulatory health-based	3	2
Non-regulatory health-based	17	2
No benchmark	43	2
Total:	63	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	21	21
Non-regulatory health-based	5	5
Non-regulatory aesthetic-based	8	8
No benchmark	13	13
Total:	47	47
Geochemical and age-dating tracers		
Regulatory	2	2
Non-regulatory	0	0
No benchmark	13	13
Total:	15	15
All constituents		
Regulatory health-based	60	32
Non-regulatory health-based	48	7
Non-regulatory aesthetic-based	8	8
No benchmark	96	28
Total:	212	75



EXPLANATION

Zinc **Name and center of symbol is the maximum relative-concentration for that constituent—** Unless indicated by following location line: (data for 39 to 50 grid wells)

Radon-222 **Name and center of symbol is the maximum relative-concentration for that constituent—** Unless indicated by following location line: (data for 22 to 38 grid wells)

Figure 8. Maximum relative-concentrations of constituents detected in grid wells, by constituent class, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, December 2008–March 2010.

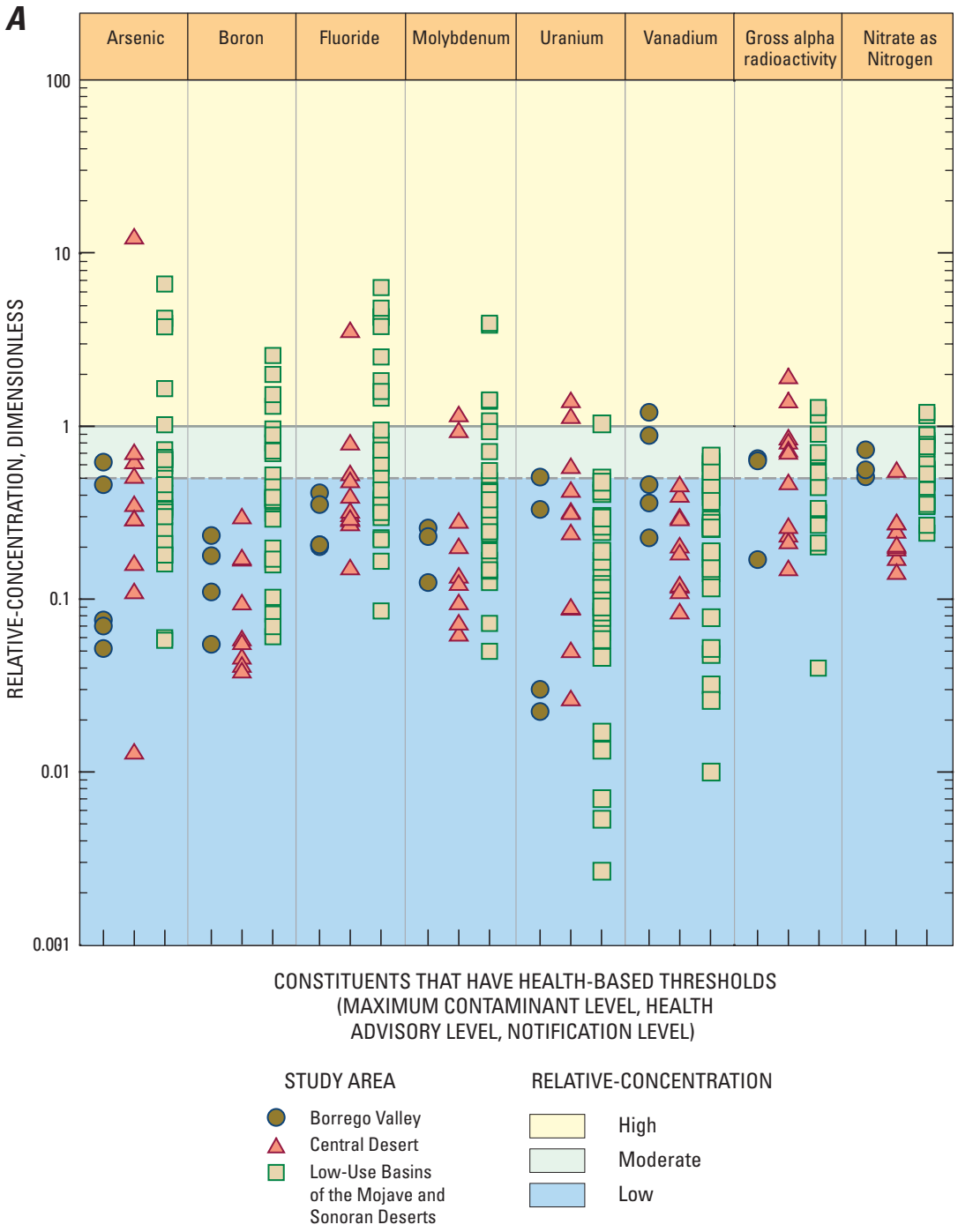


Figure 9. Relative-concentrations of inorganic constituents in samples from grid wells with (*A*) health-based or (*B*) aesthetic benchmarks categorized as high, medium, or low in grid wells, Borrego, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project, December 2008–March 2010.

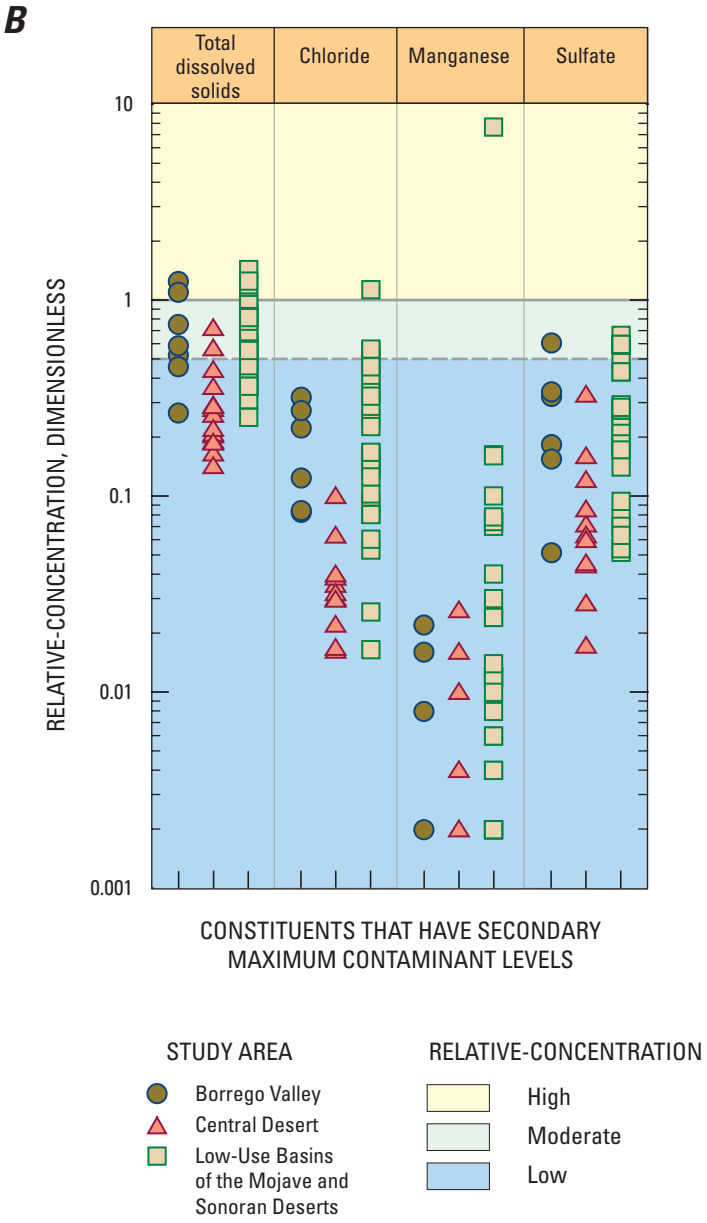


Figure 9. —Continued

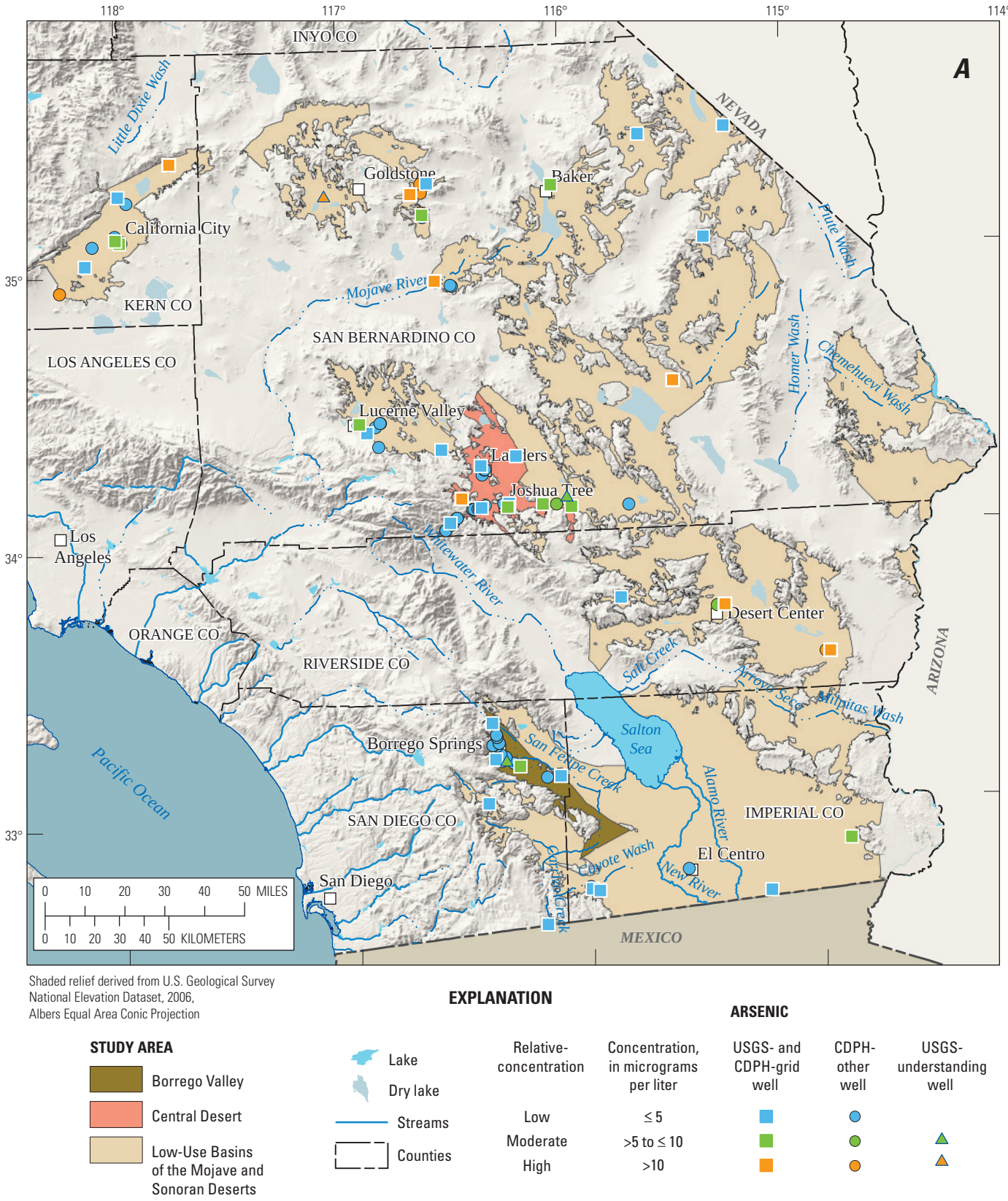
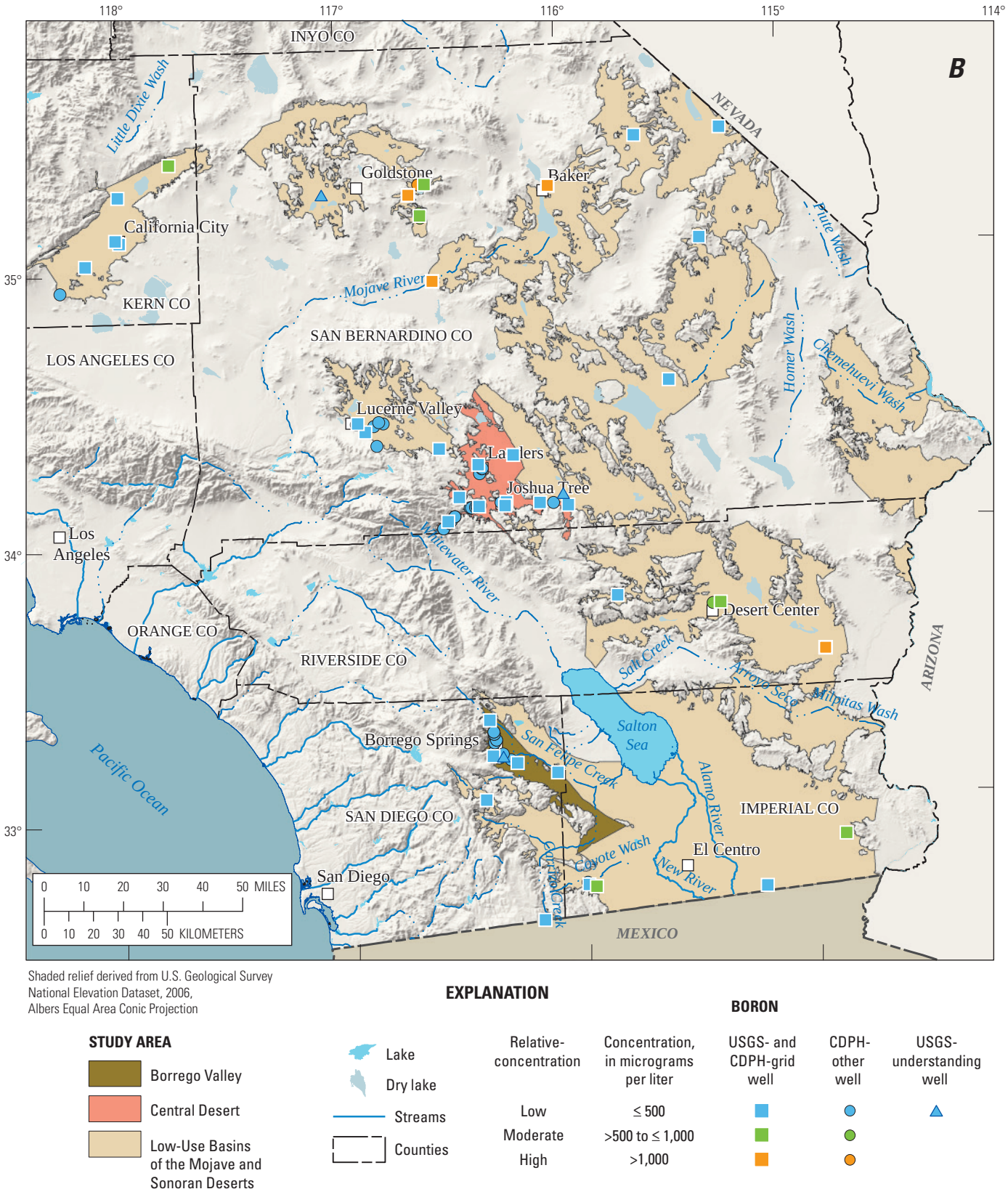


Figure 10. Relative-concentrations of selected inorganic constituents for the U.S. Geological Survey (USGS) grid wells and California Department of Public Health (CDPH) wells (data from the period December 3, 2005–December 1, 2008), Borrego, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project: (*A*) arsenic, (*B*) boron, (*C*) fluoride, (*D*) molybdenum, (*E*) uranium, (*F*) gross alpha radioactivity, (*G*) nitrate, (*H*) total dissolved solids, (*I*) chloride, (*J*) iron, and (*K*) manganese.



