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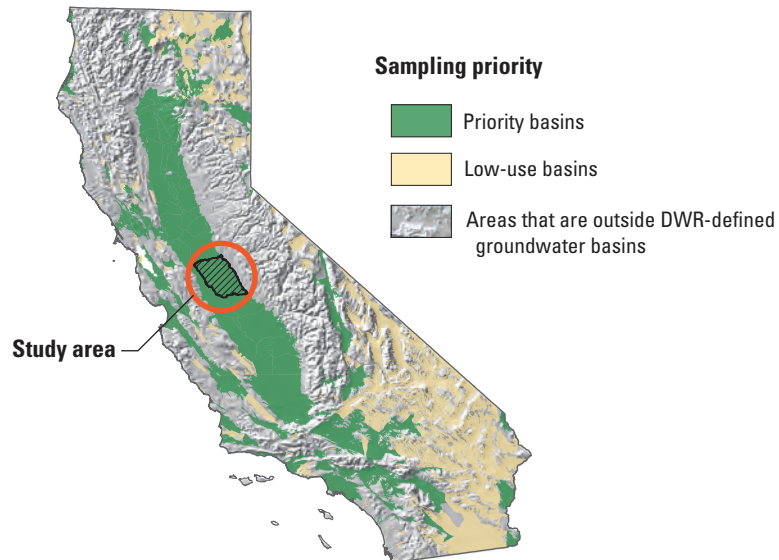
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Status and Understanding of Groundwater Quality in the Central-Eastside San Joaquin Basin, 2006: California GAMA Priority Basin Project

Scientific Investigations Report 2009-5266



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



Cover Photographs:

Front cover: Almond orchard in Stanislaus County, California. (Photograph taken by Isabel Pimentel, U.S. Geological Survey.)

Back cover: Monitoring well next to irrigation canal in Stanislaus County, California. (Photograph taken by Tyler Johnson, U.S. Geological Survey.)

Status and Understanding of Groundwater Quality in the Central–Eastside San Joaquin Basin, 2006: California GAMA Priority Basin Project

By Matthew K. Landon, Kenneth Belitz, Bryant C. Jurgens, Justin T. Kulongoski,
and Tyler D. Johnson

Prepared in cooperation with the California State Water Resources Control Board

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Abbreviations and Acronyms

AB	Assembly Bill (through the California State Assembly)
AL-US	U.S. Environmental Protection Agency action level
CE-QPC	Central Eastside Upland Basin study area grid well
CE-QPCFP	Central Eastside Upland Basin study area flow-path well (understanding well)
CE-QPCMW	Central Eastside Upland Basin study area monitoring well (not necessarily on flow path)
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
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
MER	Merced study area grid well
MERFP	Merced study area flow-path well (understanding well)
MERMW	Merced study area monitoring well (not necessarily on flow path)
MOD	Modesto study area grid well
MODFP	Modesto study area flow-path well (understanding well)
MODMW	Modesto study area monitoring well (not necessarily on flow path)
MRL	minimum reporting level
NAVD 88	North American Vertical Datum 1988
NL-CA	California Department of Public Health notification level
NWIS	National Water Information System (USGS)
PBP	Priority Basin Project
PSW	Public-Supply Wells
QC	quality control
QPC	Quaternary Pleistocene age semiconsolidated deposits (a feature of the Uplands study area)
RPD	relative percent difference
RSD	relative standard deviation
RSD5-US	U.S. Environmental Protection Agency risk-specific dose at a risk factor of 10^{-5}
SMCL-CA	California Department of Public Health secondary maximum contaminant level
SMCL-US	U.S. Environmental Protection Agency secondary maximum contaminant level
TDS	total dissolved solids
TRLK	Turlock study area grid well
TRLKFP	Turlock study area flow-path well (understanding well)
TRLKMW	Turlock study area monitoring well (not necessarily on flow path)
US	United States

V Analyte detected in associated blanks; therefore, the value was excluded from the groundwater quality analyses

Organizations

CDPH	California Department of Public Health (Department of Health Services prior to July 1, 2007)
CDWR	California Department of Water Resources
LLNL	Lawrence Livermore National Laboratory
MWH	Montgomery Watson Harza 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

Ammonia-N	ammonia as nitrogen
DBCP	1,2-dibromo-3-chloropropane
EDB	1,2-dibromoethane
NDMA	N-nitrosodimethylamine
Nitrate-N	nitrate as nitrogen
Nitrite-N	nitrite as nitrogen
PCE	tetrachloroethene
1,2,3-TCP	1,2,3-trichloropropane
TDS	total dissolved solids
THM	trihalomethane
VOC	volatile organic compound
$\delta^{15}\text{N}$ -nitrate	nitrate delta nitrogen-15-to-nitrogen-14 isotopic ratio or delta nitrogen-15 of dissolved nitrate
$\delta^{18}\text{O}$ -nitrate	nitrate oxygen-18-to-oxygen-16 isotopic ratio or delta oxygen-18 of dissolved nitrate

Units of Measure

$\text{cm}^3 \text{ STP g}^{-1}$	cubic centimeters at standard temperature and pressure per gram
δ	delta notation; the ratio of a heavier isotope to the more common lighter isotope of an element, relative to a standard reference material, expressed as per mil
ft	foot (feet)
in.	inch
kg	kilogram
L	liter
mg/L	milligrams per liter (parts per million)
mi	mile
mL	milliliter

mm	millimeter
µg/L	micrograms per liter (parts per billion)
µS/cm	microsiemens per centimeter
pCi/L	picocuries per liter
per mil	parts per thousand
pmc	percent modern carbon
TU	tritium unit
>	greater than
<	less than
≤	less than or equal to
°C	degrees Celsius
°F	degrees Fahrenheit
%	percent

Notes

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

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).

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Abstract

Groundwater quality in the approximately 1,695-square-mile Central Eastside San Joaquin Basin (Central Eastside) study unit was investigated as part of the Priority Basin Project (PBP) of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The GAMA PBP was developed in response to the California Groundwater Quality Monitoring Act of 2001, and 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 Central Eastside study unit was designed to provide a spatially unbiased assessment of untreated-groundwater quality, as well as a statistically consistent basis for comparing water quality throughout California. During March through June 2006, samples were collected from 78 wells in Stanislaus and Merced Counties, 58 of which were selected using a spatially distributed, randomized grid-based method to provide statistical representation of the study unit (grid wells), and 20 of which were sampled to evaluate changes in water chemistry along groundwater-flow paths (understanding wells). Water-quality data from the California Department of Public Health (CDPH) database also were used for the assessment.

An assessment of the current status of the groundwater quality included collecting samples from wells for analysis of anthropogenic constituents such as volatile organic compounds (VOC) and pesticides, as well as naturally occurring constituents such as major ions and trace elements. The assessment of status is intended to characterize the quality of untreated-groundwater resources within the primary aquifer system, not the treated drinking water delivered to consumers by water purveyors. The primary aquifer system (hereinafter, primary aquifer) is defined as that part of the aquifer corresponding to the perforation interval of wells listed in the CDPH database for the Central Eastside study unit. The quality of groundwater in shallower or deeper

water-bearing zones may differ from that in the primary aquifer; shallower groundwater may be more vulnerable to surficial contamination. The primary aquifer is represented by the grid wells, of which 90 percent had depths to the tops of their perforations of about 80 to 330 feet and depths to bottom of about 100 to 670 feet. Relative-concentrations (sample concentration divided by benchmark concentration) were used as the primary metric for assessing the status of water quality for those constituents that have Federal and (or) California human health or aesthetic benchmarks. A relative-concentration greater than ($>$) 1.0 indicates a concentration above a benchmark, and less than or equal to (\leq) 1.0 indicates a concentration equal to or below a benchmark. For organic and special interest constituents, relative-concentrations were classified as high (>1.0), moderate (≤ 1.0 and >0.1), or low (≤ 0.1). For inorganic constituents, relative-concentrations were classified as high (>1.0), moderate (≤ 1.0 and >0.5), or low (≤ 0.5). The threshold between low and moderate classifications was lower for organic and special interest constituents than for inorganic constituents because organic constituents generally are less prevalent and have smaller relative-concentrations than inorganic constituents.

Grid-based and spatially-weighted approaches, the latter incorporating data from all CDPH wells, were used to evaluate the proportion of the primary aquifer (aquifer-scale proportions) with high, moderate, or low relative-concentrations. For individual constituents or classes of constituents, the aquifer-scale high proportion is the percentage of the area of the study unit having high relative-concentrations within the depth-zones of the primary aquifer. Aquifer-scale moderate and low proportions are defined similarly. Spatially-weighted aquifer-scale high proportions nearly always fell within the 90-percent confidence interval of grid-based aquifer-scale high proportions, indicating that the grid-based approach yielded statistically equivalent results to the spatially-weighted approach incorporating CDPH data.

The status assessment for inorganic constituents showed that inorganic constituents (one or more) were high, relative to human-health benchmarks, in 18.0 percent of the primary aquifer, moderate in 44.0 percent, and low in 38.0 percent. Of inorganic constituents with human-health benchmarks, arsenic, vanadium, and nitrate were detected at high relative-concentrations in 15.6 percent, 3.6 percent, and 2.1 percent, respectively, of the primary aquifer. Of inorganic constituents with secondary maximum contaminant levels (SMCL), manganese, iron, and TDS were detected at high relative-concentrations in 4.5 percent, 2.2 percent, and 1.7 percent, respectively, of the primary aquifer.

The status assessment for organic constituents showed that organic constituents (one or more) were high, relative to human-health benchmarks, in a smaller proportion of the primary aquifer (1.2 percent) than inorganic constituents (18.0 percent). Organic constituents had moderate relative-concentrations in 14.3 percent, and had low relative-concentrations or were not detected in 84.5 percent, of the primary aquifer. The proportion of the primary aquifer with high relative-concentrations of organic constituents reflected high proportions of the discontinued soil fumigant 1,2-dibromo-3-chloropropane (DBCP; 1.0 percent) and the solvent tetrachloroethene (PCE; 0.2 percent). Most of the organic and special interest constituents detected in groundwater in the Central Eastside study unit have human-health benchmarks. Of the 205 organic and special interest constituents analyzed for, 36 constituents were detected. Of these constituents, 32 were detected only at low relative-concentrations. Four constituents, chloroform, carbon tetrachloride, DBCP, and perchlorate, were detected at moderate relative-concentrations in grid wells. Nine organic and special-interest constituents were detected frequently (detected in greater than 10 percent of samples): the trihalomethanes chloroform, bromoform, bromodichloromethane, and dibromochloromethane; the solvent PCE; the herbicides atrazine, simazine, and metolachlor, and special-interest constituent perchlorate.

An assessment of understanding of the groundwater quality included sampling of understanding wells, some of which were perforated in shallower or deeper portions of the aquifer system than the primary aquifer, and analysis of correlations of groundwater quality with land use, depth, age classification, and other potential explanatory factors.

The understanding assessment indicated that the concentrations of many constituents were related to depth and groundwater age. However, concentrations of individual constituents or constituent classes also were sometimes related to geochemical conditions, lateral position in the flow system, or land use.

High and moderate relative-concentrations of uranium, nitrate, and total dissolved solids (TDS) were detected in some wells where the tops of perforations are within the upper 200 feet of the aquifer system. In wells with the depth to the top of perforations below this depth, concentrations were low. A similar pattern occurred for the sum of herbicide concentrations. These vertical water-chemistry patterns are consistent with the hydrogeologic setting, in which return flows from agricultural and urban land use are the major source of recharge, and withdrawals for irrigation and urban supply are the major source of discharge, resulting in substantial vertical components of groundwater flow.

The decrease in concentrations of many constituents with depth reflects in part that groundwater gets older with depth. Tritium, helium-isotopes, and carbon-14 data were used to classify the predominant age of groundwater samples into three categories: modern (water that has entered the aquifer in the last 50 years), pre-modern (water that entered the aquifer more than 50 years, up to tens of thousands of years, ago), and mixed (mixtures of waters with modern and pre-modern ages). Uranium, nitrate, and herbicide concentrations were significantly higher in groundwater having modern- and mixed-ages than pre-modern ages, indicating that these constituents may be affected by anthropogenic activities in the last 50 years.

Other patterns in the distribution of nitrate, uranium, and TDS are evident. Isotopic and geochemical data are consistent with partial denitrification of nitrate in some reducing groundwaters in the western and deeper parts of the flow system. Uranium and TDS concentrations increase from east to west across the valley, along the direction of regional lateral groundwater flow.

High and moderate relative-concentrations of arsenic can be attributed to reductive dissolution of manganese or iron oxides, or to desorption by high pH waters. Arsenic concentrations also increased with increasing depth and groundwater age. High to moderate relative-concentrations of vanadium primarily are related to high pH under oxic conditions.

The frequency of detections of DBCP was greater in areas with orchard-vineyard land use >40 percent and at depths <200 feet. THMs and solvents were correlated positively with percent urban land use. Herbicide concentrations were correlated negatively with percent natural land use. Perchlorate concentrations were significantly greater in waters having modern and mixed ages than waters having pre-modern ages and were significantly and positively correlated with two land uses—percent orchard/vineyard land use and percent urban land use.

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 (<http://www.swrcb.ca.gov/gama>). The SWRCB initiated the GAMA Program in 2000 in response to a legislative mandate (Supplemental Report of the 1999 Budget Act 1999-00 Fiscal Year). The GAMA Priority Basins Project was initiated in response to the Groundwater Quality Monitoring Act of 2001 {Sections 10780-10782.3 of the California Water Code, Assembly Bill 599} to assess and monitor the quality of groundwater in California. The statewide GAMA program currently consists of three projects: GAMA Priority Basin Project, conducted by the USGS (<http://ca.water.usgs.gov/gama>); GAMA Domestic Well Project, conducted by the SWRCB; and GAMA Special Studies, conducted by LLNL. On a statewide basis, the Priority Basin Project focused primarily on the deeper portion of the groundwater resource and the SWRCB Domestic Well Project generally focused on the shallower aquifer systems.

The GAMA Priority Basin Project is a comprehensive assessment of statewide groundwater quality designed to help better understand and identify risks to groundwater resources, and to increase the availability of information about groundwater quality to the public. For the Priority Basin Project, the USGS, in collaboration with the SWRCB, developed the monitoring plan to assess groundwater basins through direct and other statistically reliable sample approaches (Belitz and others, 2003; State Water Resources Control Board, 2003). Additional partners in the GAMA PBP include the California Department of Public Health (CDPH), California Department of Pesticide Regulation (CDPR), California Department of Water Resources (CDWR), and local water agencies and well owners. Local participation in the PBP is voluntary.

The range of hydrologic, geologic, and climatic conditions that exist in California must be considered in an assessment of groundwater quality. Belitz and others (2003) partitioned the state into ten hydrogeologic provinces, each with distinctive hydrologic, geologic, and climatic characteristics (fig. 1). Most of these hydrogeologic provinces include groundwater basins 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 are located in designated groundwater basins. Some groundwater basins, such as the San Joaquin Valley basin, cover large areas and are further divided into groundwater subbasins by CDWR. Groundwater basins and subbasins were prioritized for sampling on the basis of the number of public-supply wells, with secondary consideration given to municipal groundwater use, agricultural pumping, registered pesticide applications, and the number of historic leaking underground fuel tanks (Belitz and others, 2003). In addition, some groundwater basins or areas outside of designated basins, having relatively few public-supply wells, were assigned high-priority status so that all hydrogeologic provinces would be represented in the assessment. The 116 priority basins were grouped into 35 study units and include approximately 85 percent of public-supply wells in California. Study units usually include one or more study areas. Study areas generally correspond to CDWR-defined groundwater basins or subbasins.

Purpose and Scope

The GAMA PBP includes three types of water-quality assessments in each study unit: (1) *Status*: assessment of the current quality of the untreated-groundwater resource in the primary aquifer system (hereinafter, primary aquifer); (2) *Understanding*: identification of the natural and human factors affecting groundwater quality; and (3) *Trends*: detection of changes in groundwater quality (Kulongoski and Belitz, 2004). PBP status assessments are designed to provide a statistically robust characterization of untreated-groundwater quality in the primary aquifers at the basin scale (Belitz and others, 2003). The statistically robust design also allows for comparison between basins and for synthesis of results at regional and statewide scales.

This report is one of a series of assessment reports presenting the *status* and *understanding* of current water-quality conditions in GAMA study units. Subsequent efforts will address the *trends* aspects of the water-quality assessments. This report describes groundwater-quality conditions in the Central Eastside San Joaquin Basin GAMA study unit, hereinafter referred to as the Central Eastside study unit (fig. 1). The purposes of this report are to (1) briefly describe the hydrogeologic setting, (2) assess the current status of untreated-groundwater quality in the primary aquifer, and (3) assess the relations between water quality and selected potential explanatory factors (*understanding*).



Figure 1. Location of Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit and California hydrogeologic provinces (modified from Belitz and others, 2003).

The status assessment in this report includes analysis of water-quality data from 58 wells, mostly public-supply wells (PSWs), but including other wells with similar perforation depth intervals, selected for sampling by USGS within spatially distributed grid cells across the Central Eastside study unit; hereinafter, these wells are referred to as USGS grid wells. Samples were collected from wells for analysis of anthropogenic constituents such as volatile organic compounds (VOCs) and pesticides, as well as naturally occurring constituents such as major ions and trace elements. Water-quality data from the California Department of Public Health (CDPH) database also were used to supplement data collected by USGS for the PBP. The primary aquifer is defined as that part of the aquifer corresponding to the perforation interval of wells listed in the CDPH database for the Central Eastside study unit. The CDPH database lists wells used for municipal and community drinking water supplies, and includes wells from systems classified as non-transient (such as cities, towns, and mobile-home parks) and transient (such as schools, campgrounds, and restaurants). 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 can be higher in shallow wells than deeper wells (Burow and others, 2007). GAMA's Voluntary Domestic Well Project, conducted by the SWRCB, is designed to assess water quality in the shallower parts of the aquifer system.

For the purposes of providing context, the water-quality data discussed in this report were compared to State and Federal drinking-water regulatory and nonregulatory benchmarks for treated drinking water. The assessments in this report are intended to characterize the quality of untreated-groundwater resources in the primary aquifer 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. Regulatory benchmarks apply to treated water that is served to the consumer, not to untreated groundwater.

The understanding assessment includes data from 20 wells sampled by USGS for the purpose of understanding (hereinafter, USGS understanding wells), used with grid-well data to assess the relations between water quality and selected potential explanatory factors. Some wells selected for understanding purposes had perforations in shallower or deeper zones (above or below the primary aquifer); therefore, some of the USGS understanding wells do not represent the primary aquifer. In addition to anthropogenic and naturally occurring constituents, samples also were collected at the understanding wells and some USGS grid wells for analysis of constituents that can be used as hydrologic tracers or

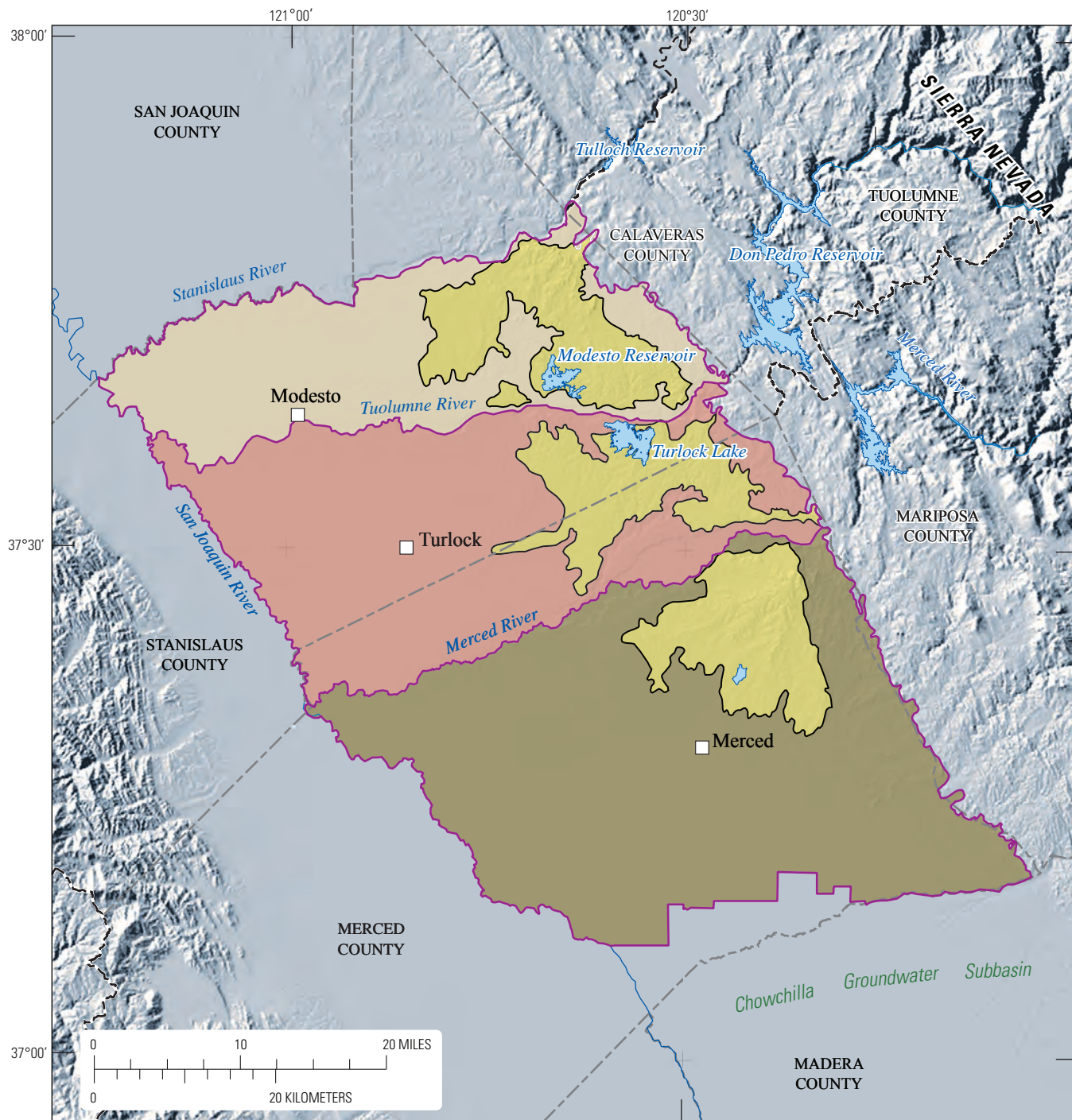
geochemical indicators. Potential explanatory factors examined included land use, depth, lateral position in the flow system, indicators of groundwater age, and geochemical-condition indicators. A comprehensive analysis of all possible explanatory factors is beyond the scope of this report.

In addition to describing the findings of the assessments for status and understanding, this report provides description of methods used in designing the sampling network, identification of CDPH data for use in the status assessment, estimation of aquifer-scale proportions of high, moderate, and low relative-concentrations of constituents, analysis of ancillary data sets, classification of groundwater age, and statistical and graphical approaches used in analyzing water-quality data. Water-quality data for samples collected by the USGS for the GAMA PBP (hereinafter, USGS–GAMA sampling) in the Central Eastside study unit and details of sample collection, analysis, and quality-assurance procedures for the Central Eastside study unit are presented by Landon and Belitz (2008).

Description of Study Unit

The Central Eastside study unit lies within the Central Valley Hydrogeologic Province described by Belitz and others (2003) and includes three CDWR San Joaquin Valley groundwater subbasins: Modesto, Turlock, and Merced (California Department of Water Resources, 2003). The study unit is bounded by the San Joaquin River to the west, the Sierra Nevada Mountains to the east, the Stanislaus River to the north, and the Chowchilla groundwater subbasin to the south ([fig. 2](#)).

The Central Eastside study unit is divided into four separate study areas: the Modesto study area (MOD), the Turlock study area (TRLK), the Merced study area (MER), and the Uplands study area (CE-QPC) ([fig. 2](#)). The exterior boundaries of the Modesto, Turlock, and Merced study areas correspond to the CDWR groundwater subbasins of the same names. However, these study areas differ from the CDWR subbasins in that the Quaternary–Pleistocene-age semiconsolidated (QPC) deposits (Jennings, 1977) were designated as a separate study area, the Uplands study area. The QPC areas were designated as a separate study area because of their wide extent, unique geology and topography, and generally higher percentage of natural land use in comparison with the rest of the Modesto, Turlock, and Merced subbasins. The QPC areas also were designated as separate study areas in PBP study units to the north in the Central Valley (Bennett and others, 2006; Dawson and others, 2007),



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

EXPLANATION

Study area:

 Merced	 Uplands
 Modesto	 Turlock

Study area boundary

Groundwater subbasin boundary
(From California Department of
Water Resources, 2003)

Figure 2. Geographic features of the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

facilitating comparison of water quality in similar upland areas from north to south along the valley.

The Central Eastside study unit has a Mediterranean climate, with hot and dry summers, and winters that are cool and moist. Average rainfall across the study unit ranges from 11 inches (in.) in the southern and western portions of the study unit to 15 in. in the eastern to northeastern portions of the study unit (California Department of Water Resources, 2004a,b, and 2006). Climatic data from six National Climatic Data Center stations (Denair, Knights Ferry, LeGrand, Merced, Modesto, Turlock; Western Regional Climate Center, 2007) in the study unit having 18 to 74 years of record indicate that 88 to 90 percent of precipitation occurs during November through April.

