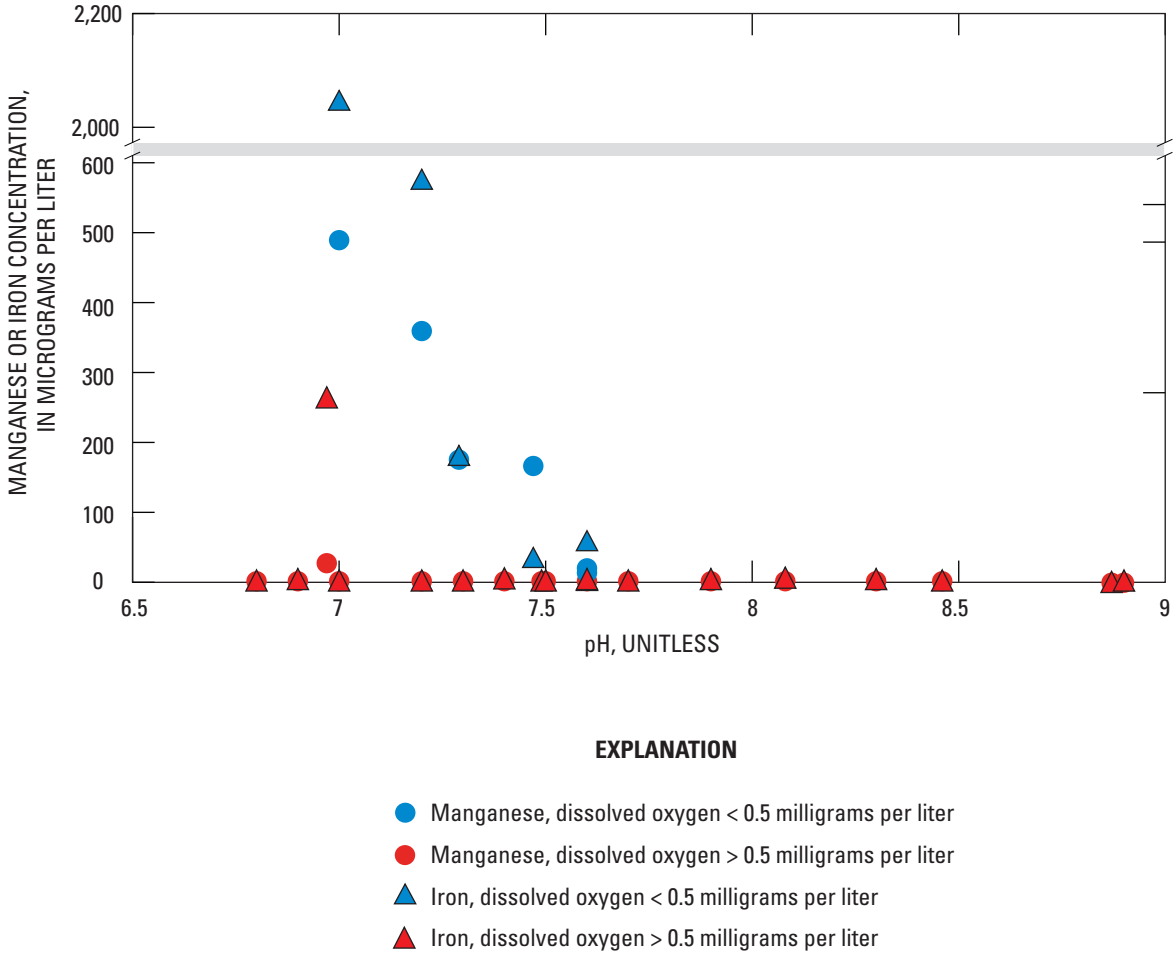

Figure 16. Relation of manganese and iron concentrations to redox conditions and pH, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

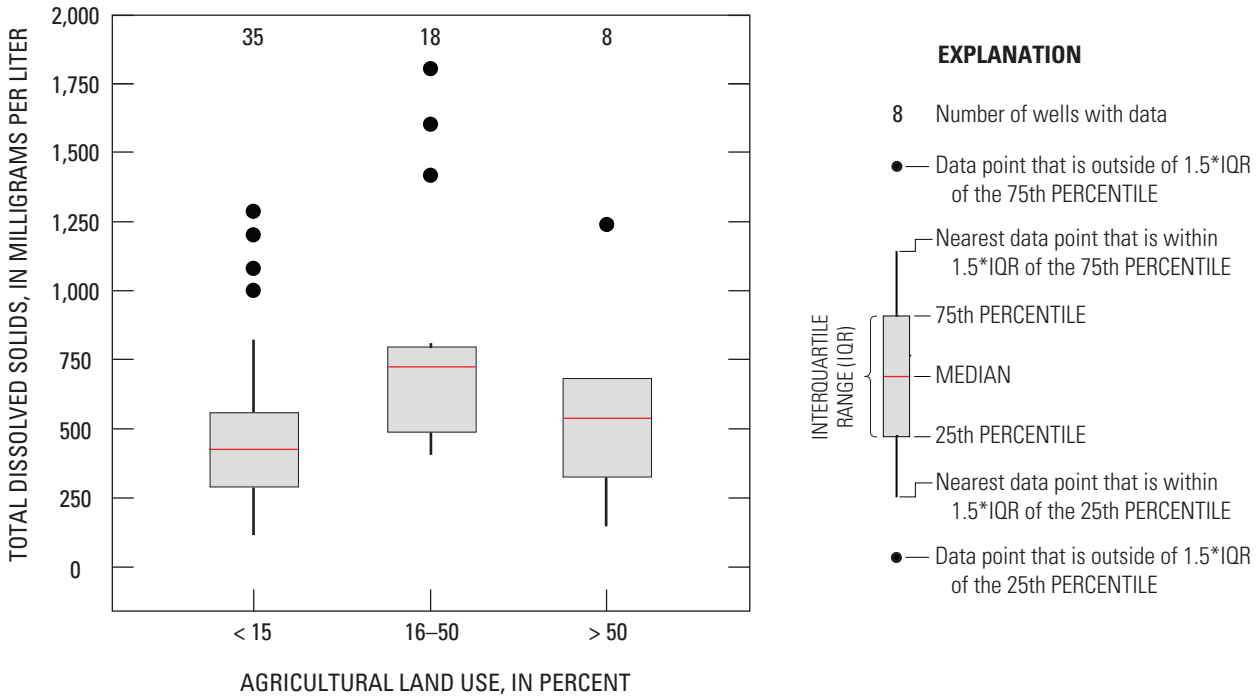

Figure 17. Boxplots of relation of total dissolved solids (TDS) concentrations to agricultural land use, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Position on the flow path also may affect TDS concentrations in groundwater. Samples collected from wells at high elevations may be tapping groundwater that is located at the proximal end of flow paths where dissolution reactions with the aquifer matrix have occurred to a lesser extent than in groundwater located at the distal ends of the flow paths. Additionally, as groundwater moves down the flow path towards discharge areas, evaporation of groundwater near the water table can increase TDS concentrations.

In the San Diego study unit, the negative correlation of TDS concentrations to depth to the top of the uppermost open interval was significant as was the positive correlation of TDS to groundwater with a component of modern recharge (fig. 18; table 9). The high TDS concentrations associated with shallow wells and modern groundwater recharge implies greater loading of dissolved constituents to groundwater in recent decades which could indicate several anthropogenic factors including agricultural and urban irrigation practices, and changes in soil chemistry as a result of historical changes in land use. The negative correlation of TDS concentrations to pH also was significant (table 9) and most likely is not the result of any geochemical processes but instead is the result of the correlation between well depth and pH (table 7).

Seawater intrusion also can cause TDS concentrations in coastal areas to increase. However, in the coastal alluvial aquifers of the San Diego study unit, previous and current studies have indicated that seawater intrusion is not a significant contributing factor to TDS concentrations (Izbicki, 1985; San Diego County Water Authority, 1997; Danskin and Church, 2005; Robert Anders, U.S. Geological Survey, personal commun., 2011).

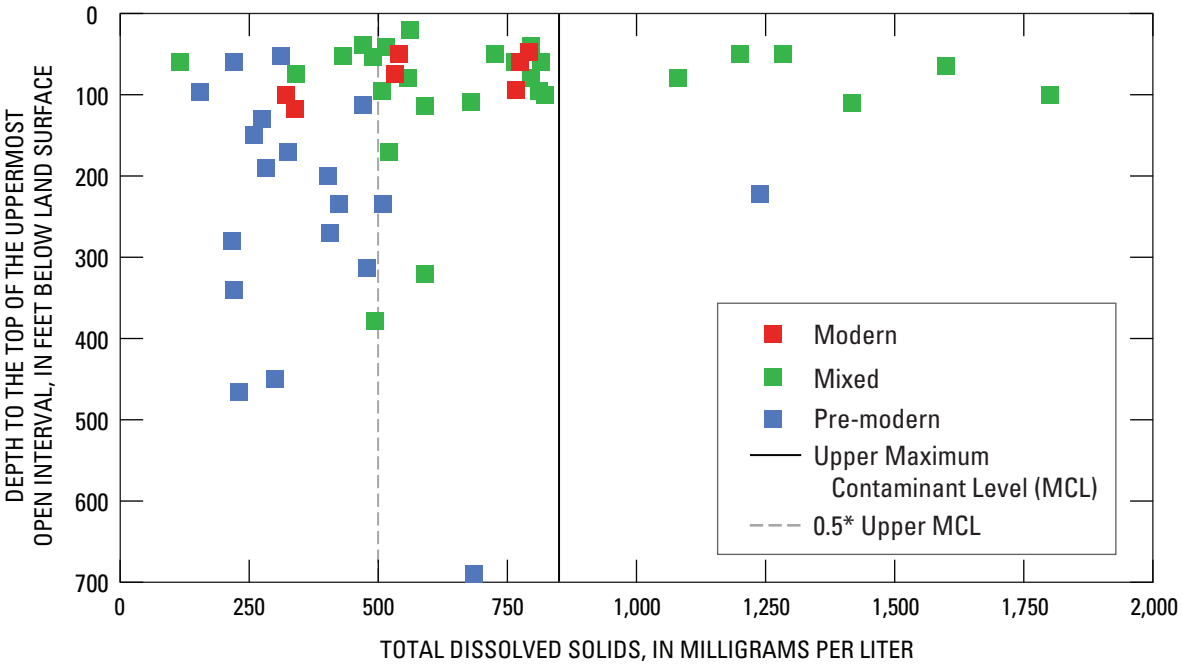

Figure 18. Relation of TDS to depth to the top of the uppermost open interval and to groundwater age classification, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Radioactive Constituents

The relative-concentrations of individual radioactive constituents meeting the selection criteria (relative-concentration ≥ 0.5) are shown in figure 10. As a class, radioactive constituents were detected at high relative-concentrations in 3.2 percent of the primary aquifers in the Alluvial Fill study areas (table 8). These constituents most frequently were detected at high relative-concentrations in the Alluvial Basins (6.7 percent) study area, and were not detected at high relative-concentrations either in the Temecula Valley or in the Warner Valley study areas (tables B2A–C). In the Hard Rock study area, radioactive constituents were detected at high relative-concentrations in 25.0 percent of the primary aquifers (table B2D). Radon-222 (5.3 percent) was the only radioactive constituent detected at high relative-concentrations in greater than or equal to 2.0 percent of the primary aquifers for all study areas in the San Diego study unit (non area-weighted aquifer-scale proportions).

The location and distribution of radon-222 in the San Diego study unit is displayed in figure 19. All but one of the radon-222 detections were at low relative-concentrations. The one detection at a high relative-concentration was in the Hard Rock study area.

