Prepared in cooperation with the California State Water Resources Control Board

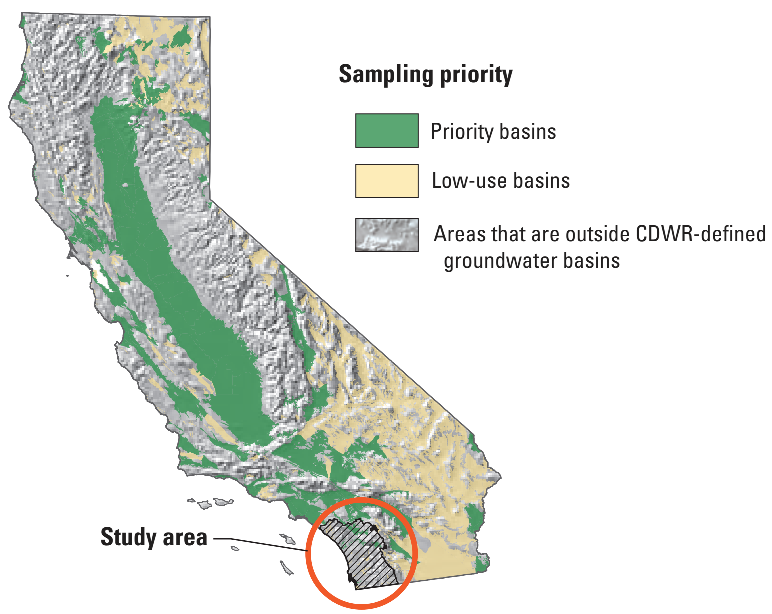
A product of the California Groundwater Ambient Monitoring and Assessment (GAMA) Program

Status and Understanding of Groundwater Quality in the San Diego Drainages Hydrogeologic Province, 2004: California GAMA Priority Basin Project

Scientific Investigations Report 2011–5154

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: Lake Henshaw in San Diego County, California. (Photograph taken by Barbara Dawson, U.S. Geological Survey).

Back cover: Citrus orchard in Pauma Valley, San Diego County, California. (Photograph taken by Jill Densmore, U.S. Geological Survey.)

Status and Understanding of Groundwater Quality in the San Diego Drainages Hydrogeologic Province, 2004: California GAMA Priority Basin Project

By Michael T. Wright and Kenneth Belitz

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

Prepared in cooperation with the California State Water Resources Control Board

Scientific Investigations Report 2011–5154

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

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

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

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

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Wright, M.T., and Belitz, K., 2011, Status and understanding of groundwater quality in the San Diego Drainages Hydrogeologic Province, 2004—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2011–5154, 100 p.

Contents

Contents—Continued

Figures

Figures—Continued

Figures—Continued

Tables

Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

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 mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F=(1.8\times°C)+32.$$

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

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is equivalent to parts per million (ppm), and micrograms per liter is equivalent to parts per billion (ppb).

cm^3 STP g^{-1}	cubic centimeters at standard temperature and pressure per gram
$\delta^{i}E$	delta notation; the ratio of the heavier isotope (i) to the more common lighter isotope of an element (E), relative to a standard reference material, expressed as per mil
mL	milliliter
pCi/L	picocuries per liter
per mil	parts per thousand
pmc	percent modern carbon
TU	tritium unit
%	percent

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

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
BLS	below land surface
DG	CDPH data from well sampled by GAMA
DPH	CDPH data from well not sampled by GAMA
E	estimated or having a higher degree of uncertainty
GAMA	Groundwater Ambient Monitoring and Assessment Program
HAL-US	U.S. Environmental Protection Agency lifetime health advisory level
HBSL	health-based screening level
LRL	laboratory reporting level
LSD	land-surface datum
LT-MDL	long-term method detection level
MCL-CA	California Department of Public Health maximum contaminant level
MCL-US	U.S. Environmental Protection Agency maximum contaminant level
MDL	method detection limit
MRL	minimum reporting level
NL-CA	California Department of Public Health notification level
NWIS	National Water Information System (USGS)
PSW	public-supply wells
RPD	relative percentage difference
RSD	relative standard deviation
RSD5-US	U.S. Environmental Protection Agency risk-specific dose at a risk factor of 10^{-5}
SDALLV	Alluvial Basins study area
SDALLVU	Alluvial Basins study area understanding well
SDHDRK	Hard Rock study area
SDHDRKU	Hard Rock study area understanding well
SDTEM	Temecula Valley study area
SDTEMFP	Temecula Valley study area flow path well
SDWARN	Warner Valley study area
SMCL-CA	California Department of Public Health secondary maximum contaminant level
SMCL-US	U.S. Environmental Protection Agency secondary maximum contaminant level
US	United States
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Organizations

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

Selected Chemical Names

DO	dissolved oxygen
Fe	iron
Nitrate-N	nitrate as nitrogen
Nitrite-N	nitrite as nitrogen
Mn	manganese
MTBE	methyl *tert*-butyl ether
PCE	perchloroethene (tetrachloroethene)
TCE	trichloroethene
TDS	total dissolved solids
THM	trihalomethane
VOC	volatile organic compound

Status and Understanding of Groundwater Quality in the San Diego Drainages Hydrogeologic Province, 2004: California GAMA Priority Basin Project

By Michael T. Wright and Kenneth Belitz

Abstract

Groundwater quality in the approximately 3,900-square-mile (mi^2) San Diego Drainages Hydrogeologic Province (hereinafter San Diego) study unit was investigated from May through July 2004 as part of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The study unit is located in southwestern California in the counties of San Diego, Riverside, and Orange. The GAMA Priority Basin Project is being conducted by the California State Water Resources Control Board in collaboration with the U.S. Geological Survey (USGS) and the Lawrence Livermore National Laboratory.

The GAMA San Diego study was designed to provide a statistically robust assessment of untreated-groundwater quality within the primary aquifer systems. The assessment is based on water-quality and ancillary data collected by the USGS from 58 wells in 2004 and water-quality data from the California Department of Public Health (CDPH) database. The primary aquifer systems (hereinafter referred to as the primary aquifers) were defined by the depth interval of the wells listed in the California Department of Public Health (CDPH) database for the San Diego study unit. The San Diego study unit consisted of four study areas: Temecula Valley (140 mi^2), Warner Valley (34 mi^2), Alluvial Basins (166 mi^2), and Hard Rock (850 mi^2). The quality of groundwater in shallow or deep water-bearing zones may differ from that in the primary aquifers. For example, shallow groundwater may be more vulnerable to surficial contamination than groundwater in deep water-bearing zones.

This study had two components: the *status assessment* and the *understanding assessment*. The first component of this study—the *status assessment* of the current quality of the groundwater resource—was assessed by using data from samples analyzed for volatile organic compounds (VOC), pesticides, and naturally occurring inorganic constituents, such as major ions and trace elements. The status assessment is intended to characterize the quality of groundwater resources within the primary aquifers of the San Diego study unit, not the treated drinking water delivered to consumers by water purveyors. The second component of this study—the *understanding assessment*—identified the natural and human factors that affect groundwater quality by evaluating land use, well construction, and geochemical conditions of the aquifer. Results from these evaluations were used to help explain the occurrence and distribution of selected constituents in the study unit.