Several creeks and rivers drain the Central Eastside study unit. The Stanislaus, Tuolumne, and Merced Rivers, as well as their tributaries, are the primary streams in the study unit (fig. 2), but most of their flow is derived from the Sierra Nevada Mountains to the east. Each of these rivers ultimately drains into the San Joaquin River, which flows northwest and empties into the Sacramento–San Joaquin Delta, which discharges into the San Francisco Bay.

Land use in the study unit is 59 percent agricultural, 34 percent natural, and 7 percent urban, on the basis of classification of USGS National Land Cover Data (Volgelmann and others, 2001; Price and others, 2003) (fig. 3). The natural land-use areas mostly are grassland. Natural land use is dominant in the eastern parts of the study unit (fig. 4). Areas of natural land use, primarily grasslands, also are in the southwestern part of the Merced study area, where a relatively shallow water table limits the suitability of the land for growth of agricultural crops. The primary crops are almonds, walnuts, peaches, grapes, grain, corn, pasture, and alfalfa (California Department of Water Resources, 2009a,b). The largest urban areas are the cities of Modesto, Turlock, and Merced. Additional areas of urban land use are located along the Stanislaus and Tuolumne Rivers and in the northern part of the Merced study area (fig. 4). Land use in the Merced, Modesto, and Turlock study areas is predominantly agricultural, whereas land use in the Uplands study area is predominantly natural (fig. 3). The Modesto study area was the most urbanized in the study unit with 59 percent agricultural, 22 percent natural, and 19 percent urban land use.

The main water-bearing units within the Modesto, Turlock, and Merced study areas include the unconsolidated alluvial-fan deposits of the Pleistocene-age Riverbank Formation, the deeper unconsolidated Pleistocene-age Turlock Lake and Pliocene-age Laguna Formations, and the semi-consolidated Miocene-Pliocene-age Mehrten Formation (Burow and others, 2004; California Department of Water Resources, 2004a,b, 2006). Holocene flood-basin and dune deposits (fig. 5) generally are not saturated except near major rivers (Burow and others, 2004). Older consolidated

deposits outcrop in the eastern portion of the Modesto, Turlock, and Merced study areas (east of the Uplands study area) and include the Valley Springs Formation of Oligocene-Miocene-age, and the Ione Formation of Eocene age (fig. 5). These older consolidated deposits generally yield only small quantities of water. The main water-bearing units within the Uplands study area include the unconsolidated alluvial-fan deposits of the Pleistocene-age Turlock Lake and Pliocene-age Laguna Formations, and consolidated deposits of the Miocene-Pliocene-age Mehrten Formation (Burow and others, 2004; California Department of Water Resources, 2004a).

Groundwater conditions are unconfined, semi-confined, and confined in different zones of the groundwater system in the Central Eastside study unit. The base of freshwater, where estimated, generally is more than 700 feet (ft) below land surface (Page, 1973), but may be as shallow as 300 ft in parts of the study unit (Burow and others, 2004). Unconfined conditions are present in unconsolidated deposits above and east of the Corcoran Clay Member of the Turlock Lake Formation (Marchand and Allwardt, 1981), which underlies the southwestern half of the study unit (fig. 5) at depths ranging from 50 to 250 ft (Davis and others, 1959; Page and Balding, 1973; Page, 1986; Burow and others, 2004; California Department of Water Resources, 2004a,b, 2006). Confined conditions are present below the Corcoran Clay. Semi-confined conditions are present at depth east of the Corcoran Clay, because of many discontinuous clay lenses.

Primary sources of recharge are percolation of irrigation return, precipitation, seepage from reservoirs and rivers, and urban return (Burow and others, 2004; Phillips and others, 2007). The irrigation supply is provided primarily by surface water draining from the Sierra Nevada, and stored in reservoirs (Phillips and others, 2007). The surface-water supplies are managed by irrigation districts and delivered to agricultural users through hundreds of miles of lined canals. Primary sources of discharge are pumping withdrawals for irrigation and municipal water supply, evaporation from areas with a shallow depth to water, and discharge to streams. Agricultural irrigation supplied by surface water and groundwater accounts for about 95 percent of the total water use in the region (Burow and others, 2004).

The Modesto study area covers approximately 277 mi², and is located primarily in Stanislaus County. The study area is bounded on the north by the Stanislaus River, on the west by the San Joaquin River, on the south by the Tuolumne River, and on the east by the foothills of the Sierra Nevada Mountains (fig. 2). The City of Modesto is the largest city, with a population of 206,872 in 2003 (U.S. Census Bureau, 2007). Outside of urban areas, land use in the Modesto study area is predominantly irrigated agricultural fields, except in the extreme eastern portion where grasslands predominate (fig. 4). An extensive distribution system diverts water from the Tuolumne River for irrigation of crops and for municipal

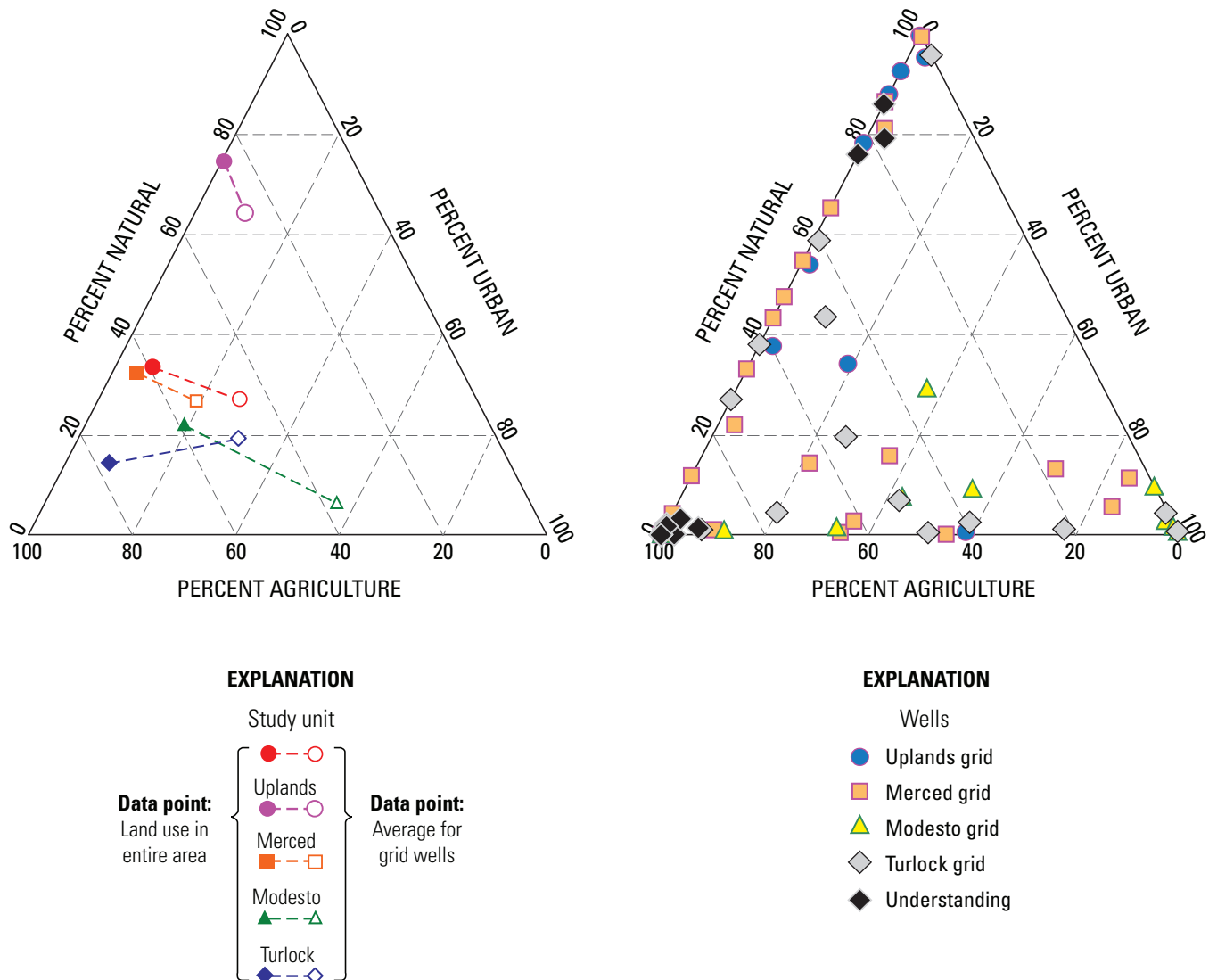
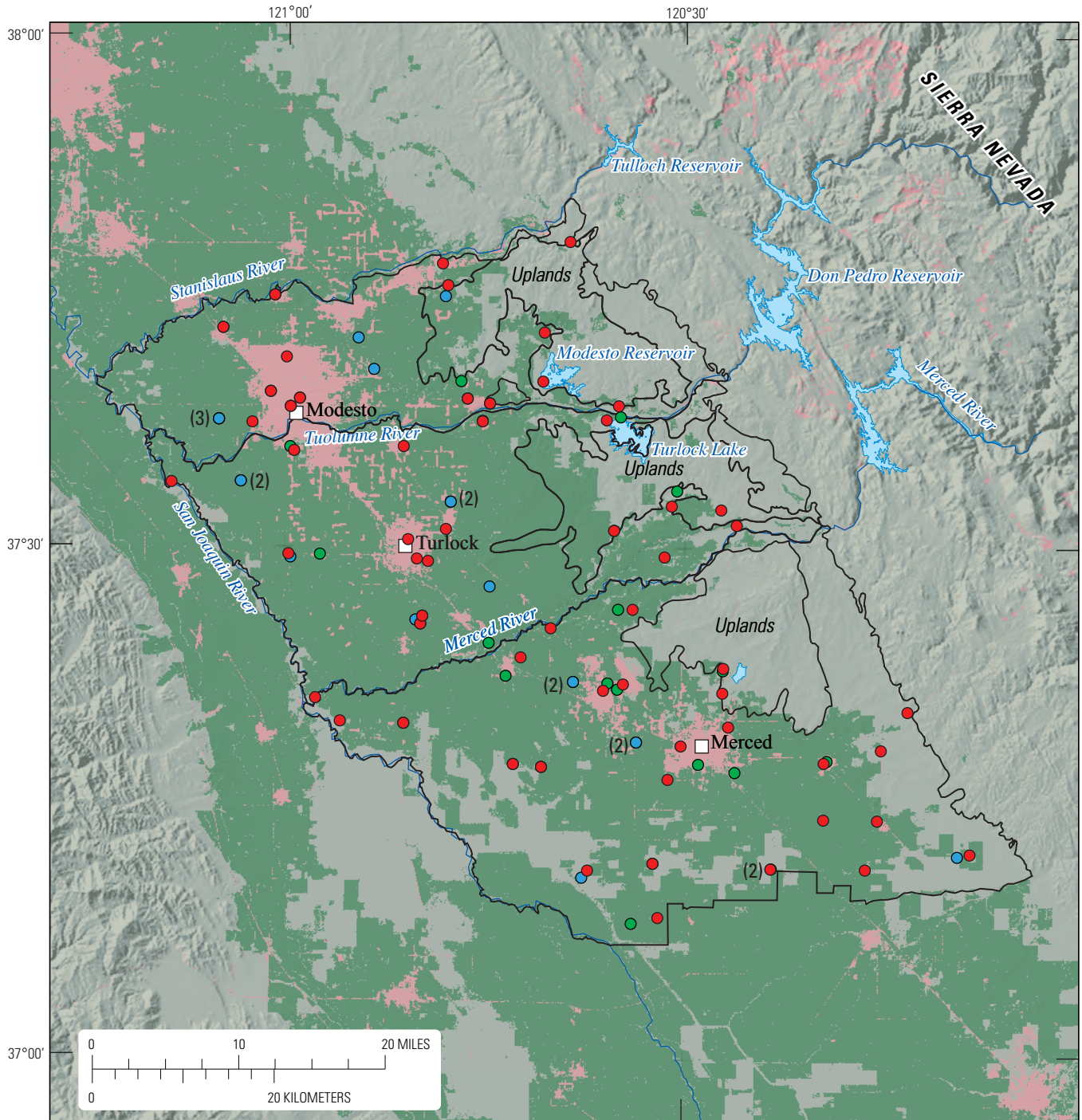


Figure 3. Ternary diagram showing proportions of urban, agricultural, and natural land uses for study unit, study areas, and wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

supply for the City of Modesto. Water also is diverted for irrigation from the Stanislaus River.

The Turlock study area covers approximately 446 mi², and is located in Stanislaus and Merced Counties. The study area is bounded on the north by the Tuolumne River, on the west by the San Joaquin River, on the south by the Merced River, and on the east by the foothills of the Sierra Nevada Mountains ([fig. 2](#)). The city of Turlock is the largest city, with a population of 13,467 in 2003 (U.S. Census Bureau, 2007). Land use in the Turlock study area predominantly is irrigated agricultural fields except in the extreme eastern portion where grasslands predominate ([fig. 4](#)). An extensive distribution system diverts water from the Tuolumne and Merced Rivers for irrigation of crops.

The Merced study area covers approximately 668 mi² and is located primarily in Merced County. The study area is bounded on the north by the Merced River, on the west by the San Joaquin River, on the south by the Chowchilla subbasin, and on the east by the foothills of the Sierra Nevada Mountains ([fig. 2](#)). The city of Merced is the largest city, with a population of 19,512 in 2003 (U.S. Census Bureau, 2007). Land use in the Merced study area predominantly is irrigated agricultural fields except in the extreme eastern portion where grasslands predominate and in some portions of the southwest ([fig. 4](#)). An extensive distribution system diverts water from



EXPLANATION

Land use		Study area boundary	
	Agricultural		USGS grid well
	Natural		CDPH grid well
	Urban		USGS understanding well
		(2)	Number of wells sampled at locations (if greater than 1)

Figure 4. Land use in the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit and locations of grid and understanding wells.

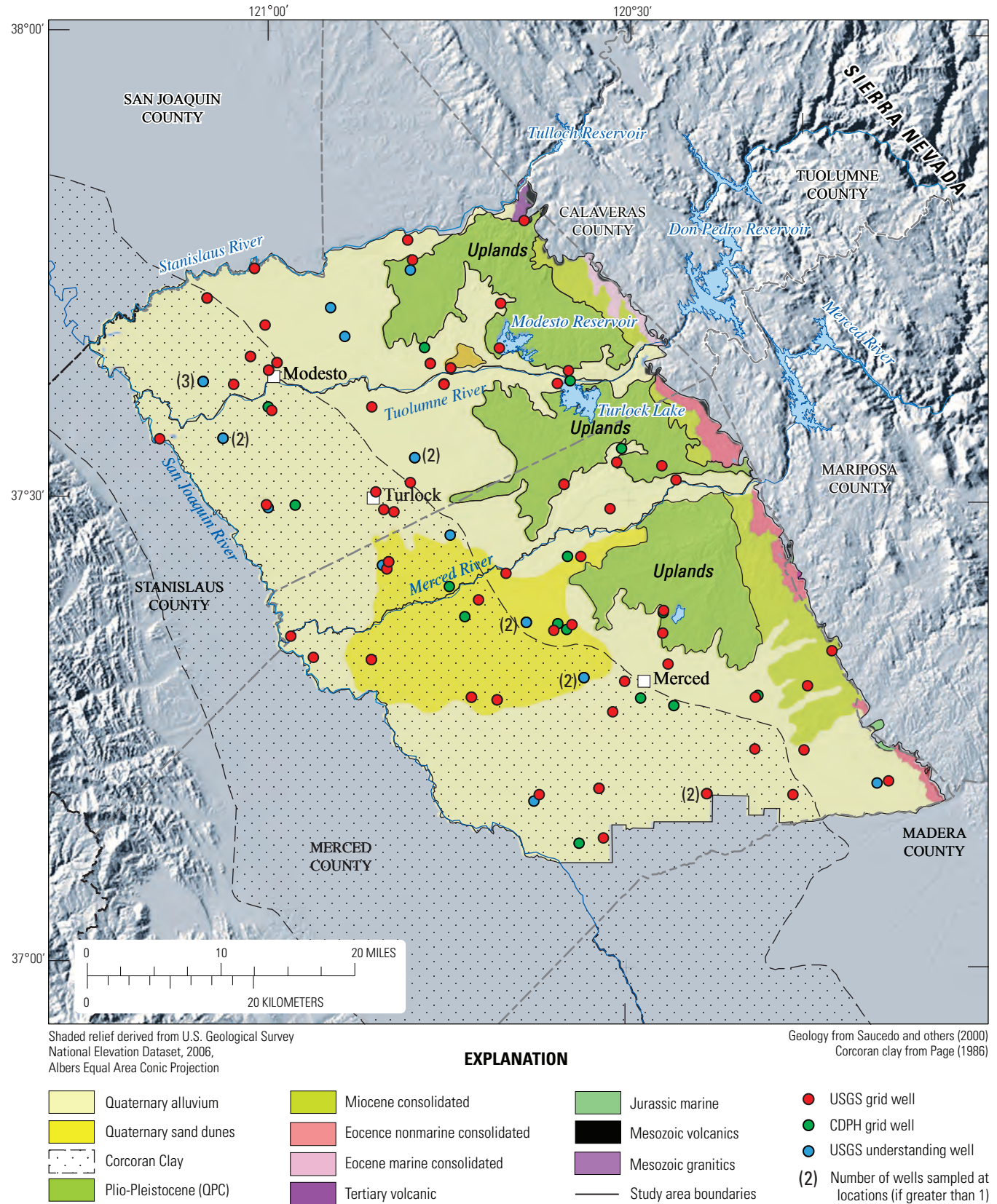


Figure 5. Geologic map of the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

the Merced River for irrigation of crops in the northern and central parts of the Merced study area.

The Uplands study area covers approximately 304 mi², and is located in Stanislaus and Merced Counties (fig. 2). There are three major areas of Uplands study area, one within the eastern portions of each of the Modesto, Turlock, and Merced study areas. Land use in the Uplands study area primarily is grassland and irrigated agricultural fields, which mostly occur in the western portions of the study area (fig. 4). Agricultural lands primarily are irrigated with groundwater except in the Uplands study area within the Modesto study area, where surface water diverted from the Stanislaus River is used for irrigation.

The conceptual model of the groundwater-flow system, based on previous investigations of Burow and others (2004) and Phillips and others (2007), is shown in figure 6. Regional lateral flow of groundwater from northeast to southwest across the study unit is driven by topography, the discharge of water to the San Joaquin River, and evaporation in the western part of the flow system. Because irrigation return flows are the major source of recharge and withdrawals for irrigation are the major source of discharge, there are substantial vertical components of flow (Burow and others, 2008b). These vertical flow components enhance vertical movement of water from recharge areas to the perforated intervals of withdrawal wells within shallow to intermediate depths in the system. These processes occur in both agricultural and urban areas. Groundwater age is vertically stratified, with water less than 50 years old in the upper parts of the system and water that may be tens of thousands of years old at depth (Burow and others, 2008a). In the western part of the study unit, the Corcoran Clay may restrict the interaction between the underlying confined and overlying unconfined groundwater. However, well-bores open to the aquifer above and below the Corcoran Clay permit water exchange across the Corcoran (Williamson and others, 1989). At the western end of the flow system, there is upward movement of groundwater towards the San Joaquin River. Wells perforated below the Corcoran Clay in the western third to half of the study unit are less abundant than in the rest of the study unit because poor-quality water in some areas [relatively high total dissolved solids and (or) iron and manganese] limit the use of the water for irrigation and domestic supply (Davis and others, 1959; Bertoldi and others, 1991).

Methods

Methods used for the PBP were selected to achieve the following objectives: (1) design a sampling plan suitable for statistical analysis; (2) combine selected existing CDPH data

with data collected by the USGS for the PBP to assess water quality; and (3) evaluate proportions of the primary aquifer having high, moderate, and low concentrations, relative to water-quality benchmarks, for constituent classes and individual constituents of interest, (4) compile and classify relevant ancillary data to identify relations of potential explanatory factors to water quality, and (5) investigate statistical relations between potential explanatory factors and water quality to provide understanding of the factors affecting the occurrence of constituents. Additional discussion of the methods used in the Central Eastside study unit can be found in Landon and Belitz (2008), including methods used to (1) collect samples in a consistent manner, (2) analyze samples using proven and reliable laboratory methods, (3) assure the quality of the groundwater data, and (4) maintain data securely and with relevant documentation.

The status assessment was designed to determine the quality of untreated groundwater resources used for public drinking-water supply. The study unit was divided into four study areas, and each study area was divided into grid cells. One randomly selected well per grid cell was sampled by the USGS for selected constituents (*USGS grid wells*). Data were selected from the CDPH database (hereinafter, *CDPH grid wells*) to supplement USGS grid well data for constituents not sampled by the USGS for each grid cell, and data for additional wells was selected from the CDPH database (*CDPH other wells*) for supplemental analysis. Using these data, grid-based and spatially-weighted approaches were used to assess proportions of high, moderate, and low concentrations of constituents and constituent classes in the primary aquifer. The grid-based approach uses one well per grid cell (hereinafter *grid wells*, which may include USGS grid wells and CDPH grid wells), in a spatially distributed randomized well network, to assess aquifer-scale proportions. The spatially-weighted approach includes many wells per grid cell, including grid and CDPH other wells. For an individual constituent or class of constituents, the aquifer-scale proportion is the percentage of the area of the study unit having concentrations above a specified threshold within the depth zones of the primary aquifer.

The understanding assessment was designed to evaluate the natural and human factors that affect groundwater quality within groundwater basins, and at regional to statewide scales. Given the complexity of aquifer systems and the uncertainties associated with the sources of elevated concentrations, the understanding assessment relies upon the use of multiple lines of evidence to investigate the relations between observed water quality and potential explanatory factors. More detailed descriptions of the methods used in the status and understanding assessments are provided in the following sections.

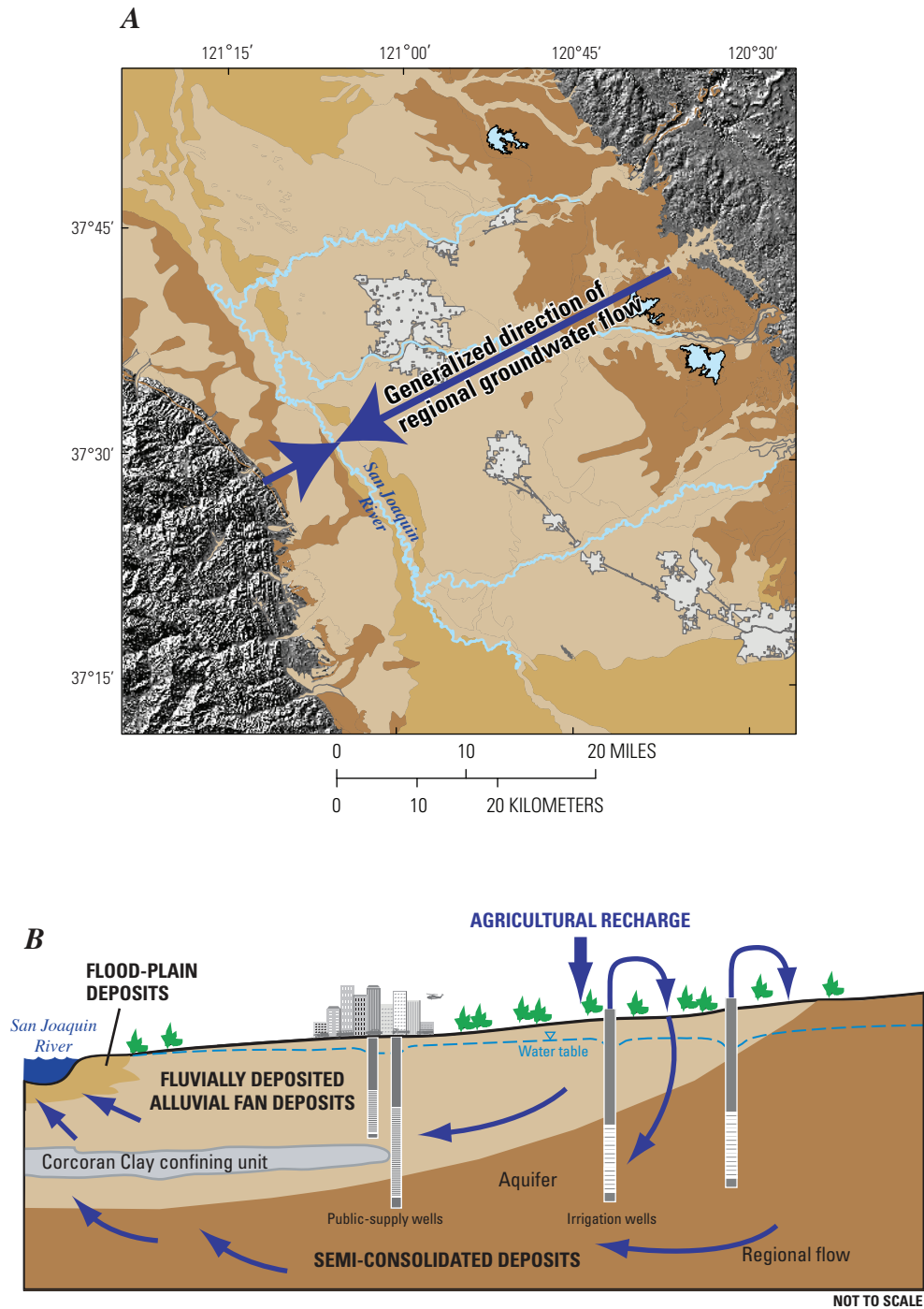


Figure 6. Conceptual diagram of (A) regional lateral groundwater flow and, (B) vertical flow influenced by agricultural practices and natural discharge zones, for the aquifer system of the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit (modified from Burow and others, 2004; Phillips and others, 2007).