Factors Affecting Radon-222

Radon-222 is a radioactive gas that occurs naturally in groundwater in the decay of uranium-238 to lead-206. Uranium-238 decays in multiples steps to radium-226, which decays to radon-222 in aquifer materials. In the San Diego study unit, the correlation between radon-222 and radium-226 activities in groundwater is not significant. This insignificant correlation in part may be a result of groundwater in crystalline rocks that generally has low radium activities because radium sorbs strongly to mineral surfaces, particularly to altered feldspars (Zapecza and Szabo, 1988; Thomas and others, 1993). Radon, however, is an inert gas that readily diffuses out of the aquifer materials and into the groundwater. Ayotte and others (2007) detected greater activities of radon-222 in groundwater from crystalline bedrock aquifers in the northern United States than in aquifers comprised of glacial sediments derived from the crystalline bedrock. The greater radon-222 activities in the crystalline bedrock aquifers was attributed to concentration of sorbed radium on fracture surfaces. The highest activities of radon-222 in this study also were detected in the crystalline rock aquifers of the Hard Rock study area. Radon-222 concentrations were not significantly correlated to any of the potential explanatory variables listed in table 9.

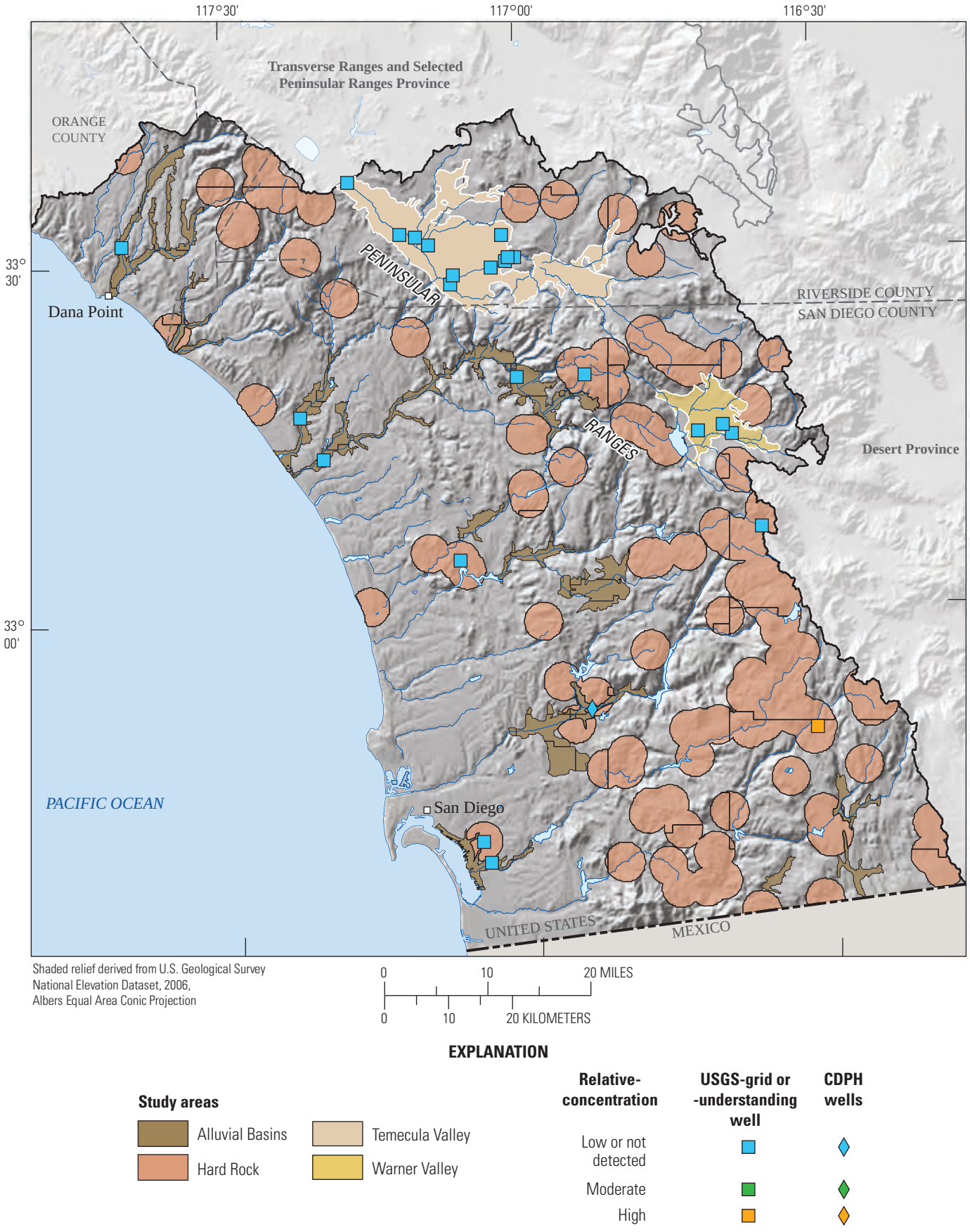

Figure 19. Values of radon-222 in USGS-grid and -understanding wells representative of the primary aquifers and the most recent analysis July 30, 2001–July 29, 2004, for CDPH wells, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Organic and Special-Interest Constituents

Volatile organic compounds can be in paints, solvents, fuels, refrigerants, can be byproducts of water disinfection, and are characterized by their tendency to evaporate. In this report, VOCs are categorized as trihalomethanes, solvents, and gasoline components. Pesticides are used to control weeds, insects, or fungi in agricultural, urban, and suburban settings. In this report, pesticides are discussed only in terms of herbicides because those were only class of pesticides detected in grid wells in the San Diego study unit.

Maximum relative-concentration and detection frequency (in grid wells not area-weighted), at any concentration, were used as selection criteria for organic and special-interest constituents and are shown in figure 20. Seven organic and special-interest constituents met the selection criteria: chloroform, 1,2-Dichloropropane, methyl *tert*-butyl ether (MTBE), atrazine, simazine, prometon, and perchlorate (fig. 21). Overall, organic constituents were detected in 62 percent of the 47 grid wells (not area-weighted) in the San Diego study unit.

Of the 12 VOCs detected with a health-based benchmark, 10 were detected only at low relative-concentrations. One VOC, 1,2-Dichloropropane, was detected at moderate relative-concentration (fig. 21). MTBE was the only VOC detected at a concentration greater than a health-based benchmark. The trihalomethane (THM) chloroform was the only VOC detected in more than 10 percent of the grid wells (fig. 21). Overall, the detection frequency for VOCs in the 47 grid wells (not area-weighted) was 34 percent.

Of the 123 pesticides and pesticide degradates analyzed, 9 pesticides were detected in grid wells with a health-based benchmark (fig. 20). In addition to these pesticides, five pesticide degradation products (daughter compounds) were detected in grid wells. All concentrations of pesticides were less than health-based benchmarks. Three pesticides—simazine, prometon, and atrazine—were detected in greater than 10 percent of the grid wells sampled (fig. 21). Overall, the detection frequency (non-area-weighted) for pesticides with health based benchmarks was 45 percent, and for any pesticide or pesticide degradate the detection frequency was 53 percent.

Overall, organic constituents with health based benchmarks were detected at high relative-concentrations in 3.0 percent of the primary aquifers in the Alluvial Fill study areas (table 8). The Alluvial Basins was the only study area in which these constituents were detected at a high relative-concentration (tables B2A–C). No high relative-concentrations were detected in the Hard Rock study area (table B2D).

Trihalomethanes

The THMs chloroform and bromodichloromethane were detected in multiple wells in the Alluvial Fill study areas. All THMs were detected at low relative-concentrations. The detection frequencies for THMs in grid wells was highest in the Alluvial Basins study area (33.3 percent), and then in the Temecula Valley studies area (25 percent), but were not detected in grid wells in the Warner Valley or Hard Rock study areas (fig. 22). THMs were the most frequently detected class of VOCs in aquifers based on national assessments by the USGS National Water-Quality Assessment (NAWQA) Program (Zogorski and others, 2006).

Factors Affecting Trihalomethane Distribution

Potential sources of THMs include recharge from landscape irrigation with disinfected water, leakage from distribution or sewer systems, and various industrial and commercial sources (Ivahnenko and Barbash, 2004). On a national scale, the detection of THMs in groundwater is correlated to urban land use (Zogorski and others, 2006). In the San Diego study unit, the positive correlation of THMs to urban land use was significant (table 9). Figure 23*A* shows detection frequency and concentration of THMs in groundwater samples as a function of urban land use. Although THMs are most frequently detected in samples collected from wells located in areas where urban landuse is greater than 50 percent, the samples with the highest THM concentrations came from wells located in a non-urban area. These wells (SDTEM-10 and SDTEMFP-04) are tapping imported water used for engineered recharge, which may be the source of THMs in this area (fig. 23*B*).

Trihalomethane concentrations were significantly higher in wells with modern groundwater age classification than in wells with mixed and pre-modern groundwater age classifications (fig. 23*B*; table 9); significant differences between wells classified as mixed and pre-modern were not detected. Trihalomethanes were detected in 57 percent of the samples classified as modern; THM concentrations also were highest in samples collected from wells with a component of modern recharge. Although THM concentrations were not significantly correlated with depth to the top of the uppermost open interval, samples with the highest concentration were collected at wells with a depth of less than 100 ft (fig. 23*B*).

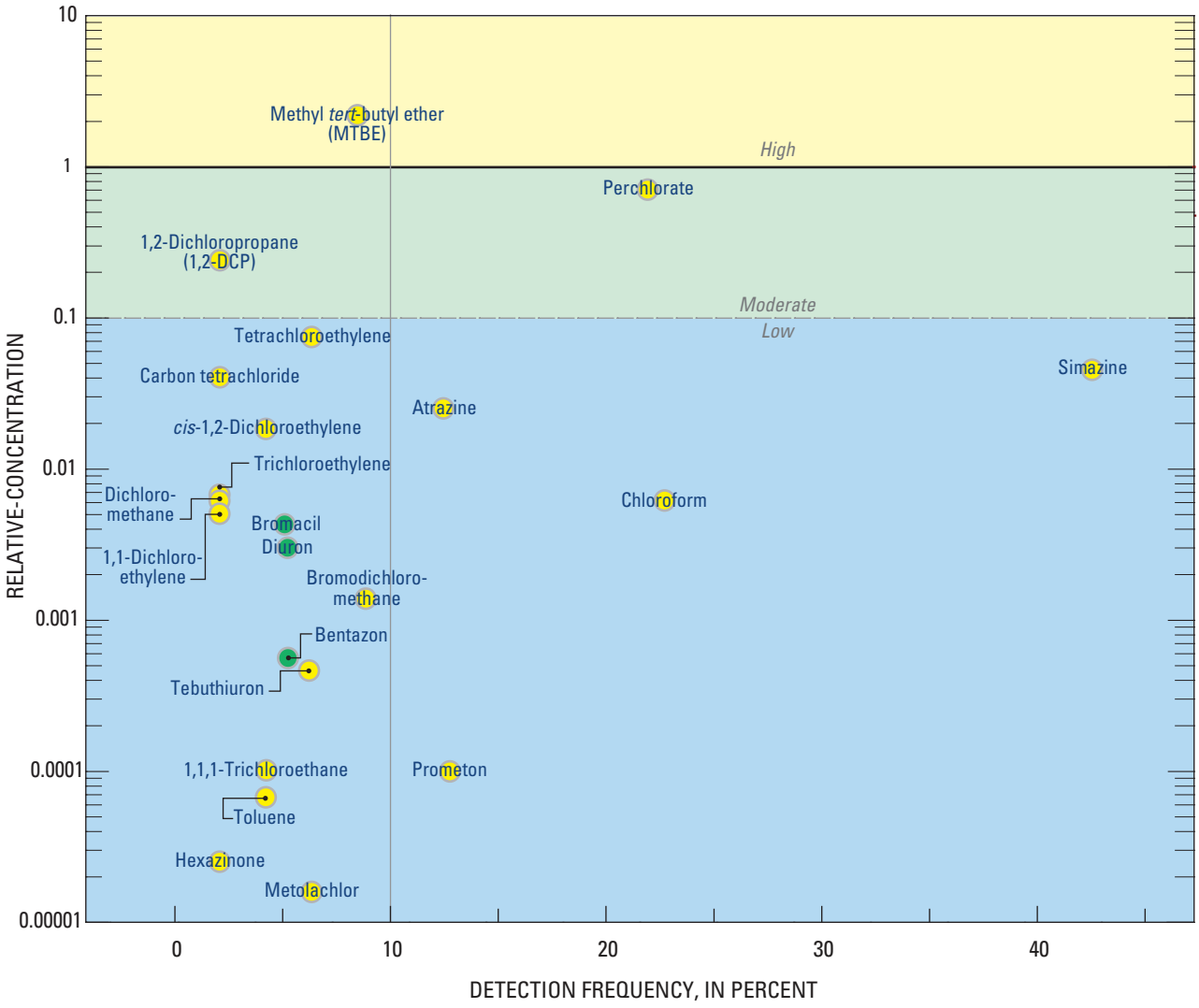

Figure 20. Detection frequency (non-area-weighted) and maximum relative-concentration for organic and special-interest constituents detected in grid wells, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