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

EXPLANATION

STUDY AREA

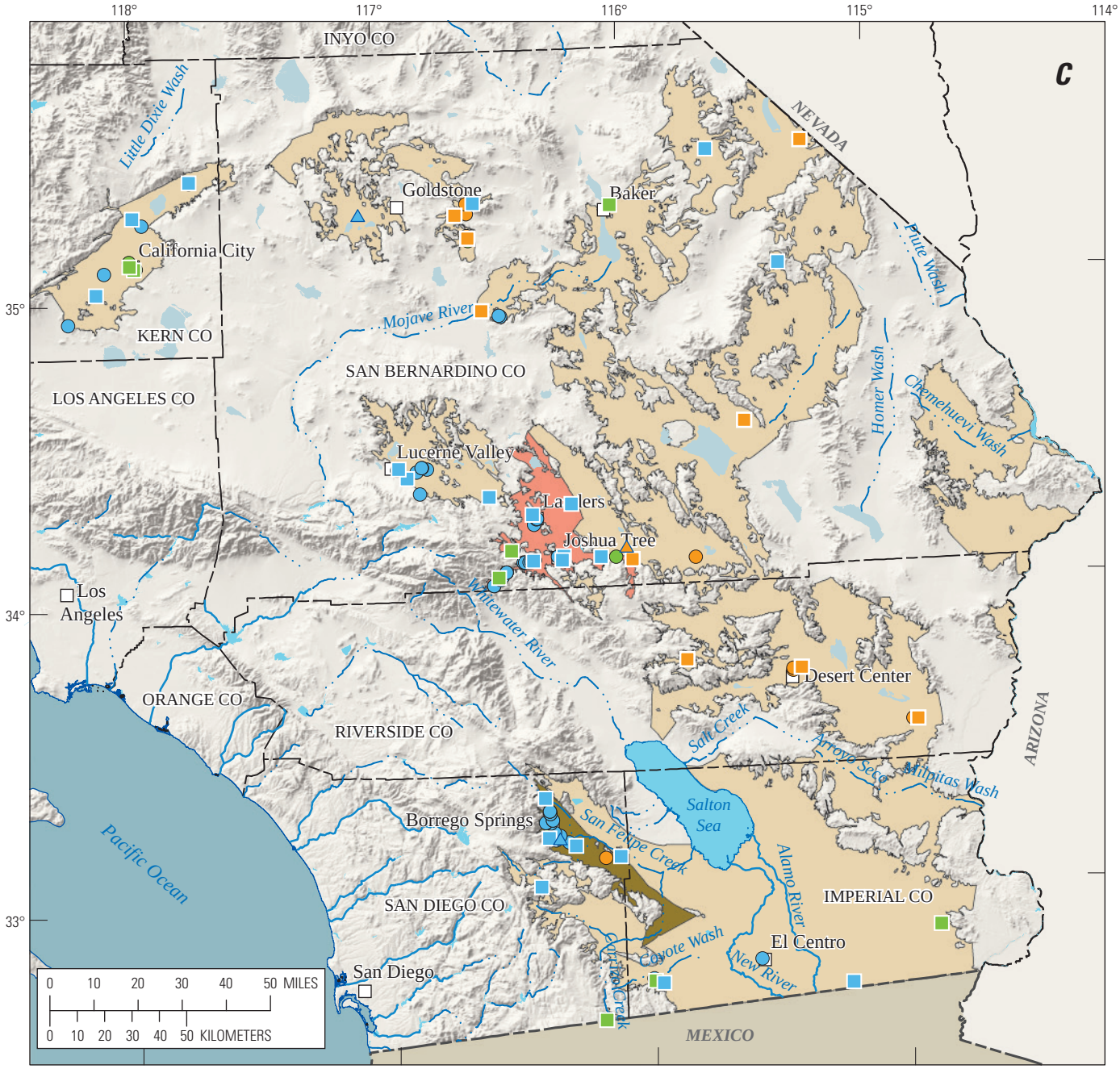
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

BORON

Relative-concentration	Concentration, in micrograms per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 500	■	●	▲
Moderate	>500 to ≤ 1,000	■	●	
High	>1,000	■	●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

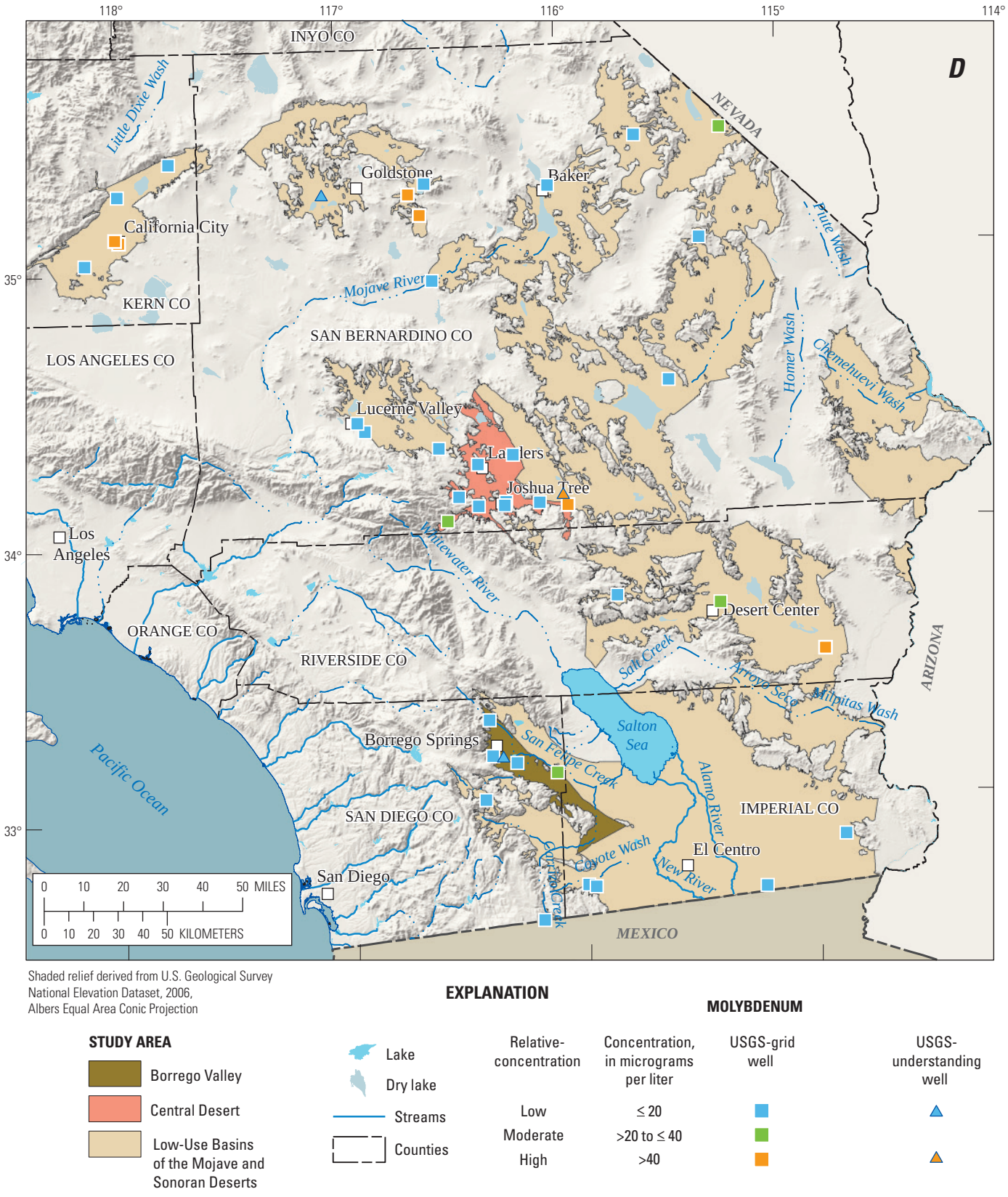
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

FLUORIDE

Relative-concentration	Concentration, in milligrams per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 1	■	●	▲
Moderate	>1 to ≤ 2	■	●	
High	>2	■	●	▲

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

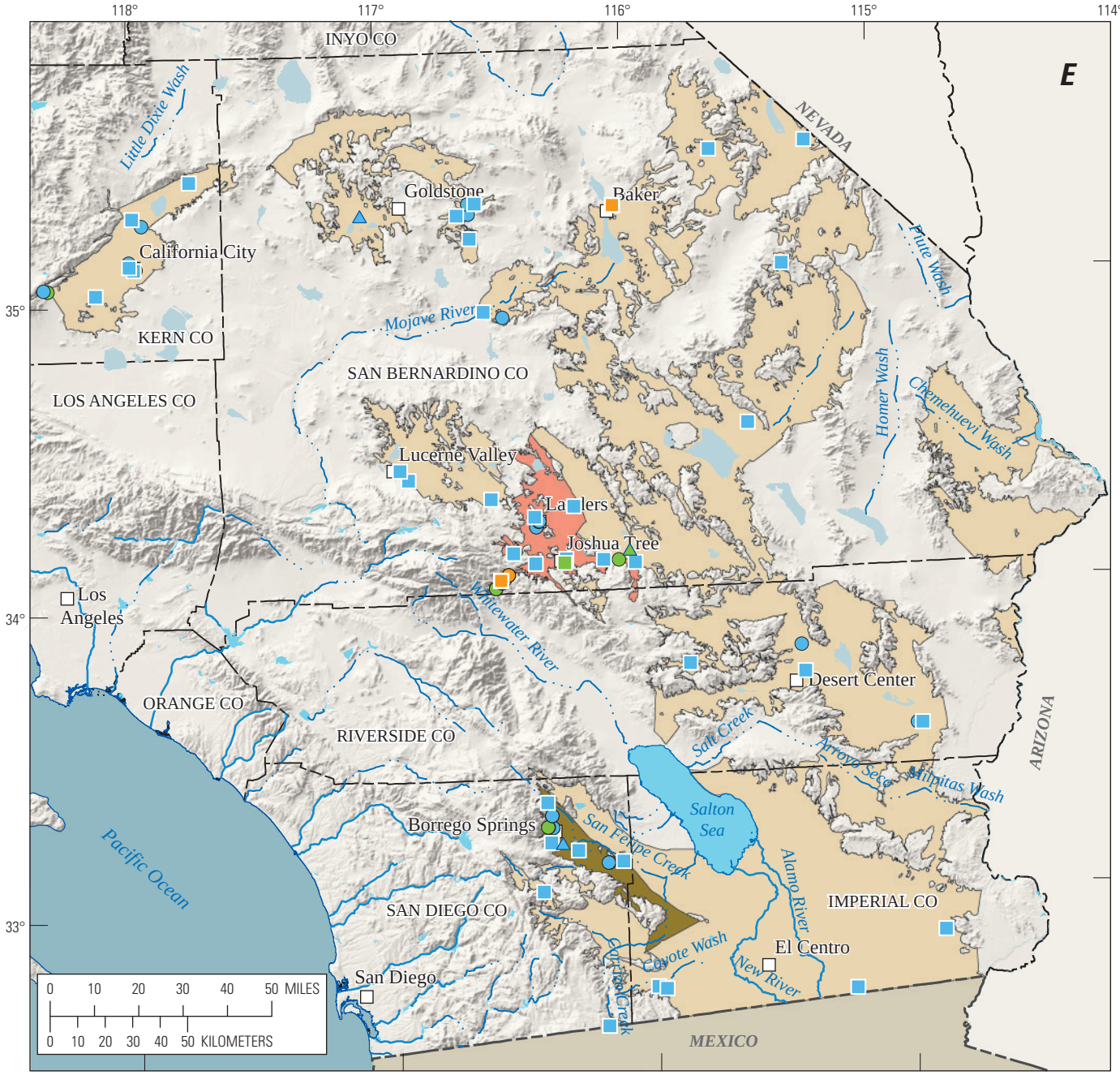
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

MOLYBDENUM

Relative-concentration	Concentration, in micrograms per liter	USGS-grid well	USGS-understanding well
Low	≤ 20	■	▲
Moderate	>20 to ≤ 40	■	
High	>40	■	▲

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

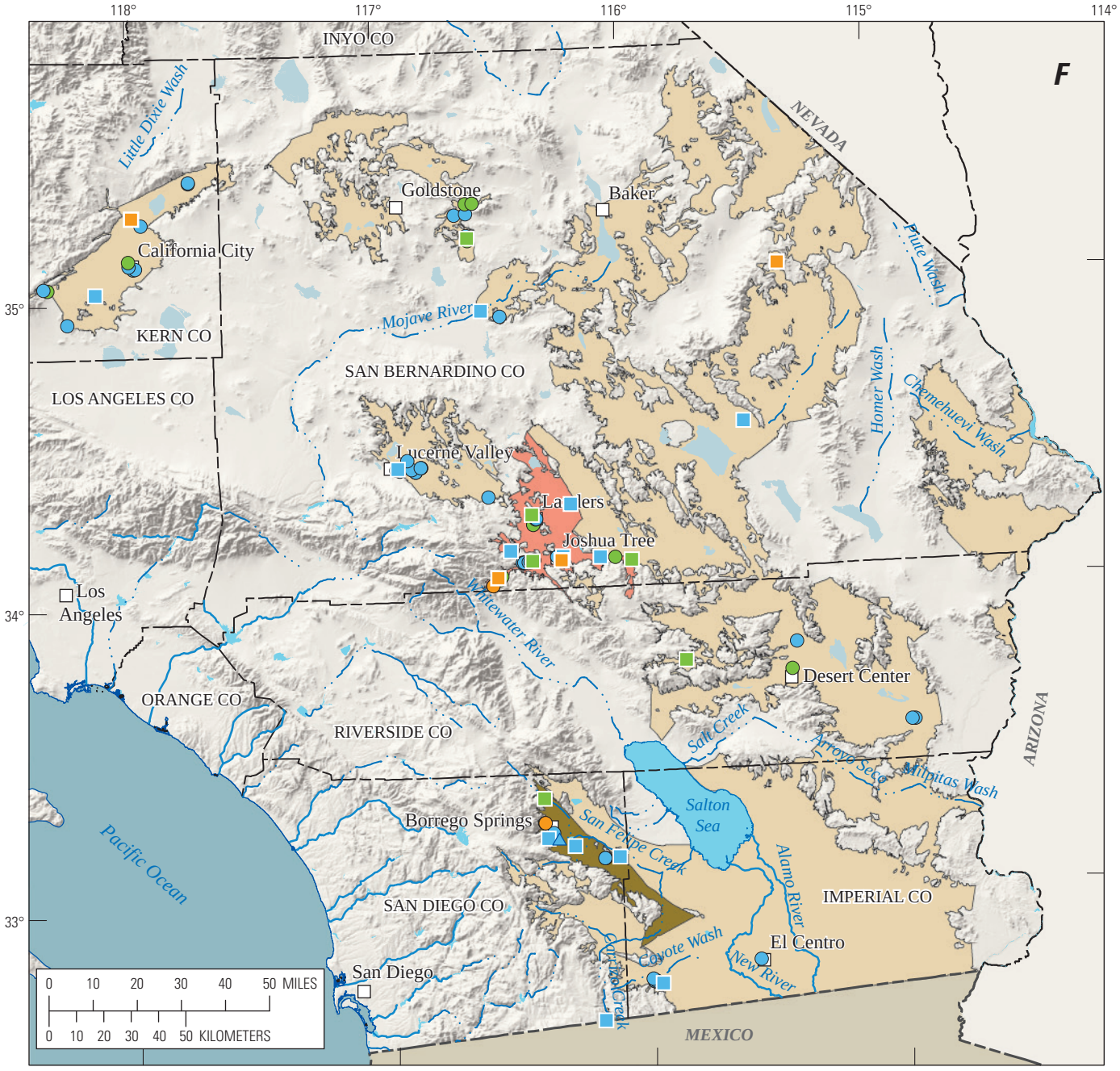
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

URANIUM

Relative-concentration	Concentration, in micrograms per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 15	■	●	▲
Moderate	>15 to ≤ 30	■	●	▲
High	>30	■	●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

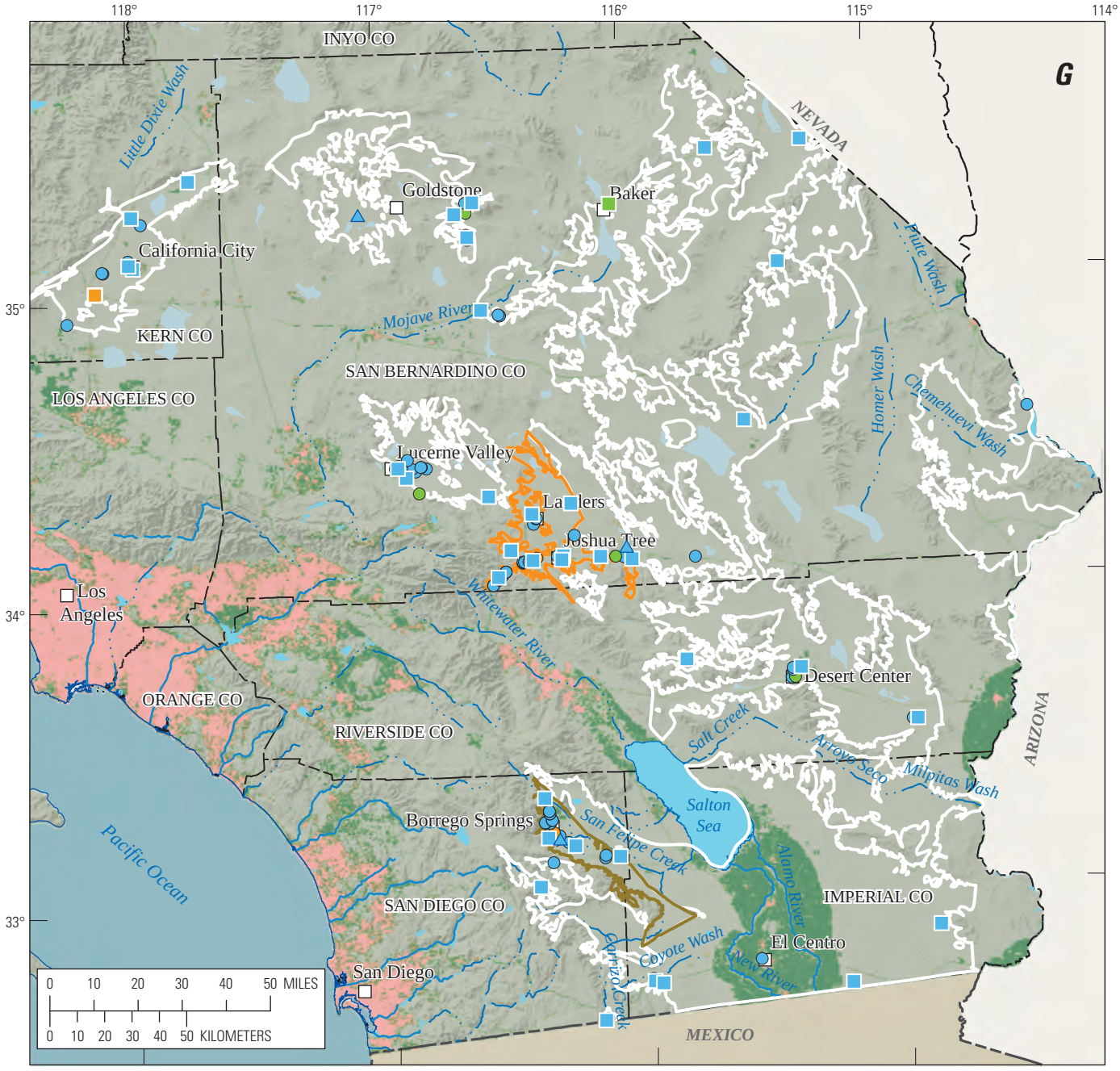
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

GROSS ALPHA RADIOACTIVITY (72-HOUR COUNT)

Relative-concentration	Concentration, in picocuries per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 7.5	■	●	▲
Moderate	>7.5 to ≤ 15	■	●	
High	>15	■	●	