Design of Sampling Networks

The wells selected for sampling by USGS in this study reflect the combination of two well-selection strategies. First, 58 wells (USGS grid wells) were selected to provide a statistically unbiased, spatially distributed assessment of the quality of groundwater resources used for public drinking-water supply. For constituents not analyzed in samples from all USGS grid wells, data from USGS grid wells were augmented with data from CDPH grid wells to populate the grid with data. Second, 20 wells, including monitoring, irrigation, drainage, and domestic wells, were selected for sampling by USGS for the PBP to provide greater density of extensive water chemistry data in several areas to address specific groundwater-quality issues in the study unit and to provide additional information for the understanding assessment (USGS understanding wells).

The spatially distributed wells (USGS grid wells) were selected using a randomized grid-based method (Scott, 1990). Each of the study areas was subdivided into grid cells approximating 28 mi² (fig. 7). This grid-cell size met PBP objectives for the Central Valley hydrogeologic province of a sampling density of one well per 19.3–38.6 mi² (50–100 square kilometers), while having at least 10 grid cells per study area. The variable shapes of the equal-area grid cells are drawn objectively using the method of Scott (1990) and are influenced by the irregular shapes of the boundaries of the study areas (fig. 7). Geographic features of the study areas may force the same grid cell to be divided into multiple pieces to obtain the designated coverage area for each cell. Locations of wells listed in statewide databases maintained by the CDPH and USGS were plotted, and one public-supply well per grid cell was selected that met basic sampling criteria (for example, sampling point prior to treatment, capability to pump for several hours, and available well-construction information) and for which permission to sample could be obtained (Landon and Belitz, 2008). If a grid cell did not contain accessible public-supply wells, then commercial, irrigation, or domestic wells were considered for sampling. The USGS grid wells were sampled by USGS for the Priority Basins Project but are owned by other organizations or individuals. USGS grid wells in the Central Eastside study unit were numbered in the order of sample collection with the prefix varying by study area: the Modesto study area (MOD), the Turlock study area (TRLK), the Merced study area (MER), and the Uplands study area (CE-QPC) (fig. A1, appendix A).

One USGS grid well was sampled in 58 of the 60 grid cells, including 10 of the 10 grid cells in the Modesto study area, 16 of the 16 grid cells in the Turlock study area, 23 of the 24 grid cells in the Merced study area, and 9 of the 10 grid cells in the Upland Basins study area (fig. 7). The two grid cells where samples were not collected had few wells, and permission to sample was not granted for wells in those cells.

The 58 USGS grid wells sampled included 43 public-supply, 8 domestic, 3 commercial, 3 irrigation wells, and one monitoring well. One monitoring well, MER-21, was included with the USGS grid wells because no public-supply, irrigation, commercial, or domestic wells were available for sampling in its grid cell. The monitoring well had perforated intervals of comparable length and depths to other grid wells used in the study.

Twenty additional wells were selected for sampling for the purpose of understanding, with particular focus on factors affecting nitrate, uranium, and arsenic concentrations in groundwater. USGS understanding wells sampled in the four study areas were designated as either flow-path (CE-QPCFP, MERFP, MODFP and TRLKFP) or other monitoring wells (MODMW, TRLKMW, and MERMW). The understanding wells included 14 monitoring, 3 irrigation, 2 drainage wells and 1 domestic well. Thirteen of the monitoring wells sampled for understanding purposes were installed by USGS as part of previous investigations (Burow and others, 1998a; Burow and others, 2004). The remaining USGS understanding wells were sampled by USGS for the Priority Basins Project but are owned by other organizations. USGS understanding wells were selected: (1) along an approximate regional groundwater flow path across the Modesto study area (fig. 7), (2) to compare water quality between shallow-to-intermediate depths of <200 ft where most of the USGS understanding wells are perforated and depths >200 ft where public-supply wells are perforated, and (3) to characterize source waters that may mix within the aquifer system, including saline waters that underlie the freshwater aquifer, recharge of surface water through canals, and groundwater recharged from valley precipitation rather than from surface water from the Sierra Nevada.

The wells in the Central Eastside study unit were sampled using a tiered analytical approach during March through June 2006 (Landon and Belitz, 2008). All wells were sampled for a standard set of constituents, including field parameters, organic constituents, and selected hydrologic tracers (table 1). The standard set of constituents was termed the “fast” schedule. Thirty-eight USGS grid wells and one USGS understanding well were sampled for the constituents on the fast schedule only. Wells on the “intermediate” schedule were sampled for all the constituents on the *fast* schedule, plus additional field parameters, inorganic constituents, and isotopic tracers of solute sources and processes (table 1). Five USGS grid wells and 19 USGS understanding wells were sampled for the constituents on the intermediate schedule. Wells on the “slow” schedule were sampled for all the constituents on the *intermediate* schedule, plus additional low-level organic constituents and radioactive and microbial constituents (table 1). Fifteen USGS grid wells were sampled for the constituents for the *slow* schedule.

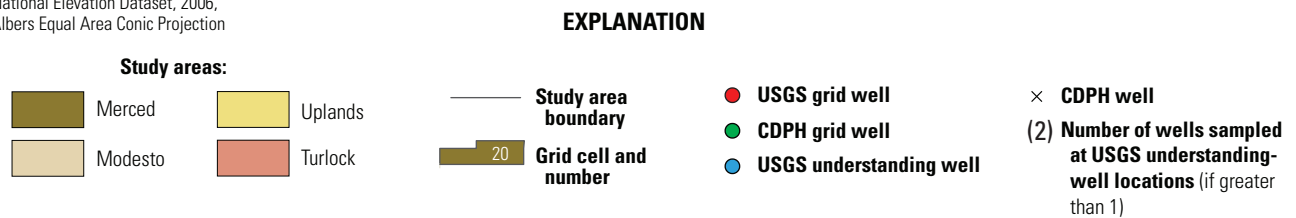
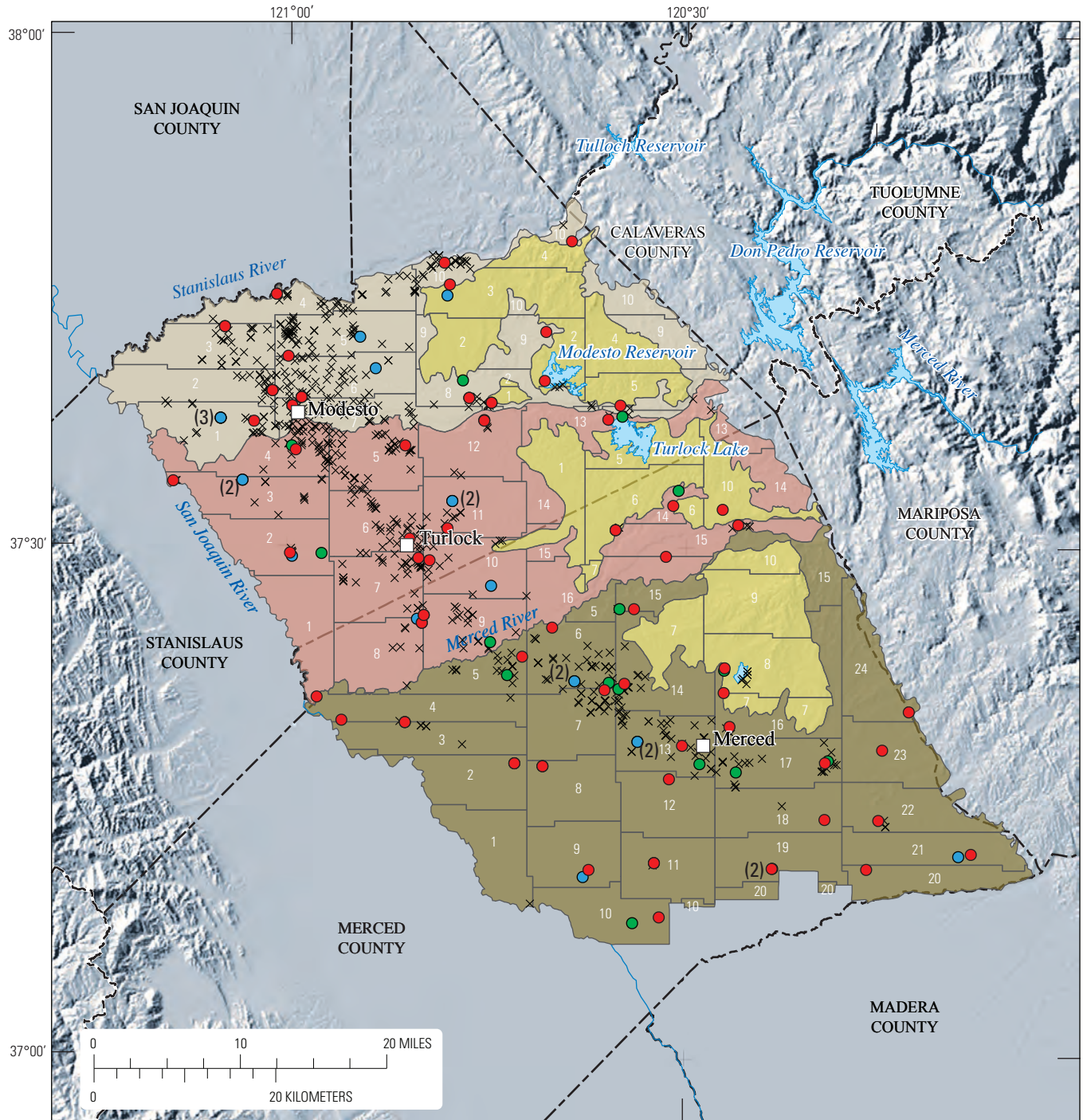


Figure 7. Locations of grid cells, grid and understanding wells sampled during March–June 2006, and grid wells at which data for inorganic constituents from the California Department of Public Health were used, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Table 1. Summary of analyte groups and number of wells sampled for different analytical schedules, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit, March–June 2006.[123-TCP, 1,2,3-Trichloropropane; NDMA, *N*-Nitrosodimethylamine; USGS, U.S. Geological Survey; LRL, laboratory reporting level]

	Schedule		
	Fast	Intermediate	Slow
Total number of wells	39	24	15
Number of grid wells sampled	38	5	15
Number of understanding wells sampled	1	19	0
Analyte Groups	Number of analytes		
Dissolved oxygen, specific conductance, temperature	3	3	3
Volatile Organic Compounds (VOC) ¹	85	85	85
Pesticides and degradates	61	61	61
Perchlorate	1	1	1
Noble gases & tritium ²	7	7	7
Stable isotopes of hydrogen and oxygen in water	2	2	2
Pharmaceuticals ³	16	16	16
Alkalinity, pH		2	2
Nutrients		5	5
Dissolved organic carbon		1	1
Nitrogen and oxygen isotopes of nitrate		2	2
Dissolved gases (nitrogen, argon, methane) ⁴		3	3
Major and minor ions, trace elements ⁵		36	36
Arsenic, chromium, and iron species		6	6
Uranium isotopes		3	3
Sulfur and oxygen isotopes of sulfate		2	2
Carbon isotopes		2	2
Boron and strontium isotopes ³		2	2
Tritium ⁶		1	1
Gasoline oxygenates ⁷			3
NDMA and low-level 123-TCP ⁸			2
Polar pesticides and degradates ⁹			54
Radon-222			1
Radium isotopes			2
Gross alpha and beta radioactivity			4
Microbial constituents			4
Low-level halogenated VOCs (chlorofluorocarbons) ^{3,10}			25
Sum:	175	240	335

¹ Includes 10 constituents classified as fumigants or fumigant synthesis byproducts.² Analyzed at Lawrence Livermore National Laboratory, Livermore, California.³ Results are not discussed in this report or Landon and Belitz (2008).⁴ Includes one analyte, dissolved nitrogen gas, in common with noble gas analyses. However, the different nitrogen values are used for different purposes and are counted as separate analyses.⁵ Includes 1 constituent, uranium, classified as a radioactive constituent later in this report.⁶ Analyzed at USGS Stable Isotope and Tritium Laboratory, Menlo Park, California.⁷ Does not include 5 constituents in common with VOCs.⁸ Includes one analyte, 123-TCP, in common with VOC analyses. However, the LRL for the low-level analysis is 0.005 microgram per liter (µg/L) compared to 0.18 µg/L for the VOC analysis. Therefore, the low-level analysis is counted as a separate analysis.⁹ Does not include 4 constituents in common with pesticides and degradates.¹⁰ Includes 22 analytes in common with VOC analyses (Plummer and others, 2008). However, the LRLs for the low-level analyses are two to three orders of magnitude lower than for the VOC analyses. Therefore, the low-level analyses are counted as separate analyses.

Analytes for the *fast* schedule mostly are common between PBP study units (Wright and others, 2005; Bennett and others, 2006; Kulongoski and others, 2006; Kulongoski and Belitz, 2007; Dawson and others, 2007; Fram and Belitz, 2007), and are collected at all grid wells. Analytes for the *slow* schedule also mostly are common between PBP study units and are collected at approximately 25 percent of USGS grid wells. Analytes for the *intermediate* schedule, beyond those included on the *fast* schedule, primarily were selected to better understand processes relevant to water quality in each study unit. In the Central Eastside study unit, analytes for the *intermediate* schedule were selected to better understand the occurrence of uranium, nitrate, and arsenic.

California State Assembly Bill AB599 directs the GAMA program to utilize existing monitoring data along with collection of new data to fill gaps. The existing statewide source of data for public-supply wells, the CDPH database, contains data for constituents with water-quality benchmarks regulated as part of Title 22. Although water-quality data also are collected by other organizations for local studies and specific purposes, the CDPH data are the only statewide database of public-supply well data available. Procedures for selecting data from the CDPH database are described in the next section of this report.

Data for some constituents, including VOCs, pesticides, inorganic constituents, and radioactive constituents, are available from both USGS–GAMA and CDPH data (table 2). However, a larger number of VOCs and pesticides are analyzed in the USGS–GAMA data than are available in the CDPH data. In addition, LRLs (laboratory reporting levels) for USGS–GAMA data typically were one to two

orders of magnitude less than those for analyses compiled by CDPH (table 2), indicating that lower concentrations can be detected in the USGS–GAMA data. The USGS–GAMA data were designed to complement the CDPH data by providing a larger number of analytes and lower laboratory reporting levels compared to the CDPH data, although the CDPH data are available for a larger number of wells. Both data sets are utilized in the status assessment.

The USGS–GAMA data includes hydrologic tracers and geochemical indicators that are not regulated water-quality constituents with benchmarks. These constituents are of importance for understanding groundwater quality and are discussed for that purpose in this report.

Status Assessment Methods

The status assessment was done by using the following methods. First, selected CDPH data were identified and incorporated into the dataset to be analyzed. Second, water-quality data were normalized to their respective water-quality benchmarks by calculating their relative-concentrations. Aquifer-scale proportions of high, moderate, and low relative-concentrations of individual constituents and constituent classes were then determined on the basis of two approaches: (1) grid-based, and (2) spatially-weighted. Results for these approaches were compared to detection frequency, and the aquifer-scale proportions from the grid-based or spatially-weighted approaches were used to identify constituents of interest for further discussion.

Table 2. Comparison of the number of compounds and laboratory reporting levels or median method detection limits by analyte group or analyte for California Department of Public Health data and data collected by the U.S. Geological Survey for the Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[CDPH, California Department of Public Health; LRL, laboratory reporting level; MDL, method detection limit; mg/L, milligrams per liter; µg/L, micrograms per liter; SSMDC, sample specific minimum detectable concentration; nc, not collected]

Analyte groups or analytes	CDPH		GAMA		
	Number of compounds	Median MDL	Number of compounds	Median LRL	Median units
Volatile organic compounds plus gasoline oxygenates (including fumigants)	83	0.5	88	0.06	µg/L
Pesticides plus degradates	74	1	115	0.019	µg/L
Nutrients, major and minor ions	12	0.4	19	0.06	mg/L
Trace elements	22	10	25	0.12	µg/L
Radioactivity constituents	4	1	11	0.045 ¹	pCi/L
Perchlorate	1	4	1	0.5	µg/L
N-Nitrosodimethylamine (NDMA)	nc	nc	1	0.002	µg/L
Pharmaceutical constituents	nc	nc	16	0.021 ²	µg/L

¹ Value is a median SSMDC for 11 radioactive constituents collected and analyzed by GAMA.

² Value is a median MDL.

Identification of CDPH Data for Status Assessment

The CDPH database is large, and targeted retrievals are required to manageably use the data to assess water-quality. For example, for the Central Eastside study unit, the historical CDPH database contains more than 600,000 records for more than 700 wells.

CDPH data were used in three ways for the status assessment. First, the CDPH data were used, along with USGS grid data, to identify constituents that have ever had concentrations above water-quality benchmarks in the Central–Eastside study unit so that these constituents could be included in the status assessment. Second, the CDPH database was used as a supplemental source of inorganic data for grid wells where a complete suite of inorganic data were not collected during USGS–GAMA sampling. Third, data from other wells from the CDPH database were used for the purpose of assessing proportions of the primary aquifer having high, moderate, and low relative-concentrations, by using spatially-weighted and detection frequency approaches.

Historically and Currently High Constituents

Constituents that had high concentrations at some time during the full period of record (April 24, 1976, through February 28, 2006) of CDPH data in the Central–Eastside study unit, but did not have high concentrations in the most recent 3-year period of CDPH data or in USGS grid data, were identified as *historically high*. These constituents do not reflect current conditions on which the status assessment is based. Constituents that had high concentrations during the most recent 3 years of data from CDPH available at the time of data analysis (March 1, 2003, through February 28, 2006, hereinafter, current period), or had high concentrations in the USGS grid data, were identified as *currently high*. For each constituent with either current or historic high concentrations, spatially-weighted aquifer-scale proportions and detection frequencies in the primary aquifer were computed using the most recent concentration available for the current period.

Selection of CDPH Grid Wells

VOC, pesticide, and perchlorate data were collected at all 58 USGS grid wells. Because the USGS–GAMA data included more constituents, and were analyzed at lower LRLs, than the CDPH data, these data were the primary data used in the status assessment for these constituent classes.

Samples for analysis of inorganic constituents were collected from 20 of the 58 USGS grid wells. For grid cells without USGS–GAMA inorganic data, a decision tree was used to select CDPH inorganic data for a single well in each cell.

The first choice for the CDPH grid well in a cell was to select the same well as the USGS grid well sampled, provided this well had the needed inorganic data from CDPH that met quality-control criteria. Cation/anion balance (Hem, 1989) was

used as the quality-control assessment metric. A cation/anion balance of greater than or equal to (\geq) 10 percent indicates uncertainty in the quality of the data. The most recent CDPH data from the well were evaluated to determine whether the CDPH data had a cation/anion balance <10 percent. If so, the CDPH inorganic data from the well were selected for use as CDPH grid-well data for inorganic constituents. It was assumed that analyses with acceptable-quality major-ion data also had acceptable-quality data for trace elements, nutrients, and radiochemical constituents. This step resulted in the selection of inorganic data from the CDPH database for 12 wells that also were USGS grid wells. For identification purposes, data from the CDPH for these grid wells were assigned GAMA identification numbers equivalent to the GAMA USGS grid well but with “DG” (for “CDPH/GAMA”) inserted between the study area prefix and sequence number (for example, CDPH grid well MER-DG-04 is the same well as USGS grid well MER-04, [table A1](#), [fig. A1](#)).

If the first step did not yield CDPH inorganic data for a grid cell, the second step was to search the CDPH database to identify the randomly ranked well with the smallest rank that had a cation/anion balance <10 percent. This step resulted in the selection of eight grid wells where CDPH inorganic data were used in the absence of inorganic data at the USGS grid wells. These CDPH grid wells were not co-located with the USGS grid well for the same cell.

If no CDPH wells in a grid cell had a cation/anion balance <10 percent or there was insufficient data to calculate the balance, the third choice for the CDPH grid well was to select the lowest randomly ranked CDPH well that had any of the needed inorganic data. This step resulted in selection of 10 grid wells where CDPH inorganic data were used. Five of these 10 wells also were USGS grid wells. At these wells, the CDPH database provided arsenic-only data at one well, nitrate-only data at two wells, and data for several other inorganic constituents at two wells. The other five wells selected in this step were CDPH grid wells that were not co-located with USGS grid wells. For identification purposes, the five CDPH grid wells that were not co-located with USGS grid wells were assigned GAMA identification 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 MER-DPH-14 is in the same grid cell as USGS grid well MER-14, [table A1](#), [fig. A1](#)).

Five of the CDPH grid wells (of the 13 not co-located with USGS grid wells) were located just outside of the target grid cells, in adjacent cells within the portion of the cell closest to the target cell. CDPH grid wells from adjacent cells were selected to increase the coverage of inorganic data in parts of the study unit where these data were relatively sparse. The CDPH grid wells were selected from adjacent cells only when they were located within the half of the adjacent cell closest to the target cell and were located in a different half of the cell from the grid well for that adjacent cell.

The result of this algorithm was selection of one grid well per cell (CDPH grid wells) having inorganic data from the CDPH database for those cells where inorganic data were not collected during USGS–GAMA sampling. Inorganic data from the CDPH database were used for 30 CDPH grid wells (table A1). Data were available for 29 CDPH grid wells for nitrate and for 23 to 25 wells for most other inorganic constituents (table 3). In combination with USGS grid well inorganic data (20 wells), inorganic data were available for grid wells located within 48 of the 60 grid cells. Analysis of the combined data sets to evaluate the occurrence of high or moderate relative-concentrations was not affected by differences in LRLs between USGS–GAMA and CDPH data because concentrations above one-half of water quality benchmarks generally were substantially higher than the highest CDPH reporting limits. The locations and USGS–GAMA identification numbers of grid and understanding wells (fig. A1), and attributes of CDPH grid wells (table A1) are presented in Appendix A. Several types of comparisons between USGS–GAMA and CDPH data are described in Appendix B.

Selection of CDPH–Other Wells

The most recent data during the current period (March 1, 2003, through February 28, 2006) for all CDPH wells in the study unit were used in spatially-weighted approaches to assess proportions of the primary aquifer having high, moderate, and low relative-concentrations for selected constituents. This approach resulted in a single concentration value being assigned to each well for each constituent assessed. All CDPH wells coded as untreated groundwater, including active, abandoned, destroyed, and inactive wells, with water-quality data for the current period, were included in the dataset for CDPH other wells.

Relative-Concentrations

Relative-concentrations were used as the primary basis for evaluating groundwater quality and were calculated from equation 1:

$$\text{Relative-concentration} = \frac{\text{sample concentration}}{\text{benchmark concentration}} \quad [1]$$

Toccalino and others (2004), Toccalino and Norman (2006), and Rowe and others (2007), previously used the ratios of measured concentration to a benchmark (either Maximum Contaminant Levels (MCLs) or Health-Based Screening Levels (HBSLs), and defined this ratio as the

benchmark quotient. Relative-concentrations used in this report are equivalent to the benchmark quotient of Toccalino and others (2004) for constituents with MCLs. HBSLs were not used in this report, as they currently are not used as benchmarks by California drinking-water regulatory agencies. Relative-concentrations provide context for the concentrations at which constituents are detected, but can be computed only for compounds with water-quality benchmarks. Relative-concentrations of less than or equal to one (≤ 1) indicate a sample concentration less than the benchmark, and values greater than one (> 1) indicate a sample concentration greater than the benchmark.

Regulatory and nonregulatory benchmarks apply to water that is served to the consumer, not to untreated groundwater. However, to provide context for the water-quality results, concentrations of constituents measured in the untreated groundwater were compared with human-health benchmarks established by the U.S. Environmental Protection Agency (USEPA) and CDPH, and benchmarks established for aesthetic concerns (secondary maximum contaminant levels, SMCL-CA) by CDPH (U.S. Environmental Protection Agency, 2006; California Department of Public Health, 2007). The human-health benchmarks used include MCLs—maximum contaminant levels, NLs—notification levels, HALs—health advisory levels, AL—Action Levels, and RSD-5s—risk specific dose (1 in 100,000). When available, Federal benchmarks were used except when California benchmarks were lower. Additional information on the types and concentrations of benchmarks for all constituents analyzed is provided by Landon and Belitz (2008).

For the purposes of simplicity and clarity, relative-concentrations were classified into *high*, *moderate*, and *low* categories. Inorganic constituents tend to be more prevalent and have larger maximum relative-concentrations than do organic and special interest constituents. Inorganic constituents tend to be present naturally in groundwater whereas organic and special interest constituents generally are present as a result of anthropogenic effects. Therefore, a smaller threshold value was used to distinguish between low and moderate relative-concentrations of organic and special interest constituents, in comparison to inorganic constituents. Use of a single threshold value to distinguish between low and moderate relative-concentrations of all constituents would have resulted in a greater number of moderate relative-concentrations of inorganic constituents (due to their greater prevalence and relative-concentrations) and fewer moderate relative-concentrations of organic and special interest constituents than would be warranted.