Relative-concentrations (sample concentration divided by benchmark concentration) were used as the primary metric for relating concentrations of constituents in groundwater samples to water-quality benchmarks for those constituents that have Federal and (or) California benchmarks. For organic and special-interest constituents, relative-concentrations were classified as high (> 1.0), moderate (> 0.1 and ≤ 1.0), and low (≤ 0.1). For inorganic constituents, relative concentrations were classified as high (> 1.0), moderate (> 0.5 and ≤ 1.0), and low (≤ 0.5). Grid-based and spatially weighted approaches were then used to evaluate the proportion of the primary aquifers (aquifer-scale proportions) with high, moderate, and low relative-concentrations for individual compounds and classes of constituents.

One or more of the inorganic constituents with health-based benchmarks were high (relative to those benchmarks) in 17.6 percent of the primary aquifers in the Temecula Valley, Warner Valley, and Alluvial Basins study areas (hereinafter also collectively referred to as the Alluvial Fill study areas because they are composed of alluvial fill aquifers), and in 25.0 percent of the Hard Rock study area. Inorganic constituents with health-based benchmarks that were frequently detected at high relative-concentrations included vanadium (V), arsenic (As), and boron (B). Vanadium and As concentrations were not significantly correlated to either urban or agricultural land use indicating natural sources as the primary contributors of these constituents to groundwater. The positive correlation of B concentration to urban land-use was significant which indicates that anthropogenic activities are a

contributing source of B to groundwater. The correlation of V, As and B concentrations to pH was positive, indicating that in alkaline groundwater these constituents are being desorbed from, or being inhibited from adsorbing to, particle surfaces.

Inorganic constituents with aesthetic benchmarks that were detected at high relative-concentrations include manganese (Mn), iron (Fe), and total dissolved solids (TDS). In the Alluvial Fill study areas, Mn and TDS were detected at high relative-concentrations in 13.7 percent of the primary aquifers, and Fe in 6.9 percent of the primary aquifers. In the Hard Rock study area, Mn was detected at high relative-concentrations in 33.3 percent of the primary aquifers, and TDS in 16.7 percent; Fe was not detected at high relative-concentrations. Total dissolved solids concentrations were significantly correlated to agricultural land use suggesting that agricultural practices are a contributing source of TDS to groundwater. Manganese and Fe concentrations were highest in groundwater with low dissolved oxygen and pH indicating that the reductive dissolution of oxyhydroxides may be an important mechanism for the mobilization of Mn and Fe in groundwater. TDS concentrations were highest in shallow wells and in modern (< 50 yrs) groundwater which indicates anthropogenic activities as a source of TDS concentrations in groundwater.

The relative-concentrations of organic constituents with health-based benchmarks were high in 3.0 percent of the primary aquifers in the Alluvial Fill study areas. A single detection in the Alluvial Basins study area of the discontinued gasoline oxygenate methyl *tert*-butyl ether (MTBE) was the only organic constituent detected at a high relative-concentration; high relative-concentrations of these constituents were not detected in the Hard Rock study area. Twelve of 88 VOCs and 14 of 123 pesticides and pesticide degradates analyzed in grid wells were detected. Chloroform was the only VOC detected in more than 10 percent of the grid wells. The herbicides simazine, atrazine, and prometon were each detected in greater than 10 percent of the grid wells. Perchlorate was detected in 22 percent of the grid wells sampled.

The *understanding assessment* showed a significant correlation of trihalomethanes (THMs) and solvents to urban land-use, indicating that detections of these constituents are more likely to occur in groundwater underlying urbanized areas of the study unit. MTBE concentrations were negatively correlated to the distance from the nearest leaking underground fuel tank, indicating that point sources are the most significant contributing factor for MTBE concentrations to groundwater in the study unit. The positive correlation of THM and herbicide concentrations to modern groundwater was significant, as was the negative correlation of herbicide concentrations to pH and anoxic groundwater. The negative correlation of herbicides to pH and anoxic groundwater was likely due to the fact that these constituents were detected more frequently in shallow wells where groundwater conditions tend to be oxic with relatively low pH.

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 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 (State of California, 2011, at http://www.waterboards.ca.gov/gama). The statewide GAMA program currently consists of three projects: the GAMA Priority Basin Project, conducted by the USGS (U.S. Geological Survey, 2011, at http://ca.water.usgs.gov/gama/); the GAMA Domestic Well Project, conducted by the SWRCB; and GAMA Special Studies, conducted by LLNL. Statewide, the Priority Basin Project primarily focused on the deep part of the groundwater resource, and the SWRCB Domestic Well Project generally focused on the shallow aquifer systems. Shallow groundwater wells, such as private domestic and environmental monitoring wells, may be particularly at risk because of surficial contamination. As a result, concentrations of contaminants, such as VOCs and nitrate, in shallow wells can be higher than in wells screened in the deep primary aquifers (Landon and others, 2010).

The SWRCB initiated the GAMA Program in 2000 in response to a legislative mandate (State of California, 1999, 2001a, Supplemental Report of the 1999 Budget Act 1999–00 Fiscal Year). The GAMA Priority Basin Project was initiated in response to the Groundwater Quality Monitoring Act of 2001 (State of California, 2001b, Sections 10780–10782.3 of the California Water Code, Assembly Bill 599) to assess and monitor the quality of groundwater in California. The GAMA Priority Basin Project is a comprehensive assessment of statewide groundwater quality designed to 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 the monitoring plan to assess groundwater basins through direct and other statistically reliable sampling approaches (Belitz and others, 2003; State Water Resources Control Board, 2003). Additional partners in the GAMA Priority Basin Project include the California Department of Public Health (CDPH), the California Department of Pesticide Regulation (CDPR), the California Department of Water Resources (CDWR), and local water agencies and well owners (Kulongoski and Belitz, 2004).

The range of hydrologic, geologic, and climatic conditions in California must be considered in an assessment of groundwater quality. Belitz and others (2003) partitioned the State into ten hydrogeologic provinces, each with distinctive hydrologic, geologic, and climatic characteristics (fig. 1).

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

Provinces from Belitz and others, 2003

Figure 1. Location of the California hydrogeologic provinces and the San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

All of these hydrogeologic provinces contain groundwater basins and subbasins designated by the CDWR (California Department of Water Resources, 2003). Groundwater basins generally consist of relatively permeable, unconsolidated deposits of alluvial or volcanic origin. Eighty percent of California's approximately 16,000 public-supply wells (PSW) are in designated groundwater basins. Groundwater basins and subbasins were prioritized for sampling on the basis of the number of PSWs, with secondary consideration given to municipal groundwater use, agricultural pumping, the number of historically leaking underground fuel tanks, and registered pesticide applications (Belitz, and others, 2003). The 116 priority basins and additional areas outside defined groundwater basins were grouped into 35 study units, which include approximately 95 percent of PSWs in California.

Purpose and Scope

The purposes of this report are to provide a (1) study unit description: description of the hydrogeologic setting of the San Diego Drainages Hydrogeologic Province Groundwater Ambient Monitoring and Assessment (GAMA) study unit (hereinafter San Diego study unit) (fig. 1), (2) *status assessment*: assessment of the status of the current quality of groundwater in the primary aquifer systems in the San Diego study unit, and (3) *understanding assessment*: identification of the natural and human factors affecting groundwater quality and explanation of the relations between water quality and those factors.