Figure 10. —Continued



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

EXPLANATION

LAND-USE CLASSIFICATION

- Urban
- Agricultural
- Natural

STUDY AREA

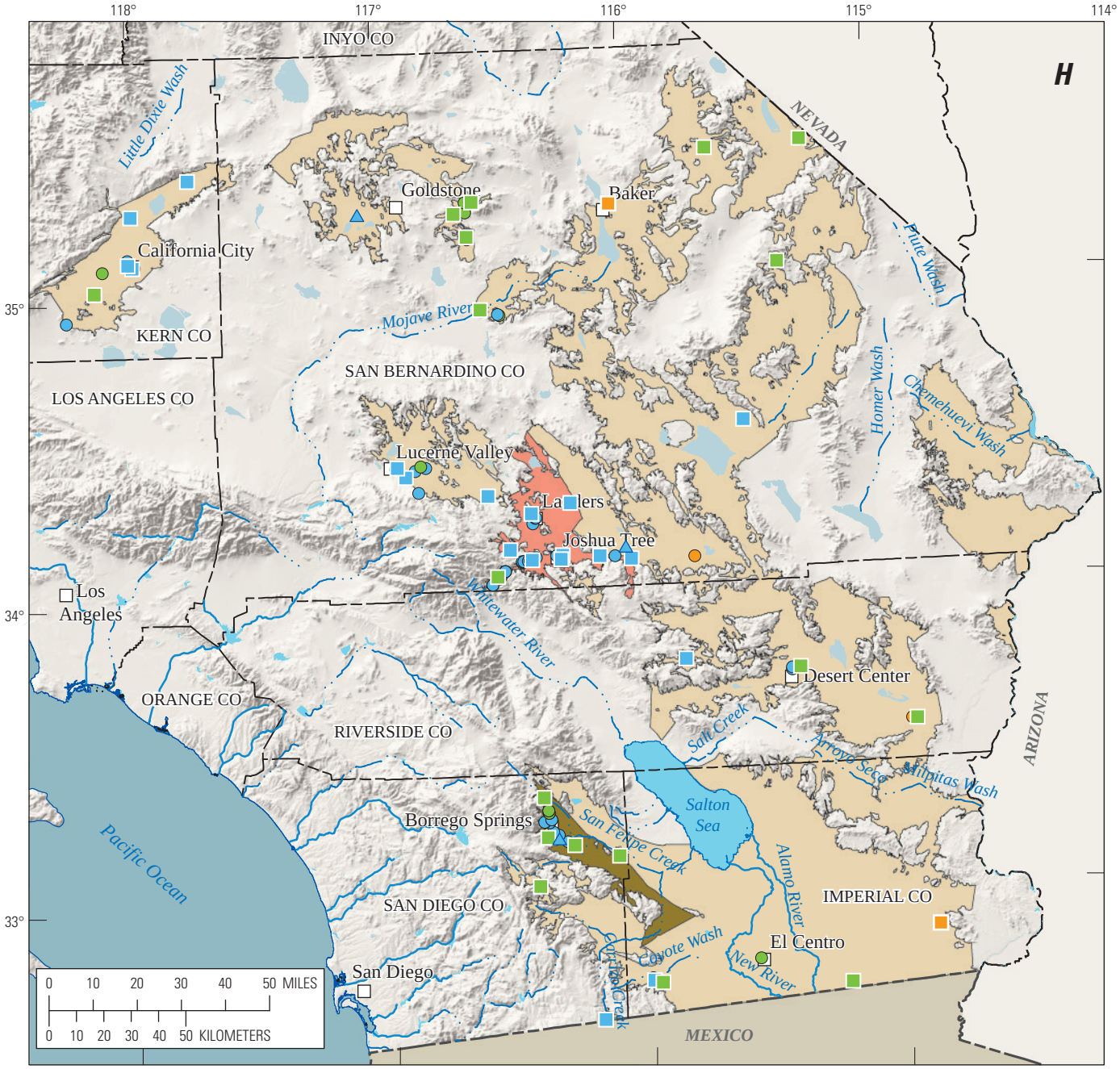
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

NITRATE, AS NITROGEN

Relative-concentration	Concentration, in milligrams per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 5	■	●	▲
Moderate	>5 to ≤ 10	■	●	
High	>10	■	●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

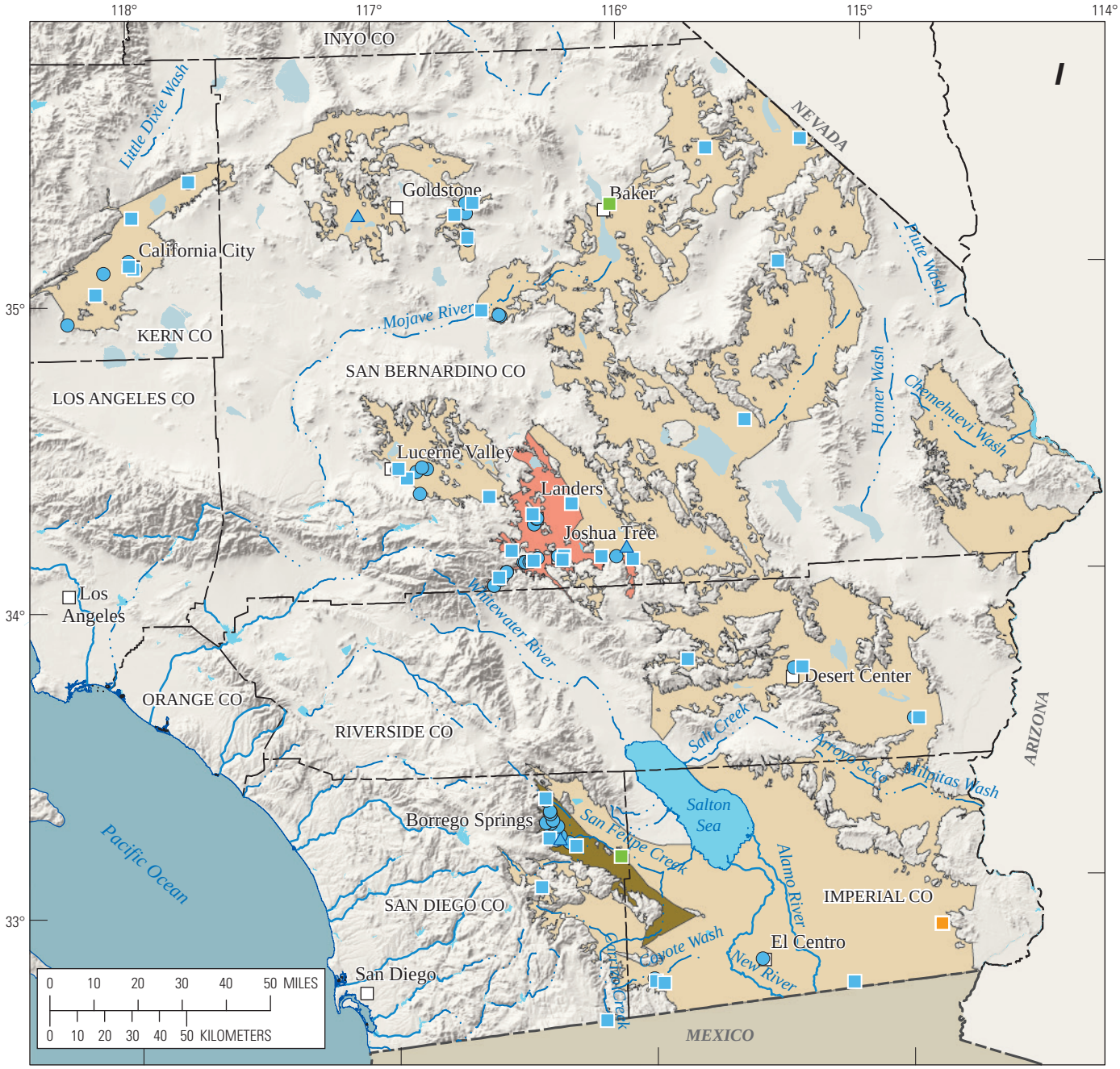
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

TOTAL DISSOLVED SOLIDS (TDS)

Relative-concentration	Concentration, in milligrams per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 500	■	●	▲
Moderate	>500 to ≤ 1,000	■	●	
High	>1,000	■	●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

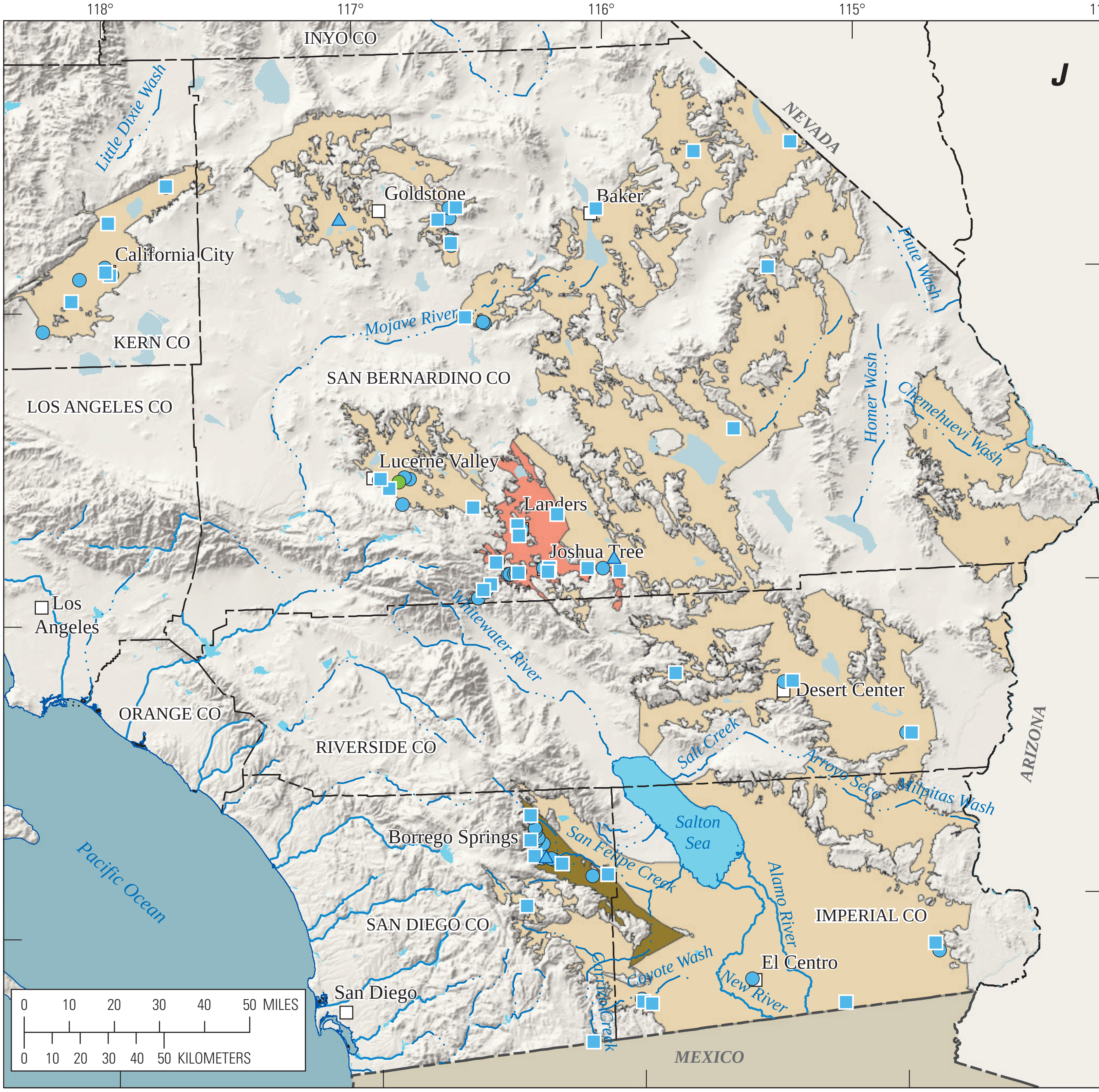
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

CHLORIDE

Relative-concentration	Concentration, in milligrams per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 250	■	●	▲
Moderate	>250 to ≤ 500	■	●	
High	>500	■	●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

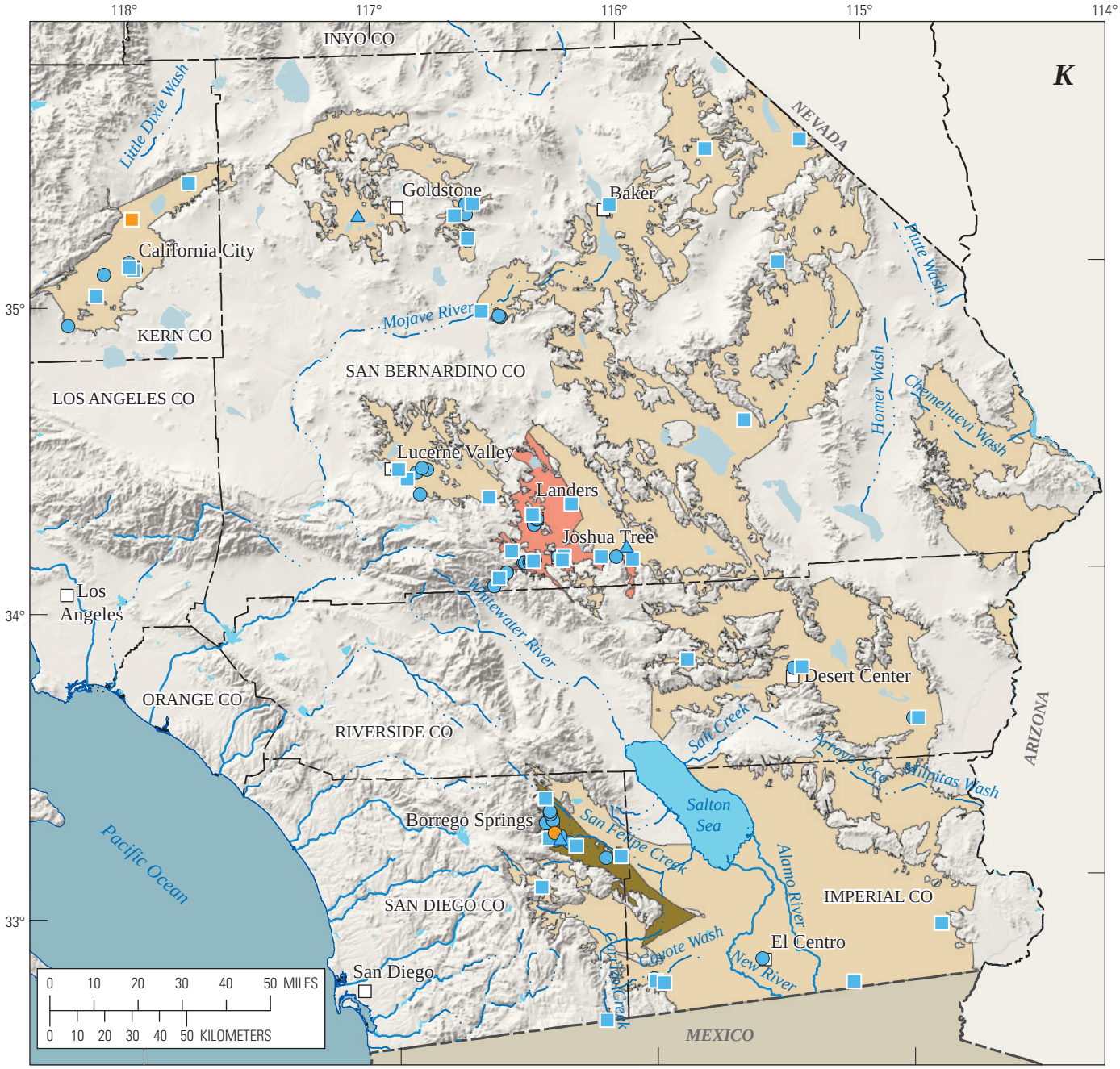
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

IRON

Relative-concentration	Concentration, in micrograms per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 150	■	●	▲
Moderate	>150 to ≤ 300	■	●	
High	>300		●	

Figure 10. —Continued



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

EXPLANATION

STUDY AREA

- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

MANGANESE

Relative-concentration	Concentration, in micrograms per liter	USGS- and CDPH-grid well	CDPH-other well	USGS-understanding well
Low	≤ 25	■	●	▲
Moderate	>25 to ≤ 50			
High	>50	■	●	

Figure 10. —Continued

Table 7A. Aquifer-scale proportions for inorganic constituent classes, Borrego Valley, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008–March 2010.

[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. SMCL, secondary maximum contaminant level]

Constituent class	Aquifer-scale proportion		
	Low relative-concentration (percent)	Moderate relative-concentration (percent)	High relative-concentration (percent)
Inorganic constituents with health-based benchmarks			
Trace and minor elements	35	23	42
Uranium and radioactive constituents [1]	68	20	12
Nutrients	95	2.7	2.7
Total for inorganic constituents with health-based benchmarks [1]	26	26	48
Inorganic constituents with SMCL benchmarks			
Salinity Indicators [2]	50	39	11
Manganese and (or) iron	95	[3] 1.9	2.8
Total for inorganic constituents with aesthetic benchmarks	48	39	13

[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.

[3] Spatially weighted result. Grid-based result was 0 percent.

Table 7B. Aquifer-scale proportions for organic constituent classes, Borrego Valley, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008–March 2010.

[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]

Constituent class	Aquifer-scale proportion			
	Low relative-concentration (percent)		Moderate relative-concentration (percent) [1]	High relative-concentration (percent)
	Not detected	Detected low [2]		
Gasoline hydrocarbons	97	1.9	0.9	0
Solvents	82	16	1.4	0
Trihalomethanes	71	27	2.2	0
Any volatile organic compound (VOC)	61	37	2.2	0
Insecticides	99	0	1.4	0
Any pesticide	90	8.2	1.4	0
Total for organic constituents with health-based benchmarks	60	35	5.0	0

[1] Proportions for moderate relative-concentrations were calculated using the spatially weighted approach.

[2] Proportions for low relative-concentrations were calculated by subtracting the spatially weighted moderate proportion from the area-weighted detection frequency in the USGS-grid wells.