Table 3. Inorganic constituents, and number of grid wells per constituent, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[CDPH, California Department of Public Health; N, nitrogen; SMCL, Secondary maximum contaminant level; HBB, Health-based benchmark (including all benchmark types except SMCL); USGS, U.S. Geological Survey]

Constituent type	Constituent	Number of grid wells sampled by USGS GAMA	Number of grid wells selected from CDPH
Nutrient-HBB	Ammonia-N	20	0
Nutrient-HBB	Nitrite-N	20	25
Nutrient-HBB	Nitrate-N	19	29
Trace element-HBB	Aluminum	20	23
Trace element-HBB	Antimony	20	23
Trace element-HBB	Arsenic	20	25
Trace element-HBB	Barium	20	23
Trace element-HBB	Beryllium	20	23
Trace element-HBB	Boron	20	4
Trace element-HBB	Cadmium	20	23
Trace element-HBB	Chromium	20	23
Trace element-HBB	Copper	20	24
Trace element-HBB	Lead	20	23
Trace element-HBB	Mercury	20	23
Trace element-HBB	Molybdenum	20	0
Trace element-HBB	Nickel	20	23
Trace element-HBB	Selenium	20	23
Trace element-HBB	Strontium	20	0
Trace element-HBB	Thallium	20	23
Trace element-HBB	Vanadium	20	8
Minor ion-HBB	Fluoride	20	25
Trace element-SMCL	Iron	20	24
Trace element-SMCL	Manganese	20	24
Trace element-SMCL	Silver	20	23
Trace element-SMCL	Zinc	20	24
Major ion-SMCL	Chloride	20	25
Major ion-SMCL	Sulfate	20	25
Major ion-SMCL	Total dissolved solids	20	26
Radioactive-HBB	Uranium	20	13
Radioactive-HBB	Gross alpha radioactivity	15	21
Radioactive-HBB	Gross beta radioactivity	15	0
Radioactive-HBB	Radon-222	15	0
Radioactive-HBB	Radium-226, -228	15	8

¹ USGS GAMA analyses are for nitrate plus nitrite. However, nitrite concentrations are negligible compared to nitrate.

Inorganic constituents were classified by their maximum relative-concentration into three groups:

- maximum relative-concentration >1 (high constituents or relative-concentrations; a high constituent is defined as a constituent that has at least one high relative-concentration),
- maximum relative-concentration ≤ 1 and >0.5 (moderate constituents or relative-concentrations; a moderate constituent is defined as a constituent that has at least one moderate relative-concentration but no high relative-concentrations),
- maximum relative-concentration ≤ 0.5 (low constituents or relative-concentrations; a low constituent is defined as a constituent that has only low relative-concentrations).

Organic constituents also were classified by their maximum relative-concentration into three groups:

- maximum relative-concentration >1 (high constituents or relative-concentrations),
- maximum relative-concentration ≤ 1 and >0.1 (moderate constituents or relative-concentrations), and
- maximum relative-concentration ≤ 0.1 (low constituents or relative-concentrations).

The USEPA previously has used a concentration of 0.1 of the regulatory benchmark as a threshold at or above which the USEPA wants to be informed of a pesticide's presence in surface water or groundwater (U.S. Environmental Protection Agency, 1998). This EPA threshold is equivalent to a relative-concentration of 0.1, used in this report as a threshold to identify noteworthy (moderate or high) concentrations of organic and special-interest constituents that occur in the primary aquifer.

Estimation of Aquifer-Scale Proportions

The aquifer-scale proportion for a particular constituent is the percentage of the area of the study unit having relative-concentrations of that constituent within a specified category (high, moderate, or low) in the primary aquifer. Two primary approaches were taken to calculate the aquifer-scale proportions in the Central Eastside study unit. The approaches used were:

1. Grid-based: One well per grid cell was used to represent the primary aquifer. Aquifer-scale proportions for the high, moderate, and low relative-concentration categories were calculated from the detection frequencies of high, moderate, and low relative-concentrations in grid wells. Confidence intervals for grid-based detection frequencies of concentrations in the high category were computed by using the Jeffrey's 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 are present at high relative-concentrations in small proportions of the primary aquifer.

2. Spatially-weighted: Within the current period, all available data from the following sources were used to calculate the aquifer-scale proportions for the high, moderate, and low relative-concentration categories: USGS grid, CDPH data (one analysis per well), and USGS understanding wells having perforation depth intervals representative of the primary aquifer (irrigation wells CE-QPC-01, MODFP-04, and MERFP-01). Other USGS understanding wells that were drainage, monitoring, or domestic wells were excluded because these wells were partially or entirely perforated at shallower depths than the primary aquifer or because of incomplete perforation data. The aquifer-scale proportions are computed using cell-declustering (Isaaks and Srivastava, 1989). In cell-declustering, the proportions (high, moderate, or low) are computed by first computing the proportion of wells (high, moderate, or low) in each grid-cell, and then averaging the proportions computed for each cell. The resulting proportions are spatially unbiased (Isaaks and Srivastava, 1989).

The detection frequency of high relative-concentrations was also calculated using the same data as the spatially-weighted approach. The detection frequency approach is not spatially unbiased because the CDPH and USGS understanding wells are not distributed uniformly. Consequently, the data from areas with a high density of wells could have a disproportionately high weight compared to data from areas with a sparser density of wells. Aquifer-scale proportions for the high category that were calculated using the detection-frequency approach are provided for comparison in this report. However, grid-based and spatially-weighted approaches were used to assess aquifer-scale proportions because they are spatially unbiased.

The assessment of status was based on aquifer-scale proportions estimated primarily on the grid-based approach, and secondarily on the spatially-weighted approach. Estimates of moderate and low aquifer-scale proportions were selected primarily from the grid-based approach because, for some constituents, the MDLs for CDPH data included in the spatially-weighted approach were too high to distinguish between moderate and low relative-concentrations.

Aquifer-scale high proportions of constituents were based on grid-based estimates unless the high proportion was zero using the grid-based approach and nonzero using the spatially-weighted approach; then, the estimate was based on the spatially-weighted approach. In these cases, it was likely that the constituent was present in high proportions in such a small fraction of the aquifer that it was more reliable to quantify its aquifer-scale high proportion with the spatially-weighted rather than the grid-based approach. Aquifer-scale high proportions discussed in this report are grid-based values, unless otherwise noted.

For the assessment of status, aquifer-scale proportions of high relative-concentrations were determined for individual constituents and for classes of constituents. The classes of organic constituents having human-health benchmarks for which aquifer-scale proportions were calculated include trihalomethanes, solvents, other VOCs, fumigants, herbicides, and insecticides. The classes of inorganic constituents having human-health benchmarks for which aquifer-scale proportions were calculated include trace elements, radioactive constituents, and nutrients. Among constituents having aesthetic benchmarks, aquifer-scale proportions were calculated for total dissolved solids, manganese, and iron.

Most aquifer-scale proportions for constituent classes were grid-based estimates, but spatially-weighted estimates were reported in some cases. For constituent classes that include individual constituents with spatially-weighted high proportions, the high proportions for the class were based on the spatially-weighted high proportions for constituents within the class. For constituent classes with high proportions based on the spatially-weighted approach, moderate proportions for constituent classes were calculated by using the grid-based moderate proportions minus the spatially-weighted high proportions. In this case, aquifer-scale high proportions were likely to be too small to be detected by using the grid-based approach and were more likely to be included in moderate than low grid-based proportions. The consequence of this approach is that the moderate proportions for constituent classes discussed later in this report are minimum estimates and the low proportions are maximum estimates.

The grid-based and spatially-weighted estimation of aquifer-scale proportions, based on an equal-area grid cell network, are intended to characterize the water quality of the depth-zones of the primary aquifer throughout the study unit. These approaches assign weights to wells on the basis of a single well per cell (grid-based) or the number of wells per cells (spatially-weighted). Another possible approach would have been to assign weights to wells on the basis of water use (withdrawal rate). However, water-use data for wells generally are not available. The weights assigned cells by using either the grid-based or spatially-weighted approaches do not include the effects of areal variations in the thickness of the primary aquifer. However, because the alluvial sediments in the San Joaquin Valley are thousands of feet thick (Faunt and others, 2009) and water quality mostly is stratified vertically, variations in the thickness of the primary aquifer that is or could be used for drinking-water supply across the Central Eastside are likely to be minor.

In the Central Eastside study unit, 90 percent of grid wells had depths to the tops of the perforations of about 80 to 330 ft and depths to the bottom of the well of about 100 to 670 ft. The aquifer-scale proportions discussed in this report do not represent the shallower or deeper parts of the aquifer system than these intervals. Previous investigations in the

study unit have shown that groundwater in shallow parts of the aquifer generally is of poorer quality than at greater depths in the aquifer (Burow and others, 1998a,b, 2007, 2008b; Jurgens and others, 2008). The State Water Board's Voluntary Domestic Well Project is designed to evaluate water quality in the shallow parts of the aquifer. Similarly, water quality at greater depths than those typically used for public supply can be of different quality, particularly with respect to higher dissolved solids concentrations (Page, 1973).

Selection Criteria for Constituents of Interest

Given the large number of analytes (>300), an algorithm was used to select those constituents of greatest importance for discussion in the report. Constituents were first classified into those whose maximum relative-concentrations in grid wells were high, moderate, or low. For all constituents having high or moderate relative-concentrations, grid-based aquifer-scale proportions and relative-concentration graphs are presented in this report. Individual constituents having only low relative-concentrations are not discussed in this report except when they are organic constituents having detection frequencies >10 percent or are useful as hydrologic tracers for the assessment for understanding. A detection was defined as any analytical result with a reported concentration above the MDL for that constituent. Detection frequencies were calculated on the basis of the number of wells with a detection, divided by the total number of wells sampled for that constituent. Organic constituents that were detected in more than 10 percent of grid wells, even if all relative-concentrations were low, are discussed in this report because of their prevalence.

Understanding Assessment Methods

For the assessment for understanding, all constituents having grid-based or spatially-weighted aquifer-scale high proportions of >2 percent were analyzed for relations to potential explanatory factors. Constituents of interest with aquifer-scale high proportions of ≤ 2 percent generally were aggregated by compound class and then analyzed for relations to potential explanatory factors.

A finite set of potential explanatory factors, including land use, depth, lateral position in the flow system, groundwater-age classification, and geochemical-condition indicators, were analyzed in relation to constituents of interest for the understanding assessment. The purpose of this assessment was to place the observed water quality within the context of physical and chemical processes. A comprehensive analysis of all possible explanatory factors is beyond the scope of this report.

Statistical tests were used to identify significant correlations between the concentrations of constituents of interest and potential explanatory factors. Selected correlated data that were most valuable for improving understanding of factors influencing water quality are shown in the figures in this report. Some significantly correlated data were not graphed because they were affected by correlations between explanatory factors. The assessment for understanding generally discusses concentrations rather than relative-concentrations, to more directly relate constituents of interest to potential explanatory factors.

The wells used in the understanding assessment included USGS and CDPH grid wells and USGS understanding wells. CDPH other wells were not used in the understanding assessment because age tracer, dissolved oxygen, and sometimes well construction data were not available. In addition, considerable effort would have been needed to attribute the well-construction data for the large number of CDPH other wells. For different potential explanatory factors, correlations were tested using either the set of grid plus understanding wells or grid wells only. Because the USGS understanding wells primarily represented relatively shallow groundwater in agricultural areas that were not selected randomly on a spatially distributed grid, they were excluded from analysis of relations between water quality and areally distributed explanatory factors (land use and lateral position) to avoid bias due to clustering. However, USGS understanding wells were included in analysis of relations between water quality and vertically distributed explanatory factors (depth, classified groundwater age, and oxidation-reduction characteristics). To identify relations to vertically distributed explanatory factors, it was necessary to include USGS understanding wells, generally representing shallow parts of the aquifer, to have data spanning a sufficient range of depths. For analysis of relations of constituents to orchard and (or) vineyard land use, a subcategory of agricultural land use, USGS understanding wells were included because they represented a sufficient range of agricultural land-use categories.

Ancillary Data Sets

Land use was classified by using an “enhanced” version of the satellite-derived (30-m pixel resolution), nationwide USGS National Land Cover Dataset (Volgelmann and others, 2001; Price and others, 2003). This dataset has been used in previous national and regional studies relating land use to water quality (Gilliom and others, 2006; Zogorski and others, 2006). The data represent land use approximately during the early 1990s. The imagery is classified into 25 land-cover classifications (Nakagaki and Wolock, 2005). These 25 land-cover classifications were aggregated into three principal land-use categories: urban, agricultural, and natural. Land-use statistics for the study unit, study areas, and for circles

with a radius of 500 meters (m) around each study well were calculated on the basis of these classified datasets using ArcGIS (version 9.2).

Well-construction data primarily were determined from driller’s logs. More rarely, well-construction data were obtained from ancillary records of well owners or from the USGS National Water Information System database. Well identification verification procedures are described by Landon and Belitz (2008).

The lateral position of wells within the valley serves as a proxy for the horizontal position in the regional groundwater-flow system. Regionally, groundwater primarily flows from the eastern margin of the valley-fill deposits along the Sierra Nevada mountain front towards the southwest to the western margin of the flow system, represented by the San Joaquin River ([fig. 6](#)). The groundwater-flow system has vertical flow components as well as horizontal flow components that deviate from the regional northeast-to-southwest flow direction in response to withdrawals and recharge related to groundwater development for irrigation since the early to mid 1900s (Phillips and others, 2007; Burow and others, 2008a,b; California Department of Water Resources, 2008). These vertical and nonparallel horizontal flow components are superimposed on the topographically driven regional flow system. The aquifer system also contains large quantities of groundwater that was recharged before the modern flow system developed; under predominantly natural conditions, groundwater primarily had moved from northeast to southwest.

The normalized lateral position (hereinafter, lateral position) was calculated as part of a regional groundwater-flow modeling study for a set of 30×30 -m-wide cells in the San Joaquin Valley (Faunt and others, 2009). Lateral positions were assigned to wells residing within those cells using ArcGIS (version 9.2). The lateral position of each well was calculated as the ratio of (a) the distance from the well to the San Joaquin River and (b) the total distance from the San Joaquin River to the east edge of the valley. The east edge of the valley was represented by the eastern boundary of the valley fill deposits and was assigned a value of 1. In the Central Eastside, the valley trough was represented by the position of the San Joaquin River and was assigned a value of 0. Both boundaries were represented as approximate line segments and lateral position was calculated along lines perpendicular to both bounding lines. Higher values of lateral position indicate locations in the upgradient or proximal portion of the flow system and lower values of lateral position indicate locations in the downgradient or distal portion of the flow system. Plotting of data, with respect to lateral position, also allows for aggregation of areally distributed data into a single, diagrammatic cross section across the study unit.

Groundwater-Age Classification

Groundwater-dating techniques provide a measure of the time since the groundwater was last in contact with the atmosphere. Groundwater age has been identified as a critical variable affecting groundwater quality (Cook and Böhlke, 2000; Böhlke, 2002) and was included in the GAMA design and assessment for understanding for this reason. Techniques aimed at estimating groundwater residence times or 'age' include those based on tritium (^3H ; Tolstikhin and Kamenskii, 1969; Torgersen and others, 1979) and ^3H in combination with its decay product helium-3 (^3He) (Schlosser and others, 1988, 1989), carbon-14 (^{14}C) activities (Vogel and Ehlig, 1963; Plummer and others, 1993; and Kalin, 2000), and dissolved noble gases, particularly helium-4 accumulation (Davis and DeWiest, 1966; Andrews and Lee, 1979; Cey and others, 2008; Kulongoski and others, 2008). Collection and analysis methods and analytical results for ^3H , ^{14}C , and noble gases are described by Landon and Belitz (2008).

Quantities of ^3H much larger than natural production were introduced into the atmosphere from above-ground nuclear bomb testing between 1951 and 1980 (peak production in 1963) (Michel, 1989; Solomon and Cook, 2000). Consequently, the presence of ^3H , a radioactive isotope of hydrogen with a half-life of 12.32 years (Lucas and Unterwieser, 2000), in groundwater may be used to identify water that has exchanged with the atmosphere in the past 50 years. By determining the ratio of ^3H to its decay product ^3He , the time that the water has resided in the aquifer can be calculated more precisely than using ^3H alone (Solomon and others, 1992). ^{14}C is a radioactive isotope of carbon having a half-life of 5,730 years, formed naturally in the atmosphere that can be used to estimate groundwater ages ranging from approximately 1,000 to 30,000 years before present (Clark and Fritz, 1997). ^{14}C values also increased in the atmosphere following atmospheric nuclear weapons testing in the 1950s and 1960s (Kalin, 2000). 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; Kalin, 2000). The ^{14}C age is calculated on the basis of the decrease in ^{14}C activity, expressed as percent modern carbon (pmc), owing to radioactive decay with time since groundwater recharge, relative to an assumed initial ^{14}C concentration (Clark and Fritz, 1997). A mean initial ^{14}C activity of 99 percent modern carbon (pmc) is assumed for this study, with estimated errors on calculated groundwater ages of up to ± 20 percent.

Helium (He) is a naturally occurring inert gas produced by the radioactive decay of lithium, thorium, and uranium in the earth. Measured groundwater He concentrations represent the sum of air-equilibrated He , He originating from excess dissolved-air bubbles, terrigenous He , and tritiogenic ^3He . The presence of terrigenous He in groundwater, from its production in aquifer material or deeper in the crust, is indicative of long

groundwater residence times. The amount of terrigenous He is defined as the concentration of the total measured He , minus He from air-equilibration and excess dissolved-air bubbles, which is estimated from recharge temperatures and neon concentrations. Samples in which more than 5 percent of the total He is terrigenous He (percent terrigenous He) likely are to represent groundwater with a residence time of more than 100 years.

Recharge temperatures for 75 samples were determined from dissolved neon, argon, krypton, and xenon using methods described in Aeschbach-Hertig and others (1999). Recharge temperatures were modeled using procedures described by Aeschbach-Hertig and others (2000).

$^3\text{H}/^3\text{He}$ apparent ages were computed as described in Solomon and Cook (2000). Samples with terrigenous He >5 percent have greater uncertainty in computed $^3\text{H}/^3\text{He}$ apparent ages because of sensitivity to the $^3\text{He}/^4\text{He}$ ratio of the terrigenous He (Plummer and others, 2000). The $^3\text{He}/^4\text{He}$ ratios of samples were determined by linear regression of the percent of terrigenous He against the $\delta^3\text{He}$ $\{\delta^3\text{He} = [(R_{\text{meas}}/R_{\text{atm}}) - 1] \times 100\}$ of samples with less than 1 tritium unit (Plummer and others, 2000).

In this study, the ages of samples are classified as pre-modern, modern, and mixed. Groundwater with ^3H less than 1 tritium unit (TU), percent terrigenous He greater than 5 percent, and ^{14}C less than 90 pmc is designated as pre-modern. Pre-modern groundwater is defined as having recharged prior to about 1950. The pre-modern category could include groundwater that recharged from about 56 to tens of thousands of years ago. Groundwater with ^3H greater than 1 TU, percent terrigenous He less than 5 percent, and ^{14}C greater than 90 pmc is designated as modern. Modern groundwater is defined as having recharged after about 1950. Samples with both pre-modern and modern components are designated as mixed groundwater. In reality, pre-modern groundwater could contain small fractions of modern water and modern groundwater could contain small fractions of pre-modern water. Previous investigations have used a range of tritium values from 0.3 to 1.0 TU as thresholds for distinguishing pre-1950 from post-1950 water (Michel, 1989; Plummer and others, 1993, p. 260; Michel and Schroeder, 1994; Clark and Fritz, 1997, p. 185; Manning and Solomon, 2005). By using a tritium value of 1.0 TU, at the upper end of the range used in the literature, for the threshold in this study, the age classification allows a slightly larger fraction of modern water to be present in a classified pre-modern age distribution than if a lower threshold were used. A lower threshold for tritium would result in fewer wells classified as pre-modern rather than mixed water, when other tracers, such as ^{14}C and terrigenous He , would have suggested that they primarily were pre-modern water. This higher threshold was considered more appropriate for this study since many of the wells are long-screened production wells and some mixing of at least some water of pre-modern and modern age likely is to have occurred.

Apparent age estimates, on the basis of the $^3\text{H}/^3\text{He}$ and ^{14}C techniques, are reported in [table A2](#). These apparent ages generally assume piston flow of water from recharge areas to the well without mixing with waters of another age. Because of uncertainties in age, in particular caused by mixing of water of widely different ages in wells with long perforation intervals and high withdrawal rates, these apparent age estimates were not used for statistically quantifying the relation between age and water quality in this report. Whereas more sophisticated lumped parameter models for analyzing age distributions that incorporate mixing are available (Cook and Böhlke, 2000), use of these alternative models to characterize age mixtures was beyond the scope of this report. Rather, classification into modern, mixed, and pre-modern categories was considered sufficient to provide a simple characterization for the purposes of examining relations of groundwater quality to age.

Statistical Analysis

Nonparametric statistical methods were used to test the significance of correlations between water-quality constituents and potential explanatory factors. Nonparametric statistics are robust techniques that generally are not affected by outliers and do not require that the data follow any particular distribution (Helsel and Hirsch, 2002). The significance level (p) used for hypothesis testing for this report was compared to a threshold value (α) of 5 percent ($\alpha = 0.05$) to evaluate whether the relation was statistically significant ($p < \alpha$). Correlations were investigated using Spearman's method to calculate the rank-order correlation coefficient (ρ) between continuous variables. The values of ρ can range from +1.0 (perfect positive correlation), through 0.0 (no correlation), to -1.0 (perfect negative correlation). For potential explanatory factors that were classified into categories (for example, groundwater age categories of modern, mixed, and pre-modern), the values of water-quality parameters between the categories were compared using the Wilcoxon rank-sum test. The Wilcoxon rank-sum test can be used to compare two independent populations (data groups or categories) to determine whether one population contains larger values than the other (Helsel and Hirsch, 2002). The null hypothesis for the Wilcoxon rank-sum test is that there is no significant difference between the observations of the two independent data groups being tested. The Wilcoxon rank-sum test was used for multiple comparisons of two independent groups rather than the multiple-stage Kruskal–Wallis test for identifying differences between three or more groups, although the probability of falsely identifying a significant difference between groups is higher for a set of Wilcoxon rank-sum tests than the Kruskal–Wallis test (Helsel and Hirsch, 2002). However, given the potentially large and variable number of differences to be evaluated, the Wilcoxon

rank-sum test was selected as a consistent and practical direct test of differences instead of the Kruskal–Wallis test, which requires multiple stages and is more complex to describe and implement. All statistical analysis was done using S-PLUS for Windows, version 7.0, Professional Edition (TIBCO Software Inc.).

Attributes of Wells

The values assigned to wells for potential explanatory factors are described in this section. Relations among explanatory factors that could affect apparent relations between explanatory factors and water quality also are described.

Land Use

On average, land use around grid wells tended to contain more urban land use, and less agricultural and natural land use, than the study unit or study areas as a whole ([fig. 3](#)). This was particularly the case for the Modesto study area, which had an average of 56 percent urban land use within 500 m of grid wells, but had 19 percent urban land use for the study area as a whole ([figs. 3 and 4](#)). The higher percentage of urbanized land use surrounding the grid wells reflects that public-supply wells often are located in or near communities. For the Modesto study area, the larger discrepancy between average urban land use for grid wells and the study area reflects that most of the grid cells intersected the urban area, which is larger than in other study areas, permitting wells in urban areas to be selected as grid wells in most cells. The grid well data, particularly in the Modesto study area, may reflect greater urban influence than might be expected on the basis of the average land use of the study areas.

Understanding wells primarily were located in agricultural areas ([fig. 3](#)), with 17 of the 20 wells having greater than 90 percent agricultural land use within 500 m. Three of the understanding wells were located in areas with >75 percent natural land use. All of the understanding wells had <7 percent urban land use within 500 m.

An additional subcategory of agricultural land use included in the analysis was percent orchard and vineyard land use. Orchard and vineyard land use previously has been shown to be related to concentrations of nitrate and selected pesticides in parts of the eastern San Joaquin Valley (Domagalski, 1997; Burow and others, 1998a). For grid wells, percent orchard and vineyard land use within 500 m ranged from 0 to 95 percent, with a median of 1.3 percent. For understanding wells, percent orchard and vineyard land use ranged from 0 to 98 percent, with a median of 48 percent.

Depth

Grid wells, primarily used for public supply, had depths ranging from 75 to 923 ft below land surface, with a median of 284 ft ([fig. 8](#)). Depths to the top of the perforations ranged from 72 to 457 ft, with a median of 162 ft. The perforation length was as much as 656 ft with a median of 104 ft. These sets of depths represent different sets of wells because the well depths were known for more wells than were depths to the tops of the perforations.

The understanding wells mostly were shallower and had shorter screens than the grid wells ([fig. 8](#)). The median well depth, depth to the top of perforations, and perforation length were 113, 102, and 10 ft, respectively, for understanding wells. The relatively short perforation lengths and shallow depths reflect that 14 of the 20 understanding wells sampled (19 with construction data) were monitoring wells.

Lateral Position

Grid wells, selected using a spatially distributed randomized design, were distributed across the entire range of lateral positions ([fig. 9](#)). Wells having lateral positions of 0.20 to 0.39, 0.40 to 0.59, and 0.60 to 0.79, made up 29 percent, 21 percent, and 24 percent of the total grid wells, respectively. Wells having lateral positions of 0.0 to <0.20 (distal or western) and >0.80 (proximal or eastern) made up 13 percent and 14 percent of the total grid wells, respectively.