Water-quality data for samples collected by the USGS for the GAMA Program in the San Diego study unit and details of sample collection, analysis, and quality-assurance procedures for the San Diego study unit are reported by Wright and others (2005). Utilizing those same data, this report describes methods used in designing the sampling network, identifying CDPH data for use in the *status assessment*, estimating aquifer-scale proportions of relative-concentrations, analyzing ancillary datasets, classifying groundwater age, and assessing the status and understanding of groundwater quality by using statistical and graphical approachess.

The *status assessment* includes analyses of water-quality data for 47 PSWs selected by the USGS for spatial coverage of one well per grid cell (hereinafter referred to as USGS-grid wells) across the San Diego study unit. Samples were collected for analysis of anthropogenic constituents, such as volatile organic compounds (VOC) and pesticides, and naturally occurring inorganic constituents such as major ions and trace elements. Water-quality data from 23 PSWs in the California Department of Public Health (CDPH) database also were used to supplement data collected by USGS for the GAMA program. The resulting set of water-quality data from USGS-grid wells and selected CDPH wells was considered to be representative of the primary aquifer systems in the San Diego study unit; the primary aquifer systems (hereinafter referred to as primary aquifers) are defined by the depth interval of the wells listed in the CDPH database for the San Diego study unit. GAMA *status assessments* are designed to provide a statistically robust characterization of groundwater quality in the primary aquifers at the basin-scale (Belitz and others, 2003). The statistically robust design also allows basins to be compared and results to be synthesized at regional and statewide scales.

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

In addition to the 47 grid-wells sampled for the *status assessment*, the *understanding assessment* also uses data from the 11 wells sampled by the USGS for the purposes of understanding (hereinafter referred to as USGS-understanding wells). Data from these wells are used to identify the natural and human factors affecting groundwater quality and to explain the relations between water quality and selected potential explanatory factors. Potential explanatory factors examined included land use, depth to the top of the uppermost open interval, indicators of groundwater age, and geochemical conditions.

Description of Study Unit

The San Diego study unit boundaries are the same as those of the San Diego Drainages Hydrogeologic Province described by Belitz and others (2003) and covers approximately 3,900 square miles (mi^2). The San Diego study unit encompasses the majority of San Diego County, as well as parts of southwestern Orange and Riverside Counties (fig. 2). Geographic boundaries of the San Diego study unit are the Transverse Ranges and Selected Peninsular Ranges Province to the north, the Desert Province to the east, the country of Mexico to the south, and the Pacific Ocean to the west.

The climate in the coastal areas of the San Diego study unit generally is mild, with temperatures averaging 64 degrees Fahrenheit (°F) and average annual precipitation ranging from 10 to 13 inches (in.) (California Regional Water Quality Control Board, San Diego Region, 1994). In the eastern part of the study unit, annual temperatures in the Peninsular Ranges average 55 °F, with average annual precipitation of approximately 45 in.

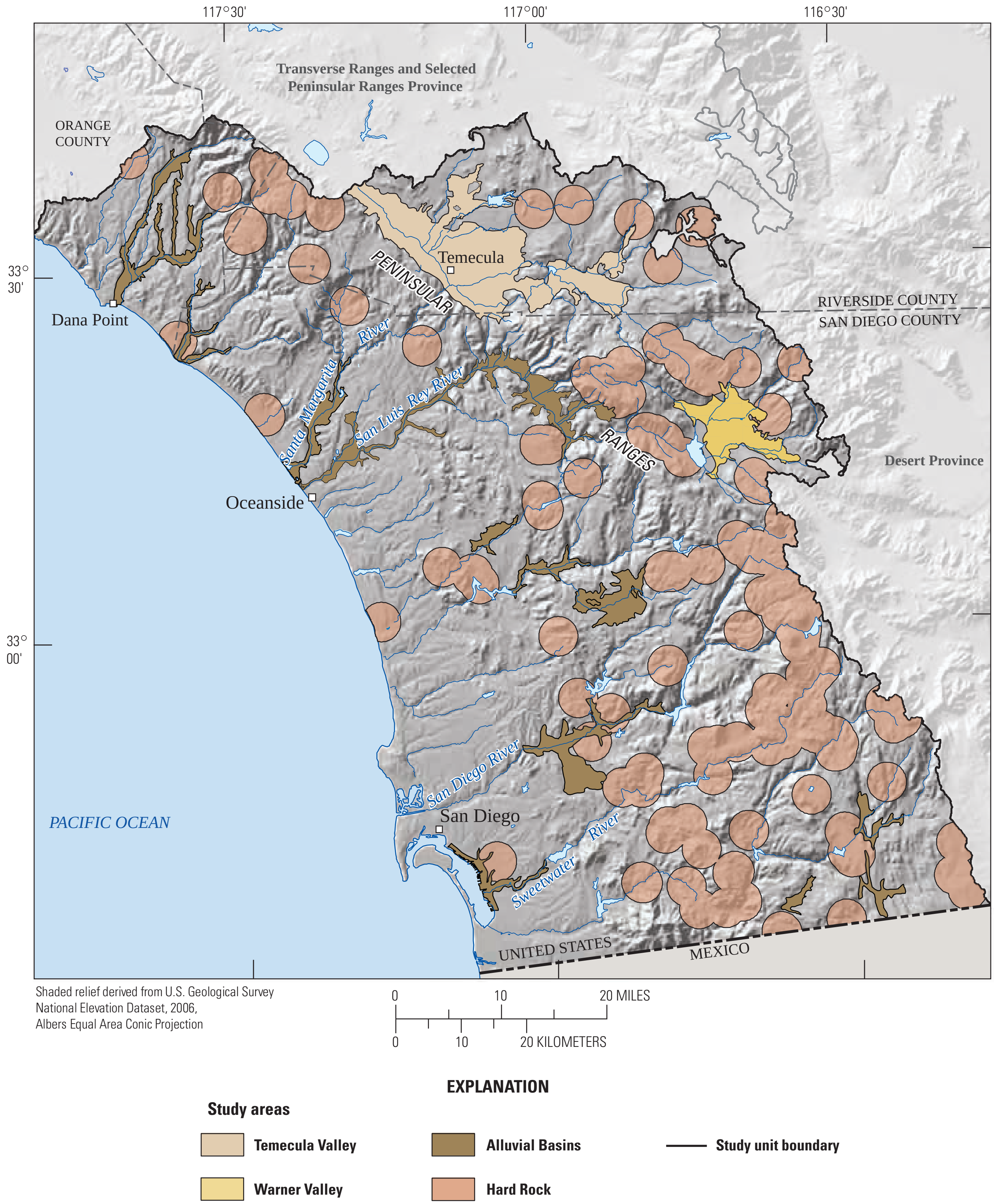


Figure 2. Geographic features and study area boundaries of the San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

The San Diego study unit is drained by a number of creeks and rivers, including the Santa Margarita and San Luis Rey Rivers in the north, and the San Diego and Sweetwater Rivers in the south (fig. 2). Runoff in the study unit is attributed mainly to rainfall; however, smaller amounts of runoff come from urban water use, snowmelt, and artesian springs. Groundwater and surface-water flow direction is primarily from the mountainous east towards the west and the Pacific Ocean. Groundwater recharges in the study unit by precipitation, irrigation returns, infiltration of reservoir and river water, and engineered recharge. Groundwater primarily discharges through pumping from wells.