Trace and Minor Elements

Trace and minor elements, as a class, had high relative-concentrations (for one or more constituents) in 42 percent of the primary aquifer system, moderate relative-concentrations in 23 percent, and low relative-concentrations in 35 percent (table 7A). High relative-concentrations of trace and minor elements result from the high relative-concentrations of fluoride (27 percent), arsenic (18 percent), molybdenum (16 percent), boron (10 percent), and vanadium (1.5 percent) (table 5). One trace element, chromium, had spatially weighted high relative-concentrations in 0.4 percent of the aquifer area, which was within the 90-percent confidence interval for this element for the grid-based approach (table 5). The spatially weighted approach includes data from a larger number of wells than the grid-based approach, and therefore is more sensitive to detecting constituents present at very low proportions of the primary aquifer system.

The trace elements antimony, lead, and selenium had high relative-concentrations in at least one well reported in the CDPH database before December 3, 2005 (table 4), but not during the current period of study (December 3, 2005–December 1, 2008); these high values represent historical values rather than current values.

Arsenic was detected at high relative-concentrations in 18 percent of the primary aquifer system, and at moderate relative-concentrations in 23 percent (table 5). It was detected at high relative-concentrations in the CD and LUB study areas (figs. 9*A*, 10*A*). The highest relative-concentration was in the CD study area (fig. 9*A*). In the LUB study area, high and moderate relative-concentrations were distributed throughout the area (fig. 10*A*).

Boron was detected at high relative-concentrations in 10 percent of the primary aquifer system, and at moderate relative-concentrations in 17 percent (table 5). High and moderate relative-concentrations of boron occurred only in the LUB study area (figs. 9*A*, 10*B*).

Fluoride, a minor ion, was detected at high relative-concentrations in 27 percent of the primary aquifer system and at moderate relative-concentrations in 22 percent (table 5). Fluoride was detected at high and moderate relative-concentrations in all three study areas (figs. 9*A*, 10*C*).

Molybdenum was detected at high relative-concentrations in 16 percent of the primary aquifer system and at moderate relative-concentrations in 10 percent (table 5). It was detected at high relative-concentrations in the CD and LUB study areas (figs. 9*A*, 10*D*).

Uranium and Radioactive Constituents

Uranium and radioactive constituents had high relative-concentrations for one or more constituents in 12 percent of the primary aquifer system, moderate relative-concentrations in 20 percent, and low relative-concentrations in 68 percent (table 7). The high and moderate relative-concentrations reflect detections of uranium and gross alpha radioactivity (table 5). The other radioactive constituents, such as radon-222, radium-226, and radium-228, were detected at low concentrations throughout the CLUB study unit. In addition, radium-226 and radium-228 were detected at high relative-concentrations in at least one well reported in the CDPH database before December 3, 2005, but not during the current period of study (table 4); these high values represent historical values rather than current values.

Uranium was detected at high relative-concentrations in 5.6 percent of the primary aquifer system and at moderate relative-concentrations in 4.3 percent (table 5). It was detected at high relative-concentrations in the CD and LUB study areas and at moderate relative-concentrations in all three study areas (figs. 9*A*, 10*E*). Uranium was detected at high relative-concentration in a grid well sampled by the CDPH during December 3, 2005, to December 1, 2008; however, this result was not the most recent value from the CDPH database representing that well and was not used in the status assessment.

Unadjusted gross alpha radioactivity was detected at high relative-concentrations in 9.7 percent of the primary aquifer system and at moderate relative-concentrations in 24 percent (table 5). It was detected at high and moderate relative-concentrations in grid wells in all three study areas (figs. 9*A*, 10*F*). Of the 14 wells with moderate or high relative-concentrations of gross alpha radioactivity, only 3 wells also had moderate or high relative-concentrations of uranium. Gross alpha radioactivity was detected at a high relative-concentration in one well by the CDPH during December 3, 2005, to December 1, 2008; however, this result was not the most recent value from the CDPH database representing that particular well.

Nutrients

Nutrients, as a class, were detected at high relative-concentrations in 2.7 percent of the primary aquifer system and at moderate relative-concentrations in 2.7 percent (table 7A) resulting from the detection of nitrate (table 5). Ammonia and nitrite were detected only at low concentrations. Nitrate was detected at high relative-concentrations in all three study areas and at moderate relative-concentrations in the CD and LUB study areas (figs. 9*A*, 10*G*).

Inorganic Constituents with Aesthetic Benchmarks

For selected constituents, the CDPH has established SMCL-CA benchmarks, which are non-enforceable benchmarks based on aesthetic properties rather than on health-based concerns. For TDS and the major ions chloride and sulfate, the CDPH defines a "recommended" and an "upper" SMCL-CA. The "upper" SMCL-CA benchmarks were used for computing relative-concentrations in this report. Inorganic constituents with SMCLs had high relative-concentrations in 13 percent of the primary aquifer system and moderate relative-concentrations in 39 percent of the primary aquifer system (table 7A).

TDS were detected at high relative-concentrations in 11 percent of the primary aquifer system and at moderate relative-concentrations in 41 percent (table 5). TDS were detected at moderate relative-concentrations in all study areas of the CLUB study unit, and at high relative-concentrations in the LUB study area (figs. 9*B*, 10*H*).

Chloride was detected at high relative-concentrations in 2.8 percent of the primary aquifer system and at moderate relative-concentrations in 4.2 percent (table 5). All samples having high or moderate relative-concentrations of chloride also had high or moderate relative-concentrations of TDS. Chloride had high and moderate relative-concentrations only in the LUB study area (figs. 9*B*, 10*I*).

Iron had spatially weighted high relative-concentrations in 2.9 percent of the primary system and spatially weighted moderate relative-concentrations in 1.9 percent (table 5). High relative-concentrations of iron were observed in all three study areas (fig. 10*J*). Iron was not detected at high or moderate relative-concentrations in the grid wells (fig. 8).

Manganese had high relative-concentrations in 2.8 percent of the primary aquifer system (table 5). High relative-concentrations of manganese were detected in the BV and LUB study areas (figs. 9*B*, 10*K*).

Organic Constituents

The organic constituents are organized into two classes: VOCs and pesticides. VOCs may be in paints, solvents, fuels, and refrigerants; VOCs also can be byproducts of water disinfection and are characterized by their volatile nature or tendency to evaporate. Pesticides are used to control weeds, insects, or fungi in agricultural, urban, and suburban settings.

Organic constituents, as a class, were not detected at high relative-concentrations in the primary aquifer system and were detected at moderate relative-concentrations in 5.0 percent of the primary aquifer system (table 7B). The trihalomethane chloroform and the solvent tetrachloroethene (PCE) were detected in more than 10 percent of the primary aquifer system (figs. 11, 12). The spatial distributions of the detections of PCE and chloroform are illustrated on maps showing data for USGS-grid and USGS-understanding wells from December 2008 to March 2010 and for CDPH-grid wells and other wells from December 3, 2005, to December 1, 2008 (figs. 13*A*,*B*). Of the 148 organic constituents analyzed for in the CLUB study unit, 12 were detected (table 6). Of these 12 organic constituents detected, 10 had regulatory or non-regulatory health-based benchmarks (fig. 11; table 6). The individual constituents that were not detected and the wells that were sampled in the study unit are listed in Mathany and others (2012).

Volatile Organic Compounds (VOCs)

VOCs were not detected at high relative-concentrations in the primary aquifer system and were detected at moderate relative-concentrations in 2.2 percent (table 7B). The area-weighted detection frequency of VOCs (one or more) in the CLUB primary aquifer system was 39 percent. Six VOCs with health-based benchmarks were detected in USGS-grid wells at low relative-concentrations only (fig. 11). The solvent tetrachloroethene (PCE) and the gasoline hydrocarbon benzene were reported at moderate relative-concentrations in one well each in the CDPH database between December 3, 2005, and December 1, 2008, and the trihalomethanes chloroform, dibromochloromethane, and (or) bromoform were reported at moderate relative-concentrations in five CDPH wells. PCE and the trihalomethane chloroform were the only VOCs with area-weighted detection frequencies greater than 10 percent in the primary aquifer system (figs. 11–13). Both are among the most commonly detected VOCs in groundwater nationally (Zogorski and others, 2006).

Solvents are used for various industrial, commercial, and domestic purposes. The solvent PCE had a spatially weighted moderate aquifer-scale proportion of 1.4 percent (tables 5, 7B). Gasoline hydrocarbons are used to increase the efficiency of combustion of fuels. The hydrocarbon benzene had a spatially weighted moderate aquifer-scale proportion of 0.9 percent (tables 5, 7B).

Water used for drinking water in domestic and municipal systems commonly is disinfected with chlorine solutions (bleach). As a side effect of disinfection, the chlorine reacts with organic matter and dissolved bromide to produce trihalomethanes (THMs) and other disinfection byproducts. Chloroform, dibromochloromethane, and bromoform had spatially weighted moderate aquifer-scale proportions of 1.2, 1.4, and 1.4 percent, respectively (table 5), and the moderate aquifer-scale proportion for THMs as a class was 2.2 percent (table 7B).

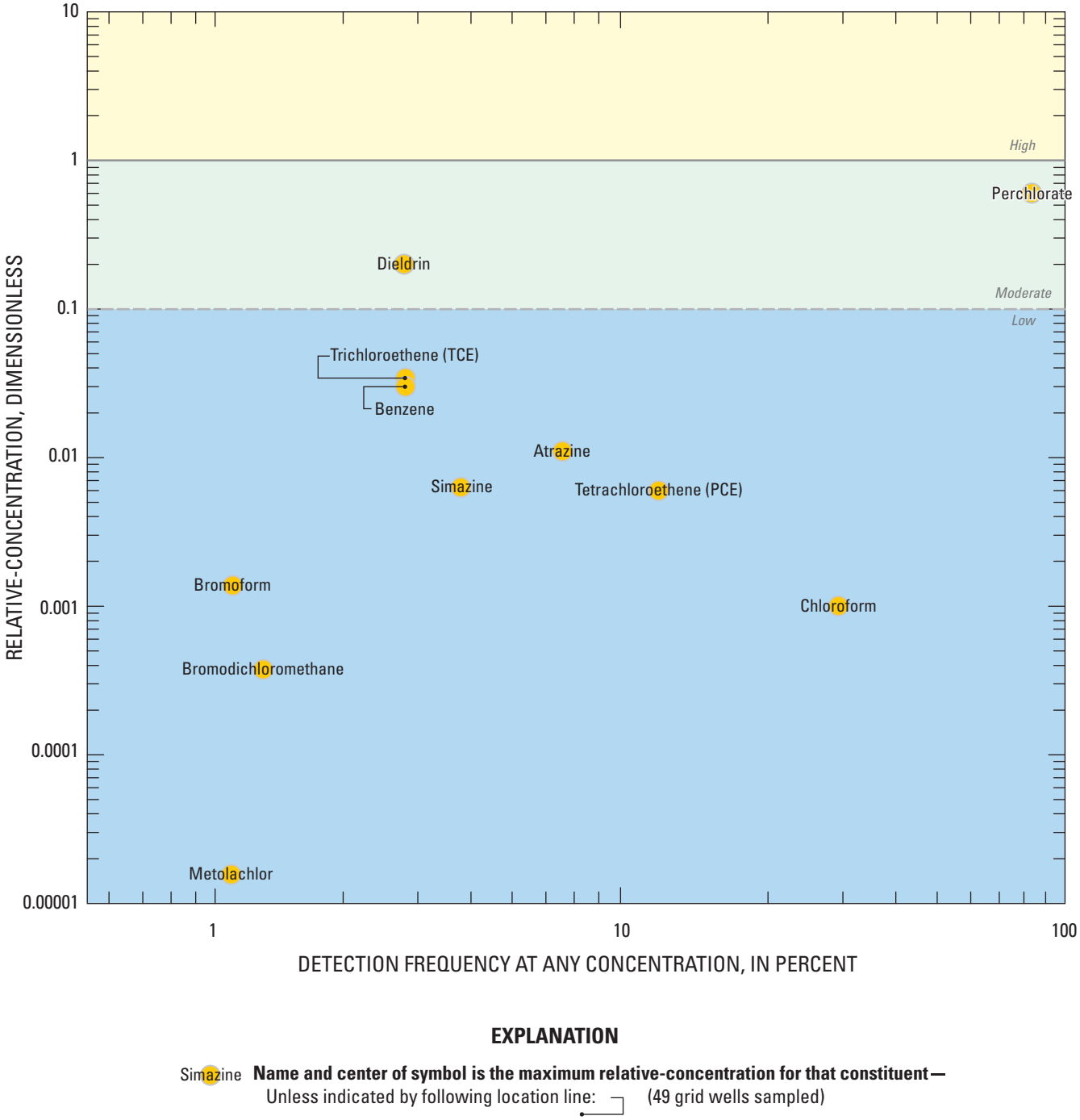


Figure 11. Detection frequency and maximum relative-concentration of organic and special-interest constituents detected in USGS-grid wells in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

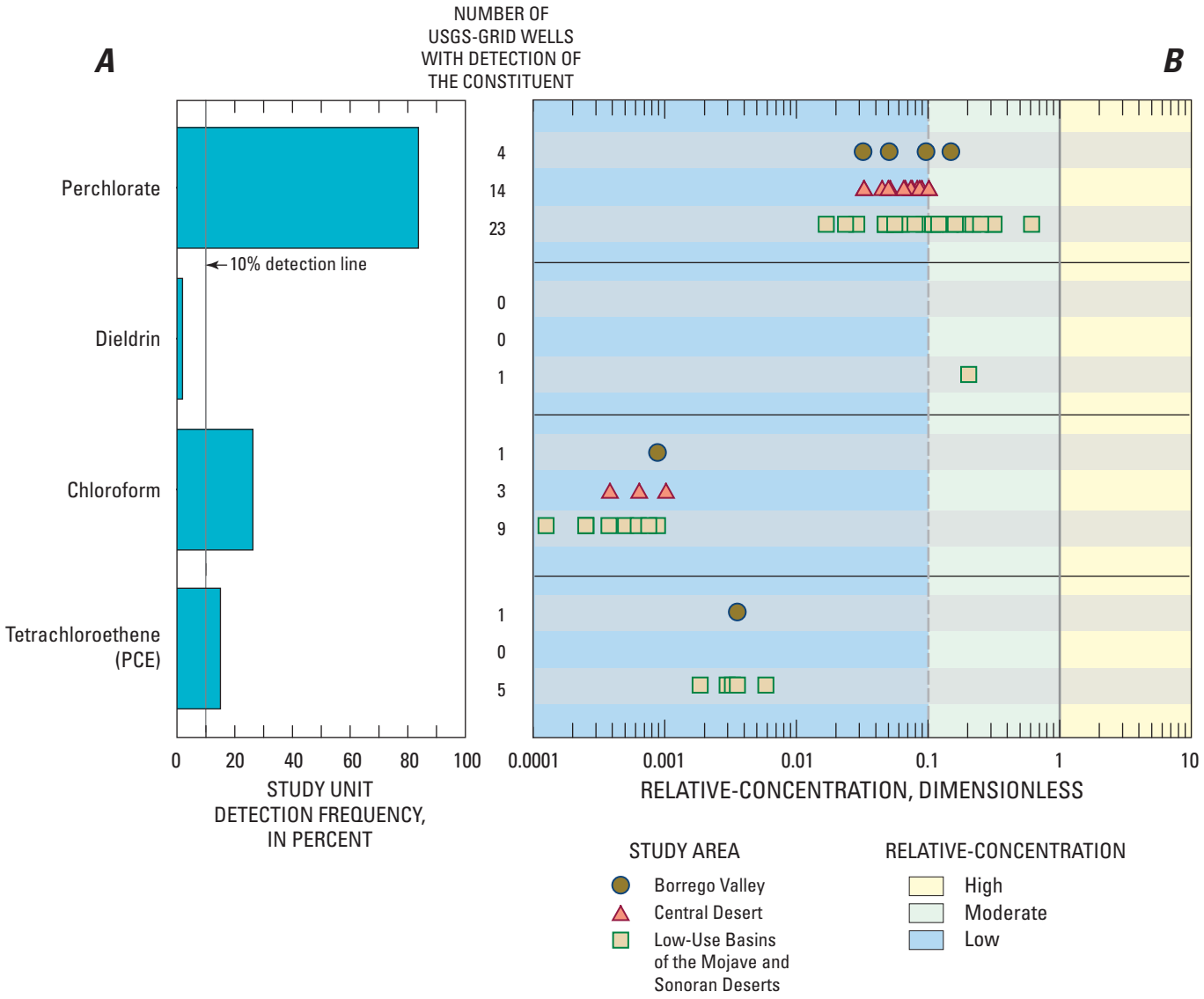
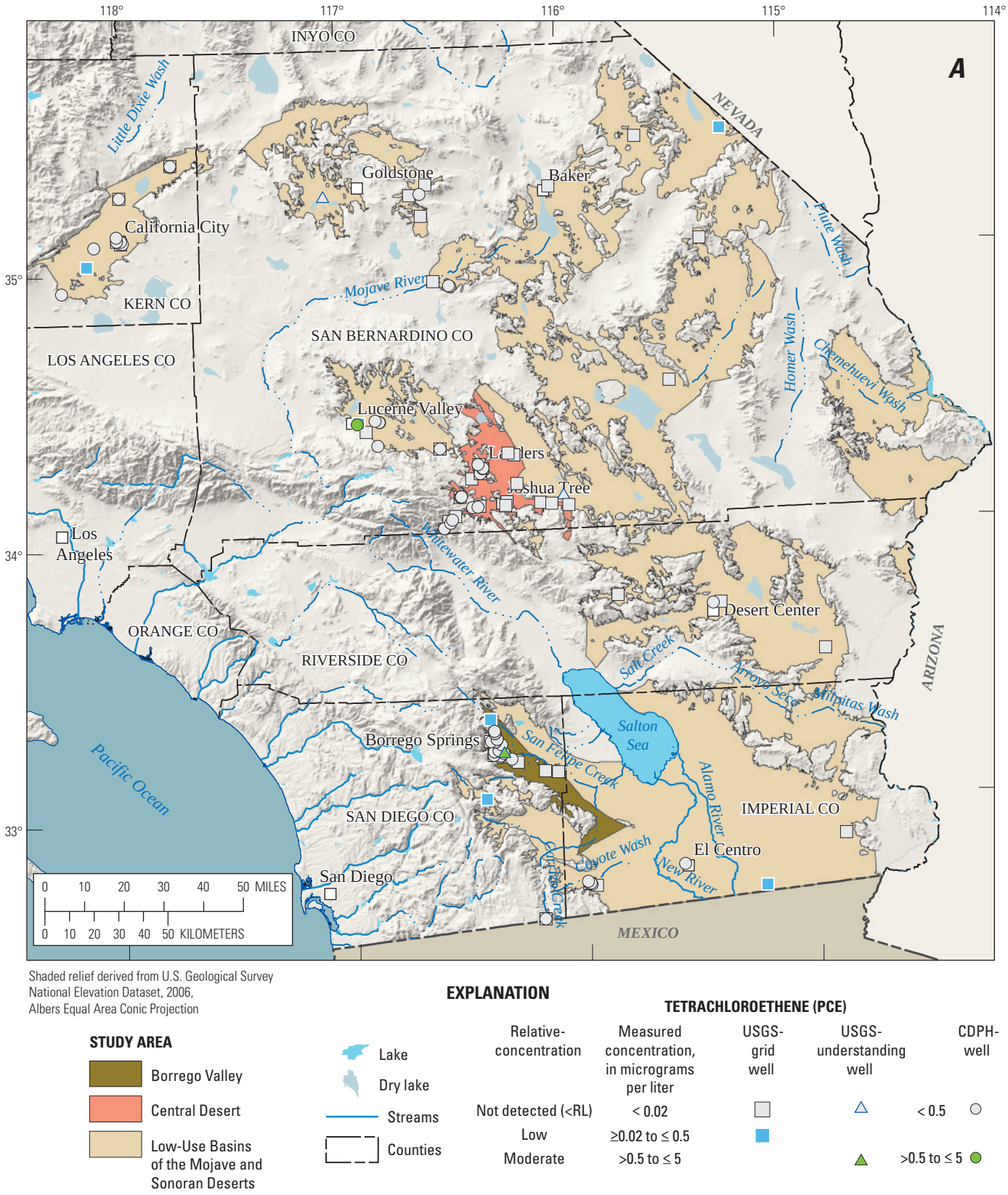


Figure 12. (*A*) Detection frequency and (*B*) relative-concentrations of selected organic and special-interest constituents in grid wells in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.