Groundwater Age

Of the 78 groundwater samples obtained by the USGS for the PBP, 24 were classified as modern, 27 were mixed, and 21 were pre-modern ([table A2](#)). Samples from six wells could not be classified because the age-tracer data were incomplete or did not meet all quality-assurance checks. Of these six wells, one well had no tritium or noble-gas data, two wells had tritium >1 TU but no noble-gas data and could be modern or mixed (labeled modern/mixed on [table A2](#)), and three wells had noble-gas data indicating >5 percent terrigenic He but no tritium data and could be mixed or pre-modern (labeled mixed/pre-modern on [table A2](#)). These wells with incomplete data were not included in the discussion below.

Classified groundwater ages generally became older with increasing depth to the tops of the perforations ([fig. 10A](#)). The depths to the tops of the perforations were significantly shallower for wells having modern and mixed ages as compared to those having pre-modern ages ([table 4](#)). The depths to the tops of the perforations were not significantly different between wells having modern and mixed ages. Relative to well depth, wells classified as modern were significantly shallower than wells classified as mixed or pre-modern ([table 4](#), [fig. 10B](#)). However, depths of wells having

mixed and pre-modern ages were not significantly different ([table 4](#)).

Most wells perforated entirely within the upper 200 ft of the aquifer were modern ([fig. 10c](#)). Most wells perforated entirely at depths >200 ft were pre-modern. Wells with the top of the perforation <200 ft but the bottom of the well >200 ft mostly were mixed.

In each of the three depth categories, there are some wells with each of the classified ages. These results indicate that there are local variations in the general age-depth relation. For example, the two wells with perforations >200 ft and modern ages are located in the eastern (upgradient) part of the study unit along the Stanislaus River (MOD-09) or adjacent to a storage reservoir of water diverted from the Tuolumne River (CE-QPC-03, [table A2](#), [fig. A1](#)). Four wells with perforations <200 ft and pre-modern ages are located either near the eastern or the western boundaries of the study unit.

Geochemical Conditions

Geochemical conditions investigated as potential explanatory factors in this report include oxidation-reduction characteristics and pH.

Oxidation-reduction (redox) conditions influence the transport of many organic and inorganic constituents (McMahon and Chapelle, 2008). Redox conditions along groundwater-flow paths commonly proceed along a well-documented sequence of Terminal Electron Acceptor Processes (TEAPs), in which a single TEAP typically dominates at a particular time and aquifer location (Chapelle and others, 1995; Chapelle, 2001). The predominant TEAPs are oxygen-reduction (oxic), nitrate-reduction, manganese-reduction, iron-reduction, sulfate-reduction, and methanogenesis. The presence of redox-sensitive chemical species indicating more than one TEAP may indicate mixing of waters from different redox zones upgradient of the well, that the well is screened across more than one redox zone, or spatial heterogeneity in microbial activity in the aquifer. In addition, different redox couples may not indicate a consistent redox condition, reflecting electrochemical disequilibrium in groundwater (Lindburg and Runnels, 1984). Thus, assessments of redox conditions could be complicated by mixing and (or) disequilibrium.

Classification of redox conditions on the basis of the framework of McMahon and Chapelle (2008) for the 78 wells sampled by USGS–GAMA is shown in [table A3](#). [Figure 11](#) shows wells classified by their dissolved oxygen (DO) concentrations plotted by normalized lateral position on the x-axis and depth on the y-axis. This figure represents all of the wells having well construction and DO data in the study unit presented on a single composite cross-section.

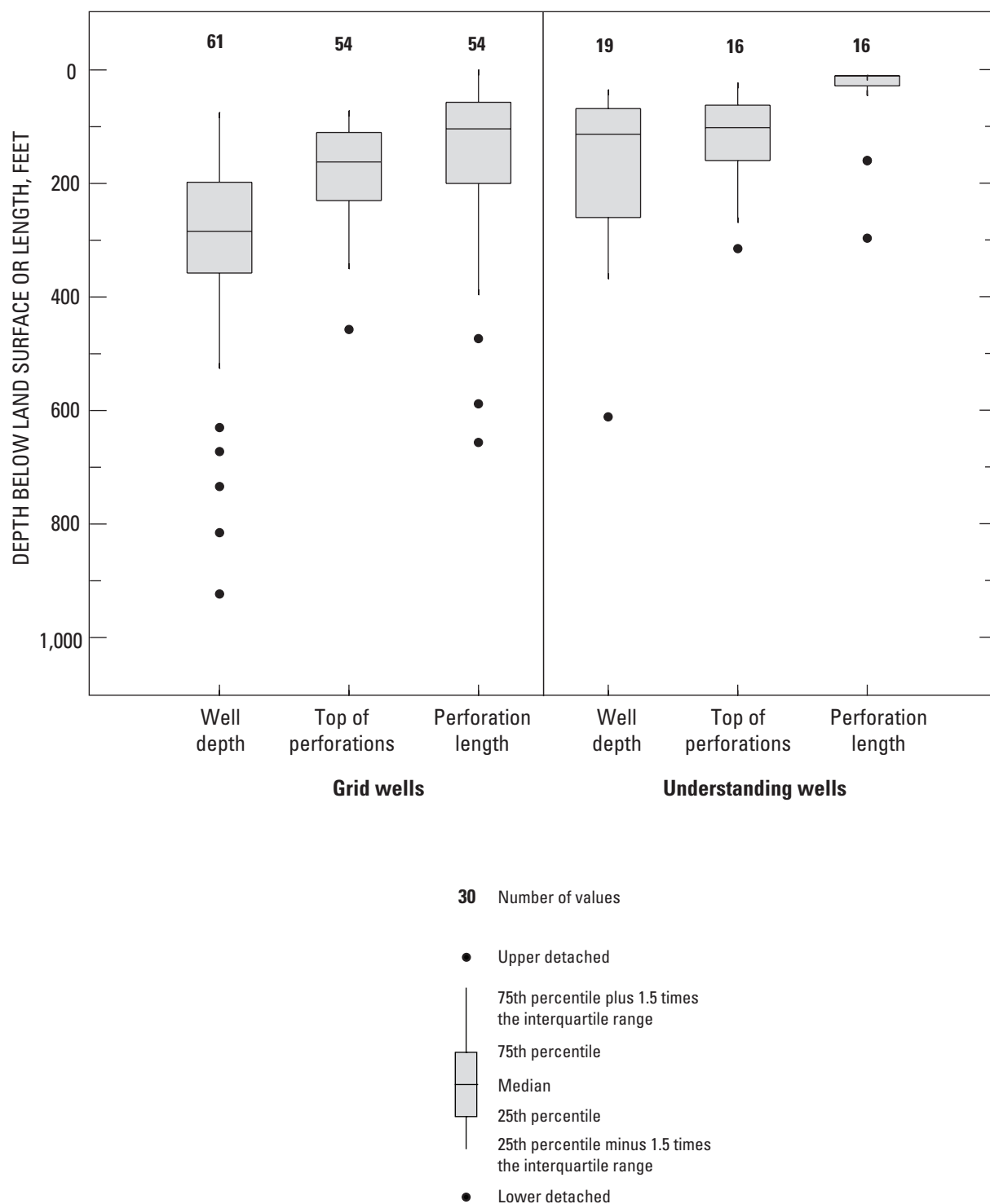


Figure 8. Boxplots showing construction characteristics for grid and understanding wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

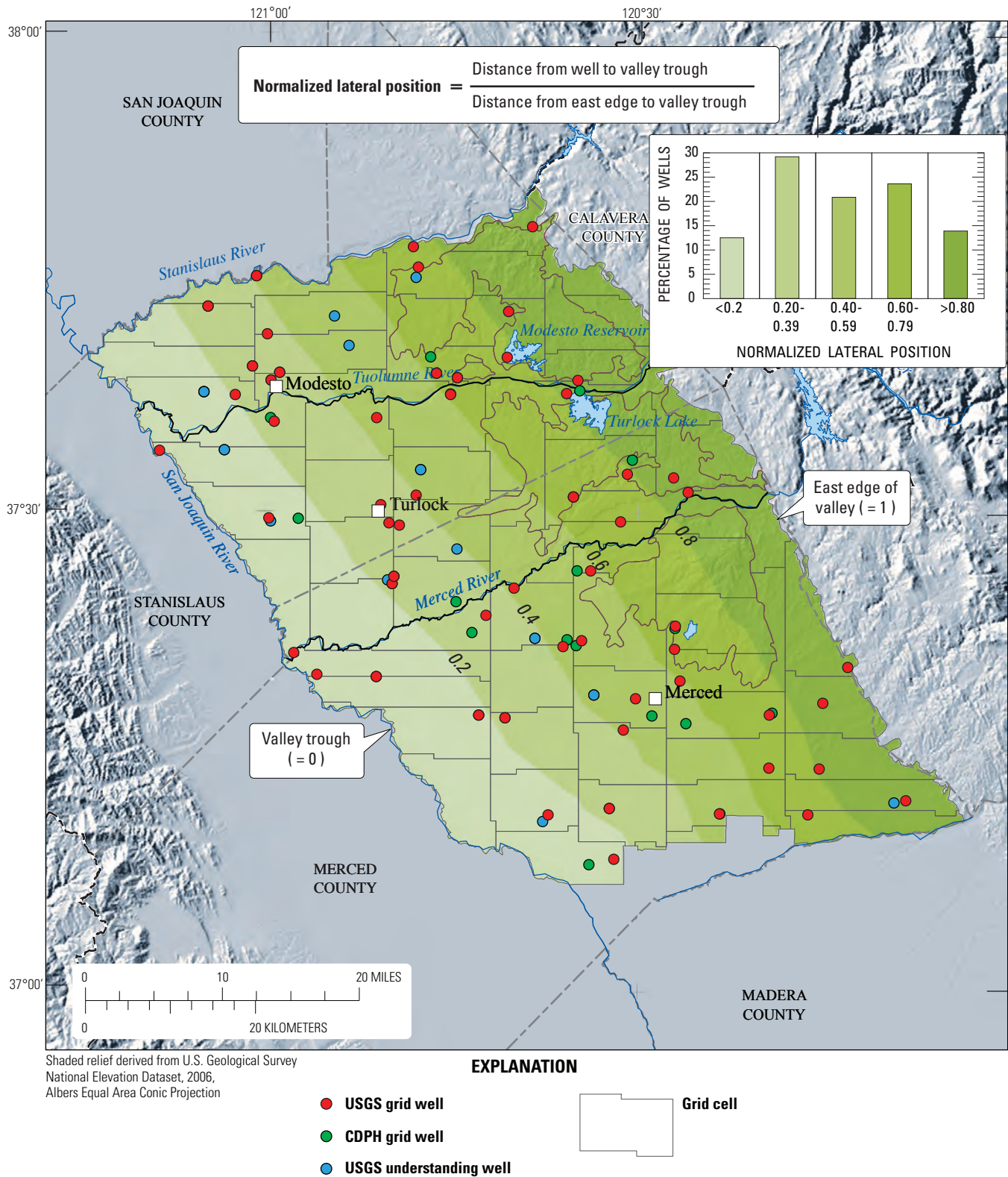


Figure 9. Wells and normalized lateral position from eastern margin of valley, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

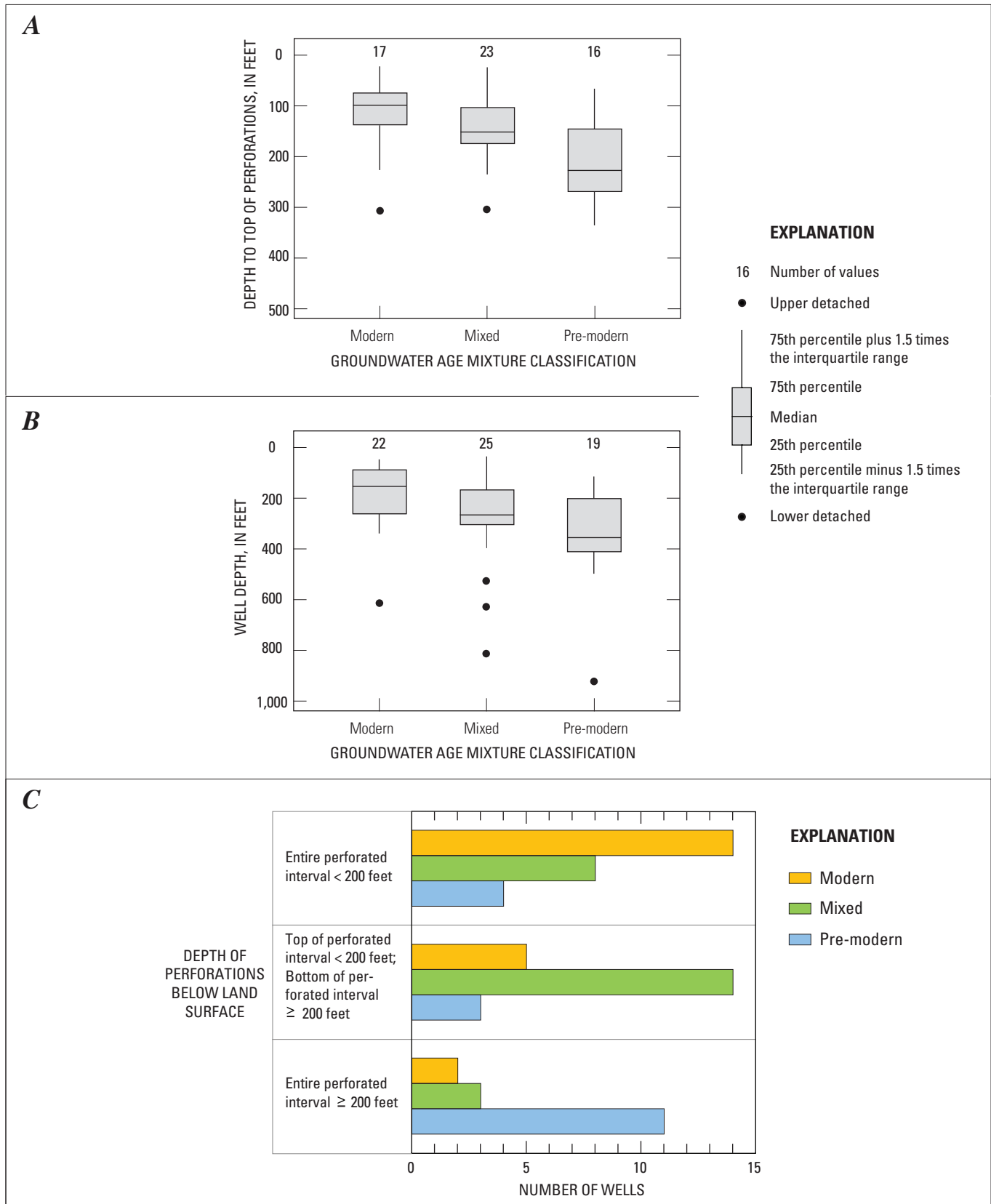


Figure 10. Relation of classified groundwater age to (A) depth to top of perforations below land surface, (B) depth to the bottom of the well below land surface, and (C) bar chart showing number of wells with modern, mixed, and pre-modern groundwater age classifications in each of three depth categories, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Table 4. Results of Wilcoxon rank-sum tests for differences in values of selected water-quality constituents and for differences in potential explanatory factors, between modern, mixed, and pre-modern groundwater age categories, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[Wilcoxon rank sum tests, based on large-sample approximation with continuity correction; Z, test statistic for Wilcoxon test; Z values are shown for Wilcoxon tests in which the two populations were determined to be significantly different (two-sided test) on the basis of *p* values (significance level of the Wilcoxon test, values not shown) less than threshold value (α) of 0.05; ns, test indicates no significant difference between groups; **blue Z values**, significantly positive Z value (first group has larger values than the second); **red Z values**, significantly negative Z value (first group has smaller values than the second)]

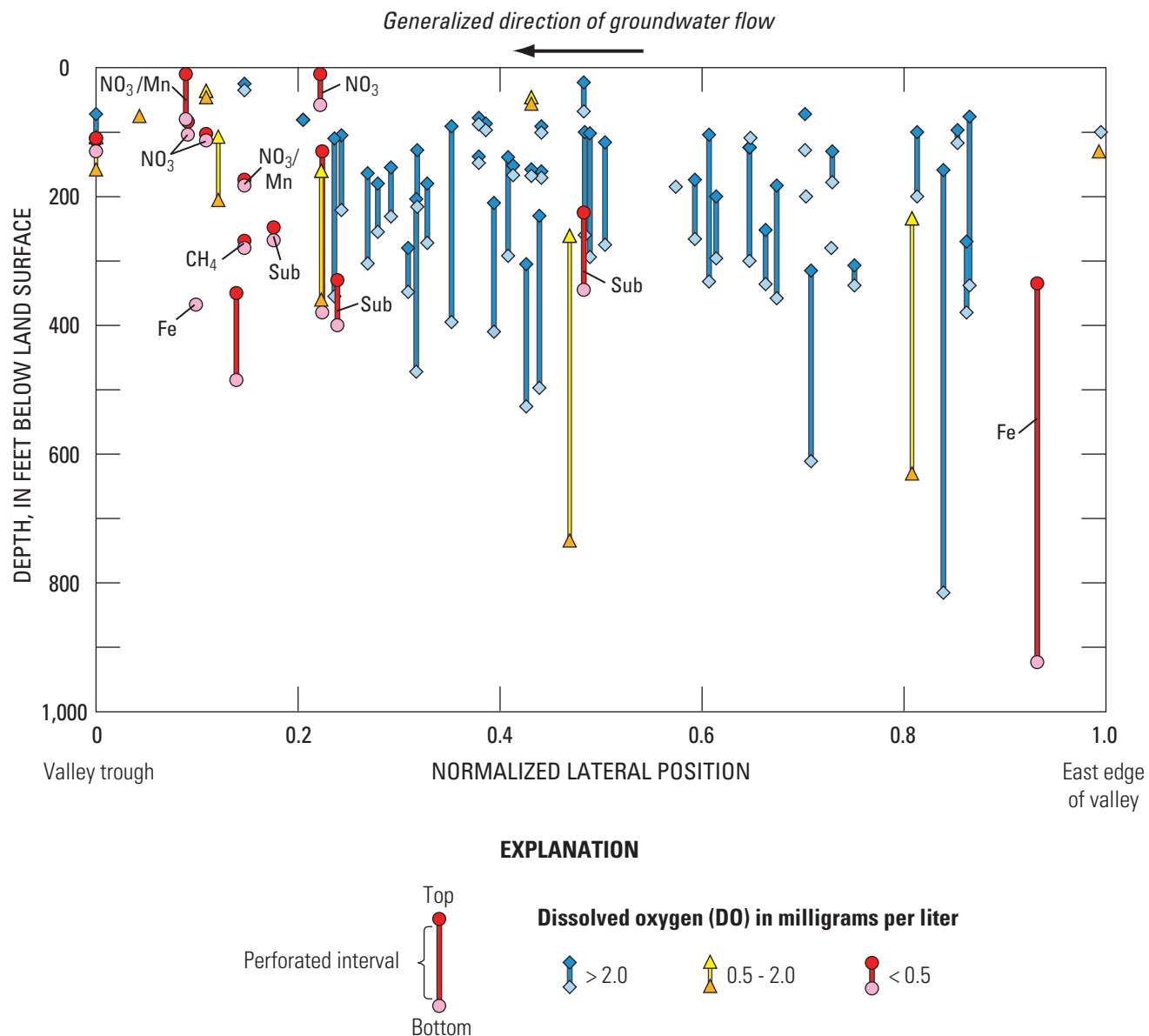
	Modern compared with mixed Z	Mixed compared with pre-modern Z	Modern compared with pre-modern Z
Selected water-quality constituents			
Arsenic	-2.282	ns	-2.029
Vanadium	ns	ns	ns
Lead	ns	ns	-2.076
Uranium	ns	2.128	2.607
Nitrate plus nitrite as nitrogen	2.718	2.637	3.756
Manganese	ns	ns	ns
Iron	ns	ns	ns
Total dissolved solids	ns	ns	ns
Sum of trihalomethane concentrations ¹	ns	ns	ns
Sum of solvent concentrations ¹	ns	ns	ns
Sum of herbicide concentrations	ns	3.920	2.823
Perchlorate	ns	2.138	3.030
Potential explanatory factors			
Percent urban land use	ns	2.274	ns
Percent agricultural land use	ns	ns	ns
Percent natural land use	2.520	ns	ns
Depth to top of perforations	ns	-2.842	-3.369
Well depth	-2.313	ns	-3.726
Dissolved oxygen	ns	2.759	3.112
pH	ns	-2.184	-2.690

¹ Grid wells only. Variables not footnoted include grid plus understanding wells.

Groundwater in the Central Eastside primarily was oxic (86 percent of USGS grid wells and 70 percent of USGS understanding wells) but becomes more reducing with depth and near the western (distal or downgradient) end of the study area. Most groundwater in the upper 500 ft of the aquifer has DO >2.0 mg/L, except for near the western end of the flow system ([fig. 11](#)). Intermediate DO concentrations of 0.5 to 2.0 mg/L, or DO of <0.5 mg/L, was increasingly prevalent at depths of about 500 ft or more, and in the western quarter of the study unit. The lateral position and depth of wells having DO of 0.5 to 2.0 mg/L is consistent with general transitions from higher to lower DO concentrations with increasing depth and from east to west.

A minority of wells (14 percent of USGS grid wells, 30 percent of USGS understanding wells) had reducing conditions ranging from suboxic to methanogenesis ([table A3](#)).

The reducing conditions primarily occurred in the western quarter of the study unit or in relatively deep groundwater ([fig. 11](#)). Wells with lateral positions less than about 0.25 primarily were suboxic or more reduced ([fig. 11](#)). These results are consistent with those of previous investigations, including Davis and others (1959), Bertoldi and others (1991), Dubrovsky and others (1993), Chapelle and others (1995), and Burow and others (1998b), noting that groundwater typically becomes more reduced towards the central trough of the San Joaquin Valley. The range of reducing conditions from suboxic to methanogenesis may reflect natural spatial variability in geochemical conditions as well as mixing of water with variable redox characteristics in wells with long perforated intervals.



Wells with DO < 0.5 milligrams per liter are labeled with oxidation-reduction (redox) classification (McMahon and Chapelle, 2008): **Sub**, Suboxic; **NO₃**, nitrate-reducing; **NO₃/Mn**, mixed nitrate and manganese reducing; **Fe**, iron reducing; **CH₄**, methanogenic; remaining wells with DO < 0.5 milligrams per liter (unlabeled) are anoxic (no other redox data but DO).

Wells with DO > 2.0 milligrams per liter (blue) and 0.5 – 2.0 milligrams per liter (yellow) are classified as oxic. Wells with DO of 0.5 – 2.0 milligrams per liter are shown to illustrate distribution of waters that may have transitional or mixed redox conditions.

Figure 11. Diagram showing relation of oxidation-reduction condition indicators (dissolved oxygen, nitrate, manganese, and iron) to lateral position and depth of perforated interval of wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Although the redox classification described above is valuable for characterizing the range and spatial distribution of redox conditions, hereinafter, DO concentrations are used as the factor for evaluating relations of redox conditions with concentrations of water-quality constituents. DO was used as a redox indicator because (1) data were available for 77 of the 78 USGS–GAMA sampled wells, whereas other redox indicators were available for fewer than 50 USGS–GAMA wells; (2) DO is a continuous numerical variable, which permits more straightforward analysis of correlations with water-quality data, rather than a categorical variable like redox classification; and (3) most groundwater in the study unit was classified as oxic, so the numbers of wells within the various reducing classes generally were too small for meaningful statistical analysis. Some redox-sensitive constituents such as arsenic also were evaluated for relations with the occurrence of manganese- and iron-reducing conditions, but there were not enough wells having these characteristics for statistical correlations to be meaningful.

pH has been identified as being positively correlated with concentrations of arsenic in the San Joaquin Valley (Belitz and others, 2003; Welch and others, 2006; Izbicki and others, 2008). pH ranged from 6.3 to 8.3 in 66 USGS grid and understanding wells in the Central Eastside study unit. USGS–GAMA and CDPH other data showed some pH values >8.0 in the central Turlock and Modesto study areas and the southern and northern Merced study area ([fig. 12A](#)).

Correlations between Explanatory Factors

It is important to identify significant correlations between explanatory factors because apparent correlations between an explanatory variable and a water-quality constituent could be affected by correlations between two or more explanatory factors. Statistically significant correlations between explanatory factors are indicated in [table 5](#) and noted below, with the exception of relations between groundwater age and depth, which were discussed earlier.

Percent natural land use is correlated significantly (positively) with lateral position ([table 5](#)). This correlation reflects that land use primarily is natural in the eastern portion of the study unit, whereas agricultural and urban land uses become more prevalent in the central and western portions ([fig. 4](#)). Percent orchard and (or) vineyard land use is correlated significantly (negatively) with well depth (but not with depth to top of perforations) ([table 5](#)). This apparent correlation may reflect that several of the USGS understanding wells were shallow monitoring wells installed in areas with large percentages of orchard and vineyard land use. Correlations between different land uses were not calculated, as these data were not independent.