The San Diego study unit is composed of relatively small groundwater basins that underlie approximately 400 mi^2 of land surface, corresponding to the Temecula Valley, Warner Valley, and Alluvial Basins study areas (fig. 2). In addition, a part of the groundwater resources in the San Diego study unit are in areas outside of defined groundwater basins. This area underlies approximately 850 mi^2 of the study unit land surface and was defined as all areas located outside a CDWR-defined groundwater basin, but within 1.9 miles (mi) of a PSW documented in the CDPH database, and corresponds to the Hard Rock study area (fig. 2).

The land use in the study unit is 7 percent agricultural, 84 percent natural, and 9 percent urban based on classification by the USGS National Land Cover Data (Vogelman and others, 2001; Price and others, 2003) (fig. 3*A*). The natural land-use areas are mostly shrub land, with lesser amounts of evergreen forest and grass lands. Natural land-use is most predominant in the eastern parts of the study unit (fig. 4*A*–*C*).

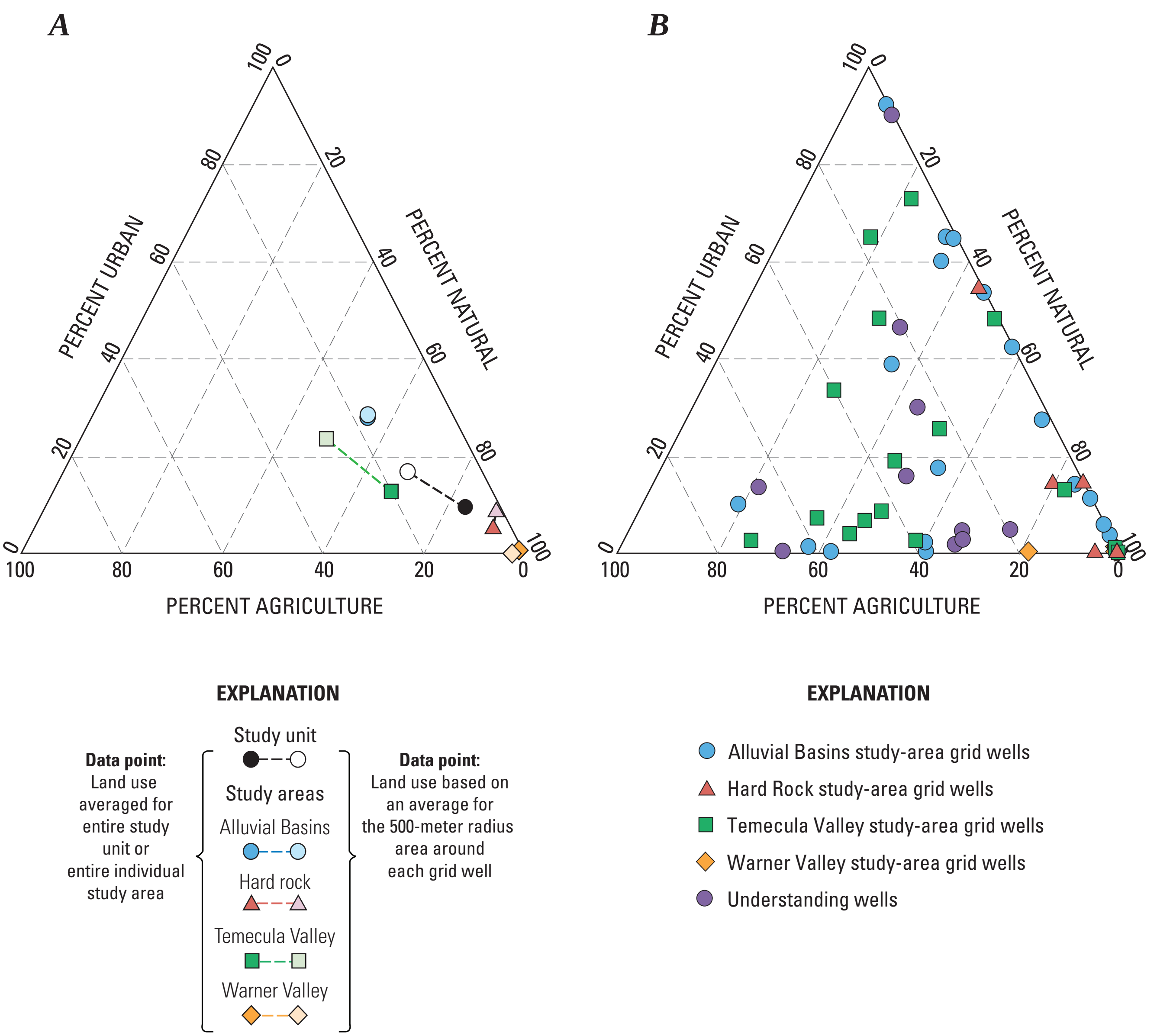


Figure 3*A*–*B*. Ternary diagram of proportions of urban, agricultural, and natural land-uses in the San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California. (*A*) Study unit and study areas, (*B*) wells.