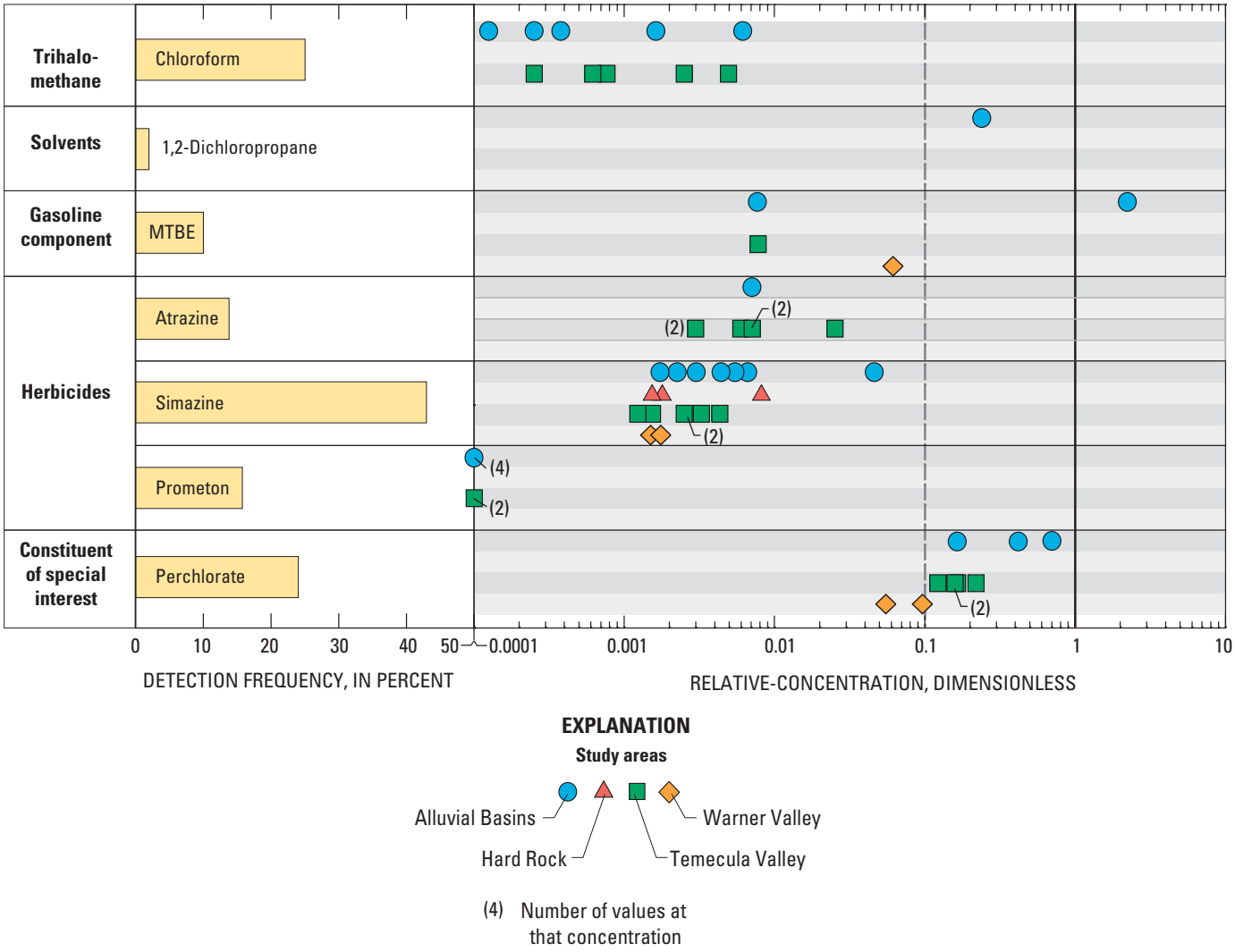

Figure 21. Detection frequency (non-area-weighted) and relative-concentrations in grid wells of selected organic and special-interest constituents, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

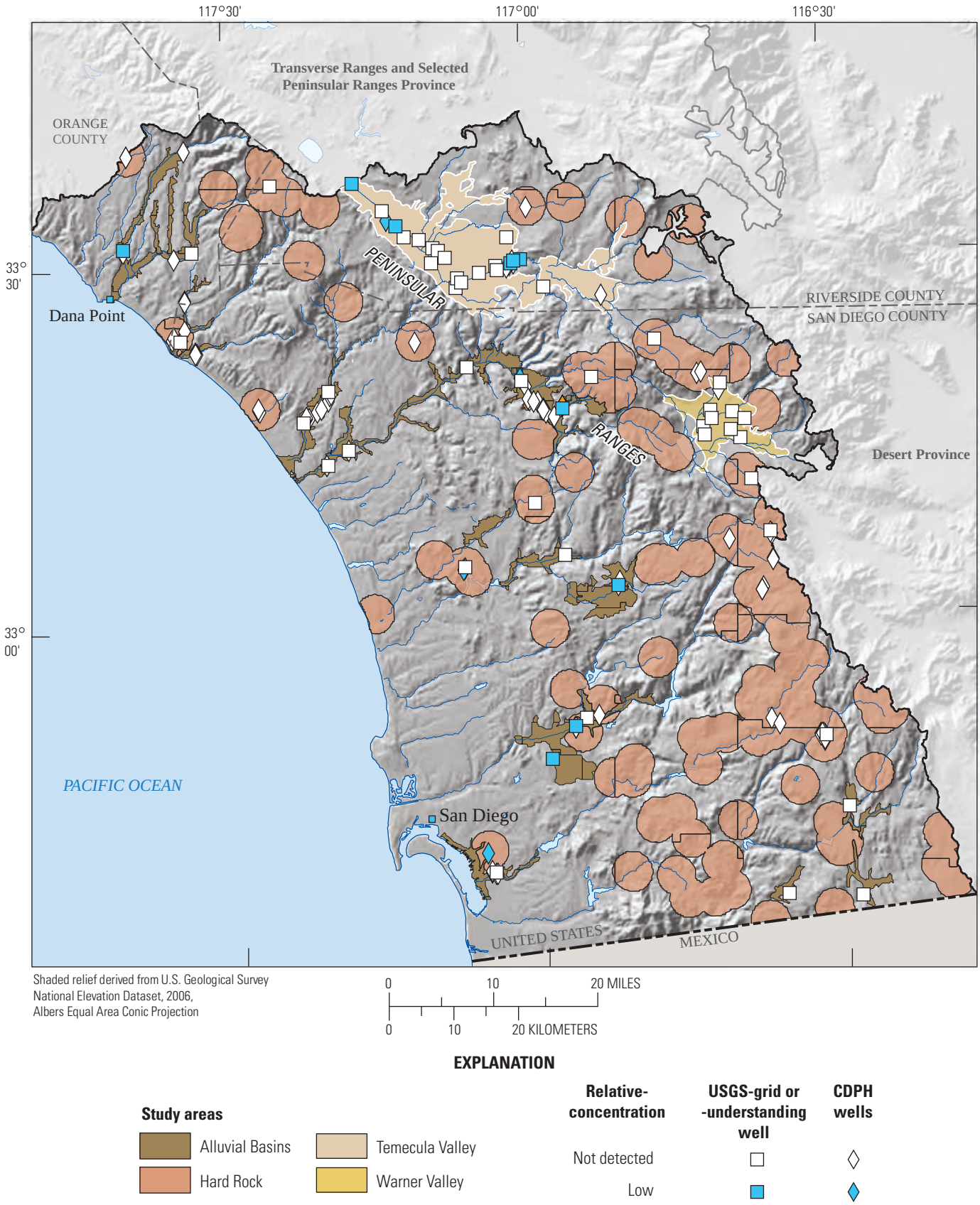

Figure 22. Sum of trihalomethanes in USGS-grid and -understanding wells representative of the primary aquifers, and CDPH data from the prior 3-year period of study (July 30, 2001 to July 29, 2004), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

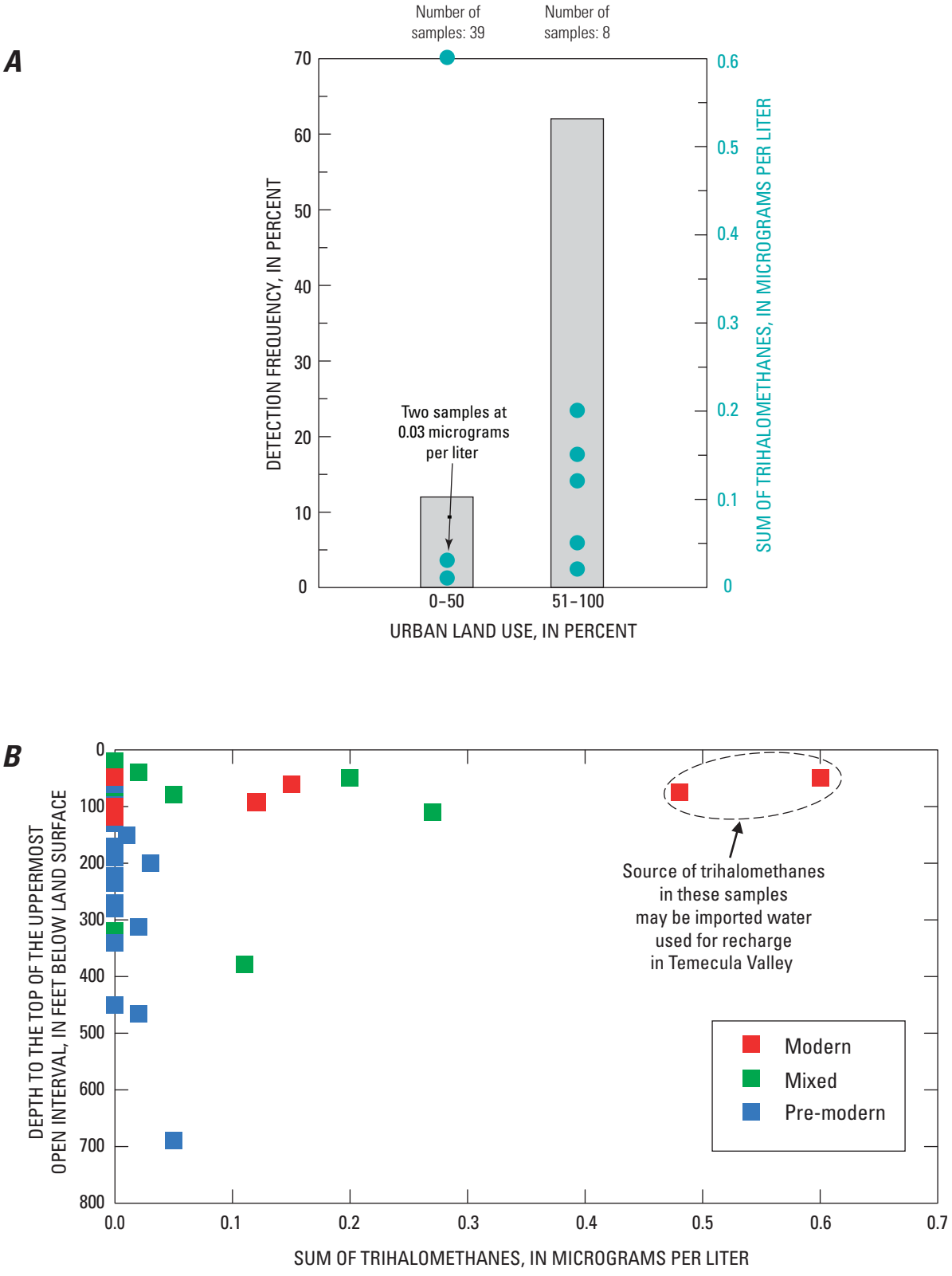

Figure 23. (*A*) Detection frequency and concentration of the trihalomethanes in relation to urban land use, and (*B*) concentration of trihalomethanes in relation to depth to the top of the uppermost open interval and groundwater age classification, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Solvents

The only solvent detected that met the selection criteria in the San Diego study unit was 1, 2-dichlororpane (fig. 20). In the CDPH database, 1, 2-dichloropropane was detected at high-relative concentrations in one well, but not during the current period (July30, 2001–July 29, 2004) (table 6). Two other solvents—tetrachloroethylene (PCE) and trichloroethylene (TCE)—were also detected at high-relative concentrations in the CDPH database, but not during the current period. Solvents were not detected at high relative-concentrations in the Alluvial Fill study areas, but were detected at moderate relative-concentrations in 3.0 percent of the primary aquifers (table 8). The detection frequency for solvents in grid wells was highest in the Temecula Valley study area (16.7 percent), and then the Alluvial Basins study area (13.3 percent), but was not detected in grid wells either in the Warner Valley or in the Hard Rock study areas (fig. 24).