Concentrations of DO were correlated significantly (positively) with lateral position ([table 5](#)), consistent with the visual patterns evident in [figure 11](#). Wilcoxon tests indicated

significantly higher DO in wells classified as having modern and mixed ages compared to pre-modern ages ([table 4](#)). Wells having modern and mixed classified ages did not have significantly different DO.

pH was correlated positively with well depth and depth to the top of the perforations ([table 5](#), [fig. 12B](#)). Wilcoxon tests indicated significantly lower pH in wells classified as having modern and mixed ages compared to pre-modern ages ([table 4](#)). For wells having similar depths, those of pre-modern age often had higher pH than those of mixed and modern age ([fig. 12B](#)). Wells having modern and mixed classified ages did not have significantly different pH. Also, pH was correlated significantly (positively) with urban land use. This relation may reflect that grid wells with >50 percent urban land use and pH ≥ 7.8 generally had larger perforation intervals than wells with <50 percent urban land use. The longer perforation intervals may draw relatively high pH waters at depth to the wells. Another observation consistent with this interpretation is that wells with mixed ages had a significantly larger percent urban land use than pre-modern wells ([table 4](#)). The negative correlation between pH and orchard and (or) vineyard land use probably reflects that both of these factors are related to well depth ([table 5](#)). Implications of correlations between explanatory factors are discussed later in the report as part of analysis of factors affecting individual constituents.

Status and Understanding of Water Quality

Approximately 11,000 individual analytical results were included in the assessment of groundwater quality for the Central Eastside study unit. The results are summarized in [figure 13](#). Detected constituents having data in <20 grid wells (hereinafter, constituents sampled for in a subset of wells) are identified with green dots on [figure 13](#) to distinguish them from constituents having data in a larger number of grid wells (24 to 58 wells, yellow dots). All of the constituents shown have human-health benchmarks except for those in the inorganic-SMCL group, which have aesthetic benchmarks (Landon and Belitz, 2008).

Inorganic constituents detected at high maximum relative-concentrations in USGS or CDPH grid wells were arsenic, vanadium, lead, nitrate, manganese, and TDS; moderate maximum relative-concentrations were detected for these constituents and boron, uranium, and gross alpha radioactivity. Organic and special-interest constituents were not detected at high relative-concentrations in USGS grid wells; moderate relative-concentrations were detected for carbon tetrachloride, chloroform, DBCP, and perchlorate. Constituents with moderate or high maximum relative-concentrations are discussed individually later in this report.

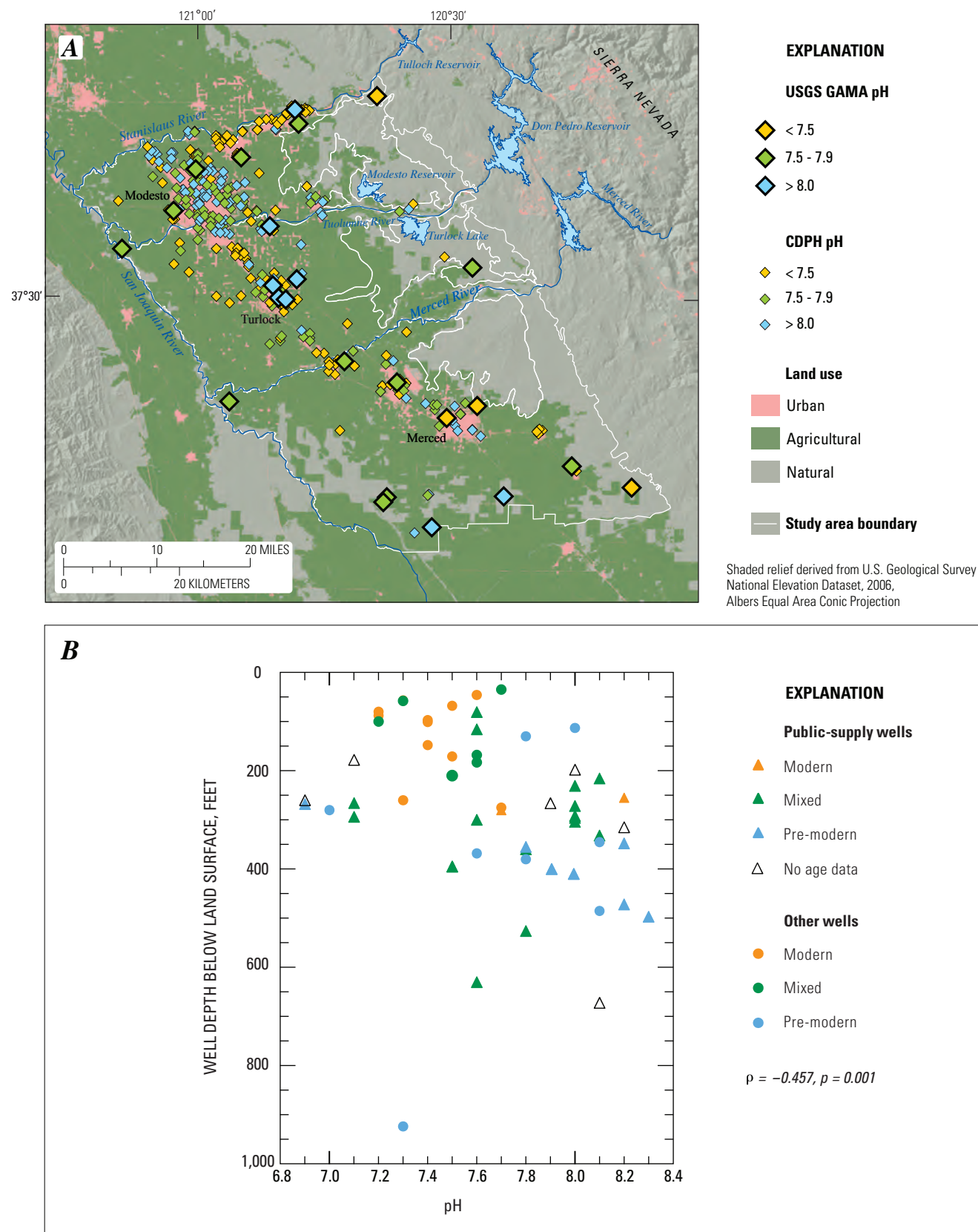


Figure 12. Plots showing values of pH, (A) map of pH in USGS grid and USGS understanding wells representative of the primary aquifer and the most recent analysis during March 1, 2003–February 28, 2006 for CDPH wells, and (B) graph showing pH and well depth by well type and groundwater-age classification, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[ρ , Spearman's correlation statistic; p values are shown for tests in which the variables were determined to be significantly correlated on the basis of p values (significance level of the Spearman's test) less than threshold value (α) of 0.05; ns, Spearman's test indicates no significant correlation between groups; **blue text**, significant positive correlation; **red text**, significant negative correlation; NC, not calculated due to lack of independence of variables]

Wells included in analysis		Normalized lateral position from valley trough	Depth to top of perforations below land surface (feet)	Depth of well below land surface (feet)	Dissolved oxygen concentration (mg/L)	pH, pH units	Percent orchard and vineyard land use
		ρ	ρ	ρ	ρ	ρ	ρ
Grid wells	Percent urban land use	ns	ns	ns	ns	0.325	NC
Grid wells	Percent agricultural land use	ns	ns	ns	ns	ns	NC
Grid wells	Percent natural land use	0.325	ns	ns	ns	ns	NC
Grid wells	Normalized lateral position from valley trough		ns	ns	0.368	ns	ns
Grid and understanding wells	Depth to top of perforations below land surface, in feet			0.765	ns	0.401	ns
Grid and understanding wells	Depth of well below land surface, in feet				ns	0.457	-0.268
Grid and understanding wells	Dissolved oxygen concentration, in mg/L					ns	ns
Grid and understanding wells	pH, pH units						-0.334

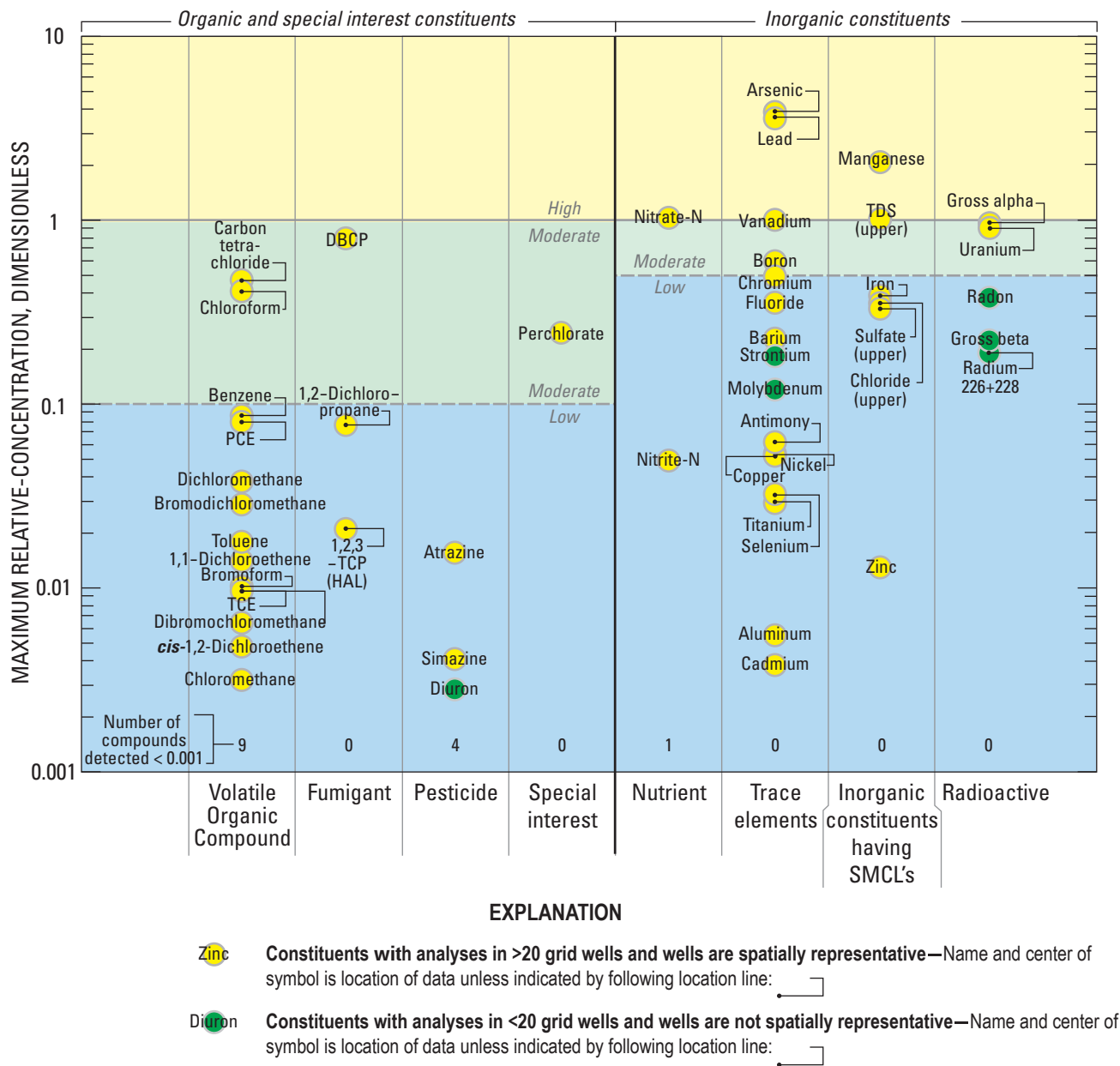


Figure 13. Maximum relative-concentration in grid wells for constituents detected, by type of constituent, in the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Most of the organic and special-interest constituents detected (31 of the 36) have some type of human-health benchmark (table 6). Of the five detected constituents that did not have benchmarks, three (de-ethylatrazine, de-isopropylatrazine, 3,4-dichloroaniline) are pesticide degradates. Some of the parent compounds (atrazine, diuron) of these degradates have human-health benchmarks. The other two detected constituents that did not have benchmarks were

a solvent, dibromomethane, and an herbicide, norflurazon (Landon and Belitz, 2008).

In contrast to organic and special-interest constituents, inorganic constituents nearly always were detected (48 of 51, table 6). Approximately one-third of inorganic constituents (15 of 51) had no human-health or aesthetic benchmarks. Most of these constituents without benchmarks are major or minor ions that are present naturally in nearly all groundwater.

Table 6. Number of constituents analyzed and detected by benchmark and constituent class or analyte group, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit, March to June 2006.

[VOCs, Volatile Organic Compounds; NWQL, USGS National Water Quality Laboratory; USEPA, U.S. Environmental Protection Agency; CDPH, California Department of Public Health; MCL, USEPA or CDPH Maximum Contaminant Level; HAL, USEPA Health Advisory Level; NL, CDPH Notification Level; RSD5, USEPA Risk Specific Dose at 10^{-5} ; AL, USEPA Action Level; SMCL, USEPA or CDPH Secondary Maximum Contaminant Level]

Benchmark type	Number of constituents	
	Analyzed	Detected
VOCs and Gasoline Oxygenates (excluding fumigants)		
MCL	29	16
HAL	6	2
NL	14	3
RSD5	2	0
AL	0	0
SMCL	0	0
None	27	1
Total	78	22
Fumigants		
MCL	4	2
HAL	2	1
NL	0	0
RSD5	2	0
AL	0	0
SMCL	0	0
None	2	0
Total	10	3
Pesticides and degradates (NWQL Schedule 2003)		
MCL	3	3
HAL	14	2
NL	0	0
RSD5	3	0
AL	0	0
SMCL	0	0
None	41	2
Total	61	7
Polar pesticides and degradates (NWQL Schedule 2060)		
MCL	9	0
HAL	9	1
NL	0	0
RSD5	0	0

Benchmark type	Number of constituents	
	Analyzed	Detected
Polar pesticides and degradates (NWQL Schedule 2060)—Continued		
AL	0	0
SMCL	0	0
None	36	2
Total	54	3
Special interest constituents		
MCL	0	0
HAL	0	0
NL	2	1
RSD5	0	0
AL	0	0
SMCL	0	0
None	0	0
Total	2	1
Sum of Organic and Special Interest Constituents		
MCL	45	21
HAL	31	6
NL	16	4
RSD5	7	0
AL	0	0
SMCL	0	0
None	106	5
Total	205	36
Sum of Inorganic constituents		
MCL	22	20
HAL	4	4
NL	2	2
RSD5	0	0
AL	2	2
SMCL	6	5
None	15	15
Total	51	48

Relations to potential explanatory factors were analyzed for three individual constituents or parameters that were the only constituents in their class with moderate relative-concentrations, aquifer-scale-high proportions <2 percent, or detection frequencies >10 percent. The three constituents were: total dissolved solids (TDS) (in the constituent class of inorganic constituents with SMCLs); 1,2-dibromo-3-chloropropane (DBCP) (in the constituent class of fumigants); and perchlorate (in the class of constituents of special interest to the PBP).

Inorganic Constituents

Nine inorganic constituents met the selection criteria of having maximum relative-concentrations >0.5 (moderate or high) in the grid-based assessment ([fig. 13](#)): the trace elements arsenic, boron, lead, and vanadium; the radioactive constituents uranium and gross alpha radioactivity; the nutrient nitrate; and the inorganic constituents with SMCLs manganese and TDS. In addition, iron met the selection criteria of having >2 percent high relative-concentrations based on the spatially-weighted analysis ([table 7A](#)). Analysis of potential explanatory factors is included below for arsenic, vanadium, lead, uranium, nitrate, manganese, iron, and TDS.

For inorganic constituents having human-health benchmarks (nutrients, trace elements, and radioactive constituents), 18.0 percent of the aquifer had high relative-concentrations of at least one constituent, 44.0 percent had moderate relative-concentrations of at least one constituent, and 38.0 percent had low relative-concentrations of all constituents ([table 8](#)). The aquifer-scale high proportion of inorganic constituents reflected high relative-concentrations of trace elements in 17.4 percent of the aquifer, radioactive constituents in 3.6 percent of the aquifer, and nitrate in 2.1 percent of the aquifer.

Trace Elements

As a class, 17.4 percent of the aquifer had high relative-concentrations of at least one trace element having human-health benchmarks, 32.6 percent had moderate relative-concentrations of at least one trace element, and 50.0 percent had low relative-concentrations of all trace elements ([table 8](#)). The aquifer-scale high proportion of trace elements reflected high relative-concentrations of arsenic in 15.6 percent of the aquifer and vanadium in 3.6 percent of the aquifer ([table 7A](#)). A high relative-concentration of lead and arsenic co-occurred in one grid well (Landon and Belitz, 2008); consequently, the high value of lead did not change the aquifer-scale high proportion of trace elements as a constituent class.

Status Assessment for Trace Elements

[Figure 14](#) shows relative-concentrations of inorganic constituents with high or moderate maximum relative-concentrations in USGS or CDPH grid wells. [Figure 15](#) shows data for six constituents (arsenic, vanadium, uranium, nitrate, manganese, and total dissolved solids) from USGS grid wells, USGS understanding wells that were considered to be representative of the primary aquifer, and the most recent analysis during March 1, 2003–February 28, 2006, from all CDPH wells. Maps for these six constituents are shown in [figure 15](#) to illustrate the spatial distribution of concentrations of inorganic constituents having high and moderate aquifer-scale proportions greater than 10 percent.

Arsenic had high relative-concentrations in 15.6 percent of the aquifer and moderate relative-concentrations in 28.9 percent ([table 7A](#), [fig. 14](#)). High relative-concentrations of arsenic occurred in the Merced, west-central Turlock, and the western Modesto study areas ([fig. 15A](#)). Moderate relative-concentrations of arsenic were present in all four study areas.

Boron was detected at moderate relative-concentrations in 4.2 percent of the aquifer ([table 7B](#)). The single grid well having a moderate relative-concentration of boron was located in the Turlock study area ([fig. 14](#)).

Lead was detected at a high relative-concentration in 2.4 percent of the aquifer ([table 7A](#)). The single grid well having a high relative-concentration of lead was located in the Turlock study area ([fig. 14](#)). Lead had a moderate relative-concentration in 2.4 percent of the aquifer. The single grid well having a moderate relative-concentration of lead was located in the Merced study area ([fig. 14](#)). Although lead had a maximum relative-concentration that was higher than all other constituents except arsenic ([fig. 13](#)), it was detected at high relative-concentrations only in one grid well and in two other CDPH wells ([table 7A](#)).

Vanadium had high relative-concentrations in 3.6 percent of the aquifer and moderate relative-concentrations in 21.4 percent ([table 7A](#), [fig. 14](#)). High relative-concentrations of vanadium primarily occurred in the central part of the Turlock study area ([fig. 15B](#)). Moderate relative-concentrations occurred throughout the central portion of the study unit, particularly within the Turlock study area, and one moderate value occurred in the upland study area ([fig. 15B](#)).

Three trace elements (antimony, copper, and selenium), had aquifer-scale high proportions from the spatially-weighted approach of 0.2 to 0.3 percent of the aquifer ([table 7A](#)) but were not detected at high relative-concentrations in grid wells. The trace elements, barium and boron, had high relative-concentrations in at least one well in the CDPH database before 2003 but not during the current period analyzed ([table 7B](#)). The high relative-concentrations for barium and boron represented historic rather than current conditions.

Table 7A. Aquifer-scale proportions using grid-based and spatially weighted methods for those constituents that had concentrations above water-quality benchmarks (high relative-concentrations) during the current period (March 1, 2003, to February 28, 2006) from the California Department of Public Health database or in samples collected from grid wells, March–June 2006, Central Eastside Groundwater Ambient Monitoring and Assessment study unit.

[High; concentrations greater than water-quality benchmark; moderate, concentrations between 11 and 100 percent of benchmark for organic constituents or 51 and 100 percent of benchmark for inorganic constituents; low, concentrations less than or equal to 10 percent of benchmark for organic constituents or 50 percent of benchmark for inorganic constituents; CDPH, California Department of Public Health; MCL-US; U.S. Environmental Protection Agency maximum contaminant level; MCL-CA, CDPH maximum contaminant level; NL-CA, CDPH notification level; SMCL-CA, CDPH secondary maximum contaminant level; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; NA, not applicable]

Constituent	Threshold type	Threshold value	Threshold units	Grid-based aquifer-scale proportion ¹				90-percent confidence interval for grid-based proportion ²		Detection-frequency-based aquifer-scale proportion ³			Spatially weighted aquifer-scale proportion ³
				Number of wells	High proportion (in percent)	Moderate proportion (in percent)	Low proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)	Number of wells	Number of high wells	High proportion (in percent)	
Trace Elements													
Arsenic	MCL-US	10	µg/L	45	15.6	28.9	55.6	8.3	25.9	348	31	8.9	12.7
Vanadium	NL-CA	50	µg/L	28	3.6	21.4	75.0	0.6	13.1	133	7	5.3	1.4
Lead	MCL-US	15	µg/L	42	2.4	2.4	95.2	0.4	8.9	325	2	0.6	0.4
Copper	MCL-US	1,300	µg/L	44	0.0	0.0	100.0	0.0	3.0	332	1	0.3	0.3
Antimony	MCL-US	6	µg/L	43	0.0	0.0	100.0	0.0	3.1	336	1	0.3	0.2
Selenium	MCL-US	50	µg/L	43	0.0	0.0	100.0	0.0	3.1	337	1	0.3	0.2
Radioactive Constituents													
Gross-alpha radioactivity, 30 day count	MCL-US	15	pCi/L	37	0.0	10.8	89.2	0.0	3.6	282	23	8.2	5.9
Uranium	MCL-US	30	µg/L	33	0.0	15.2	84.8	0.0	4.0	191	12	6.3	3.6
Nutrients													
Nitrate, as nitrogen	MCL-US	10	mg/L	48	2.1	14.6	83.3	0.4	7.9	480	24	5.0	3.4
Inorganic constituents with SMCLs													
Manganese	SMCL-CA	50	µg/L	44	4.5	9.1	86.4	1.3	12.0	332	15	4.5	10.2
Iron	SMCL-CA	300	µg/L	44	0.0	0.0	100.0	0.0	3.0	334	8	2.4	2.2
Total dissolved solids (TDS)	SMCL-CA	1,000	mg/L	58	1.7	8.6	89.7	0.3	6.5	363	4	1.1	1.1
Solvents													
Tetrachloroethene (PCE)	MCL-US	5	µg/L	58	0.0	0.0	100.0	0.0	2.3	365	3	0.8	0.2
Fumigants													
1,2-Dibromo-3-chloropropane (DBCP)	MCL-US	0.2	µg/L	58	0.0	8.6	91.4	0.0	2.3	372	13	3.5	1.0

¹ Grid-based aquifer-scale proportions for organic constituents are based on samples collected by the U.S. Geological Survey from 58 grid wells during March–June 2006.

² Based on the Jeffrey's interval for the binomial distribution (Brown and others, 2001).

³ Based on most recent analysis for each CDPH well during March 1, 2003–February 28, 2006, combined with GAMA grid-based data.

Table 7B. Aquifer-scale proportions using grid-based and spatially weighted methods for those constituents that had concentrations above water-quality benchmarks (high relative-concentrations) during April 24, 1976, to February 28, 2003, (historically high) from the California Department of Public Health database or had moderate relative concentrations in samples collected from grid wells, March–June 2006, Central Eastside Groundwater Ambient Monitoring and Assessment study unit.