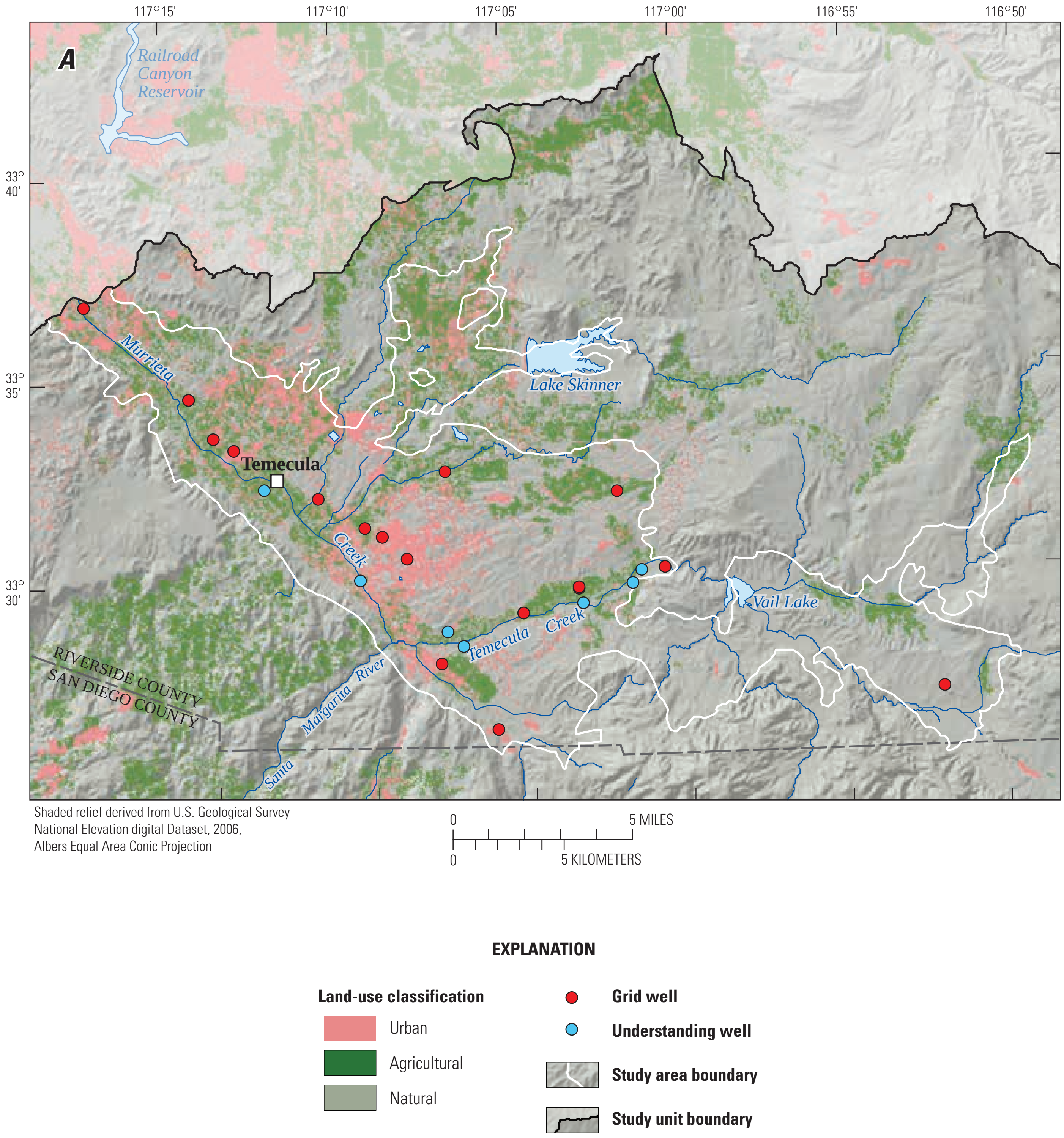


Figure 4*A*–*C*. Land-use classification in the San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, and locations of grid and understanding wells. (*A*) Temecula Valley, (*B*) Warner Valley, (*C*) Alluvial Basins, and Hard Rock study areas.