Factors Affecting Solvent Distribution

Solvents are used for a variety of industrial, commercial, and domestic purposes (Zogorski and others, 2006). Solvents can be introduced into the subsurface through leaking storage tanks and disposal of waste streams from industrial and commercial processes. Nationally, solvent concentrations have been correlated with urban land-use (Zogorski and others, 2006; Moran and others, 2007). Like THM concentrations, a positive correlation of the sum of solvent concentrations to urban land-use was significant in the San Diego study unit (table 9). The sum of solvents was calculated from the summation of concentrations of all four solvents detected—PCE, TCE, 1,2-dichloropropane, and carbon tetrachloride. Figure 25 shows detection frequency and sum of the detected solvent concentrations in groundwater samples as a function of urban land-use. The detection frequency for solvents in samples collected from wells in areas with urban land-use greater than 50 percent was 38 percent compared to the detection frequency of just 5 percent for solvents in samples collected from wells in areas where the urban land use was 50 percent or less. In addition, the sum of solvent concentrations was higher in samples collected in urbanized areas than in non-urbanized areas.

The sum of solvent concentrations was not significantly different between groundwater age classes, or between wells with varying depth to the top of the uppermost open interval (table 9). Solvents were more frequently detected in pre-modern water (16 percent) than either in modern (11 percent) or in mixed (12 percent) waters. It is expected that solvents would be more prevalent in younger rather than older groundwater because these compounds most likely were used more in the last 60 years or so. However, because some solvents were used before 1950, it is plausible that these compounds could be present in pre-modern water. Additionally, solvents in pre-modern water could indicate short-circuit mechanisms resulting from well construction, well operation processes, or other non-advective transport processes.

Methyl *Tert*-Butyl Ether (MTBE) and Gasoline Components

MTBE was the only gasoline component detected that met the selection criteria in the San Diego study unit (fig. 26). In the CDPH database, MTBE was detected at high-relative concentrations in two wells; one detection was during the current period (July30, 2001–July 29, 2004) (table 4). The only other gasoline component detected was benzene; a single detection, high-relative concentration of this compound was recorded in the CDPH database during the current period. Gasoline components were detected at high relative-concentrations in 3.0 percent of the primary aquifers in the Alluvial Fill study areas (table 8). The detection frequency at any concentration for gasoline components in grid wells was highest in the Alluvial Basins study area (18.8 percent), followed by the Warner Valley (11.1 percent) and then by the Temecula Valley (8.3 percent) study areas (fig. 26). Gasoline components were not detected in USGS-grid wells in the Hard Rock study area, but were detected in five wells listed in the CDPH.

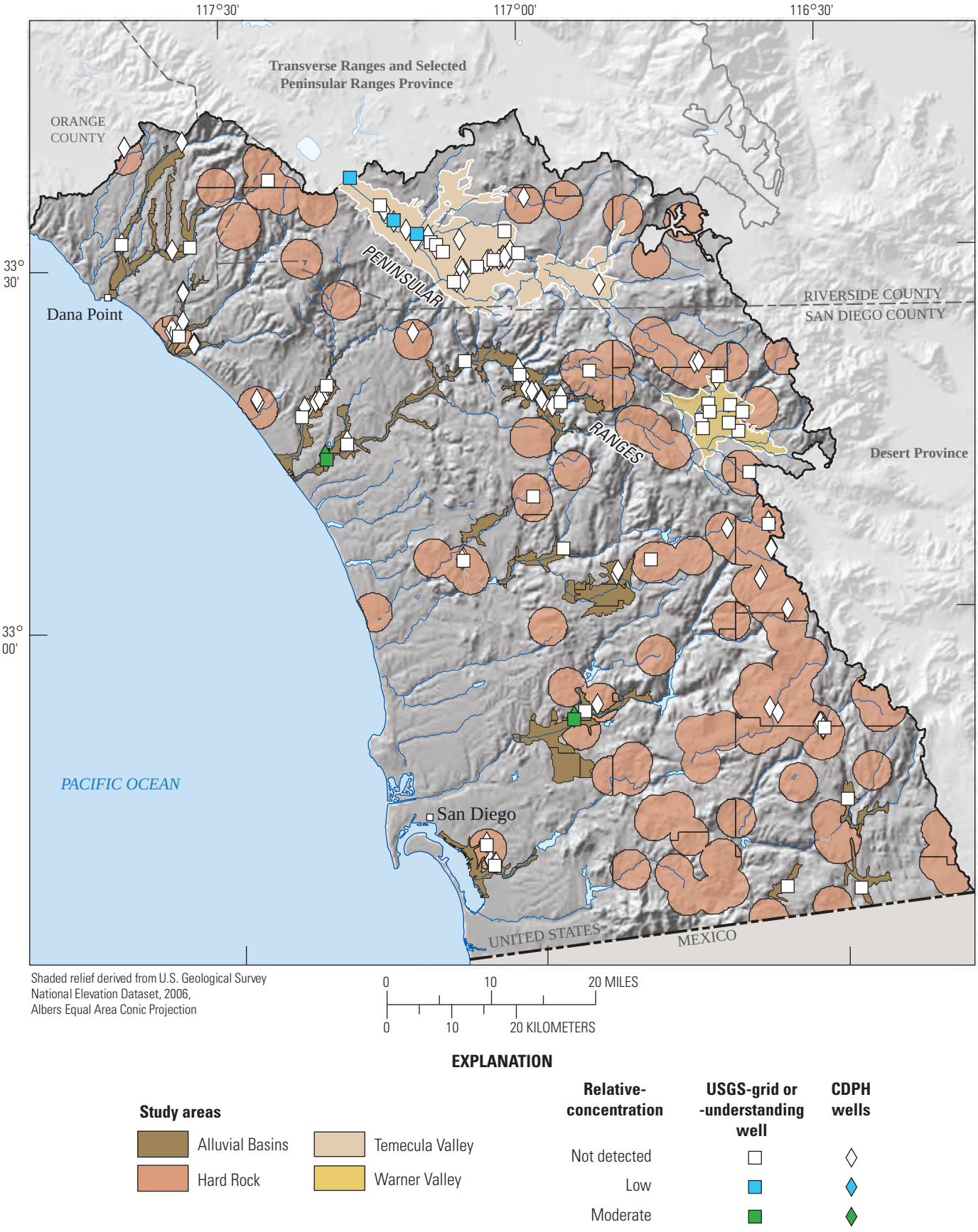

Figure 24. Sum of the solvents 1,2-dichloropropane, tetrachloroethylene (PCE), trichloroethylene (TCE), and carbon tetrachloride in USGS-grid wells representative of the primary aquifers, and CDPH data from the current period (July 30, 2001–July 29, 2004), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

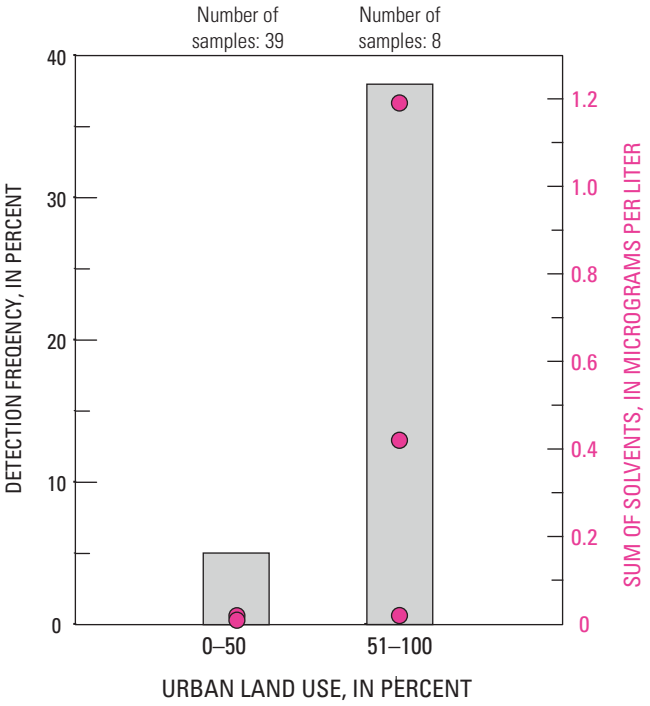

Figure 25. Detection frequency and sum of solvents concentration in relation to urban land use, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

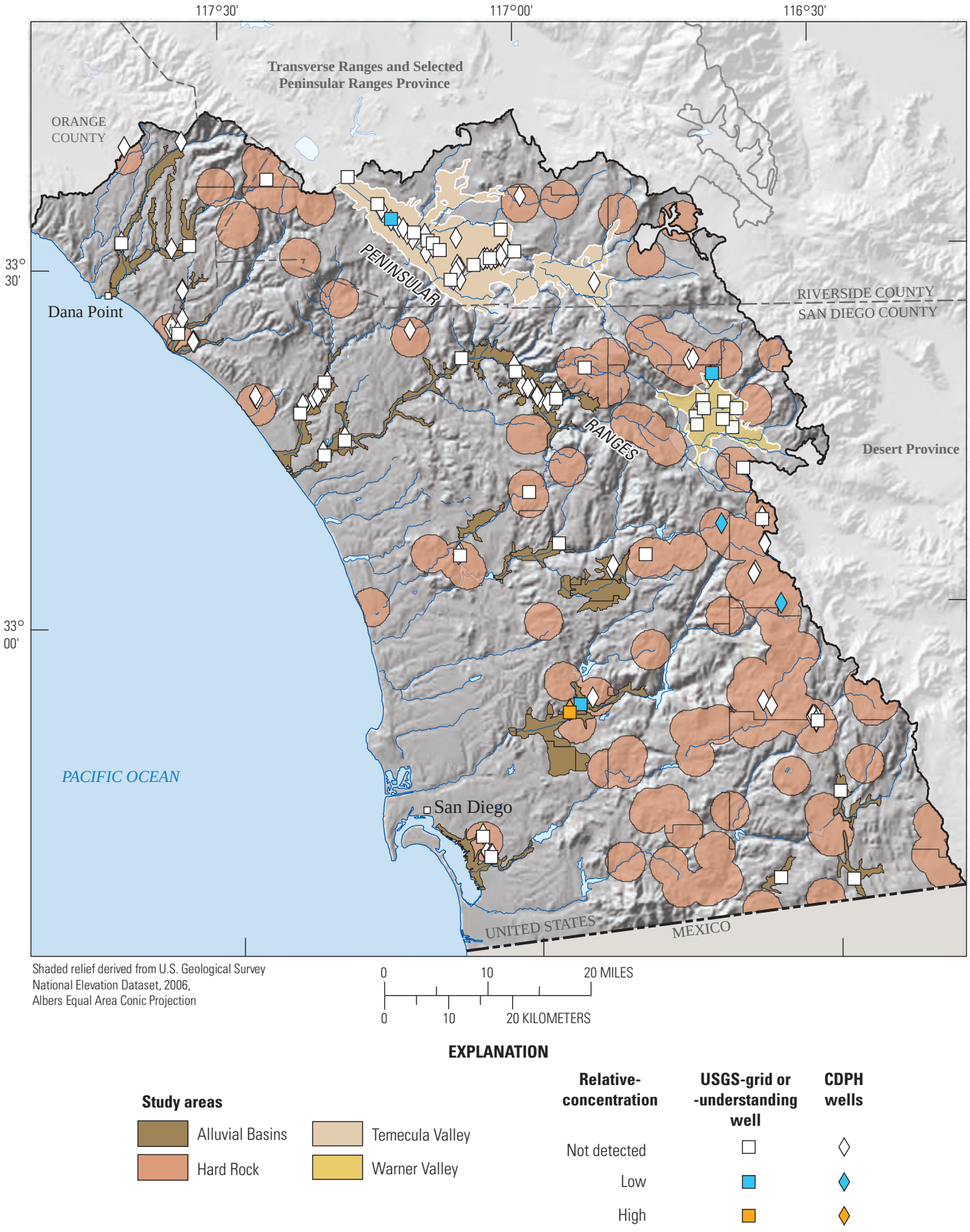

Figure 26. Sum of the gasoline components methyl *tert*-butyl ether (MTBE) and benzene in USGS-grid wells and from CDPH data for the prior 3-year period of study (July 30, 2001–July 29, 2004), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