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

EXPLANATION

STUDY AREA

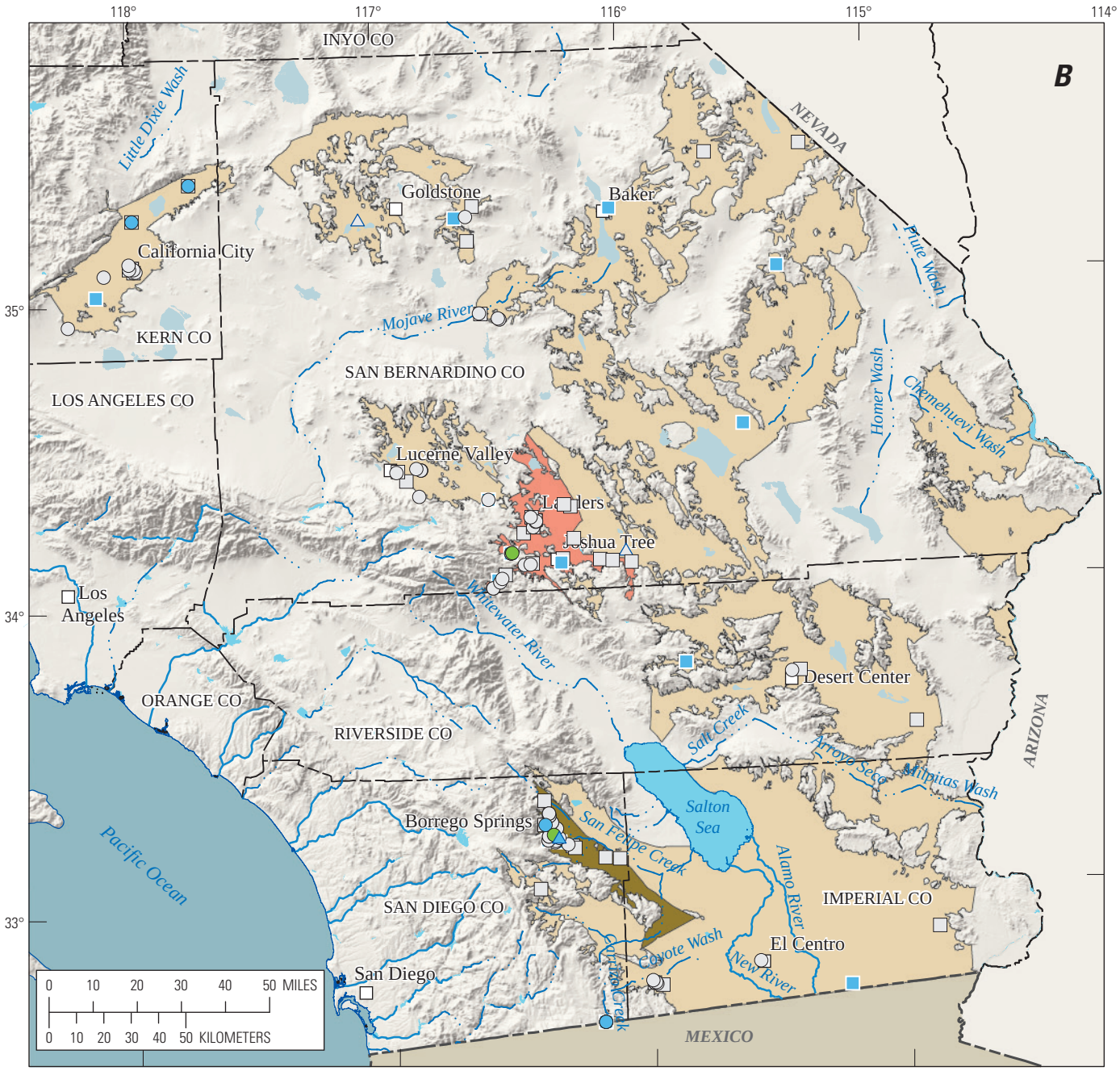
- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

TETRACHLOROETHENE (PCE)

Relative-concentration	Measured concentration, in micrograms per liter	USGS-grid well	USGS-understanding well	CDPH-well
Not detected (<RL)	< 0.02	□	△	< 0.5 ○
Low	≥0.02 to ≤ 0.5	■		
Moderate	>0.5 to ≤ 5		▲	>0.5 to ≤ 5 ●

Figure 13. Concentrations of selected organic and special-interest constituents in the U.S. Geological Survey (USGS) grid wells and California Department of Public Health (CDPH) wells (data from the period December 3, 2005–December 1, 2008), Borrego, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project: (*A*) tetrachloroethene (PCE), (*B*) chloroform, and (*C*) perchlorate.



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

STUDY AREA

- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

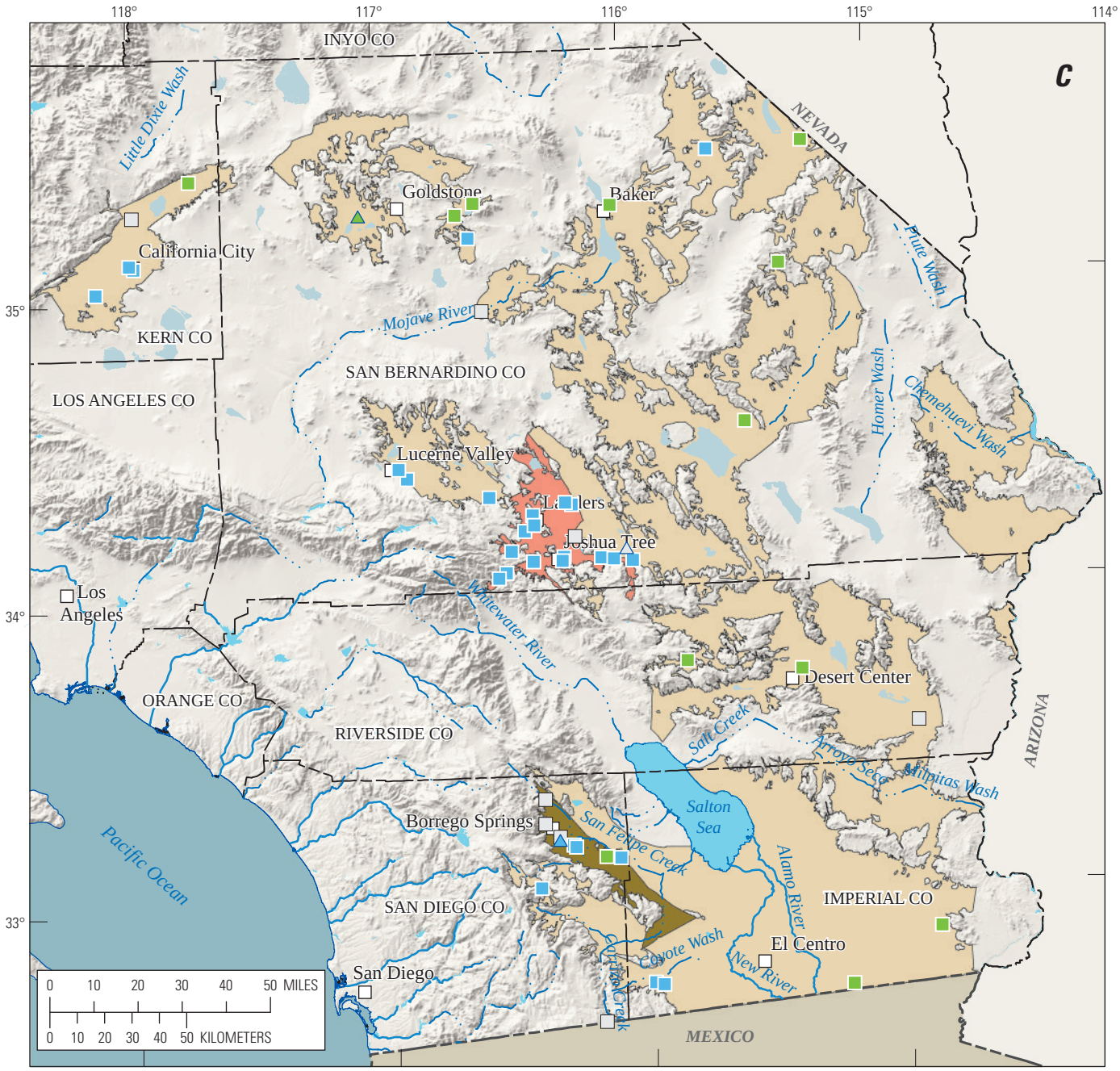
EXPLANATION

- Lake
- Dry lake
- Streams
- Counties

CHLOROFORM

Relative-concentration	Measured concentration, in micrograms per liter	USGS-grid well	USGS-understanding well	CDPH-well
Not detected (<RL)	<0.01	□	△	<0.5 ○
Low	≥0.01 to ≤ 8	■	▲	
Moderate				>0.5 to ≤ 5 ●

Figure 13. —Continued



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

EXPLANATION

STUDY AREA

- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties

PERCHLORATE

Relative-concentration	Measured concentration, in micrograms per liter	USGS-grid well	USGS-understanding well
Not detected (<RL)	<0.1	□	△
Low	≥0.1 to ≤0.6	■	▲
Moderate	>0.6 to ≤6	■	▲

Figure 13. —Continued

Pesticides

Pesticides were not detected at high relative-concentrations in the primary aquifer system, and were detected at moderate relative-concentrations in 1.4 percent (table 7B). The area-weighted detection frequency of pesticides (one or more) in the primary aquifer system was 9.6 percent (table 7B). Three herbicides were detected in USGS-grid wells at low relative-concentrations, and the insecticide dieldrin was detected at moderate relative-concentrations (fig. 11). No individual pesticide constituent had an area-weighted detection frequency greater than 10 percent.

No detections of pesticides were reported in the CDPH database from December 3, 2005, to December 1, 2008. High values for the insecticide aldrin and the degradate aldicarb sulfone were recorded in the CDPH database for the period before December 3, 2005 (table 4), but not during the current period of study. Aldrin is an organochlorine insecticide that was widely used until the 1970s to treat seed and soil. Aldicarb sulfone is a degradate of the carbamate insecticide and pesticide aldicarb.

Special-Interest Constituents

The special-interest constituents analyzed for in the CLUB study unit were perchlorate and *N*-nitrosodimethylamine (NDMA). When the USGS began sampling for the GAMA Priority Basin Project in 2004, these constituents were selected as special-interest constituents because they recently had been detected in drinking-water supplies or were considered to have the potential to reach drinking-water supplies (California Department of Public Health, 2008a,b). An MCL-CA benchmark for perchlorate was promulgated in 2007. Perchlorate was not detected at high relative-concentrations in the primary aquifer system and was detected at moderate relative-concentrations in 32 percent of the primary aquifer system (table 5). Perchlorate was detected at moderate or low relative-concentrations in 84 percent of the primary aquifer system (figs. 11, 12). Moderate relative-concentrations of perchlorate were detected in the BV and LUB study areas, and low relative-concentrations were detected in all three study areas (fig. 13*C*). NDMA, a semi-volatile organic chemical, was not detected in the grid wells sampled (Mathany and others, 2012).

Summary

Groundwater quality in the approximately 963-square-mile Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts (CLUB) study unit, which includes the Borrego Valley (BV), Central Desert (CD), and Low-Use Basins of the Mojave and Sonoran Desert (LUB) study areas, was investigated as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The CLUB study was designed to provide a spatially unbiased characterization of untreated groundwater quality in the primary aquifer system within this study unit. The assessment is based on water-quality and ancillary data collected during 2008–2010 by the U.S. Geological Survey (USGS) from 51 wells and on water-quality data from the California Department of Public Health (CDPH) database (for the period December 3, 2005–December 1, 2008).

The status of the current quality of the groundwater resource was assessed by evaluating data from samples analyzed for volatile organic compounds (VOCs), pesticides, and naturally occurring inorganic constituents such as major ions and trace elements. The status assessment characterizes the quality of groundwater resources in the primary aquifer system of the BV, CD, and LUB study areas, 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 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 proportions for individual constituents and classes of constituents. Grid-based and spatially weighted estimates were comparable in the CLUB study unit (within 90-percent confidence intervals). The spatially weighted approach is more likely to reflect concentrations of a constituent that is high in a small fraction of the primary aquifer system.

Relative-concentrations of one or more inorganic constituents with health-based benchmarks were high in 48 percent of the primary aquifer system, moderate in 26 percent, and low (or not detected) in 26 percent. The high aquifer-scale proportion of inorganic constituents with health-based benchmarks primarily reflected high aquifer-scale proportions of fluoride (27 percent), arsenic (18 percent), molybdenum (16 percent), boron (10 percent), uranium (5.6 percent), gross alpha activity (9.7 percent), and nitrate (2.7 percent). Three inorganic constituents with secondary maximum contaminant levels, total dissolved solids, manganese, and chloride, had high relative-concentrations in 11 percent, 2.8 percent, and 2.8 percent of the primary aquifer system, respectively.

Relative-concentrations of one or more organic constituents were high in 0 percent, moderate in 5.0 percent, and low in 35 percent of the primary aquifer system. Organic constituents were not detected in 60 percent of the primary aquifer system. Of the 148 organic constituents analyzed, 12 constituents were detected. Chloroform and tetrachloroethene (PCE) were the only organic constituents detected in more than 10 percent of the primary aquifer system.

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Appendix A. Ancillary Datasets

Well identification numbers are presented in table A1. Land-use classifications and percentages of each classification, well construction information, groundwater age data and classifications, and geochemical conditions are listed in tables A2–A5.

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 classifications (Nakagaki and Wolock, 2005). These 25 land-cover classifications were aggregated into three principal land-use classes—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 A2) were calculated using ArcGIS (version 9.2) (Johnson and Belitz, 2009).

Well Construction Information

Well construction data primarily were obtained from driller's logs filed with CDWR. Other sources of well construction data were ancillary records from 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 (2012). Well depths, depths to the tops and bottoms of the perforated intervals, and lengths of the perforated intervals for wells are listed in table A3.

Groundwater Age Classification

Groundwater dating techniques provide a measure of the time since the groundwater was last in contact with the atmosphere (residence time in the aquifer). 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).

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 CLUB study unit in 2008–2010, tritium values greater than a threshold of 1.0 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 of carbon in the absence of ^{14}C contributed by above-ground nuclear explosions (Clark and Fritz, 1997). For the CLUB study unit, ^{14}C activity <90 pmc was defined as indicating the presence of groundwater recharged before the modern era (Kulongoski and others, 2010; Landon 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 A4. 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 CLUB study unit, groundwater ages were classified as follows:

Classification	Tritium (TU)	^{14}C (pmc)
Modern	≥1.0	≥ 90
Pre-modern	< 1.0	< 90 or no data
Mixed	≥ 1.0	< 90
Mixed	< 1.0	≥ 90

Classification of Geochemical Condition

Geochemical conditions investigated as potential explanatory variables in this report include oxidation-reduction characteristics (table A5). 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 using a modified version of the classification scheme of McMahon and Chapelle (2008) and Jurgens and others (2009) (table A5). Samples with DO > 0.5 mg/L were classified as oxic, and samples with DO ≤ 0.5 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 where available and from the CDPH database (“DG” CDPH-grid wells). Inorganic constituent data were not available for all oxic samples.