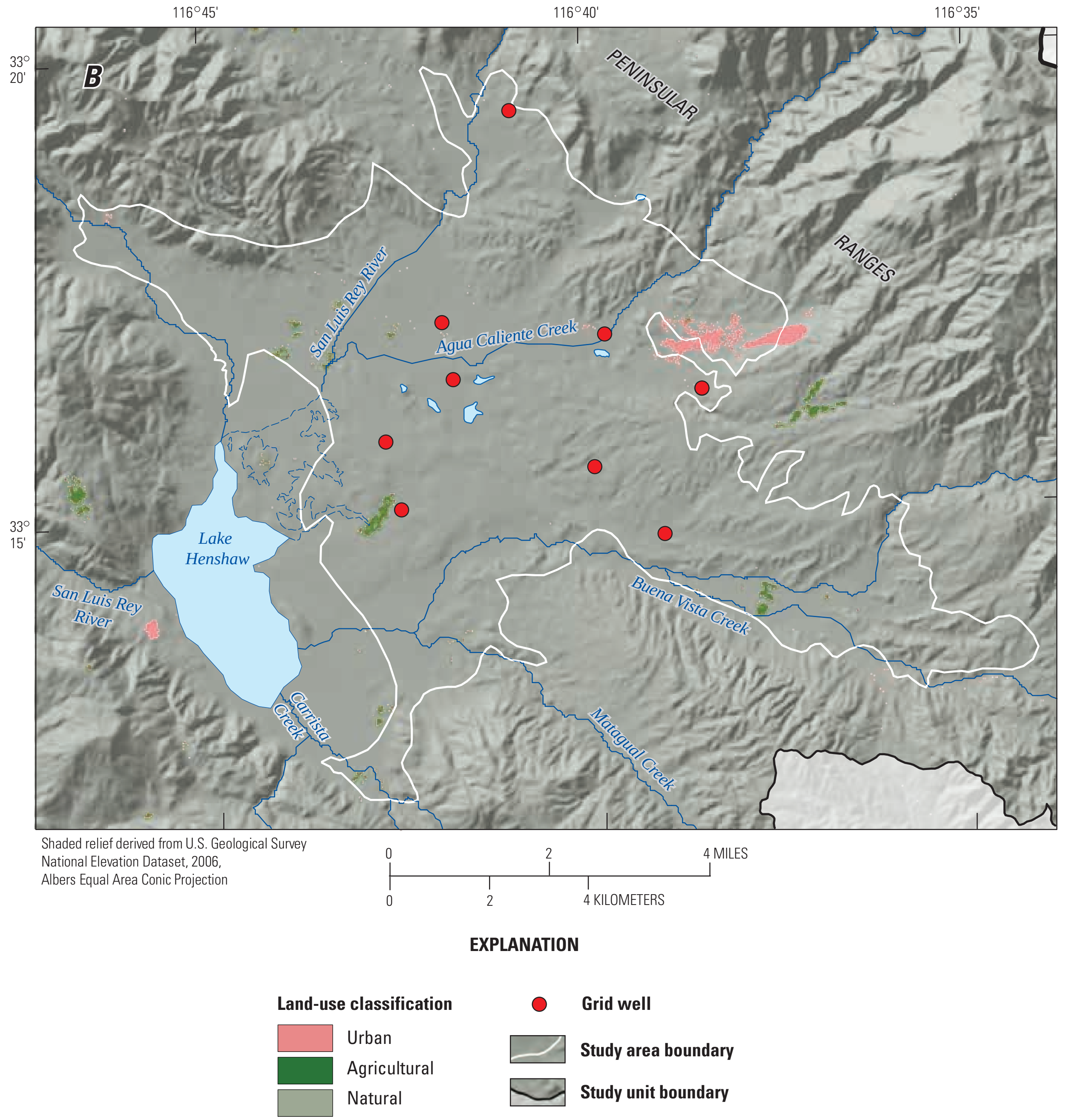


Figure 4*A*–*C*.—Continued

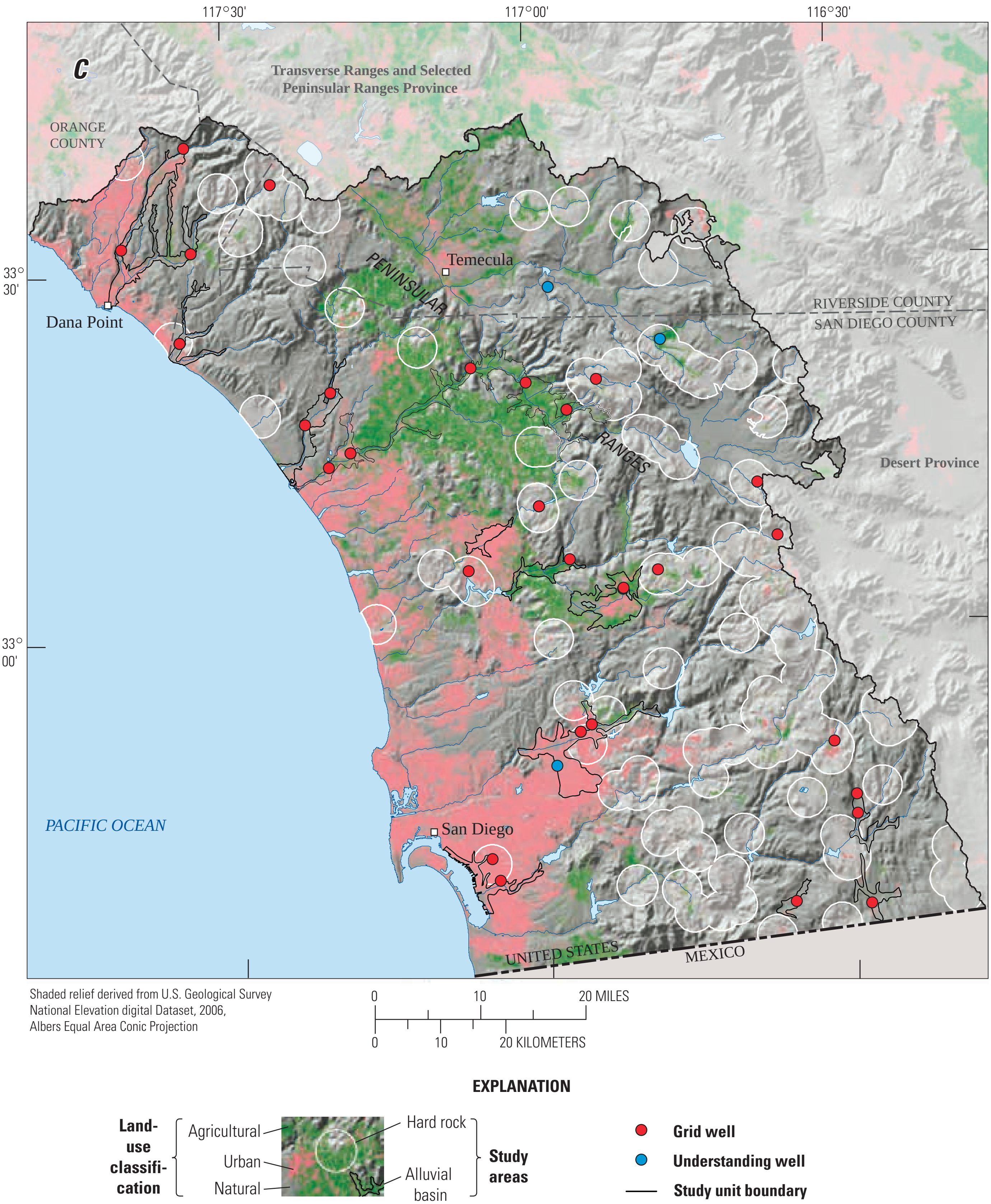


Figure 4*A*–*C*.—Continued

Agricultural land-use in the study unit is equal parts orchards and pasture land, with a small percentage of row crops. Urban land-use primarily is found in the coastal areas of the study unit and the largest urban center is the San Diego metropolitan area. The majority of land use in all study areas is natural; the Warner Valley and Hard Rock study areas are classified as 99 and 91 percent natural, respectively (fig. 3*A*). The Alluvial Basins and Temecula Valley study areas are the most urbanized in the San Diego study unit (28 and 13 percent, respectively); the largest amount of agricultural land-use also is in these study areas (17 and 20 percent respectively).

Description of Study Areas

The boundaries of the Temecula Valley study area (fig. 2) are the same as those of the Temecula Valley groundwater basin as described by the California Department of Water Resources, (2004a). The Temecula Valley study area primarily is in southwestern Riverside County with a very small part of the basin extending into northern San Diego County. The Temecula Valley study area covers approximately 140 mi^2 and is bounded by the relatively impermeable rocks of the Peninsular Ranges on three sides. The main water-bearing units are Quaternary alluvium that is estimated to be as great as 2,500 feet (ft) thick; generally it is unconfined except in areas where faults cut across the basin (California Department of Water Resources, 1956; Kennedy, 1977). Rock types that bound the groundwater-bearing deposits in the study area include Mesozoic granites and gabbros and Jurassic marine sedimentary rocks (fig. 5*A*) (Saucedo, 2000). Sources of groundwater recharge in the basin include percolation of precipitation, infiltration of irrigation and domestic return water, and engineered recharge from spreading basins along Temecula Creek. Groundwater primarily discharges through groundwater pumping. Average annual precipitation ranges from 7 to 15 in. Surface water drains to several creeks, including Temecula and Murrieta Creeks that discharge into the Santa Margarita River, which then flows westward out of the valley.

The boundaries of the Warner Valley study area (fig. 2) are the same as those of the Warner Valley groundwater basin, which is located in northeastern San Diego County (California Department of Water Resources, 2004b). The Warner Valley study area has a surface area of 37 mi^2; it is bounded on the west by Lake Henshaw and on all other sides by the crystalline rocks of the Peninsular Ranges. The main water-bearing unit consists of alluvium and residuum (California Department of Water Resources, 1971). The alluvium is as great as 900 ft thick and generally is unconsolidated. The crystalline rocks that bound the groundwater-bearing deposits in this study area consist primarily of Mesozoic granite and metamorphic rocks of pre-Cenozoic age (fig. 5*B*) (Saucedo, 2000). Sources of groundwater recharge include percolation of precipitation, and river and stream runoff. Groundwater discharges primarily through groundwater pumping. Annual precipitation ranges from 15 to 21 in. The Warner Valley study area is primarily drained by the Agua Caliente and Buena Vista Creeks, and the San Luis Rey River, all of which flow westward into Lake Henshaw.

The Alluvial Basins study area (fig. 2) is composed of all alluvial basins in the study unit that have one or more PSWs. The 12 groundwater basins in this study area are the San Juan, San Mateo, Santa Margarita, San Luis Rey, San Pasqual, Santa Maria, San Diego River, El Cajon, Sweetwater, Cottonwood, Campo, and Potrero Valleys (California Department of Water Resources, 2003). The collective surface area of the study area is approximately 166 mi^2, with individual basins ranging in area from as small as 3 mi^2 (California Department of Water Resources, 2004c), to as large as 46 mi^2 (California Department of Water Resources, 2004d). The main water-bearing units are Quaternary age alluvium and residuum, with an average thickness of alluvium that ranges from approximately 15 ft in the San Mateo Valley groundwater basin (California Department of Water Resources, 1991) to 60 ft in the San Luis Rey groundwater basin (Izbicki, 1985). Inland alluvial basins generally are bound by the Mesozoic granites of the Peninsular Ranges, whereas coastal alluvial basins generally are bounded by Cenozoic-aged sedimentary rocks (fig. 5*C*) (Saucedo, 2000). Sources of groundwater recharge include percolation of precipitation, river and stream runoff, agricultural and domestic returns, discharge of wastewater to rivers, and septic systems. Groundwater primarily discharges through groundwater pumping. The average annual precipitation in these basins range from as little as 8 in. to as great as 21 in. Runoff from precipitation primarily is drained to the southwest towards the Pacific Ocean, but some basins are internally drained.

The Hard Rock study area (fig. 2) consists of all areas outside of CDWR-defined groundwater basins that are within 3 km of a PSW. The study area covers approximately 850 mi^2 and most of the study area is in the inland areas of the study unit. Surficial geology in the study area primarily is composed of granitic and metamorphic rocks with small amounts of Mesozoic volcanic and Cenozoic marine sedimentary rocks (fig. 5*C*). Well completion reports for the PSWs sampled by the GAMA program indicate that wells are withdrawing water primarily from fractured and decomposed granite. Sources of groundwater recharge include percolation of precipitation, and river and stream runoff.