Factors Affecting the Distribution of Methyl *Tert*-Butyl Ether (MTBE) and other Gasoline Components

Gasoline components, in particular MTBE, can be introduced to the sub-surface environment through several pathways. These components may be released into groundwater from point sources, such as leaking underground fuel tanks (LUFT), (Zogorski and others, 2006; Moran and others, 2007), or non-point sources, such as urban precipitation and storm water runoff (Pankow and others, 1997; Moran and others, 1999). Previous water-quality studies in California have indicated both point and non-point sources as the source of MTBE in groundwater (Happel and others, 1998; Belitz and others, 2003; Moran and others, 2004).

The sum of gasoline components was not significantly correlated to any of the explanatory factors listed in table 9. An additional analysis was done by comparing MTBE concentrations in groundwater samples to the distance from the nearest LUFT. Data for the LUFTs were obtained from the California State Water Resource Control Board's Geotracker Database (State Water Resources Control Board, 2011). The negative correlation of MTBE concentrations to distance from the nearest LUFT was significant (ρ = -0.54) (fig. 27). Of the 13 wells sampled within 500 m of a LUFT, MTBE was detected at 62 percent; MTBE was not detected in any sample collected greater than 500 m from a well. These results suggest that LUFTs are the primary source of MTBE detected in groundwater in the San Diego study unit. It must be noted however, that MTBEs were not detected in five wells sampled within 500 m of a LUFT. Non-detections in these wells may be a result of several factors, such as MTBE not being a component of the liquid "contained" within the LUFT, severity of the leak, well pumping intensity, dilution with unaffected water, and (or) rates of biodegradation.

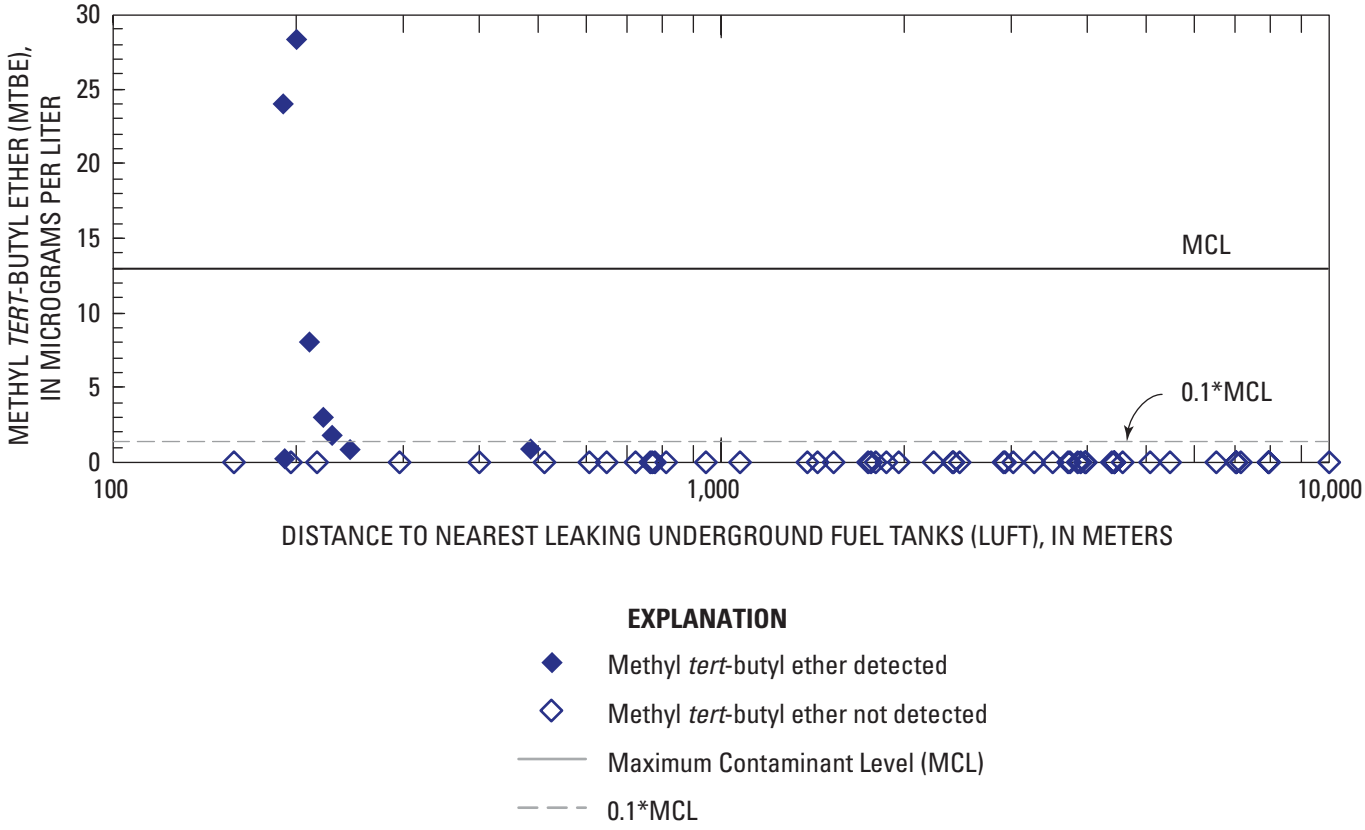

Figure 27. Relation of methyl *tert*-butyl ether (MTBE) concentrations to distance from nearest leaking underground fuel tank (LUFT), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Pesticides

The only pesticides sampled for in the San Diego study unit that met the selection criteria were simazine, atrazine, prometon. Results from a study of major aquifers across the United States showed that these three compounds were frequently detected in groundwater (Gilliom and others, 2006). A groundwater study conducted in California showed that simazine was the most frequently detected triazine herbicide in groundwater (Troiano and others, 2001). Figure 28 shows the distribution of the sum of herbicide concentrations detected in the San Diego study unit. All detections of herbicides were observed at low relative-concentrations in the Alluvial Fill study areas (table 8). Herbicides most frequently were detected in grid wells in the Temecula Valley study area (66.7 percent), followed by grid wells in the Alluvial Basins (62.5 percent), in the Hard Rock (40 percent), and in the Warner Valley (22.2 percent) study areas.

Factors Affecting Pesticide Distribution

Simazine and prometon frequently are used for nonagricultural applications including weed control on bare ground, around buildings, along roadsides, and in other right-of-ways. Simazine also is used on a variety of crops including citrus and vineyards, whereas prometon has no registered agricultural uses (Gilliom and others, 2006). On the other hand, atrazine mostly is used for agricultural purposes in the control of weeds in row crops; some use is reported for the control of weeds in right of ways. The sum of herbicide concentrations was not significantly correlated to any land-use type in the San Diego study unit (table 9).

Concentrations of herbicides were highest in shallow wells with modern and mixed groundwater ages (fig. 29); the correlation between depth to the top of the uppermost open interval (at the 90 percent confidence level) and groundwater age classification are significant (table 9). Herbicides primarily were detected in wells with depths to the top of the open interval less than 200 ft. The reason that the correlation of herbicides to shallow well depths is stronger than are that of THMs, solvents, and gasoline components is likely because the soil organic carbon/water partition coefficient (K_{oc}) values for herbicides are higher than those values for VOCs. Compounds with relatively high K_{oc} are hydrophobic and are more likely to accumulate in soil and sediment than compounds with a low K_{oc} which are more likely to be dissolved in water. Therefore, herbicides as a result of a high K_{oc} tend to be less readily transported through soil and into groundwater.

Some herbicides were detected in relatively deep wells that are tapping pre-modern water. Detections of herbicides in relatively deep wells with pre-modern groundwater ages potentially could be influenced by short-circuiting mechanisms that allow small quantities of modern water with dissolved herbicides to mix with herbicide-free pre-modern water. Results from a USGS study in the San Joaquin Valley suggests that inter-borehole flow may cause mixing of shallow and deep groundwater during non-pumping conditions (Jurgens and others, 2008).

Herbicide concentrations also were significantly correlated with redox conditions (fig. 29*B*; table 9). Concentrations were higher in samples collected from wells tapping oxic waters with relatively low pH. Although geochemical parameters such as oxygen content and pH of groundwater may possibly affect the distribution of herbicides, this may not be the cause for the distribution of herbicides reported in this study. The correlation observed for oxic water and pH may result from shallow wells that tend to tap groundwater with a lower pH (table 7) and higher oxygen content than deeper wells

Perchlorate and Special-Interest Constituents

Constituents of special interest analyzed for in the San Diego study unit were NDMA, 1, 4-dioxane, and perchlorate. These constituents were selected because they recently were detected in, or are considered to have the potential to reach, drinking-water supplies (California Department of Public Health, 2008 b,c,d). NDMA and 1-4-dioxane were not detected in any wells (Wright and others, 2005). However, perchlorate was detected in eight grid wells and three CDPH wells (fig. 30). In the CDPH database perchlorate was detected as high in one well during the current period (July 30, 2001–July 29, 2004) (table 4). Perchlorate was detected at high relative-concentrations in 0.2 percent (calculated using spatially weighted approach) of the primary aquifers in the Alluvial Fill study areas (table 8). Perchlorate most frequently was detected in grid wells in the Temecula Valley study area (33.3 percent), followed by grid wells in the Warner Valley (22.2 percent) and in the Alluvial Basins (18.8) study areas; perchlorate was not detected in grid wells in the Hard Rock study area.