[High, concentrations greater than water-quality benchmark; moderate, concentrations between 11 and 100 percent of benchmark for organic constituents or 51 and 100 percent of benchmark for inorganic constituents; low, concentrations less than or equal to 10 percent of benchmark for organic constituents or 50 percent of benchmark for inorganic constituents; CDPH, California Department of Public Health; MCL-US; U.S. Environmental Protection Agency maximum contaminant level; MCL-CA, CDPH maximum contaminant level; NL-CA, CDPH notification level; SMCL-CA, CDPH secondary maximum contaminant level; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; NA, not applicable]

Constituent	Threshold type	Threshold value	Threshold units	Date of most recent high value	Grid-based aquifer-scale proportion ¹				90-percent confidence interval for grid-based high proportion ²		Detection-frequency-based aquifer-scale proportion ³			Spatially weighted aquifer-scale proportion ³
					Number of wells	High proportion (in percent) (in percent)	Moderate proportion (in percent)	Low proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)	Number of wells	Number of high wells	High proportion (in percent) (in percent)	
Trace Elements														
Boron	NL-CA	1,000	µg/L	7/16/2002 ⁴	24	0.0	4.2	95.8	0.0	5.4	109	0	0.0	0.0
Barium	MCL-CA	1,000	µg/L	7/21/1992 ⁴	43	0.0	0.0	100.0	0.0	3.1	339	0	0.0	0.0
Nutrients														
Nitrite, as nitrogen	MCL-US	1	mg/L	2/24/2004 ⁵	45	0.0	0.0	100.0	0.0	2.9	394	0	0.0	0.0
Inorganic constituents with SMCLs														
Chloride	SMCL-CA	500	mg/L	2/8/2000 ⁴	45	0.0	0.0	100.0	0.0	2.9	334	0	0.0	0.0
Trihalomethanes														
Chloroform	MCL-US	80 ⁶	µg/L	none	58	0.0	3.4	96.6	0.0	2.3	363	0	0.0	0.0
Solvents														
Carbon tetrachloride- (tetrachloromethane)	MCL-CA	0.5	µg/L	6/15/2005 ⁵	58	0.0	3.4	96.6	0.0	2.3	365	0	0.0	0.0
Trichloroethene (TCE)	MCL-US	5	µg/L	10/25/2005 ⁵	58	0.0	0.0	100.0	0.0	2.3	365	0	0.0	0.0
Dichloromethane (methylene chloride)	MCL-US	5	µg/L	3/1/1994 ⁴	58	0.0	0.0	100.0	0.0	2.3	365	0	0.0	0.0
1,2-Dichloroethane	MCL-CA	0.5	µg/L	12/3/1997 ⁴	58	0.0	0.0	100.0	0.0	2.3	365	0	0.0	0.0

Table 7B. Aquifer-scale proportions using grid-based and spatially weighted methods for those constituents that had concentrations above water-quality benchmarks (high relative-concentrations) during April 24, 1976, to February 28, 2003, (historically high) from the California Department of Public Health database or had moderate relative-concentrations in samples collected from grid wells, March–June 2006, Central Eastside Groundwater Ambient Monitoring and Assessment study unit. —Continued

[High, concentrations greater than water-quality benchmark; moderate, concentrations between 11 and 100 percent of benchmark for organic constituents or 51 and 100 percent of benchmark for inorganic constituents; low, concentrations less than or equal to 10 percent of benchmark for organic constituents or 50 percent of benchmark for inorganic constituents; CDPH, California Department of Public Health; MCL-US; U.S. Environmental Protection Agency maximum contaminant level; MCL-CA, CDPH maximum contaminant level; NL-CA, CDPH notification level; SMCL-CA, CDPH secondary maximum contaminant level; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; NA, not applicable]

Constituent	Threshold type	Threshold value	Threshold units	Date of most recent high value	Grid-based aquifer-scale proportion ¹				90-percent confidence interval for grid-based high proportion ²		Detection-frequency-based aquifer-scale proportion ³			Spatially weighted aquifer-scale proportion ³
					Number of wells	High proportion (in percent) (in percent)	Moderate proportion (in percent)	Low proportion (in percent)	Lower limit (in percent)	Upper limit (in percent)	Number of wells	Number of high wells	High proportion (in percent)	
Other VOCs														
Vinyl chloride	MCL-CA	0.5	µg/L	2/14/1989 ⁴	58	0.0	0.0	100.0	0.0	2.3	365	0	0.0	0.0
Naphthalene	NL-CA	17	µg/L	10/27/1992 ⁴	58	0.0	0.0	100.0	0.0	2.3	338	0	0.0	0.0
Fumigants														
1,2-Dibromoethane (EDB)	MCL-US	0.05	µg/L	3/16/1999 ⁴	58	0.0	0.0	100.0	0.0	2.3	362	0	0.0	0.0
Herbicides														
Atrazine	MCL-CA	1	µg/L	4/11/1989 ⁴	58	0.0	0.0	100.0	0.0	2.3	261	0	0.0	0.0
Insecticide														
Diazinon	HAL-US	1	µg/L	3/10/1994 ⁴	58	0.0	0.0	100.0	0.0	2.3	230	0	0.0	0.0
Constituents of special interest														
Perchlorate	MCL-CA	6	µg/L	none	58	0.0	20.7	79.3	0.0	2.3	189	0	0.0	0.0

¹ Grid-based aquifer-scale proportions for organic constituents are based on samples collected by the U.S. Geological Survey from 58 grid wells during March–June 2006.

¹ Grid-based aquifer-scale proportions for organic constituents are based on samples collected by the U.S. Geological Survey from 58 grid wells during March–June 2006.

² Based on the Jeffrey's interval for the binomial distribution (Brown and others, 2001).

³ Based on most recent analysis for each CDPH well during March 1, 2003–February 28, 2006, combined with GAMA grid-based data.

⁴ Date of most recent high value is not within the 3-year period of CDPH data analyzed and were not used in calculating high aquifer proportion for current conditions.

⁵ High value occurred in at least one well within the 3-year period of CDPH data analyzed but not in the most recent sample.

⁶ The MCL-US threshold for trihalomethanes is the sum of chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

Table 8. Aquifer-scale proportions for constituent classes, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) Program study unit.

[CDPH, California Department of Public Health; THMs, Trihalomethanes; PCE, tetrachloroethene; TCE, trichloroethene; VOCs, volatile organic compounds; DBCP, 1,2-Dibromo-3-chloropropane; SMCL, secondary maximum contaminant level; values are grid based unless otherwise noted]

Constituent class	Aquifer-scale proportion		
	High relative-concentrations (percent)	Moderate relative-concentrations (percent)	Low relative-concentrations (percent)
Inorganics with health-based benchmarks			
Trace elements	17.4	32.6	50.0
Radioactive	¹ 3.6	² 11.6	84.8
Nutrients	2.1	14.6	83.3
Any inorganic with health-based benchmarks	18.0	44.0	38.0
Inorganics with aesthetic benchmarks			
Total dissolved solids (SMCL)	1.7	8.6	89.7
Manganese and(or) iron (SMCL)	4.5	9.1	86.4
Organics with health-based benchmarks			
Trihalomethanes	0.0	3.4	96.6
Solvents	¹ 0.2	3.4	96.4
Other VOCs	0.0	0.0	100.0
Fumigants	¹ 1.0	² 7.6	91.4
Herbicides	0.0	0.0	100.0
Insecticides	0.0	0.0	100.0
Any organic with health-based benchmarks	³ 1.2	² 14.3	84.5
Constituents of special interest			
Perchlorate (constituent of special interest)	0.0	20.7	79.3

¹ Spatially weighted value.

² Calculated from the grid-based moderate proportion for the class minus the spatially weighted high proportion. Because the CDPH data usually could not be used to distinguish low from moderate relative-concentrations for all constituents in a class, the grid-based data were used to estimate low aquifer-scale proportions. Grid-based moderate proportions were adjusted downward by the amount of the spatially weighted high proportions because the CDPH data could generally be used to distinguish between high and moderate relative-concentrations.

³ Maximum high proportion is shown. The high proportion is between a minimum of 1.0 percent, based on the fumigant DBCP, and a maximum of 1.2 percent, assuming no co-occurrence of high values of the solvent PCE and DBCP. Additional statistical estimates considering overlap of high constituents are beyond the scope of this report.

Understanding Assessment for Arsenic

Arsenic concentrations were significantly higher in older (table 4, fig. 16A) and deeper (table 9, fig. 16B) groundwater. Arsenic concentrations in samples having a groundwater age classified as modern were significantly lower than samples classified as having mixed or pre-modern ages (table 4, fig. 16A) but were not significantly different between samples having mixed and pre-modern ages. Izbicki and others (2008) also determined that relatively high concentrations of arsenic were associated with older groundwaters in a study area in the San Joaquin Valley located north of the Central Eastside study unit. Arsenic concentrations also were correlated significantly (negatively) with normalized lateral position (table 9); this correlation reflects that most high concentrations of arsenic

were detected in the western portion of the study unit, whereas most samples from the eastern portion of the study unit had low concentrations of arsenic (fig. 15A).

Previous investigations of arsenic in the San Joaquin Valley (Belitz and others, 2003; Welch and others, 2006; Izbicki and others, 2008) and literature reviews (Welch and others, 2000; Stollenwerk, 2003) primarily have attributed elevated arsenic in groundwater to two mechanisms. One is the release of arsenic from dissolution of iron or manganese oxyhydroxides under iron- or manganese-reducing conditions. The other is desorption from aquifer sediments or inhibition of sorption to aquifer sediments with increasing pH.

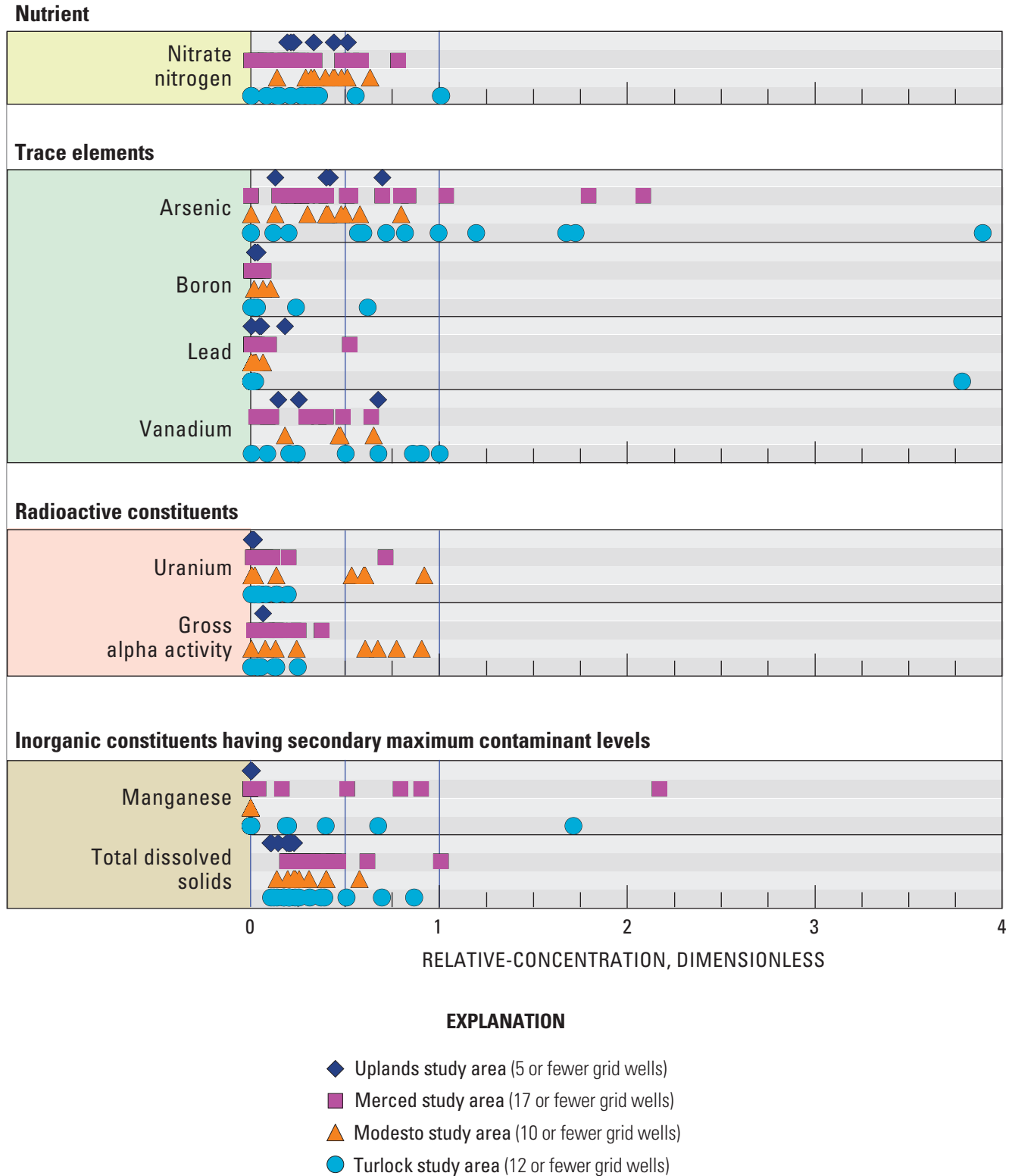


Figure 14. Dot plots showing relative-concentrations of selected trace elements, radioactive constituents, nutrients, and inorganic constituents with secondary maximum contaminant levels in grid wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

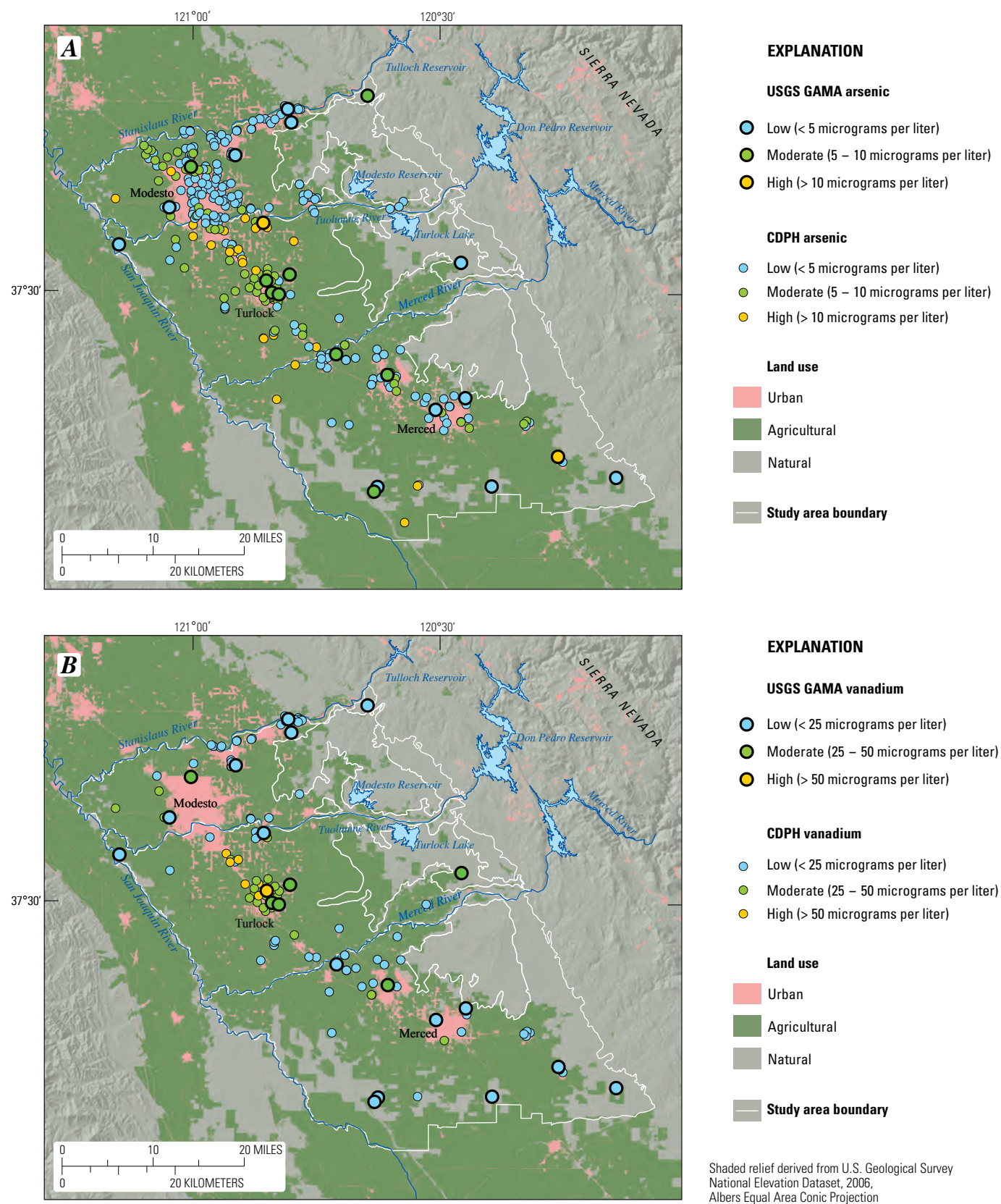


Figure 15. Concentrations of selected inorganic constituents in USGS grid and USGS understanding wells representative of the primary aquifer and the most recent analysis during March 1, 2003–February 28, 2006, for CDPH wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit (A) arsenic, (B) vanadium, (C) uranium, (D) nitrate nitrogen, (E) manganese, and (F) total dissolved solids.

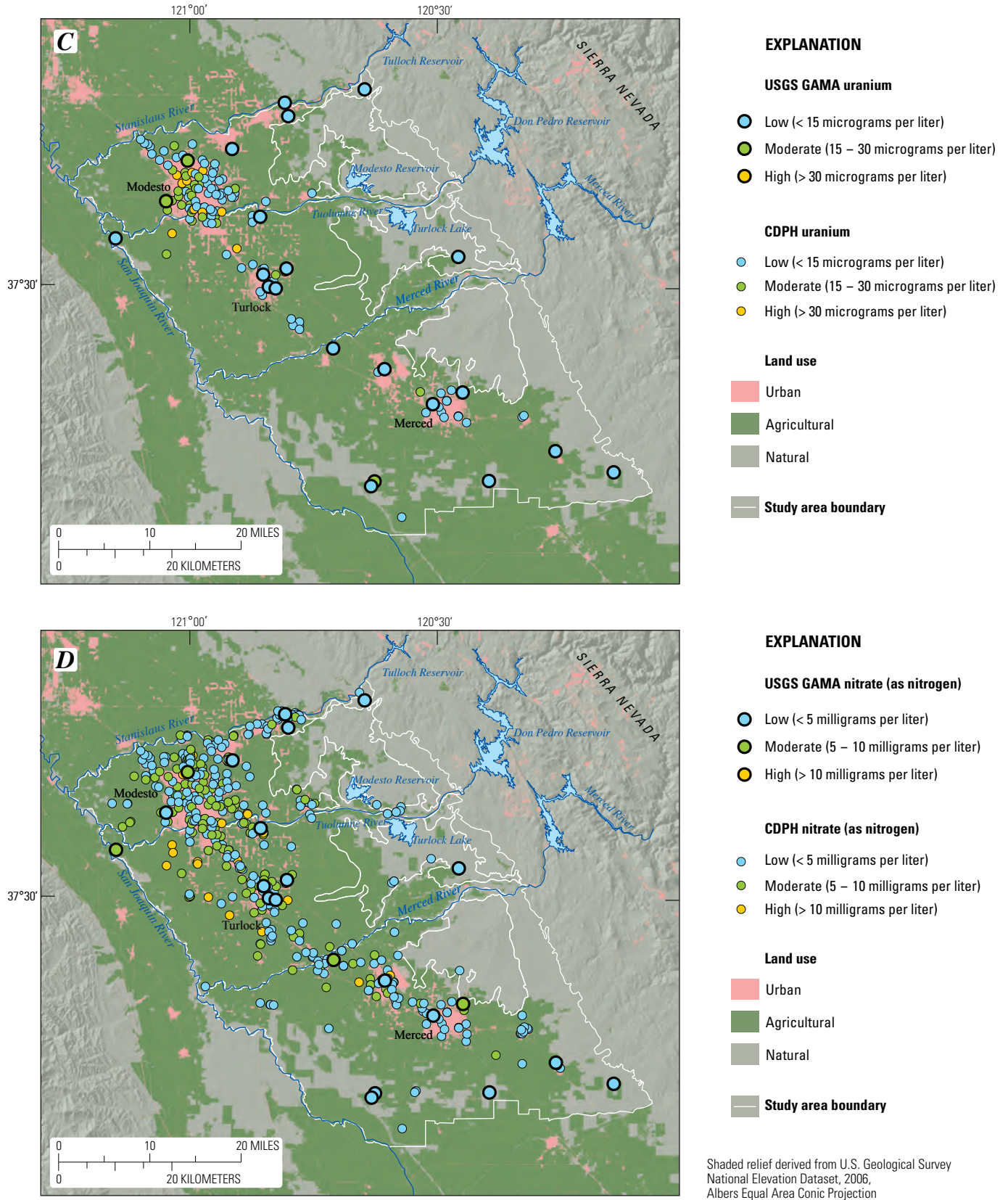


Figure 15. Continued.

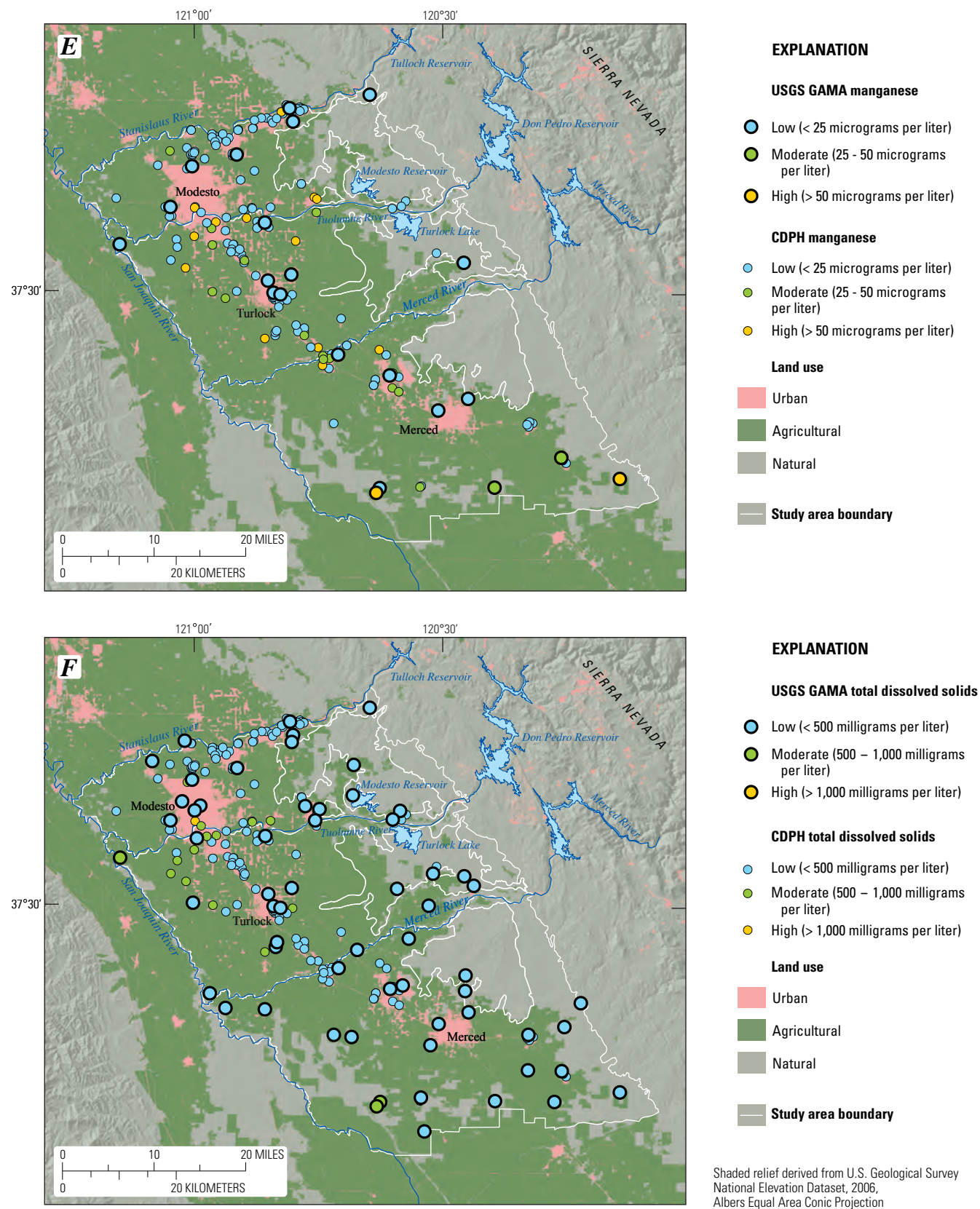


Figure 15. Continued.