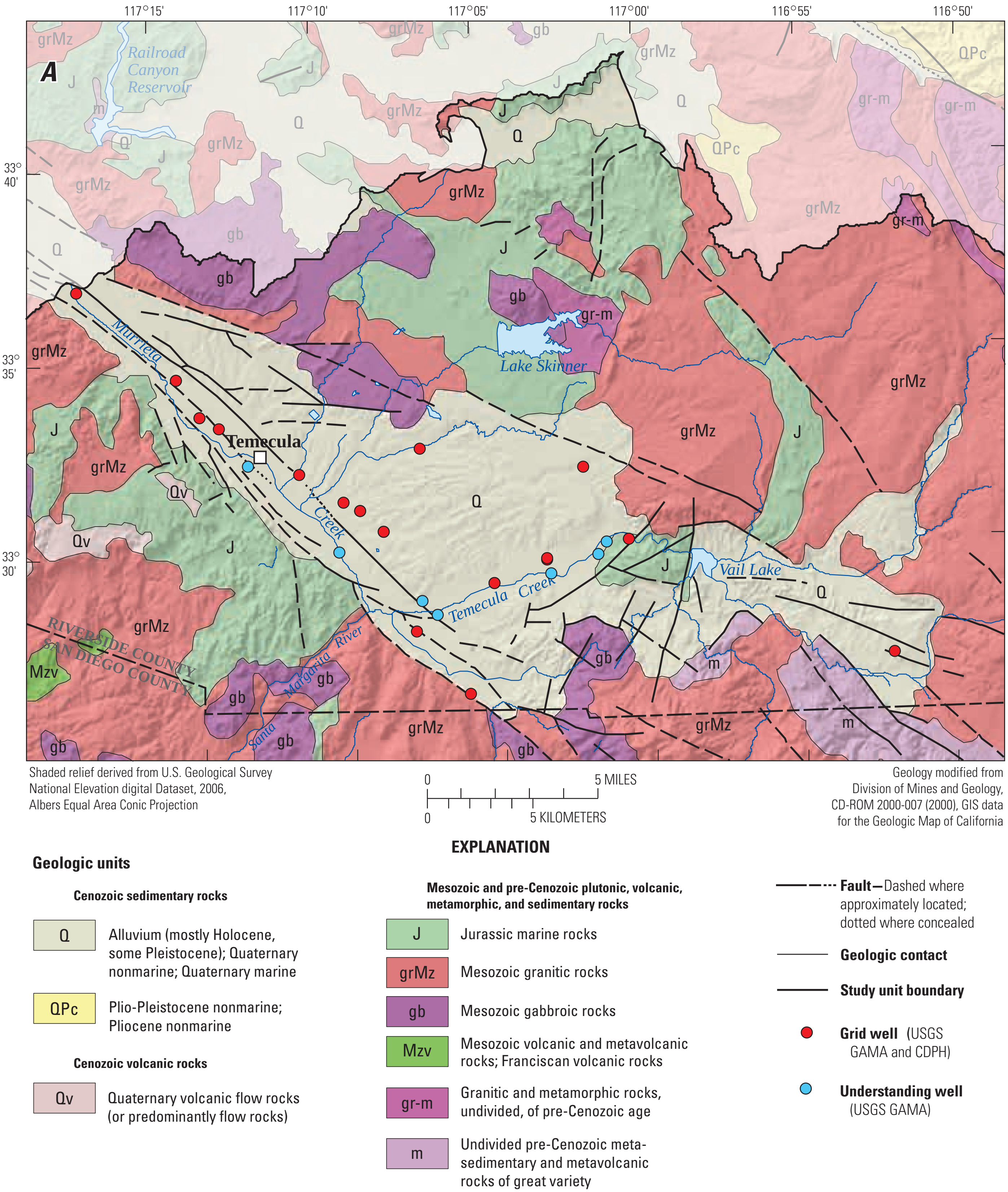


Figure 5*A*–*C*. The geology of the San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit and study areas: (*A*) Temecula Valley, (*B*) Warner Valley, (*C*) Alluvial Basins, and Hard Rock study areas.

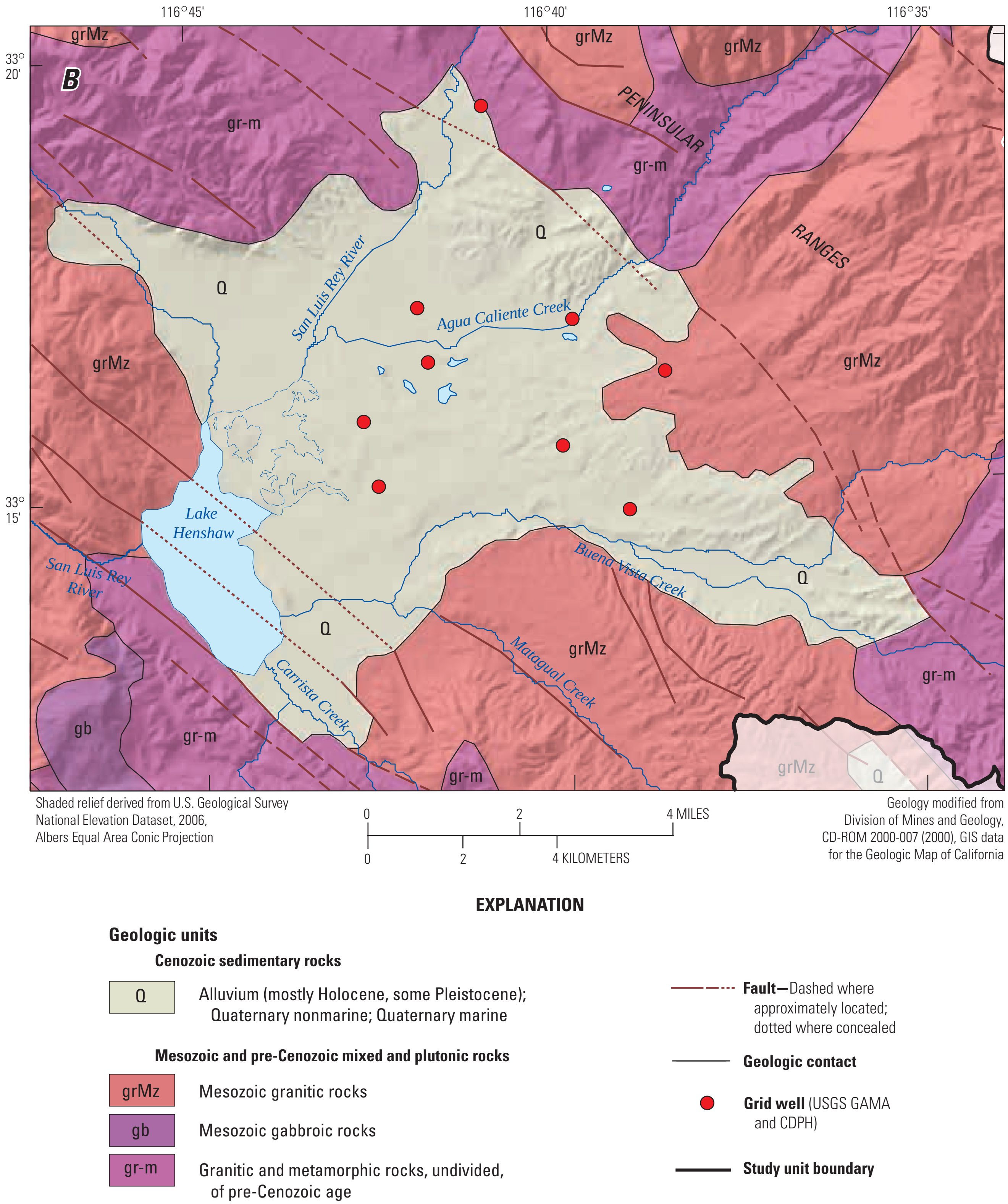
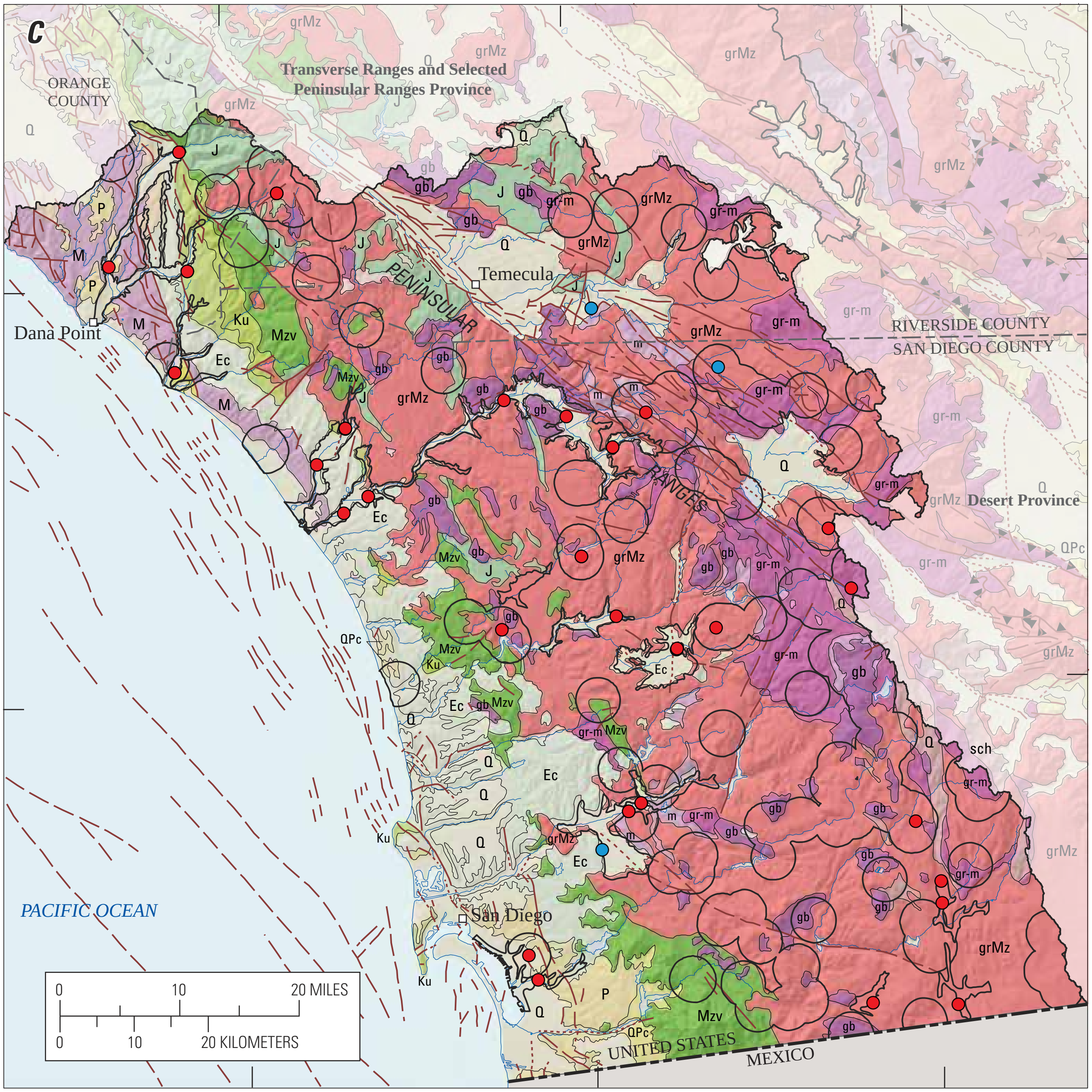