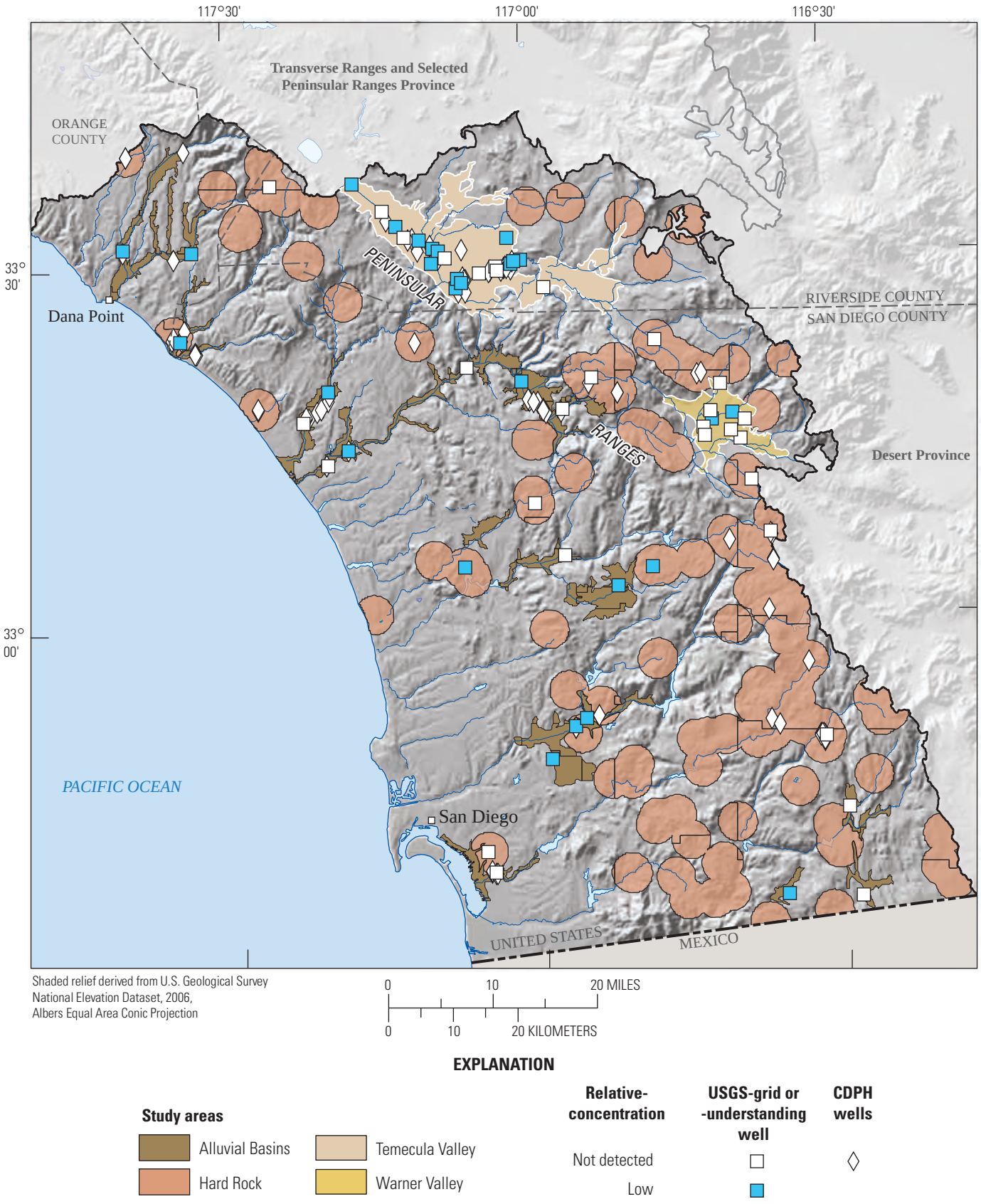

Figure 28. Sum of herbicides in USGS-grid wells and from CDPH data for the prior 3-year period of study (July 30, 2001–July 29, 2004), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

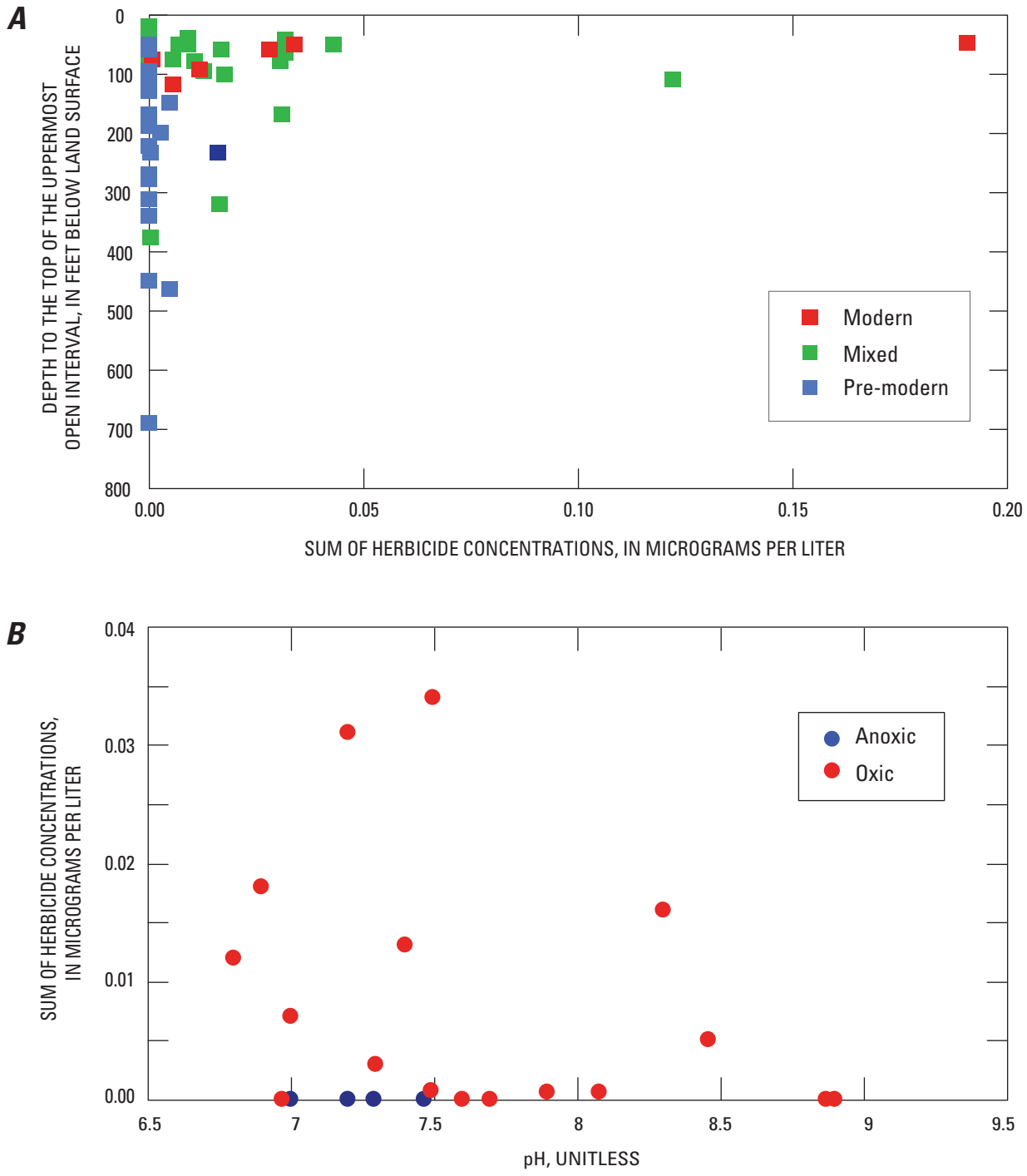

Figure 29. Sum of herbicide concentrations in relation to (*A*) depth to the top of the uppermost open interval and groundwater age classification, and in relation to (*B*) redox condition of groundwater, San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

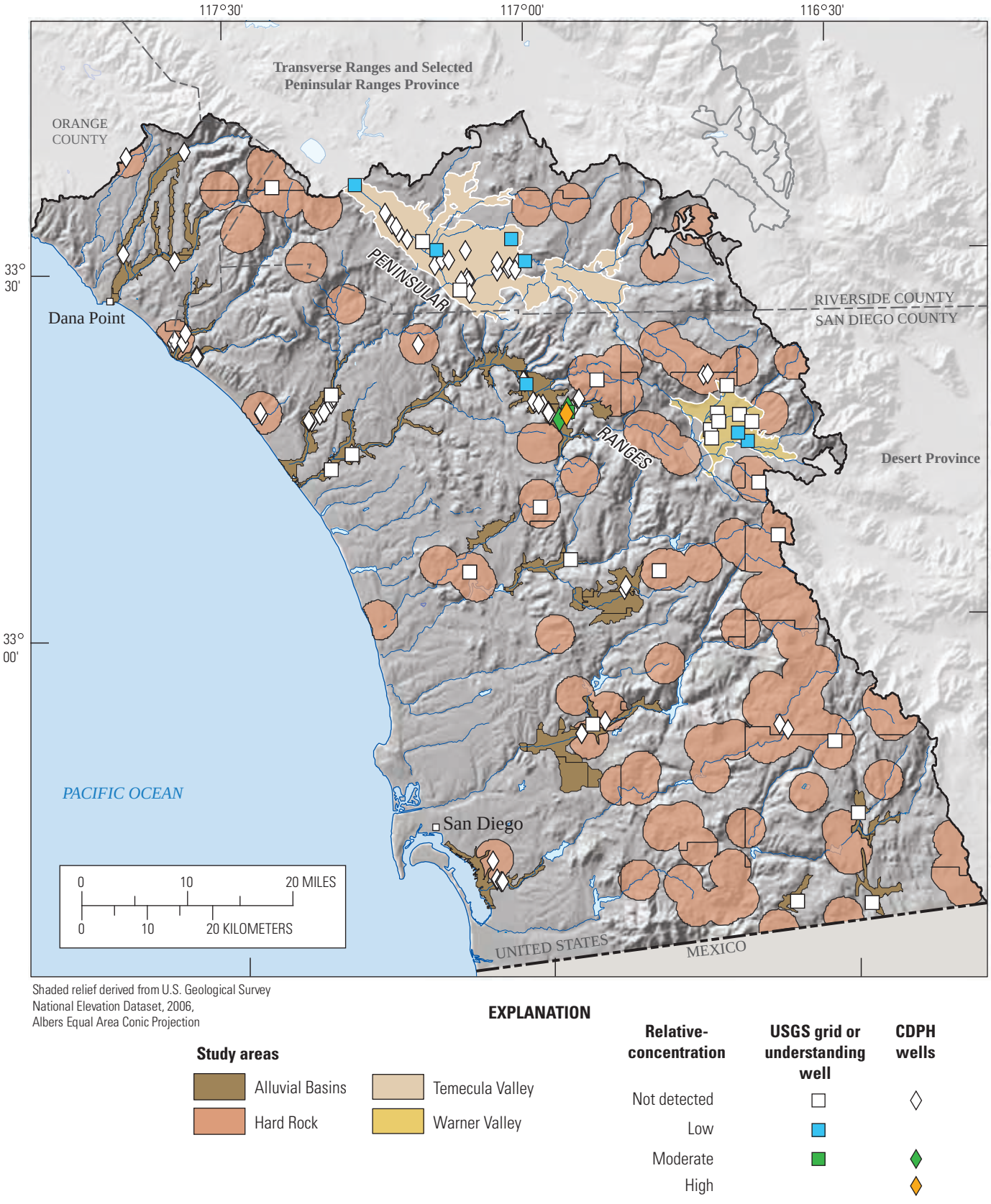

Figure 30. Perchlorate in USGS-grid wells and from CDPH data for the prior 3-year period of study (July 30, 2001–July 29, 2004), San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California, May–July 2004.

Factors Affecting Perchlorate Distribution

Potential anthropogenic sources of perchlorate include nitrate fertilizers (Dasgupta and others, 2006) and the production and use of explosives, road flares, and automobile air-bag systems (Parker and others, 2008). In addition, Colorado River water, which is imported into the San Diego study unit for public supply and agricultural irrigation, is known to contain perchlorate (California Department of Public Health, 2008b). Perchlorate also has been detected in groundwater in some highly arid desert environments as a result of natural atmospheric and soil processes (Dasgupta and others, 2005; Plummer and others, 2006); However, it is unclear whether these processes are occurring, or have occurred, in the San Diego study unit.

Perchlorate concentrations were only significantly correlated (negatively) to natural land-use in this study (table 9). Perchlorate concentrations, however, were positively correlated to agricultural areas at the 90 percent confidence level indicating that the use of nitrate fertilizers, and (or) Colorado River water that is used for irrigation, are contributing sources of perchlorate in groundwater of the San Diego study unit. Additionally, a detection of perchlorate (which is an order of magnitude below the MCL-CA) may be the result of a sample collected from a well (SDTEM-10) that is located down-gradient from an engineered recharge facility that uses Colorado River water.

Summary

The Groundwater Ambient Monitoring and Assessment (GAMA) Program was created by the California State Water Resources Control Board (State Water Board) to provide a comprehensive groundwater-quality baseline for the State of California. The program is a comprehensive assessment of statewide groundwater quality designed to improve ambient groundwater-quality monitoring and to increase the availability of information about groundwater quality to the public. The GAMA program includes the Priority Basin Project, conducted by the U.S. Geological Survey (USGS) in collaboration with the State Water Board and Lawrence Livermore National Laboratory (LLNL). This report is one of a series of reports presenting the *status* and *understanding* of current groundwater-quality conditions in study units of the GAMA Priority Basin Project.