Table A1. USGS-GAMA well identification numbers and grid cell numbers for well data used in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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-GAMA well identification number with 'DG' indicates the use of CDPH inorganic data from the grid well; a CDPH-GAMA well identification number with 'DPH' indicates the use of CDPH data from a different well. BV, Borrego Valley study area well; CD, Central Desert study area well; LUB, Low-Use Basin of the Mojave and Sonoran Deserts study area well; BVU or LUBU, understanding well; —, no wells sampled or selected]

USGS-GAMA well identification number	Grid cell number	Grid supplemented by CDPH data from same well	Grid supplemented by CDPH data from different well
Borrego Valley study area grid wells			
BV-01	6	—	BV-DPH-01
BV-02	2	BV-DG-02	BV-DPH-02
BV-03	3	—	—
BV-04	1	—	—
BV-05 [1]	5	BV-DG-05	—
BV-06	8	BV-DG-06	BV-DPH-06
BV-07	9	—	—
Central Desert study area grid wells			
CD-01	5	—	—
CD-02	4	—	—
CD-03	3	—	—
CD-04	15	—	—
CD-05	16	—	CD-DPH-05
CD-06	2	CD-DG-06	CD-DPH-06
CD-07	10	—	—
CD-08	14	CD-DG-08	—
CD-09	8	—	—
CD-10	6	CD-DG-10	—
CD-11	1	—	—
CD-12	9	—	—
CD-13	17	—	—
CD-14	12	—	—
CD-15	13	—	—
Low-Use Basins study area grid wells			
LUB-01	1	—	—
LUB-02	2	LUB-DG-02	—
LUB-03	5	—	—
LUB-04	3	LUB-DG-04	—
LUB-05	12	LUB-DG-05	LUB-DPH-05
LUB-06	9	LUB-DG-06	—
LUB-07	10	—	—
LUB-08	8	LUB-DG-08	—
LUB-09	18	LUB-DG-09	--
LUB-10	17	—	—
LUB-11	6	LUB-DG-11	—
LUB-12	16	LUB-DG-12	—
LUB-13	11	—	—
LUB-14	14	—	—
LUB-15	24	LUB-DG-15	—
LUB-16	36	—	—
LUB-17	34	—	—
LUB-18	13	—	—
LUB-19	15	—	—
LUB-20	25	—	—
LUB-21	26	—	LUB-DPH-21
LUB-22	32	—	LUB-DPH-22
LUB-23	23	—	—
LUB-24	20	—	—
LUB-25	30	LUB-DG-25	—
LUB-26	29	—	—
LUB-27	21	—	—
—	22	—	LUB-DPH-37
—	27	—	LUB-DPH-38
USGS-understanding wells			
BVU-01	5	—	—
LUBU-01	15	—	—
LUBU-02	9	—	—

[1] Data from USGS-understanding well BVU-01 were used to supplement the grid-well data in this cell.

Table A2. Well type, percent land use by category, land-use classification, septic density, leaking underground fuel tank density, grid cell number, and USGS-GAMA well identification number for GAMA well data and CDPH-grid well data used in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[**USGS-GAMA well identification number**: BV, Borrego Valley study area well; CD, Central Desert study area well; LUB, Low-Use Basins of the Mojave and Sonoran Deserts study area well. **Well types**: PROD, production well; UN, unused 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]

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			
Borrego Valley study area grid wells							
BV-01	PROD	0	100	0	Natural	2.6	0.006
BV-02	PROD	0	97	3	Natural	0.5	0.004
BV-03	PROD	0	100	0	Natural	0.5	0.004
BV-04	PROD	0	100	0	Natural	2.6	0.004
BV-05	PROD	0	100	0	Natural	2.6	0.061
BV-06	PROD	0	100	0	Natural	0.2	0.001
BV-07	PROD	0	100	0	Natural	2.0	0.006
Central Desert study area grid wells							
CD-01	PROD	0	33	67	Urban	2.5	0.003
CD-02	PROD	0	36	64	Urban	1.5	0.010
CD-03	PROD	0	100	0	Natural	1.5	0.004
CD-04	PROD	0	100	0	Natural	11.3	0.008
CD-05	PROD	0	82	18	Natural	73.2	0.008
CD-06	PROD	0	60	40	Natural	12.9	0.004
CD-07	PROD	0	94	6	Natural	9.4	0.002
CD-08	PROD	0	91	9	Natural	5.3	0.002
CD-09	PROD	0	63	63	Natural	71.1	0.010
CD-10	PROD	0	100	0	Natural	2.5	0.003
CD-11	PROD	0	50	50	Natural	21.2	0.003
CD-12	PROD	0	100	0	Natural	10.4	0.002
CD-13	PROD	0	93	7	Natural	9.8	0.001
CD-14	PROD	0	100	0	Natural	0.0	0.001
CD-15	PROD	0	100	0	Natural	0.0	0.002
Low-Use Basins study area grid wells							
LUB-01	PROD	3	96	1	Natural	7.4	0.029
LUB-02	UN	0	98	2	Natural	59.1	0.004
LUB-03	PROD	3	88	10	Natural	0.4	0.002
LUB-04	PROD	15	84	0	Natural	2.4	0.004
LUB-05	PROD	0	100	0	Natural	7.6	0.004
LUB-06	PROD	0	74	26	Natural	0.1	0.003
LUB-07	PROD	0	100	0	Natural	0.1	0.003
LUB-08	PROD	0	100	0	Natural	0.1	0.003
LUB-09	PROD	0	81	19	Natural	0.0	0.001
LUB-10	PROD	0	100	0	Natural	0.3	0.003
LUB-11	PROD	0	100	0	Natural	0.4	0.002
LUB-12	PROD	0	86	14	Natural	1.5	0.003
LUB-13	PROD	1	69	29	Natural	5.6	0.005

Table A2. Well type, percent land use by category, land-use classification, septic density, leaking underground fuel tank density, grid cell number and USGS-GAMA well identification number for GAMA well data and CDPH-grid well data used in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.—Continued

[**USGS-GAMA well identification number**: BV, Borrego Valley study area well; CD, Central Desert study area well; LUB, Low-Use Basins of the Mojave and Sonoran Deserts study area well. **Well types**: PROD, production well; UN, unused 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]

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			
Low-Use Basins study area grid wells—Continued							
LUB-14	PROD	0	100	0	Natural	0.2	0.005
LUB-15	PROD	0	57	43	Natural	8.8	0.003
LUB-16	PROD	0	91	9	Natural	0.0	0.003
LUB-17	PROD	0	100	0	Natural	0.0	0.001
LUB-18	PROD	0	72	28	Natural	4.6	0.099
LUB-19	PROD	0	100	0	Natural	0.2	0.001
LUB-20	PROD	0	96	4	Natural	0.1	0.003
LUB-21	PROD	46	43	12	Mixed	0.0	0.001
LUB-22	PROD	0	98	2	Natural	0.1	0.001
LUB-23	PROD	0	100	0	Natural	0.0	0.001
LUB-24	PROD	0	87	13	Natural	0.0	0.001
LUB-25	PROD	0	98	2	Natural	0.0	0.003
LUB-26	PROD	0	100	0	Natural	0.0	0.001
LUB-27	PROD	0	90	10	Natural	0.0	0.000
CDPH-grid wells							
BV-DPH-01	PROD	0	96	4	Natural	na	na
CD-DPH-05	PROD	0	75	25	Natural	na	na
CD-DPH-06	PROD	1	56	43	Natural	na	na
LUB-DPH-05	PROD	0	84	16	Natural	na	na
LUB-DPH-21	PROD	18	61	21	Natural	na	na
LUB-DPH-22	PROD	0	100	0	Natural	na	na
LUB-DPH-37	PROD	0	99	1	Natural	na	na
LUB-DPH-38	PROD	0	100	0	Natural	na	na
USGS-understanding wells							
BVU-01	PROD	0	96	4	Natural	2.6	0.061
LUBU-01	PROD	3	76	24	Natural	63.1	0.003
LUBU-02	UN	0	100	0	Natural	0.1	0.000

[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).

Table A3. Well construction information and aridity index for wells used in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[**USGS-GAMA well identification number**: BV, Borrego Valley study area well; CD, Central Desert study area well; LUB, Low-Use Basins study area well; BVU or LUBU, understanding well. **Other abbreviations**: USGS, U.S. Geological Survey; na, not available; ft, feet; LSD, land-surface datum]

USGS-GAMA well identification number	Construction information				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 top perforated interval to bottom of well (ft)	
Borrego Valley study area grid wells					
BV-01	na	na	na	na	0.08
BV-02	490	na	na	na	0.09
BV-03	350	150	350	200	0.11
BV-04	630	420	630	210	0.09
BV-05	580	248	568	320	0.08
BV-06	391	252	285	33	0.08
BV-07	95	na	na	na	0.08
Central Desert study area grid wells					
CD-01	na	na	na	na	0.11
CD-02	358	na	na	na	0.14
CD-03	na	na	na	na	0.18
CD-04	350	195	345	150	0.10
CD-05	430	220	420	200	0.09
CD-06	na	na	na	na	0.18
CD-07	740	470	720	250	0.13
CD-08	425	na	na	na	0.10
CD-09	1,115	550	1,115	565	0.16
CD-10	604	220	580	360	0.13
CD-11	na	na	na	na	0.19
CD-12	550	na	na	na	0.14
CD-13	260	147	247	100	0.07
CD-14	240	na	na	na	0.08
CD-15	600	390	580	190	0.08
Low-Use Basins study area grid wells					
LUB-01	381	205	381	176	0.10
LUB-02	543	na	na	na	0.10
LUB-03	456	na	na	na	0.09
LUB-04	na	na	na	na	0.10
LUB-05	490	322	480	158	0.12
LUB-06	490	220	475	255	0.08
LUB-07	660	160	440	280	0.08
LUB-08	800	300	780	480	0.08
LUB-09	224	184	224	40	0.07
LUB-10	300	190	300	110	0.06
LUB-11	600	452	590	138	0.11
LUB-12	840	650	800	150	0.10
LUB-13	500	100	500	400	0.10
LUB-14	240	na	na	na	0.19

Table A3. Well construction information and aridity index for wells used in the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.—Continued

[**USGS-GAMA well identification number**: BV, Borrego Valley study area well; CD, Central Desert study area well; LUB, Low-Use Basins study area well; BVU or LUBU, understanding well. **Other abbreviations**: USGS, U.S. Geological Survey; na, not available; ft, feet; LSD, land-surface datum]

USGS-GAMA well identification number	Construction information				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 top perforated interval to bottom of well (ft)	
Low-Use Basins study area grid wells—Continued					
LUB-15	312	212	312	100	0.06
LUB-16	105	0	105	105	0.06
LUB-17	584	484	584	100	0.06
LUB-18	36	15	36	21	0.26
LUB-19	na	na	na	na	0.07
LUB-20	100	70	na	na	0.06
LUB-21	400	300	400	100	0.06
LUB-22	1,200	690	1,190	500	0.07
LUB-23	403	200	400	200	0.10
LUB-24	788	235	na	553	0.13
LUB-25	866	534	864	330	0.11
LUB-26	711	na	na	na	0.15
LUB-27	400	140	400	260	0.07
USGS-understanding wells					
BVU-01	392	162	372	210	0.08
LUBU-01	1,010	350	940	590	0.07
LUBU-02	400	140	380	240	0.09

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

Table A4. Tritium, percent modern carbon, and age classification of samples, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[modern, recharged after 1952; mixed, modern and pre-modern water; pre-modern, recharged prior to 1952; ns, not sampled; <, less than; TU, tritium units]

USGS-GAMA well identification number	Tritium (TU)	Percent modern carbon	Age classification
Borrego Valley study area grid wells			
BV-01	<1	44	Pre-modern
BV-02	1.2	116	Modern
BV-03	<1	102	Mixed
BV-04	<1	81	Pre-modern
BV-05	<1	28	Pre-modern
BV-06	<1	4.5	Pre-modern
BV-07	<1	ns	Pre-modern
Central Desert study area grid wells			
CD-01	<1	88	Pre-modern
CD-02	<1	88	Pre-modern
CD-03	1.4	78	Mixed
CD-04	<1	90	Mixed
CD-05	<1	82	Pre-modern
CD-06	1.4	96	Modern
CD-07	<1	62	Pre-modern
CD-08	<1	13	Pre-modern
CD-09	2.2	94	Modern
CD-10	<1	93	Mixed
CD-11	1.4	110	Modern
CD-12	<1	27	Pre-modern
CD-13	<1	33	Pre-modern
CD-14	<1	27	Pre-modern
CD-15	<1	57	Pre-modern
Low-Use Basins study area grid wells			
LUB-01	<1	47	Pre-modern
LUB-02	<1	22	Pre-modern
LUB-03	<1	52	Pre-modern
LUB-04	<1	20	Pre-modern
LUB-05	<1	62	Pre-modern
LUB-06	<1	23	Pre-modern
LUB-07	<1	6.3	Pre-modern
LUB-08	<1	8.5	Pre-modern
LUB-09	<1	23	Pre-modern
LUB-10	<1	15	Pre-modern
LUB-11	<1	7.0	Pre-modern
LUB-12	<1	26	Pre-modern
LUB-13	<1	16	Pre-modern
LUB-14	<1	58	Pre-modern
LUB-15	<1	33	Pre-modern
LUB-16	5.6	93	Modern
LUB-17	<1	9.8	Pre-modern
LUB-18	<1	92	Mixed
LUB-19	<1	32	Pre-modern
LUB-20	<1	35	Pre-modern
LUB-21	<1	15	Pre-modern
LUB-22	<1	3.2	Pre-modern
LUB-23	<1	56	Pre-modern
LUB-24	<1	4.4	Pre-modern
LUB-25	<1	10	Pre-modern
LUB-26	1.2	103	Modern
LUB-27	<1	11	Pre-modern
USGS-understanding wells			
BVU-01	<1	19	Pre-modern
LUBU-01	<1	40	Pre-modern
LUBU-02	<1	19	Pre-modern

Table A5. Oxidation-reduction constituents and redox classification for samples from the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

[Redox classification based on framework of McMahon and Chapelle (2008) and Jurgens and others (2009). Non-detections are reported as <RL, where RL is the reporting limit. **Chemical abbreviations**: DO, dissolved oxygen; NO3-N, nitrate as nitrogen; NO_3-red, nitrate reducing; Mn, manganese; Mn-red, manganese reducing; Fe, iron. **Redox classifications**: oxic, DO > 0.5 mg/L; anoxic (suboxic), DO < 0.5 mg/L, NO3-N < 0.5 mg/L, Mn < 50 µg/L, and Fe < 100 µg/L; anoxic (NO_3-red), DO < 0.5 mg/L, NO3-N > 0.5 mg/L, Mn < 50 µg/L, and Fe < 100 µg/L; anoxic (Mn-red), DO < 0.5 mg/L, NO3-N < 0.5 mg/L, Mn > 50 µg/L, and Fe < 100 µg/L. **Other abbreviations**: mg/L, milligrams per liter; µg/L, micrograms per liter; redox, oxidation-reduction; >, greater than; <, less than; na, not available]

USGS-GAMA well identification number	Source of inorganic data	Dissolved oxygen (mg/L)	Nitrate, as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Redox classification
Borrego Valley study area						
BV-01	na	4.1	na	na	na	Oxic
BV-02	CDPH	7.1	0.43	0.4	<20	Oxic
BV-03	GAMA	6.2	0.28	1.1	15	Oxic
BV-04	GAMA	4.4	2.44	<0.2	<6	Oxic
BV-05	CDPH	1.1	0.38	<20	<100	Oxic
BV-06	CDPH	3.3	0.25	na	na	Oxic
BV-07	GAMA	2.0	0.99	0.8	7	Oxic
Central Desert study area						
CD-01	GAMA	6.2	1.55	<0.2	<6	Oxic
CD-02	na	4.8	na	na	na	Oxic
CD-03	GAMA	6.6	2.03	1.3	18	Oxic
CD-04	GAMA	7.0	1.41	0.2	<6	Oxic
CD-05	na	5.8	1.99	na	na	Oxic
CD-06	CDPH	6.2	<0.1	<20	<100	Oxic
CD-07	GAMA	4.5	2.62	<0.2	<6	Oxic
CD-08	CDPH	2.4	0.47	na	na	Oxic
CD-09	GAMA	6.3	2.20	0.8	20	Oxic
CD-10	CDPH	4.4	0.99	<20	<100	Oxic
CD-11	GAMA	7.2	1.24	<0.2	<6	Oxic
CD-12	GAMA	3.3	1.90	<0.2	<6	Oxic
CD-13	GAMA	5.1	1.63	<0.2	<6	Oxic
CD-14	GAMA	1.1	1.19	0.5	<6	Oxic
CD-15	na	5.1	na	na	na	Oxic

Table A5. Oxidation-reduction constituents and redox classification for samples from the Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.—Continued

[Redox classification based on framework of McMahon and Chapelle (2008) and Jurgens and others (2009). Non-detections are reported as <RL, where RL is the reporting limit. **Chemical abbreviations**: DO, dissolved oxygen; NO3-N, nitrate as nitrogen; NO_3-red, nitrate reducing; Mn, manganese; Mn-red, manganese reducing; Fe, iron. **Redox classifications**: oxic, DO > 0.5 mg/L; anoxic (suboxic), DO < 0.5 mg/L, NO3-N < 0.5 mg/L, Mn < 50 µg/L, and Fe < 100 µg/L; anoxic (NO_3-red), DO < 0.5 mg/L, NO3-N > 0.5 mg/L, Mn < 50 µg/L, and Fe < 100 µg/L; anoxic (Mn-red), DO < 0.5 mg/L, NO3-N < 0.5 mg/L, Mn > 50 µg/L, and Fe < 100 µg/L. **Other abbreviations**: mg/L, milligrams per liter; µg/L, micrograms per liter; redox, oxidation-reduction; >, greater than; <, less than; na, not available]

USGS-GAMA well identification number	Source of inorganic data	Dissolved oxygen (mg/L)	Nitrate, as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Redox classification
Low-Use Basins study area						
LUB-01	GAMA	6.1	12.10	1.5	40	Oxic
LUB-02	GAMA	5.5	0.41	<0.2	<6	Oxic
LUB-03	GAMA	<0.2	0.09	376	22	Anoxic (Mn-red)
LUB-04	GAMA	4.2	0.38	<0.2	8	Oxic
LUB-05	GAMA	6.8	1.03	1.2	18	Oxic
LUB-06	GAMA	3.4	3.60	0.4	6	Oxic
LUB-07	GAMA	1.9	1.57	0.2	<6	Oxic
LUB-08	GAMA	2.6	4.94	0.6	9	Oxic
LUB-09	GAMA	3.9	5.11	<0.2	<6	Oxic
LUB-10	GAMA	0.2	<0.04	3.7	<6	Anoxic (suboxic)
LUB-11	GAMA	1.2	4.10	0.6	13	Oxic
LUB-12	GAMA	2.3	1.50	5	23	Oxic
LUB-13	GAMA	3.5	0.92	0.3	6	Oxic
LUB-14	GAMA	2.1	0.60	0.6	9	Oxic
LUB-15	GAMA	2.9	2.06	0.5	7	Oxic
LUB-16	GAMA	2.0	0.35	8	<6	Oxic
LUB-17	GAMA	1.9	1.35	0.3	11	Oxic
LUB-18	GAMA	1.2	0.25	8.1	17	Oxic
LUB-19	GAMA	0.4	1.22	<0.2	<6	Anoxic (NO_3-red)
LUB-20	GAMA	3.6	1.71	<0.2	<6	Oxic
LUB-21	GAMA	2.6	4.51	0.7	9	Oxic
LUB-22	GAMA	0.2	<0.04	1.2	7	Anoxic (suboxic)
LUB-23	GAMA	7.6	1.47	2	9	Oxic
LUB-24	GAMA	1.3	0.65	3.5	25	Oxic
LUB-25	GAMA	3.6	3.03	3.9	45	Oxic
LUB-26	GAMA	3.8	4.55	3.7	16	Oxic
LUB-27	GAMA	2.5	2.69	<0.2	<6	Oxic
USGS-understanding wells						
BVU-01	GAMA	2	3.02	<0.2	<6	Oxic
LUBU-01	GAMA	2.4	0.33	<0.2	<6	Oxic
LUBU-02	GAMA	2.9	2.48	1.6	16	Oxic

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

For the CLUB study unit, the historical CDPH database contains more than 103,506 records distributed across more than 202 wells, requiring targeted retrievals to manageably use the data to assess water quality. The following paragraphs summarize the selection process for wells and data from the CDPH database for use in the grid-based status assessment (fig. B1).