Figure 5*A*–*C*.—Continued



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

EXPLANATION

Geologic units

Cenozoic sedimentary rocks

- Q — Alluvium (mostly Holocene, some Pleistocene); Quaternary nonmarine; Quaternary marine
- QPc — Plio-Pleistocene nonmarine; Pliocene nonmarine
- P — Pliocene nonmarine
- Ec — Eocene nonmarine

Cenozoic volcanic rocks

- Qv — Quaternary volcanic flow rocks (or predominantly flow rocks)

Mesozoic and pre-Cenozoic plutonic, volcanic, metamorphic, and sedimentary rocks

- J — Jurassic marine
- grMz — Mesozoic granitic rocks
- gb — Mesozoic gabbroic rocks
- Mzv — Mesozoic volcanic and metavolcanic rocks; Franciscan volcanic rocks
- gr-m — Granitic and metamorphic rocks, undivided, of pre-Cenozoic age
- m — Undivided pre-Cenozoic meta-sedimentary and metavolcanic rocks of great variety

Fault—Dashed where approximately located; dotted where concealed

Geologic contact

Grid well (USGS GAMA and CDPH)

Understanding well (USGS GAMA)

Hard Rock study unit

Alluvial BasinS study unit

Figure 5*A*–*C*.—Continued

Methods

The *status assessment* provides a spatially unbiased assessment of groundwater quality within in the primary aquifers, whereas the *understanding assessment* was designed to evaluate the natural and human factors that affect the groundwater quality of the San Diego study unit. The *status assessment* was conducted for each study area. This section describes the methods used for (1) defining groundwater quality, (2) assembling the datasets used for the *status assessment*, (3) determining which constituents warrant assessment, (4) calculating aquifer-scale proportions, and (5) analyzing statistics for the *understanding assessment*.

The primary metric for defining groundwater quality is *relative-concentration*, which references concentrations of constituents measured in groundwater to regulatory and non-regulatory benchmarks used to evaluate drinking water quality. Constituents are included or not included in the assessment on the basis of objective criteria by using these relative-concentrations. Groundwater-quality data collected by 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 calculated aquifer-scale proportions of low, moderate, or high relative-concentrations: the “grid-based” method uses one value per cell to represent groundwater quality and the “spatially weighted” method uses many values per cell.

The CDPH database contains historical records from more than 25,000 wells, necessitating targeted retrievals to effectively access relevant water-quality data. 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 identify constituents for inclusion 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*:

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

Relative-concentrations were used because they provide context for the measured concentrations in the sample: relative-concentrations less than 1 indicate sample concentrations less than the benchmark, and values greater than 1 indicate sample concentrations greater than the benchmark. The use of relative-concentrations also permits comparison on a single scale of constituents present at a wide range of concentration.

Toccalino and others (2004), Toccalino and Norman (2006), and Rowe and others (2007) previously used the ratio of measured sample concentration to the benchmark concentration (either maximum contaminant levels (MCLs) or Health-Based Screening Levels (HBSL)), and defined this ratio as the benchmark quotient. Relative-concentrations used in this report are equivalent to the benchmark quotient reported by Toccalino and others (2004) for constituents that have MCLs. However, HBSLs were not used in this report, as they are not currently used as benchmarks by California drinking-water regulatory agencies. Relative-concentrations can be computed only for constituents with water-quality benchmarks; therefore, constituents lacking water-quality benchmarks are not included in the *status assessment*.

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). 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, respectively), USEPA action levels and treatment technique levels (AL-US and TT-US, respectively).

2. Non-regulatory CDPH and USEPA secondary maximum contaminant levels (SMCL-CA and SMCL-US, respectively). 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 for 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.

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

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