The approximately 3,900-square mile (mi^2) San Diego study unit lies in the southwestern-most corner of California and is composed of four study areas—Temecula Valley (140 mi^2), Warner Valley (37 mi^2), Alluvial Basins (166 mi^2), and the Hard Rock (850 mi^2). The purposes of this report are (1) to describe briefly the hydrogeologic setting of the San Diego study unit, (2) to assess the current status of untreated groundwater quality in the primary aquifers in the San Diego study unit, and (3) to assess the relations between water quality and selected potential explanatory factors.

The GAMA San Diego study was designed to provide a statistically robust assessment of untreated groundwater quality within the primary aquifer systems. 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. Forty-seven grid wells were selected randomly within spatially distributed grid cells across the San Diego study unit. Grid wells were selected for sampling in each study area: 12 in the Temecula Valley, 9 in the Warner Valley, 16 in the Alluvial Basins, and 10 in the Hard Rock. In addition, 23 CDPH wells with data from the prior 3-year period (July 30, 2001–July 29, 2004) were used to complement USGS data. Grid-based and spatially weighted approaches were used to assess aquifer-scale proportions of constituents at high, moderate, and low relative-concentrations in the primary aquifers in order to characterize the quality of untreated groundwater in the study unit. Area weighting was used to account for the disparate size of the study areas relative to each other.

Given the large number of analytes, an objective algorithm was used to select those constituents of greatest importance to water quality in the primary aquifers for discussion in the report. To provide context, concentrations of constituents measured in the untreated groundwater were compared with regulatory and non-regulatory human-health and aesthetic benchmarks. Relative-concentrations (sample concentration divided by benchmark concentration) were used as the primary metric for evaluating groundwater quality. Constituents were classified into those whose maximum relative-concentrations were high, moderate, or low. Inorganic constituents with high relative-concentrations in greater than or equal to 2 percent of the grid wells (based on non area-weighted detections for all study areas in the San Diego study unit) were tested for relations to a set of potential explanatory factors that included land use, classified groundwater age, and geochemical-condition indicators. For organic and special-interest constituents to be tested for relations with potential explanatory variables detection frequencies had to be greater than 10 percent in grid wells (non area-weighted) at any concentration, or be detected at least once in a grid well at a moderate or high relative-concentration.

Inorganic constituents with human-health benchmarks were high in 17.6 percent of the primary aquifers in the Alluvial Fill study areas. Aquifer-scale high proportions of inorganic constituents with human-health based benchmarks indicated high relative-concentrations of trace elements, nutrients, and radioactive constituents. Trace elements with high concentrations in greater than or equal to 2 percent of the primary aquifers in the San Diego study unit were vanadium (V), arsenic (As), and boron (B). Inorganic constituents with non-health based benchmarks at high relative-concentrations in greater than or equal to 2 percent in the primary aquifers in the San Diego study unit were manganese (Mn), iron (Fe), and total dissolved solids (TDS).

The relation between the concentrations of V, As, Mn, and Fe in groundwater and in urban or agricultural land-use was not significant. This result suggests that natural sources (dissolution of rocks) are the significant contributing factor of these constituents in groundwater. Concentrations of B and TDS had a significant positive correlation to land use. Boron was correlated with urban land use and TDS with agricultural land-use, thus indicating anthropogenic activities as significant sources of these constituents in groundwater in the San Diego study unit.

pH and redox conditions of groundwater were important factors that affect the concentrations of inorganic constituents in groundwater. Generally, concentrations of the trace elements V, As, and B were high in alkaline groundwater which suggests that these trace elements are being desorbed from, or are inhibited from adsorbing onto, mineral surfaces. Vanadium and As are redox-sensitive species, but only the correlation of V to redox conditions was significant. Vanadium concentrations were higher in oxic groundwater than in anoxic groundwater, indicating that in the San Diego study unit V is most mobile under oxic and alkaline conditions. Concentrations of V and As also were higher in deep wells rather than in shallow wells and in samples that were partially or entirely composed of pre-modern (> 50 yrs) groundwater. The correlations between concentrations and depth and groundwater age likely are because of the significant positive correlation of deep wells and pre-modern groundwaters to pH.

The negative correlation of Mn and Fe to pH and dissolved oxygen (DO) was statistically significant, a result of the differing mechanisms that enhance the mobility of Mn and Fe in groundwater. The negative correlation of TDS to pH also was significant; however, this relation likely is not the result of any geochemical chemical processes, but because the TDS concentrations were highest in shallow wells where the pH of groundwater is significantly lower than the pH of groundwater being tapped by deeper wells.

Organic and special-interest constituents were detected at high relative-concentrations in a smaller proportion of the primary aquifers in the Alluvial Fill study areas (3.0 percent) than were inorganic constituents (17.6 percent). Relative-concentrations of organic constituents were moderate in 3.0 percent of the primary aquifers in the Alluvial Fill study areas. The proportion of the primary aquifers with high relative-concentrations of organic constituents was due to a detection of the discontinued gasoline oxygenate MTBE. One organic and one special-interest constituent were each detected at moderate relative-concentrations in grid wells—1,2-dichloropropane and perchlorate.

The status assessment for organic constituents indicated that 12 of the 88 VOCs and 14 of the 123 pesticides and pesticide degradates analyzed in grid wells were detected. Of the 12 VOCs detected, 10 were detected at low relative-concentration, one at a moderate relative-concentration, and one at a high relative-concentration. Only one VOC, chloroform, was detected in greater than or equal to 10 percent of the grid wells. Of the nine herbicides with health-based benchmarks that were detected, all had low relative-concentrations. Detection frequencies for simazine, atrazine, and prometon were greater than or equal to 10 percent. Perchlorate was the only special interest constituent detected in groundwater samples; it was detected in 22 percent of samples.

The positive correlation of the sum of THMs and solvent concentrations to urban land-use was significant, indicating that in the San Diego study unit groundwater located underneath urbanized areas is more likely to have detections of these anthropogenic constituents. MTBE concentrations were negatively correlated to the distance from the nearest leaking underground fuel tank, indicating that these point sources are the most significant contributing factor for MTBE concentrations to groundwater in the San Diego study unit.

The positive correlation of concentrations of THMs and herbicides to modern groundwater was significant. The negative correlation of herbicides to pH and anoxic groundwater also was significant. Although pH and redox conditions may affect the distribution of herbicides in groundwater, the correlations observed in this study likely are because herbicides were detected more frequently and at high concentrations in shallow wells where groundwater conditions tend to be oxic with relatively low pH.

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Appendix A. Selection of CDHP-Well Data

The strategy used to select CDPH inorganic data for a single well in each cell where the USGS did not obtain a sample for analysis for inorganic constituents involved prioritizing data from different sources. The first choice was to select CDPH data for the grid well sampled by the USGS for other constituents, provided the CDPH data met quality-control criteria and was collected within three years prior to the end of sampling in the San Diego study unit (July 30, 2001 to July 29, 2004). The most recent CDPH data from the well were evaluated to determine whether the cation/anion balance for the CDPH data less than 10 percent. If so, the CDPH inorganic data from the well were selected for use as grid-well data for inorganic constituents. It was assumed that analyses using major ion data with a cation-anion balance less than 10 percent also resulted in high-quality data for trace elements, nutrients, and radiochemical constituents. This step resulted in the selection of inorganic data from CDPH at 16 wells that also were USGS-grid wells. For identification purposes, data from the CDPH for these grid wells were assigned GAMA identifications numbers equivalent to the GAMA USGS-grid well but with DG inserted between the study area prefix and sequence number (for example, CDPH-grid well SDTEM-DG-08 is the same well as USGS-grid well SDTEM-08) (table A1).

If the first step did not yield CDPH inorganic data for a grid cell, then the second step was to search the CDPH database to identify the highest randomly ranked well within a cell with a cation/anion imbalance less than 10 percent. This step did not result in the selection of any wells.

If no CDPH wells in a grid cell met the charge-balance criteria or if there was insufficient data to evaluate charge balance, then the third choice for the CDPH-grid well was to select the highest randomly ranked CDPH well with any of the targeted inorganic data. This step resulted in selection of seven grid wells from which CDPH inorganic data were used. For identification purposes, data from the CDPH for these grid wells not collocated with USGS-grid wells were assigned GAMA identifications numbers equivalent to the GAMA USGS-grid well for the cell but with DPH inserted between the study area prefix and sequence number (for example, CDPH-grid well SDTEM-DPH-08 in a grid cell with no USGS wells).

Inorganic data from the CDPH database were used at 23 grid wells (table 2). In combination with USGS-grid well inorganic data (19 wells), inorganic data was available for 42 of the 60 grid cells. Analysis of the combined data sets to evaluate the occurrence of relatively high or moderate concentrations was not affected by differences in laboratory reporting levels (LRLs) between GAMA-collected and CDPH data because concentrations greater than one-half of water-quality benchmarks generally were substantially higher than the highest LRLs. The locations, GAMA identification numbers of grid and understanding wells (fig. A1*A*-A1*C*), and attributes of CDPH-grid wells are located table A1. Comparisons between USGS-collected and CDPH data are described in appendix D.

Table A1. Identification and attributes of grid and understanding wells sampled during May 17–July 29, 2004, and grid wells using data for inorganic constituents from the California Department of Public Health (CDPH), San Diego Ground-Water Ambient Monitoring and Assessment (GAMA) study unit, California.

[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; DG, CDPH data from well sampled by GAMA; DPH, CDPH data from well not sampled by GAMA; ft, feet; m, meter; LSD, land surface datum; USGS, U.S. Geological Survey; PSW, public-supply well; –, no data]

USGS GAMA well identification number	CDPH GAMA well identification number	Well type	Agricultural land use (percent)	Natural land use (percent)	Urban land use (percent)	Construction information			
						Well depth	Top of uppermost open interval	Bottom of lowermost open interval	Length from top of uppermost open interval to bottom of the lowermost open interval
Grid wells									
SDALLV-01	–	PSW	62	37	1	200	100	180	80
SDALLV-02	SDALLV-DG-12	PSW	5	34	60	130	94	117	23
SDALLV-03	–	PSW	0	34	65	606	222	566	344
SDALLV-04	–	PSW	71	19	10	180	80	180	100
SDALLV-05	SDALLV-DG-05	PSW	58	42	0	582	234	513	279
SDALLV-06	–	PSW	2	33	65	200	100	142	42
SDALLV-07[1]	SDALLV-DG-07	PSW	2	84	14	200	39	–	–
SDALLV-08	SDALLV-DG-08	PSW	38	60	2	87	50	78	28
SDALLV-09	–	PSW	0	7	93	810	690	800	110
SDALLV-10	SDALLV-DG-10	PSW	26	35	39	135	65	130	65
SDALLV-11[1]	SDALLV-DG-11	PSW	0	46	54	148	50	148	98
SDALLV-12	–	PSW	0	58	42	230	60	220	160
SDALLV-13[1]	–	PSW	0	94	6	181	96	176	80
SDALLV-14	–	PSW	38	62	0	80	40	80	40
SDALLV-15	–	PSW	2	71	27	107	54	107	53
SDALLV-16[1]	SDALLV-DG-16	PSW	0	97	3	120	48	120	72
SDHDRK-04	–	PSW	0	100	0	315	–	–	–
SDHDRK-05	–	PSW	0	86	14	450	50	450	400
SDHDRK-06	–	PSW	1	45	55	1,000	52	1000	948
SDHDRK-07	–	PSW	6	80	14	400	97	400	303
SDHDRK-08	–	PSW	5	95	0	500	60	500	440
SDHDRK-09	–	PSW	0	100	0	400	75	400	325
SDHDRK-10	SDHDRK-DG-10	PSW	0	100	0	–	–	–	–
SDHDRK-11	SDHDRK-DG-11	PSW	0	100	0	455	20	455	435
SDHDRK-12	–	PSW	0	100	0	186	60	186	126
SDHDRK-13	–	PSW	0	100	0	46	41	–	–
SDTEM-01	–	PSW	57	36	7	1,000	150	1,000	850
SDTEM-03	SDTEM-DG-03	PSW	5	22	74	–	466	909	443
SDTEM-04[1]	SDTEM-DG-04	PSW	72	25	3	252	95	295	200
SDTEM-05	–	PSW	23	51	26	960	200	900	700
SDTEM-06	–	PSW	23	28	49	–	170	470	300
SDTEM-07	–	PSW	17	18	66	307	60	307	247
SDTEM-08	SDTEM-DG-08	PSW	52	44	4	–	114	426	312
SDTEM-09[1]	SDTEM-DG-09	PSW	43	48	9	970	450	950	500
SDTEM-10[1]	–	PSW	0	100	0	250	50	210	160
SDTEM-11	SDTEM-DG-11	PSW	0	51	49	1,000	340	980	640
SDTEM-12[1]	–	PSW	39	58	3	546	96	542	446
SDTEM-13	–	PSW	35	46	19	860	235	860	625
SDWARN-01	–	PSW	0	100	0	473	113	473	360
SDWARN-02[1]	–	PSW	1	99	0	585	100	575	475
SDWARN-03	–	PSW	0	100	0	550	118	550	432
SDWARN-04	–	PSW	18	82	0	438	170	438	268