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 62 grid cells in the CLUB study unit, 23 cells had USGS-grid wells with the full complement of inorganic constituent data collected by USGS-GAMA, 26 cells had USGS-grid wells with data for trace elements, major ions, and nutrients but were missing data for radioactive constituents, and 13 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 (December 3, 2005–December 1, 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 data in the CDPH database are of unknown quality, and the database does not contain data for quality-control samples with which to make a comprehensive quality-control assessment of the data. Cation-anion imbalance was used as a rough quality-control metric. Because water is electrically neutral and must have a balance between positive (cations) and negative (anions) electrically charged dissolved species, the cation/anion imbalance commonly is used as a quality-assurance check for water-sample analysis (Hem, 1985). An imbalance of less than 10 percent was defined as indicating acceptable quality of the major ion data for the sample. It was assumed that if the quality of the major ion data were acceptable, then the quality of the data for the other inorganic constituents also would be acceptable. In practice, however, some wells did not have data for major ion constituents, so the cation-anion imbalance could not be evaluated.

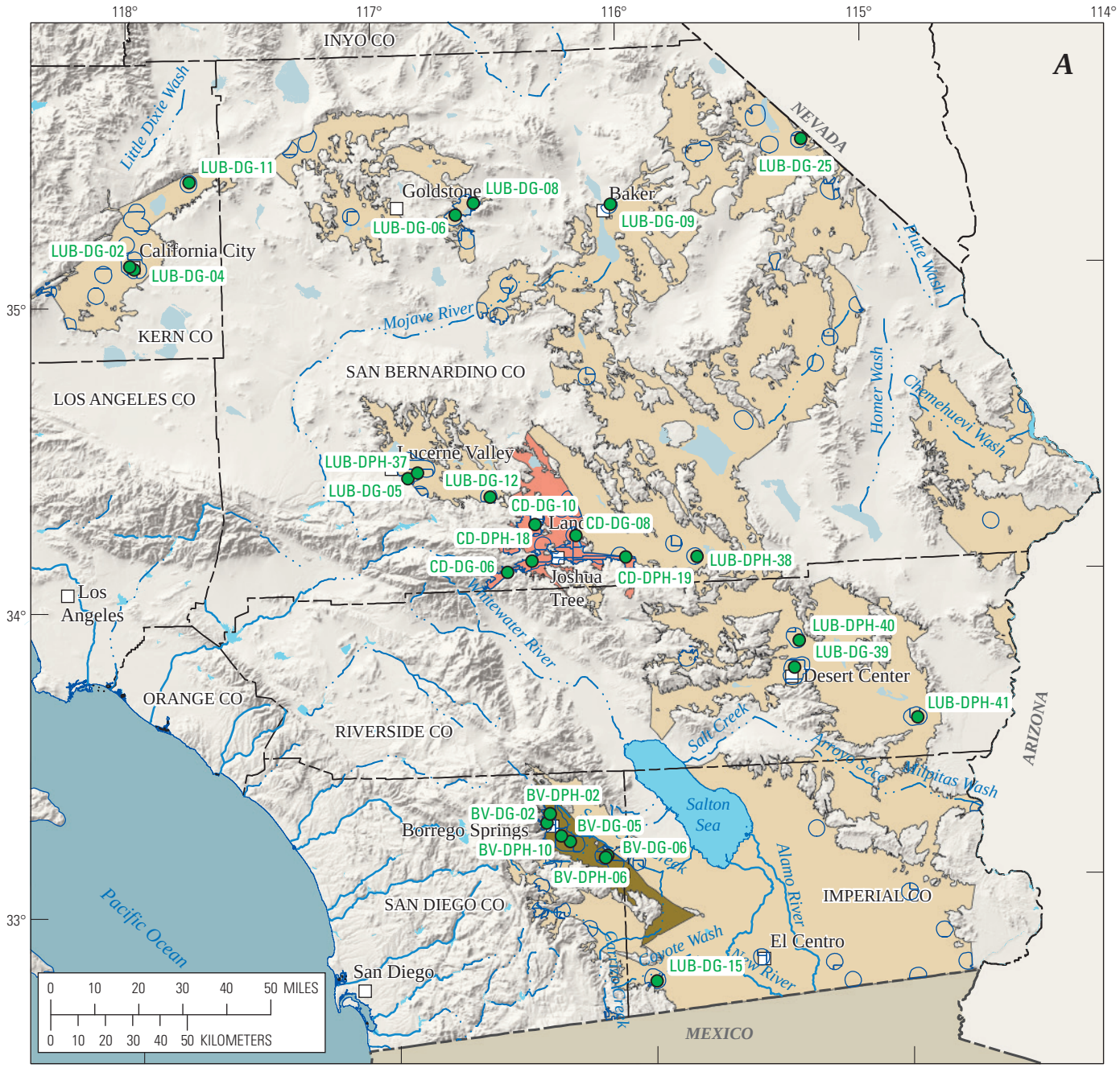
The first choice was to select CDPH inorganic data for the grid well sampled by the USGS (fig. B1*B*) for other constituents, provided the CDPH data met the cation/anion balance criteria. This approach resulted in the selection of supplemental inorganic data from the CDPH database for six USGS-grid wells. To identify the USGS-grid wells that incorporated CDPH inorganic data, a well ID was created that added “DG” to the GAMA ID for these wells (for example, BV-02 with CDPH data was assigned the well identification BV-DG-02; table A1).

If the first step did not yield CDPH inorganic data for the USGS-grid well, the second step was to search the CDPH database to identify the highest-ranked well with a cation/anion imbalance less than 10 percent in each grid cell. This step resulted in selecting CDPH inorganic data from additional CDPH wells that were not USGS-grid wells for five grid cells. To identify these new CDPH-grid wells, a well ID was created that added “DPH” after the study unit prefix. For cells that contained a USGS-grid well, the identification number of the CDPH-grid well remained the same as that of the USGS-grid well identifier (for example, CDPH-grid well BV-DPH-01; table A1). For cells that did not contain a USGS-grid well, the CDPH-grid well was given a sequential number starting after the last GAMA cell number for the study area (for example, CDPH-grid well LUB-DPH-37; table A1).

If no wells in a grid cell met the cation/anion balance criteria or if there were insufficient data to evaluate charge balance, the third choice for a CDPH-grid well was to select the highest-ranked CDPH well with any of the needed inorganic data. These new CDPH-grid wells were labeled using the same prefix as the other new CDPH-grid wells.

The result of these steps was that 51 of the 62 grid cells were represented by inorganic constituent data from the USGS database, the CDPH database, or both databases. In some cases, to achieve one value for each constituent per cell, it was necessary to select an additional well in a cell for certain constituents; hence, some cells have data from two CDPH wells. Inorganic data from the CDPH database were used for 22 grid cells. CDPH data were available from the CDPH database for gross alpha radioactivity and radium-228 for 14 and 15 wells, respectively, and for 0 to 9 wells for most other inorganic constituents (table 2). 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).

Differences in constituent reporting levels associated with USGS and CDPH data did not affect analysis of high or moderate relative-concentrations because concentrations in these categories were substantially higher than the reporting levels. Several types of comparisons between USGS-collected and CDPH data are described in appendix E.



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

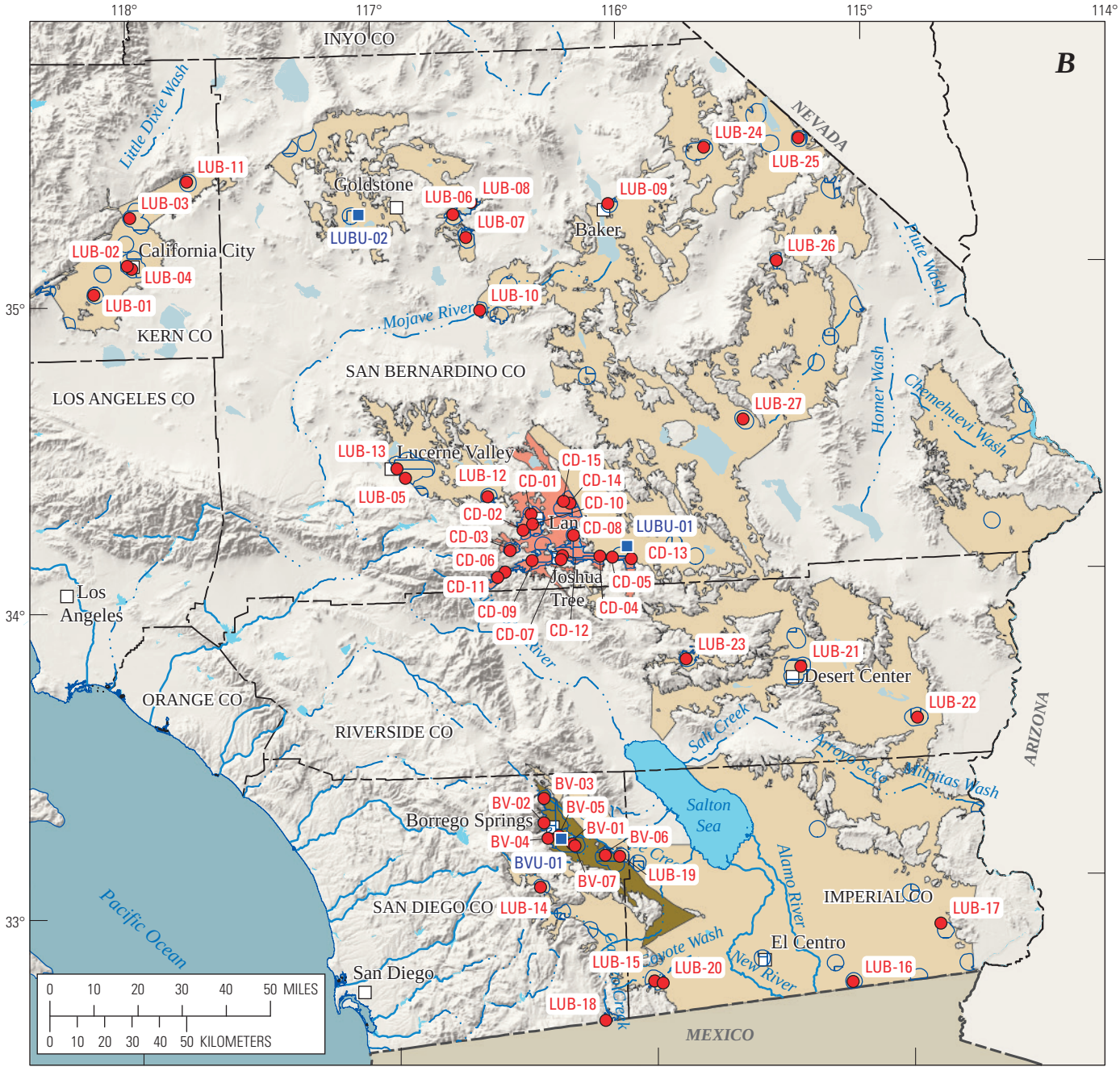
EXPLANATION

STUDY AREA

- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties
- LUB-DPH-41 — California Department of Public Health (CDPH) well and identifier
- Grid cell

Figure B1. Maps showing identifiers and locations of (*A*) CDPH-grid wells, and (*B*) USGS-grid and USGS-understanding wells sampled during December 2008–March 2010, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.



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

EXPLANATION

STUDY AREA

- Borrego Valley
- Central Desert
- Low-Use Basins of the Mojave and Sonoran Deserts

- Lake
- Dry lake
- Streams
- Counties
- LUB-16 — USGS-grid well and identifier
- BVU-01 — USGS-understanding well and identifier
- Grid cell

Figure B1. —Continued

Appendix C. Estimation of Aquifer-Scale Proportions

For the grid-based calculations of aquifer-scale proportions, one well in each grid cell, a "grid well," was randomly selected to represent the primary aquifer system (Belitz and others, 2010). For organic constituents, the one value in each grid cell was obtained from samples analyzed by USGS-GAMA from 49 grid wells. For inorganic constituents, the one value in each grid cell was obtained from samples analyzed by USGS-GAMA and data selected from the CDPH database (appendix B). The proportion of the primary aquifer system with high relative-concentrations was calculated by dividing the number of cells with concentrations greater than the benchmark (relative-concentration greater than 1) by the total number of grid wells in each of the study areas (Belitz and others, 2010). The proportion for each study area is calculated individually because grid cell sizes are not uniform across the study areas. The proportion for the study unit is then determined by calculating the area-weighted sum by using the following equation:

$$AQP_{SU} = \sum AQP_{SA} F_{SA} \quad \text{(A1)}$$

where:

AQP_{SU} is the aquifer proportion for the study unit,
AQP_{SA} is the aquifer proportion for a study area, and
F_{SA} is the fraction of the total study unit area occupied by the study area.

The F_{SA} for the study areas are: Borrego Valley, 0.09; Central Desert, 0.16, and the Low-Use Basins of the Mojave and Sonoran Deserts, 0.75. Proportions containing moderate and low relative-concentrations were calculated similarly. Aquifer-scale proportions for individual constituents for each study area are listed in tables C1A–C and for classes of constituents in tables C2A–B. Confidence intervals for grid-based aquifer proportions were computed using the Jeffreys interval for the binomial distribution (Brown and others, 2001). The grid-based estimate is spatially unbiased; however, the grid-based approach may not identify constituents that exist at high concentrations in small proportions of the primary aquifer system.

The spatially weighted approach relied on USGS-grid well data collected from December 2, 2008, to March 4, 2010, and CDPH data collected from December 3, 2005, to December 1, 2008 (most recent analyses per well for all wells within each grid cell), and USGS-understanding public-supply well data. However, instead of data from only one well per grid cell, the spatially weighted approach uses all wells in each cell. The proportion of high relative-concentrations for each constituent for each study area 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). The spatially weighted high proportion for the study unit was calculated by summing the area-weighted values for each study area in the same manner as was used in the grid-based approach. Calculations for individual constituents for each study area are listed in tables C1A–C and for classes of constituents in tables C2A–B. The resulting proportions are spatially unbiased.

The raw detection frequency was calculated by considering all of the available data in the period from December 3, 2005, to December 1, 2008, for the CDPH wells (the most recent analysis per well for all wells), the USGS-grid wells, and USGS-understanding wells. However, this approach is spatially biased because the CDPH and USGS-understanding wells are not uniformly distributed. Consequently, high values (or low values) for wells clustered in a particular area represent a small part of the primary aquifer system and could be given a disproportionately high (or low) weight compared to that given by spatially unbiased approaches.