Table A1. Identification and attributes of grid and understanding wells sampled during May 17–July 29 2004, and grid wells using data for inorganic constituents from the California Department of Public Health (CDPH), San Diego Ground-Water Ambient Monitoring and Assessment (GAMA) study unit, California.—Continued

[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; DG, CDPH data from well sampled by GAMA; DPH, CDPH data from well not sampled by GAMA; ft, feet; m, meter; LSD, land surface datum; USGS, U.S. Geological Survey; PSW, public-supply well; –, no data]

USGS GAMA well identification number	CDPH GAMA well identification number	Well type	Agricultural land use (percent)	Natural land use (percent)	Urban land use (percent)	Construction information			
						Well depth	Top of uppermost open interval	Bottom of lowermost open interval	Length from top of uppermost open interval to bottom of the lowermost open interval
Grid wells—Continued									
SDWARN-05	–	PSW	0	100	0	743	130	743	613
SDWARN-06	–	PSW	0	100	0	730	190	730	540
SDWARN-07	–	PSW	0	99	1	295	70	165	95
SDWARN-08	SDWARN-DG-08	PSW	0	100	0	700	280	600	320
SDWARN-09	SDWARN-DG-09	PSW	0	100	0	642	60	642	582
–	SDALLV-DPH-17	PSW	0	88	12	–	–	–	–
–	SDALLV-DPH-18	PSW	27	54	19	–	–	–	–
–	SDALLV-DPH-19	PSW	0	98	2	–	–	–	–
–	SDTEM-DPH-14	PSW	40	26	34	–	–	–	–
–	SDTEM-DPH-15	PSW	49	43	8	–	–	–	–
–	SDTEM-DPH-16	PSW	4	81	15	–	–	–	–
–	SDTEM-DPH-17	PSW	0	98	2	–	–	–	–
Understanding wells									
SDALLVU-01[2]	–	PSW	67	33	0	–	–	–	–
SDHDRKU-01[2]	–	PSW	0	9	91	906	110	906	796
SDHDRKU-02[2]	–	PSW	0	100	0	92	52	92	40
SDHDRKU-03[2]	–	PSW	25	45	30	510	80	510	430
SDTEMFP-01	–	PSW	35	50	16	2,500	234	2,147	1,913
SDTEMFP-02	–	PSW	30	68	3	858	378	838	460
SDTEMFP-03	–	PSW	32	67	1	865	305	845	540
SDTEMFP-04	–	PSW	29	67	4	482	75	465	390
SDTEMFP-05	–	PSW	19	76	5	280	80	270	190
SDTEMFP-06[2]	–	PSW	20	33	47	–	320	1,110	790
SDTEMFP-07[2]	–	PSW	65	21	13	–	270	1,000	730

[1]Well construction information has been updated subsequent to the publication of the San Diego Ground-Water Ambient Monitoring and Assessment (GAMA) study unit data report (Wright and others, 2005).

[2]Well has been reclassified from grid to understanding subsequent to the publication of the San Diego Ground-Water Ambient Monitoring and Assessment (GAMA) study unit data report (Wright and others, 2005).

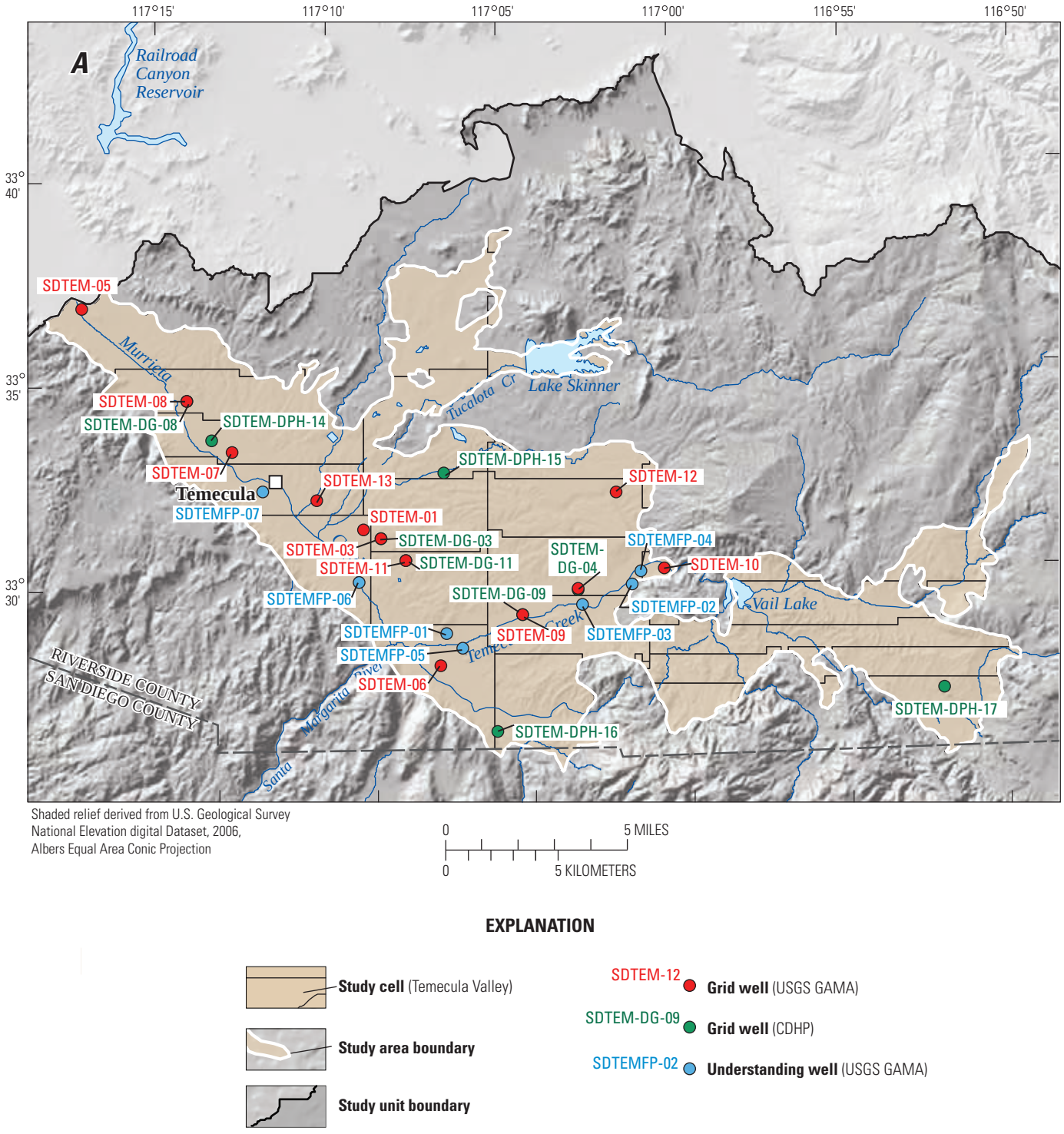

Figure *A1A–A1C*. Identifiers and locations of grid and understanding wells sampled during May–July 2004, and grid wells at which data for inorganic constituents from the California Department of Public Health were used in the study areas of San Diego Groundwater Ambient Monitoring and Assessment (GAMA) study unit, California.

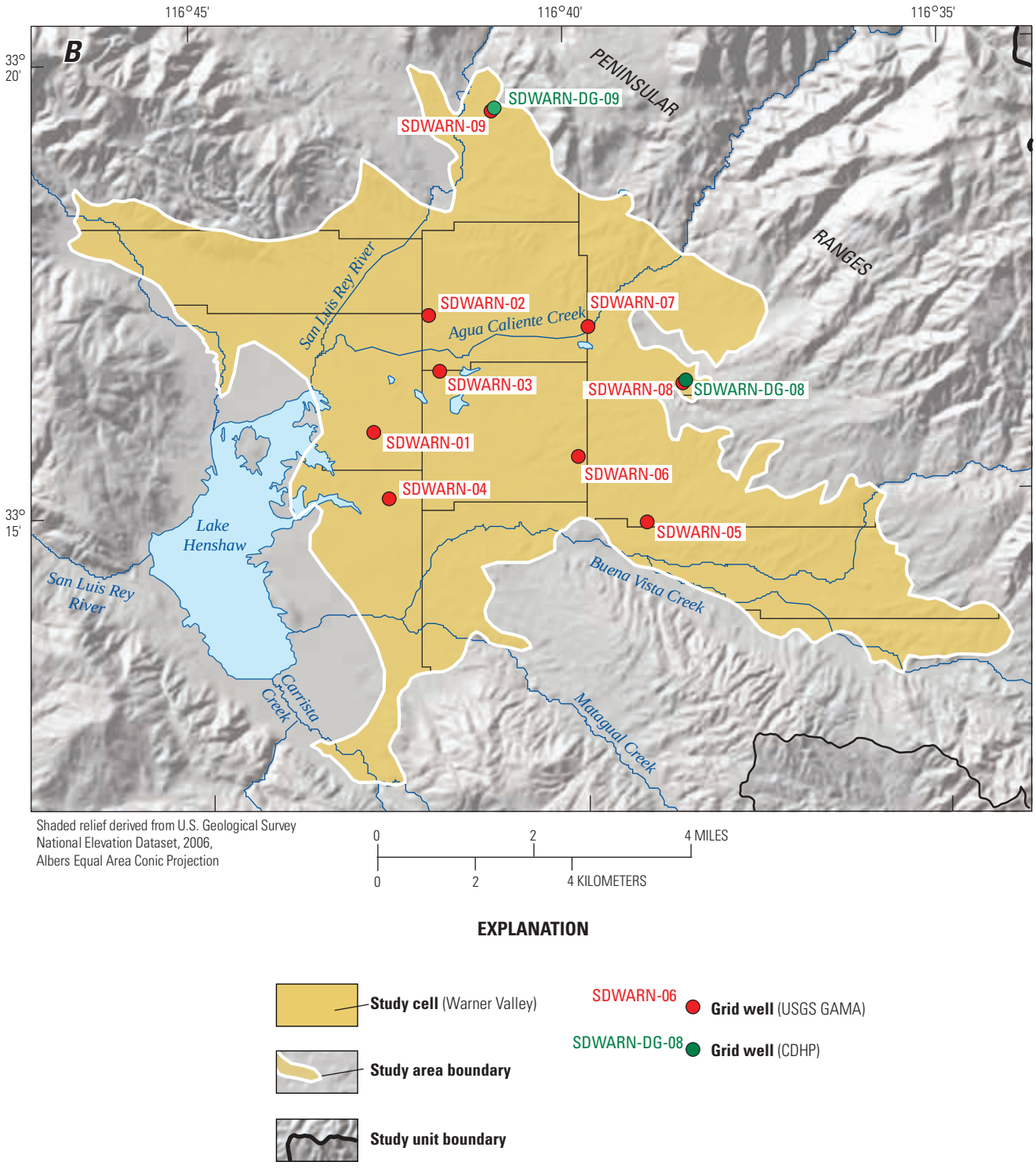

Figure *A1A–A1C.*—Continued