Table C1A. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010) for the Borrego Valley study area, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency [1]			Spatially weighted aquifer-scale proportion [1]			Grid-based aquifer-scale proportion			90-percent 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)
Trace and minor elements											
Arsenic	18	11	0	7	18	0	7	14	0	0	19
Boron	14	0	0	6	0	0	6	0	0	0	23
Chromium	18	0	1.0	7	0	0	7	0	0	0	19
Fluoride	18	5.6	5.6	7	4.8	14	7	0	14	2.6	44
Molybdenum	4	0	0	4	0	0	4	0	0	0	34
Vanadium	14	21	21	6	29	25	6	17	17	3.0	50
Radioactive constituents											
Gross alpha activity [3]	10	20	10	6	25	8.3	6	33	0	0	27
Uranium	11	18	0	6	8	0	6	17	0	0	27
Nutrients											
Nitrate	19	0	5.3	7	0	4.8	7	0	0	0	17
Inorganic constituents with SMCLs											
Iron	18	0	5.6	7	0	2.4	7	0	0	0	19
Manganese	18	0	5.6	7	0	4.8	7	0	0	0	19
Chloride	17	0	0	7	0	0	6	0	0	0	19
Sulfate	17	12	0	7	19	0	6	17	0	0	19
Total dissolved solids (TDS)	17	41	0	7	45	21	7	43	29	8.8	59
Volatile organic compounds (VOCs)											
Benzene	18	0	0	7	0	0	7	0	0	0	17
Tetrachloroethene (PCE)	18	0	0	7	0	0	7	0	0	0	17
Bromoform	18	0	0	7	0	0	7	0	0	0	17

Table C1A. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010) for the Borrego Valley study area, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency [1]			Spatially weighted aquifer-scale proportion [1]			Grid-based aquifer-scale proportion			90-percent 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)
Volatile organic compounds (VOCs)—Continued											
Chloroform	18	5.6	0	7	3.6	0	7	0	0	0	17
Dibromochloromethane	18	0	0	7	0	0	7	0	0	0	17
Pesticides											
Dieldrin	8	0	0	7	0	0	7	0	0	0	17
Special interest											
Perchlorate	22	4.5	0	7	3.6	0	7	14	0	0	17

[1] Based on the most recent data for each CDPH well during the period December 3, 2005–December 1, 2008, combined with GAMA grid and understanding well 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 C1B. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010) for the Central Desert study area, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency [1]			Spatially weighted aquifer-scale proportion [1]			Grid-based aquifer-scale proportion			90-percent 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)
Trace and minor elements											
Arsenic	35	11	17	11	27	13	11	27	9.1	1.6	31
Boron	34	0	0	11	0	0	11	0	0	0	11
Chromium	32	0	3.1	11	0	2.3	11	0	0	0	11
Fluoride	34	8.8	8.8	11	8.3	14	11	18	9.1	1.3	31
Molybdenum	9	11	11	9	11	11	9	11	11	2.0	36
Vanadium	32	0	0	11	0	0	11	0	0	0	11
Radioactive constituents											
Gross alpha activity [3]	32	31	16	11	40	17	11	36	18	5.4	42
Uranium	25	36	16	11	25	10	11	9.1	18	5.4	42
Nutrients											
Nitrate	40	2.5	2.5	13	3.8	2.6	13	0	0	0	10
Inorganic constituents with SMCLs											
Iron	34	0	2.9	11	0	2.3	11	0	0	0	11
Manganese	34	0	0	11	0	0	11	0	0	0	11
Chloride	35	0	0	11	0	0	11	0	0	0	11
Sulfate	35	0	0	11	0	0	11	0	0	0	11
Total dissolved solids (TDS)	36	11	0	11	11	0	15	13	0	0	8.5
Volatile organic compounds (VOCs)											
Benzene	26	0	0	15	0	0	15	0	0	0	8.5
Tetrachloroethene (PCE)	26	0	0	15	0	0	15	0	0	0	8.5
Bromoform	26	0	0	15	0	0	15	0	0	0	8.5
Chloroform	26	3.8	0	15	2.2	0	15	0	0	0	8.5
Dibromochloromethane	26	0	0	15	0	0	15	0	0	0	8.5

Table C1B. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010) for the Central Desert study area, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency [1]			Spatially weighted aquifer-scale proportion [1]			Grid-based aquifer-scale proportion			90-percent 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)
Pesticides											
Dieldrin	22	0	0	14	0	0	13	0	0	0	9.7
Special interest											
Perchlorate	43	0	0	15	0	0	15	0	0	0	8.5

[1] Based on the most recent data for each CDPH well during the period December 3, 2005–December 1, 2008, combined with GAMA grid and understanding well 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 C1C. Aquifer-scale proportions from grid-based and spatially weighted approaches for (1) constituents with high relative-concentrations during December 3, 2005–December 1, 2008, from the California Department of Public Health (CDPH) database, (2) constituents with moderate or high relative-concentrations in samples collected from USGS-grid wells (December 2008–March 2010), or (3) organic constituents with detection frequencies of greater than 10 percent in the USGS-grid wells (December 2008–March 2010) for the Low-Use Basins of the Mojave and Sonoran Deserts study area, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts 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 2 and 3]

Constituent	Raw detection frequency[1]			Spatially weighted aquifer-scale proportion[1]			Grid-based aquifer-scale proportion			90-percent 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)
Trace and minor elements											
Arsenic	57	16	25	28	17	23	28	21	21	11	36
Boron	42	21	12	27	20	15	27	22	15	6.4	29
Chromium	54	0	0	27	0	0	27	0	0	0	4.8
Fluoride	59	19	31	28	18	32	28	25	32	19	48
Molybdenum	29	10	21	27	9.3	19	27	11	19	8.9	33
Vanadium	41	17	0	27	12	0	27	15	0	0	4.8
Radioactive constituents											
Gross alpha activity[3]	48	17	4.2	22	19	6.8	22	18	9.1	2.7	23
Uranium	44	4.6	2.3	28	2.7	3.6	28	0	3.6	0.6	13
Nutrient											
Nitrate	72	6.9	1.4	28	7.9	1.8	28	3.6	3.6	0.6	13
Inorganic constituents with SMCLs											
Iron	55	3.6	3.6	27	2.5	3.1	27	0	0	0	4.8
Manganese	55	0	1.8	27	0	3.7	27	0	3.7	0.7	14
Chloride	55	3.6	1.8	27	5.6	3.7	27	7.4	3.7	0.7	14
Sulfate	55	16	0	27	21	0	27	19	0	0	4.8
Total dissolved solids (TDS)	58	40	8.6	28	42	13	28	50	11.0	2.2	19
Volatile organic compounds (VOCs)											
Benzene	50	2.0	0	27	1.2	0	27	0	0	0	4.8
Tetrachloroethene (PCE)	50	2.0	0	27	1.9	0	27	0	0	0	4.8
Bromoform	50	4.0	0	27	1.9	0	27	0	0	0	4.8
Chloroform	50	0	0	27	0	0	27	0	0	0	4.8
Dibromochloromethane	50	4.0	0	27	1.9	0	27	0	0	0	4.8
Pesticide											
Dieldrin	37	2.7	0	27	1.9	0	27	3.7	0	0	4.8
Special interest											
Perchlorate	80	16	0	27	31	0	27	41	0	0	4.8

[1] Based on the most recent data for each CDPH well during the period December 3, 2005–December 1, 2008, combined with GAMA grid and understanding well 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 C2A. Aquifer-scale proportions for inorganic constituent classes in the three study areas, Borrego Valley, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008–March 2010.

[**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. Proportions calculated using the grid-based method unless footnoted. **Study areas**: BV, Borrego Valley; CD, Central Desert; LUB, Low-Use Basins of the Mojave and Sonoran Deserts. SMCL, secondary maximum contaminant level]

Constituent class and study area	Aquifer-scale proportion		
	Low relative-concentration (percent)	Moderate relative-concentration (percent)	High relative-concentration (percent)
Trace and minor elements			
BV	57	14	29
CD	55	27	18
LUB	29	23	48
Radioactive constituents [1]			
BV	67	33	[2] 4.2
CD	41	36	23
LUB	75	14	11
Nutrients			
BV	96	0	[2] 4.8
CD	94	[2] 3.8	[2] 2.6
LUB	93	3.6	3.6
All inorganic constituents with health-based benchmarks			
BV	43	36	21
CD	34	31	35
LUB	23	24	53
Salinity indicators [3]			
BV	36	43	21
CD	87	13	0
LUB	43	45	12
Manganese and (or) iron			
BV	96	0	[2] 7.1
CD	98	0	[2] 2.3
LUB	94	[2] 2.5	3.7
All inorganic constituent with SMCL benchmarks			
BV	43	43	14
CD	85	13	0
LUB	39	45	16

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

[2] Spatially weighted result. Grid-based result was zero percent.

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

Table C2B. Aquifer-scale proportions for organic constituent classes in the three study areas, Borrego Valley, Central Desert, and Low-Use Basins of the Desert study unit, California GAMA Priority Basin Project, December 2008–March 2010.

[**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. **Study areas**: BV, Borrego Valley; CD, Central Desert; LUB, Low-Use Basins of the Mojave and Sonoran Deserts]

Constituent class and study area	Aquifer-scale proportion			
	Low relative-concentration (percent)		Moderate relative-concentration (percent) [2]	High relative-concentration (percent)
	Not detected	Detected low [1]		
Gasoline hydrocarbons				
BV	100	0	0	0
CD	100	0	0	0
LUB	96	2.5	1.2	0
Solvents				
BV	86	14	0	0
CD	100	0	0	0
LUB	78	20	1.8	0
Trihalomethanes				
BV	86	9.5	4.8	0
CD	80	18	2.2	0
LUB	67	32	1.8	0
All volatile organic compounds (VOCs)				
BV	71	24	4.8	0
CD	80	18	2.2	0
LUB	56	43	1.8	0
Insecticides				
BV	100	0	0	0
CD	100	0	0	0
LUB	98	0	1.8	0
All pesticides				
BV	100	0	0	0
CD	92	7.7	0	0
LUB	89	9.3	1.8	0
All organic constituents with health-based benchmarks				
BV	71	24	4.8	0
CD	73	25	2.2	0
LUB	56	39	5.6	0

[1] Proportions for detected at low relative-concentrations were calculated by subtracting the spatially weighted moderate proportion from the area-weighted detection frequency in the USGS-grid wells.

[2] Proportions for moderate relative-concentrations were calculated using the spatially weighted approach.

Appendix D. Calculating Total Dissolved Solids

Specific conductance, an electrical measure of TDS, was measured for 49 grid and 3 understanding wells sampled by the USGS, whereas TDS was only measured directly as residue on evaporation for 42 of these wells. For wells that had no measured TDS, TDS values were calculated from specific conductance (SC) values using a linear regression equation ($TDS = 0.57 \times SC + 40.09$; coefficient of determination, $R^2 = 0.976$). TDS values from the CDPH database were combined with USGS measured and calculated TDS values.

Appendix E. Comparison of Data from the CDPH and USGS-GAMA Program

CDPH and USGS-GAMA data were compared to assess the validity of combining data from these different sources. Because laboratory reporting levels for most organic constituents and trace elements were substantially lower for USGS-GAMA data than for CDPH data (Fram and Belitz, 2012), only concentrations of constituents greater than the CDPH data laboratory reporting levels could be compared, and as a result, there were insufficient data from which to evaluate agreement between CDPH and USGS-GAMA data. However, concentrations of inorganic constituents (sodium, calcium, magnesium, chloride, sulfate, TDS, and nitrate), which generally are prevalent at concentrations greater than reporting levels, were compared for each well using data from both sources. The USGS and CDPH databases contained data for major ions or nitrate for 43 to 48 wells. Wilcoxon signed rank tests of paired analyses for these seven constituents indicated no significant differences between USGS-GAMA and CDPH data for these constituents. Although differences between the paired datasets occurred for some wells, most sample pairs plotted close to a 1:1 line (fig. E1). These plots indicated that the GAMA and CDPH inorganic data were comparable.

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 respective ion content of the water (fig. E2). Trilinear diagrams often are used to define groundwater type (Hem, 1985). All cation/anion 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. E2). In most samples, bicarbonate accounted for 20 to 80 percent of the total anions, and chloride and sulfate each accounted for 10 to 60 percent. Sodium and potassium accounted for 40 to 100 percent of the cations. Many samples are described as *calcium-sodium-bicarbonate* or *sodium–mixed anion* type waters.

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 most of the types of water present within the primary aquifer system in the CLUB study unit.

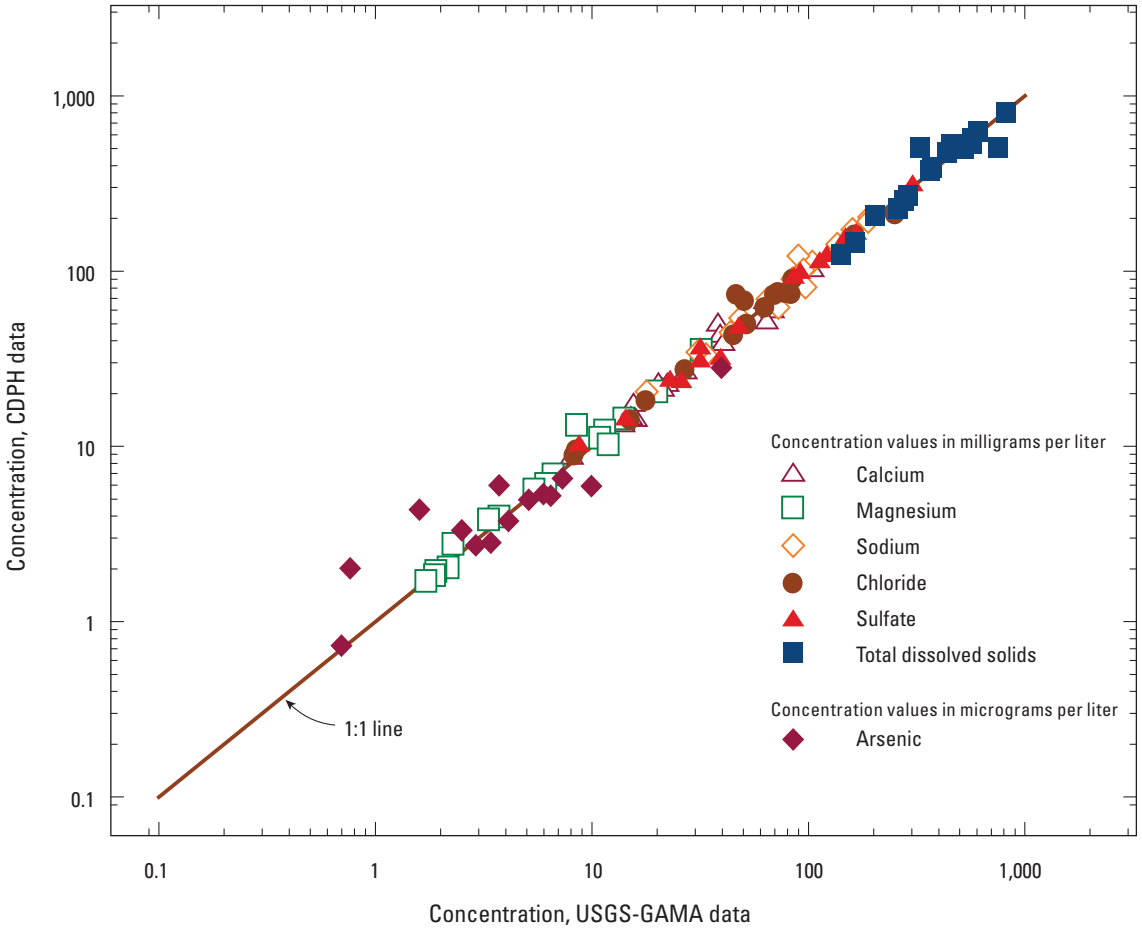


Figure E1. Graph showing paired inorganic constituent concentrations from wells sampled by the GAMA Program from December 3, 2005, to December 1, 2008, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

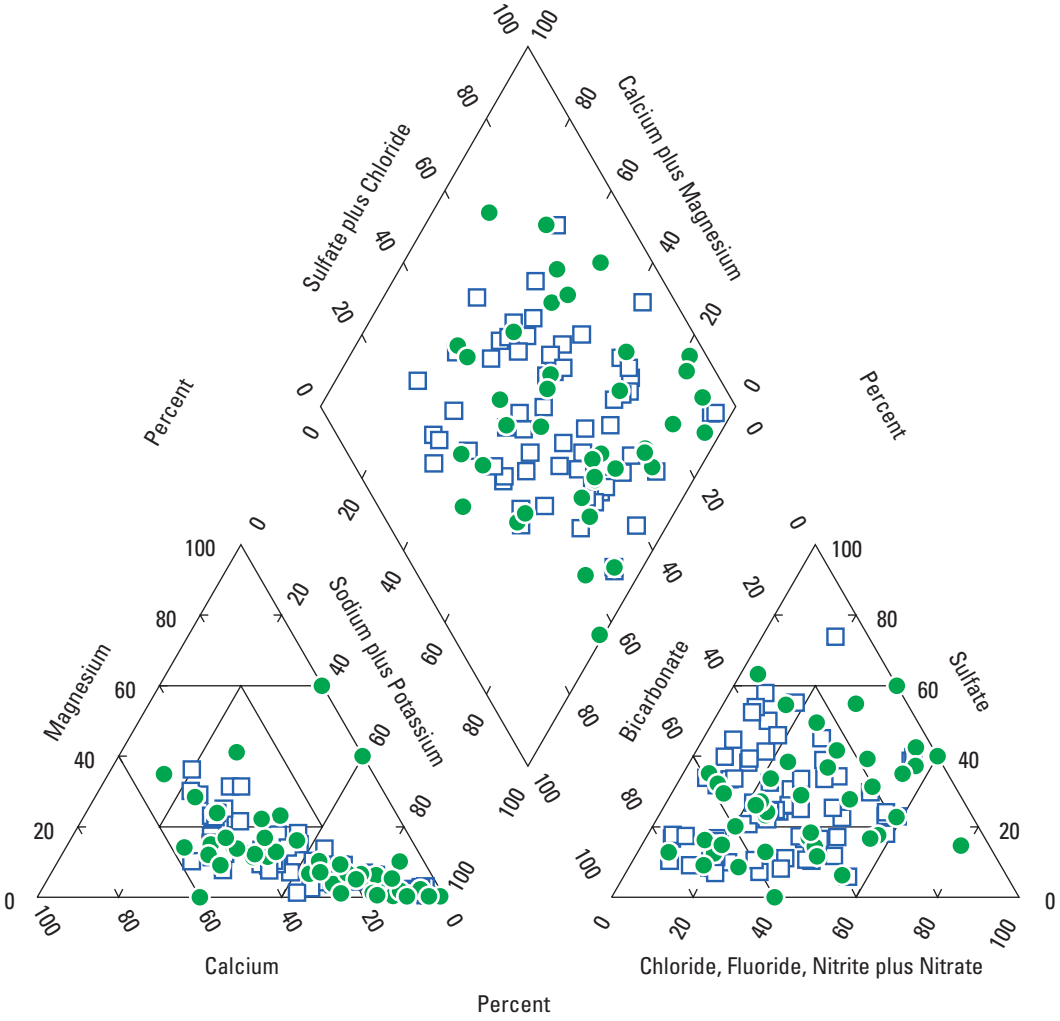


Figure E2. Trilinear diagram showing U.S. Geological Survey (USGS) grid well data and data from all wells in the California Department of Public Health (CDPH) database that have a charge imbalance of less than 10 percent, Borrego Valley, Central Desert, and Low-Use Basins of the Mojave and Sonoran Deserts study unit, California GAMA Priority Basin Project.

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