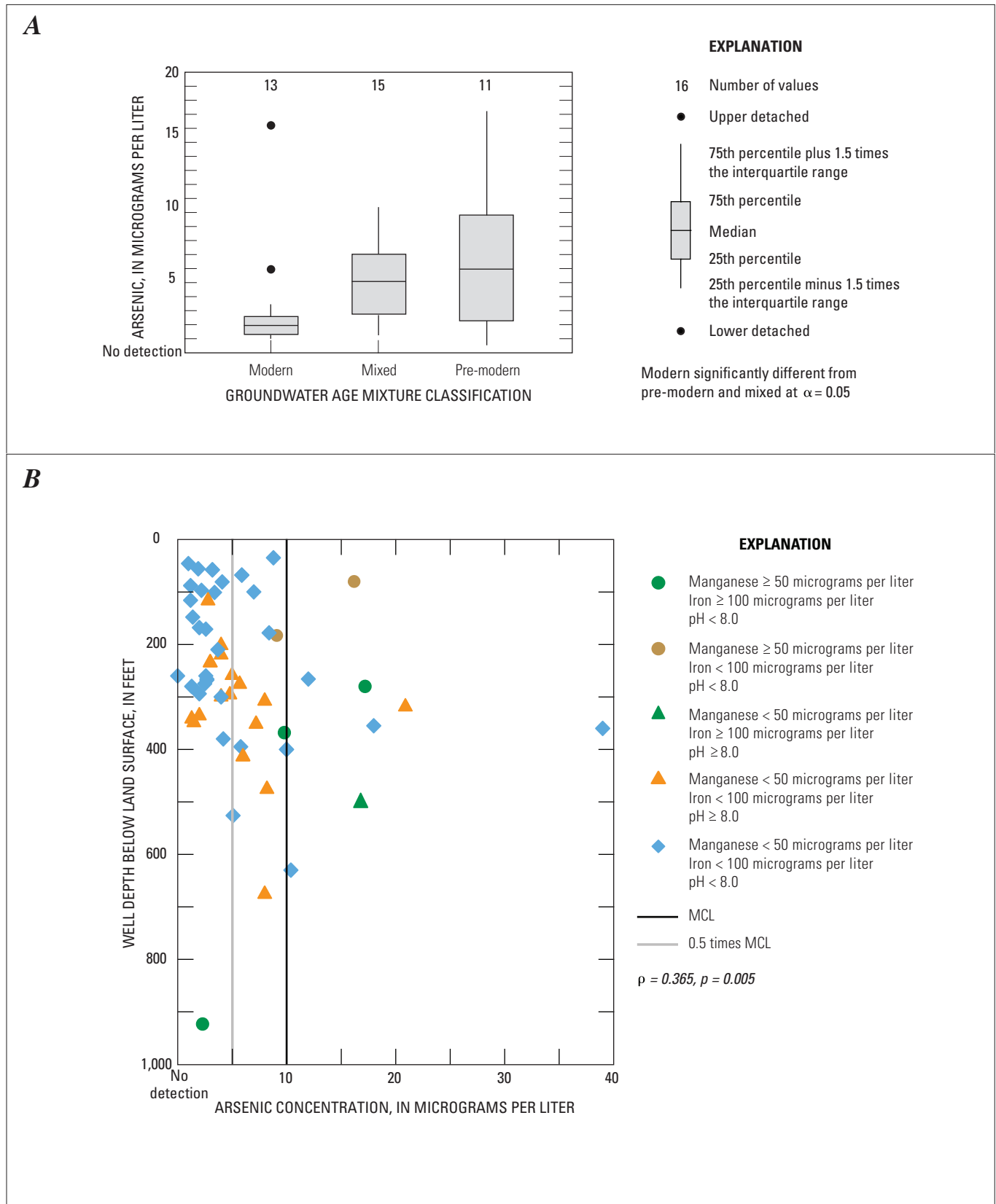


Figure 16. Plots relating arsenic to explanatory factors and (A). boxplots showing relation of arsenic to classified groundwater age, and graphs showing relation of arsenic to (B). well depth, and (C). pH, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

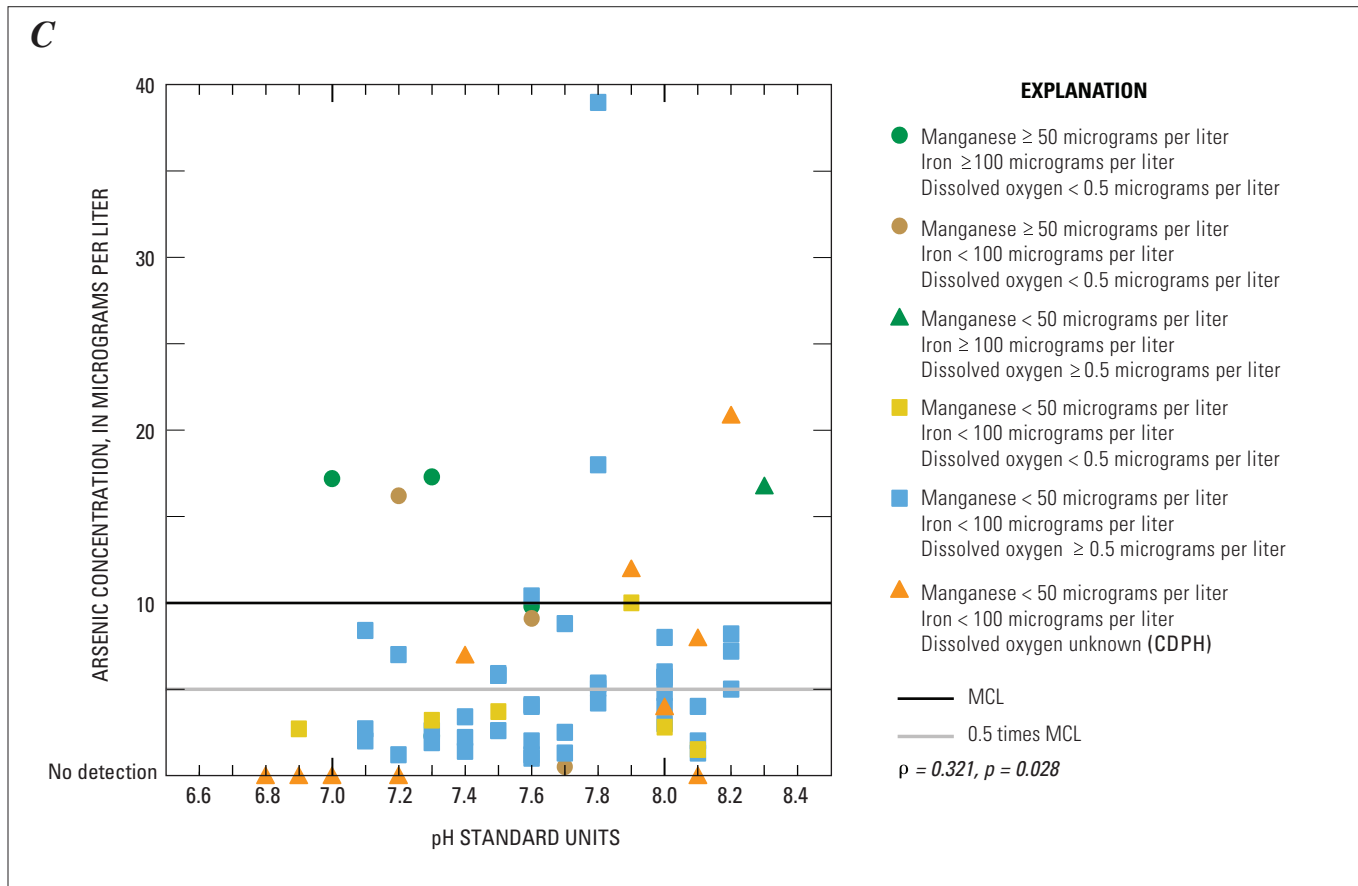


Figure 16. Continued.

In the Central Eastside study unit, evidence for the first mechanism includes association of high and moderate relative-concentrations of arsenic with manganese- and iron-reducing conditions in the western part of the study unit and the occurrence of arsenite as the dominant arsenic species in some wells with iron-reducing conditions. Six of the eight wells having manganese > 50 $\mu\text{g/L}$ (manganese-reducing conditions) and (or) iron > 100 $\mu\text{g/L}$ (iron-reducing conditions) had high (> 10 $\mu\text{g/L}$) or moderate (5–10 $\mu\text{g/L}$) relative-concentrations of arsenic (fig. 16B; not all wells are shown because well depth was unknown for two wells). These results imply that arsenic mobilization can be related to either manganese- or iron-reducing conditions.

The presence of arsenite as the dominant dissolved arsenic species in iron-reduced water in the Central Eastside is consistent with mobilization under iron-reducing conditions. The two wells having the highest iron concentrations also had arsenite (As^{+3}) as the dominant arsenic species, in contrast to 37 wells in the study unit with lower iron concentrations,

which had arsenate (As^{+5}) as the dominant arsenic species (Landon and Belitz, 2009, tables 10 and 11). Analysis of core samples from the Modesto area for arsenic species indicated that arsenate was the dominant form present in the aquifer sediments (Jurgens and others, 2008). However, under iron-reducing conditions, laboratory reaction experiments by Islam and others (2004) on sediments from Bangladesh have shown that arsenite can be the dominant arsenic species resulting from reductive dissolution of iron oxides even when arsenate is the dominant arsenic species in the solid-phase. At conditions less than iron-reducing conditions, it is expected that dissolved arsenate would not be reduced to arsenite; this observation fits with the observation that arsenate is the dominant species in all but some iron-reduced waters from the Central Eastside. The significant correlation (negative) of arsenic with normalized lateral distance from the valley trough (table 9) likely reflects the increasingly reduced redox conditions that occur in the western part of the valley.

Table 9. Results of non-parametric (Spearman's method) analysis of correlations between selected water-quality constituents and potential explanatory factors, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[ρ , Spearman's correlation statistic; ρ values are shown for tests in which the variables were determined to be significantly correlated on the basis of p values (significance level of the Spearman's test) less than threshold value (α) of 0.05; ns, Spearman's test indicates no significant correlation between variables; **blue text**, significant positive correlation; **red text**, significant negative correlation; DBCP, 1,2-Dibromo-3-chloropropane; THMs, trihalomethanes; TDS, total dissolved solids; SC, specific conductance (an electrical measure of TDS)]

Constituent group	Constituent	Benchmark type	High aquifer proportion (percent)	Data analyzed: Grid plus understanding wells					Data analyzed: Grid wells				
				Depth to top of perforations	Well depth	Dissolved oxygen	pH	Percent orchard/vineyard land use ¹	Normalized lateral position from valley trough	Percent urban land use ¹	Percent agricultural land use ¹	Percent natural land use ¹	
													ρ
Inorganic constituents													
	Arsenic ²	MCL-US	15.6	ns	0.365	ns	0.321	ns	-0.262	0.374	ns	-0.308	
	Vanadium ²	NL-CA	3.6	ns	ns	0.402	ns	ns	ns	0.493	-0.414	-0.388	
	Lead ²	MCL-US	2.4	ns	ns	ns	ns	-0.274	ns	-0.322	ns	0.424	
	Uranium ²	MCL-US	3.6	-0.562	-0.555	ns	-0.341	ns	-0.550	ns	ns	ns	
	Nitrate ²	MCL-US	2.1	-0.622	-0.563	0.439	-0.288	0.288	ns	0.334	ns	ns	
	Manganese ²	SMCL-CA	4.5	ns	ns	-0.458	ns	ns	ns	-0.426	0.345	ns	
	Iron ²	SMCL-CA	2.2	ns	ns	-0.351	ns	ns	ns	-0.258	ns	ns	
	TDS ³	SMCL-CA	1.7	-0.378	-0.329	-0.383	-0.316	ns	-0.532	ns	ns	ns	
Organic constituents and constituent classes													
	THMS, total ⁴	MCL-US	0.0	ns	ns	0.228	ns	ns	ns	0.669	-0.298	-0.341	
	Solvents, sum of concentrations ⁴	variable	0.2	ns	ns	ns	ns	ns	ns	0.572	-0.296	ns	
	DBCP ³	MCL-US	1.0	ns	ns	ns	ns	0.260	ns	ns	ns	ns	
	Herbicides, sum of concentrations ⁴	variable	0.0	-0.361	-0.233	0.230	-0.539	ns	ns	0.283	ns	-0.410	
Constituents of special interest													
	Perchlorate ³	MCL-US	0.0	ns	ns	0.245	ns	0.228	ns	0.415	ns	ns	

¹ Land use percentages are within a circle with a radius of 500 meters centered around each well included in analysis.

² Constituents with > 2 percent high aquifer proportion.

³ Single constituents with high values < 2 percent, moderate values, or detection frequencies at any concentration > 10 percent, which represent classes of constituents.

⁴ Classes of compounds that include constituents with high values < 2 percent, moderate values, or detection frequencies at any concentration > 10 percent.

Evidence for the second mechanism includes association of high arsenic with high pH in some wells (figs. 16B,C). Eight of the 19 wells having $\text{pH} \geq 8$ had high or moderate relative-concentrations of arsenic (fig. 16C). Arsenic and pH were correlated significantly (positively) (table 9, fig. 16C). The variability of arsenic concentrations in groundwater with oxic alkaline ($\text{pH} > 7$) conditions suggests that the relation of arsenic concentrations to pH is complex and perhaps less dominant than the relation of arsenic concentrations to iron- and manganese-reducing conditions. Five wells with arsenic $> 10 \mu\text{g/L}$, $\text{pH} \geq 7.5$, and oxic conditions (fig. 16C) were located in the central Turlock and southern Merced study areas. One well had pH of 8.3 and iron $> 100 \mu\text{g/L}$ (figs. 16B,C). This well has a long perforation interval from 230 to 500 ft, and may reflect mixing of groundwater affected by iron-reducing and alkaline–arsenic mobilization processes.

The correlations of arsenic with urban land use (positive) and percent natural land use (negative) likely reflect other factors. Because pH is correlated to well depth and percent urban land use (table 5), high arsenic concentrations in urban wells probably reflect higher pH and relatively old groundwater. Similar results for vanadium are discussed in more detail in the following section.

Understanding Assessment for Vanadium

Vanadium concentrations were correlated significantly (positively) with dissolved oxygen and percent urban land use (table 9). Moderate-to-high vanadium concentrations often were associated with high pH. The correlation of vanadium and percent urban land use may reflect other factors independent of land use. These analyses suggest that high-to-moderate vanadium concentrations primarily were associated with oxic conditions with increasing pH.

The positive correlation of vanadium with DO primarily reflected that vanadium concentrations were low in most samples having $\text{DO} < 0.5$; many of the wells having low vanadium and DO had pre-modern ages. In addition, manganese and vanadium concentrations were significantly negatively correlated ($\rho = -0.437$, $p = 0.003$). These correlations are both consistent with smaller concentrations of vanadium in reducing groundwater.

Similar to arsenic, vanadium adsorbs to iron and manganese oxyhydroxides on sediment surfaces, and desorbs from sediment or is inhibited from sorbing as pH increases (Hem, 1989; Naeem and others, 2007). Because arsenic and vanadium can be affected by similar processes, it was expected that concentrations of both constituents would increase with pH. For oxic ($\text{DO} > 0.5 \text{ mg/L}$) samples, vanadium and arsenic concentrations generally both increased as pH increased (figs. 16C and 17).

The study data indicate that high pH contributes to mobilization of vanadium in oxic groundwater, including in some samples with pre-modern ages. Because the dominant vanadium forms are anionic complexes with oxygen and hydrogen, the solubility of vanadium is highest in oxidizing

alkaline environments (Hem, 1989). Although pH and vanadium were not correlated overall in the Central Eastside study unit (table 9), they were correlated in samples having $\text{DO} > 0.5 \text{ mg/L}$ ($\rho = 0.386$, $p = 0.041$, fig. 17).

Most moderate and high vanadium concentrations were associated with $\text{pH} \geq 7.5$ under oxic conditions (fig. 17). Among 21 wells with oxic conditions and $\text{pH} \geq 7.5$, high or moderate relative-concentrations of vanadium occurred in 9 wells (43 percent). Among 23 wells with reducing conditions (manganese-reducing, iron-reducing, or $\text{DO} < 0.5 \text{ mg/L}$), or $\text{pH} < 7.5$, moderate relative-concentrations of vanadium occurred in 3 wells (13 percent). Although high and moderate relative-concentrations of vanadium primarily occurred in groundwater with $\text{pH} \geq 7.5$ and oxic conditions, a majority of samples representing these conditions (57 percent) had low relative-concentrations of vanadium. Thus, oxic alkaline conditions do not always result in moderate or high vanadium. Wells with oxic alkaline conditions and low vanadium occurred across a range of study areas and land-use settings.

The three USGS grid wells with the highest vanadium concentrations (43 to 50 $\mu\text{g/L}$) in the Central Eastside were oxic, had pH of 8.0 to 8.2 (fig. 17), and had depths to the tops of the perforations > 200 ft and pre-modern ages. These three wells (TRLK-05, TRLK-01, and TRLK-11, fig. A1, tables A1,A2) were located in the Turlock study area. Although vanadium concentrations were not significantly related to groundwater-age classification overall, the association of the highest vanadium concentrations with pre-modern groundwater suggests that groundwater residence time in the aquifer under oxic alkaline conditions could result in increased vanadium concentrations.

The significant, positive correlation between urban land use and vanadium may reflect relations between urban land use, well depth, and pH. Relations between anthropogenic sources and vanadium in groundwater have been noted in some studies. Mejia and others (2007) attributed elevated vanadium in soil and groundwater to particulate emissions from burning fuel with high vanadium content. Elevated vanadium in air and soil also can be related to oil refinery processing, domestic heating, and automobile emissions (Soldi and others, 1996). Several factors need to be considered in analyzing the relation of vanadium and urban land use in the Central Eastside study unit. First, the highest vanadium concentrations are associated with three wells in the central Turlock study area having high pH, DO, and pre-modern age (figs. 15B, 17). These wells happen to be located in areas of relatively high urban land use. The pre-modern ages imply that vanadium concentrations would be unaffected by modern urban land use. Although wells with pre-modern ages can contain minor amounts of water affected by modern land use, simple mixing calculations suggest that vanadium concentrations in modern water would have to be unrealistically high to represent the source of vanadium to these wells. However, after removing all pre-modern wells from the data set, vanadium and percent urban land use still were significantly and positively correlated in grid wells

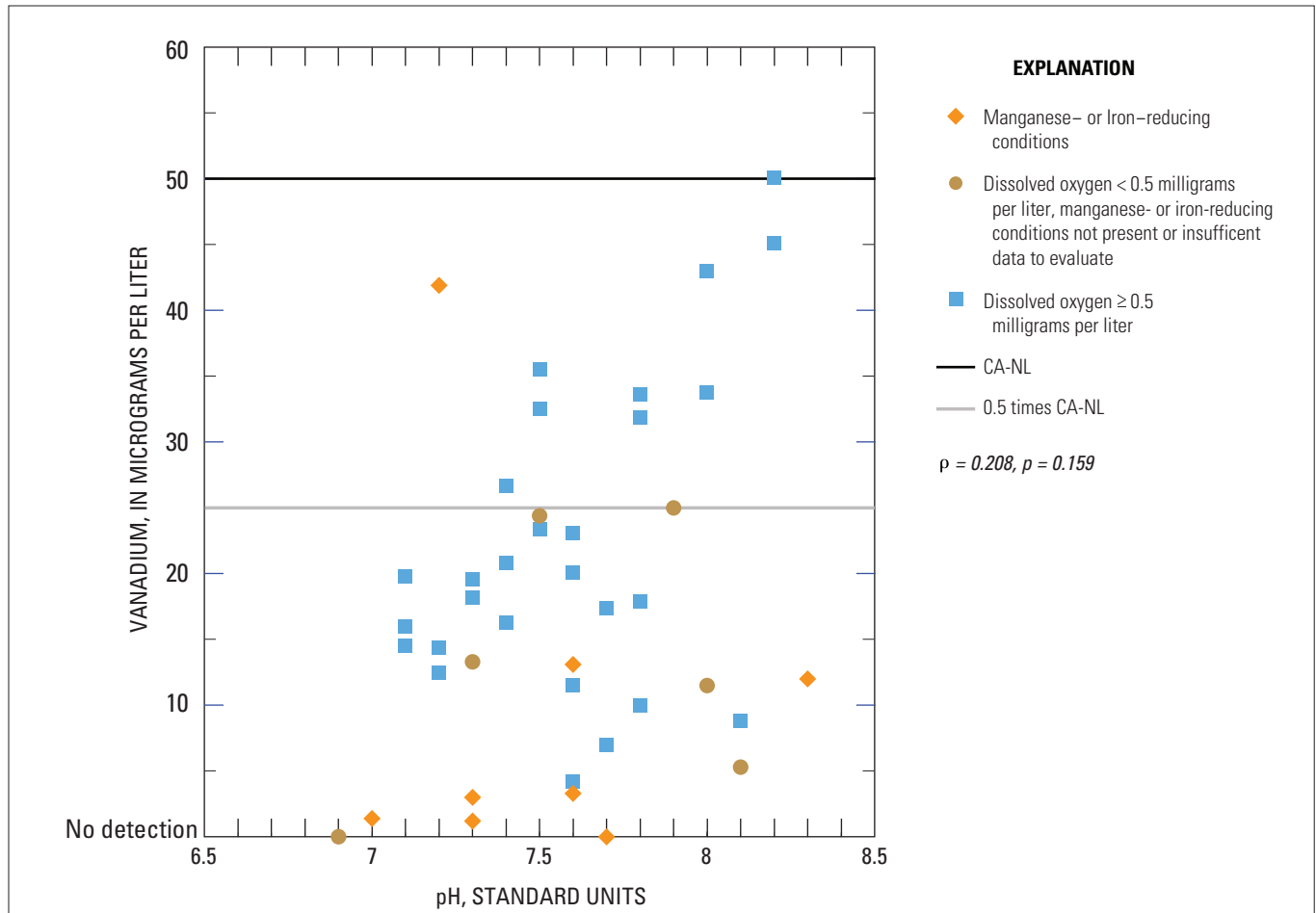


Figure 17. Plot showing relation of vanadium to pH, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

($\rho = 0.491, p = 0.008$). The remaining grid wells with moderate vanadium concentrations are located primarily in urban areas in the Modesto study area and the northern part of the Merced study area and have mixed ages, relatively large well depths of 395 to 526 ft, and pH of 7.5–7.8 with DO >4.8 mg/L (conditions favorable for high to moderate relative-concentrations of vanadium). These wells could reflect a mixture of pre-modern water with high pH, DO, and vanadium with modern water having smaller pH and vanadium. Although age tracer and DO data are not available for CDPH other wells, comparison of the most recent vanadium and pH data for CDPH other wells during March 1, 2003–February 28, 2006, (46 wells, vanadium data shown on [fig. 15B](#)) indicates that 4 of the 6 CDPH wells with vanadium >50 $\mu\text{g/L}$ also have pH of 7.8–8.1. Alternatively, given the strength of the correlation between vanadium and percent urban land use after removing pre-modern wells, it is possible that there are

urban sources or processes that might enhance mobilization of natural vanadium that may be contributing to moderate vanadium concentrations in the Central Eastside study unit.

Moderate vanadium concentrations also occurred in four USGS understanding wells (MODFP-03, MERMW-05, TRLKFP-01, TRLKMW-04; [fig. A1](#)) that were shallow, entirely perforated within 100 ft of land surface, and located in areas of agricultural or natural land use ([table A1](#)). Two of these wells had pH of 7.5–7.7 and oxic conditions, indicating oxic alkaline conditions contributing to vanadium mobility occurred in these shallow aquifer settings. The other two wells had pH <7.5 and one of the wells had reducing conditions; processes resulting in moderate vanadium concentrations in these wells are unknown but the data suggest that shallow sources of vanadium also may occur.

Understanding Assessment for Lead

Lead concentrations in samples having a groundwater age classified as modern were significantly lower than samples classified as having a pre-modern age, but were not significantly different between samples having mixed and modern ages (table 4). Correlations of lead with urban (negative) and natural (positive) land use (table 9) primarily reflected relations among samples having relative-concentrations of lead <0.1 ; the explanation for these apparent relations is unknown but is of relatively little consequence for groundwater quality because the concentrations were so small.

Radioactive Constituents

For radioactive constituents as a class, 3.6 percent of the aquifer had high relative-concentrations of at least one radioactive constituent having human-health benchmarks, 11.6 percent had moderate relative-concentrations of at least one trace element, and 84.8 percent had low relative-concentrations of all radioactive constituents (table 8). As a class, radioactive constituents had aquifer-scale proportions that were dominated by the occurrence of uranium (table 7A).

Status Assessment for Radioactive Constituents

Uranium had high relative-concentrations in 3.6 percent of the aquifer (spatially-weighted value, table 7A). High relative-concentrations of uranium primarily were located in the Modesto and Turlock study areas (fig. 15C). Uranium had moderate aquifer proportions in 15.2 percent of the aquifer (table 7A). Moderate relative-concentrations of uranium in grid wells and CDPH wells were present in the Modesto, Turlock, and Merced study areas.

Gross alpha radioactivity had a moderate aquifer-scale proportion of 10.8 percent (table 7A). Four grid wells having moderate relative-concentrations were located in the Modesto study area (fig. 14).

Uranium and gross alpha radioactivity were positively correlated significantly ($p = 0.630$, $p = 0.001$). Uranium was the most abundant radioactive constituent present in the Central Eastside study unit (Landon and Belitz, 2008). These results suggest that gross alpha radioactivity measurements primarily reflect uranium concentrations in the Central Eastside. For this reason, gross alpha radioactivity is not discussed further in this report but is considered to reflect uranium concentrations, for which more data are available for the understanding assessment.

Understanding Assessment for Uranium

Uranium concentrations were significantly larger in modern and mixed age groundwater than pre-modern age groundwater (table 4, fig. 18A), and were correlated significantly (negatively) with depth to the tops of the

perforations (table 9, fig. 18B) and with normalized lateral distance from the valley trough (table 9, fig. 18C). The correlation with normalized lateral position was determined on the basis of grid wells only, in order to remove relations with respect to depth.

In addition to the significant decrease in uranium concentrations with increasing depth (of the top of the perforations, fig. 18B), uranium concentrations also were correlated significantly (positively) with calcium ($p = 0.638$, $p = <0.001$) and alkalinity ($p = 0.773$, $p = <0.001$). The results for the Central Eastside mirror results of a local-scale investigation in the Modesto area (Jurgens and others, 2008) and a regional investigation in the eastern San Joaquin Valley (Jurgens and others, 2009). Elevated uranium in shallow groundwater was attributed by Jurgens and others (2008, 2009) to enhanced desorption of uranium from sediments by irrigation and urban recharge having high bicarbonate (alkalinity) concentrations. Increases in uranium-activity ratios (UAR, ratios of uranium-234 to uranium-238 isotopes) with depth also are consistent with mobilization of uranium from shallow sediments (Jurgens and others, 2008). In this study, UAR was negatively correlated strongly with depth to the tops of the perforations ($p = 0.127$, $p = <0.001$), similar to the results of the local Modesto study.

The association of higher uranium with modern and mixed ages is consistent with the mobilization of uranium by irrigation and urban recharge in the shallow part of the aquifer, as described above. The pattern of decreasing uranium with increasing groundwater age and depth is opposite the pattern for arsenic, which increased with depth and groundwater age. These divergent patterns with depth reflect different mobilization processes.

Uranium concentrations increase from east to west across the study unit (table 9, fig. 18C). This correlation may be influenced by a land-use gradient from east to west across the study unit from primarily natural land use in the eastern part of the study unit to primarily agricultural and urban land use, and intensive irrigation in the western portion of the study unit (fig. 4). Percent natural land use is correlated significantly (positively) with normalized lateral position (table 5), but was not correlated directly with uranium concentrations (table 9). Additional linear regression analysis, not described in this report, indicated that uranium concentrations still were related to normalized lateral position after accounting for possible differences in depth to the top of perforations from west to east. The relation between uranium and normalized lateral position also may reflect other factors such as predevelopment groundwater conditions, geology, or historical land-use patterns; further investigation is beyond the scope of this report.

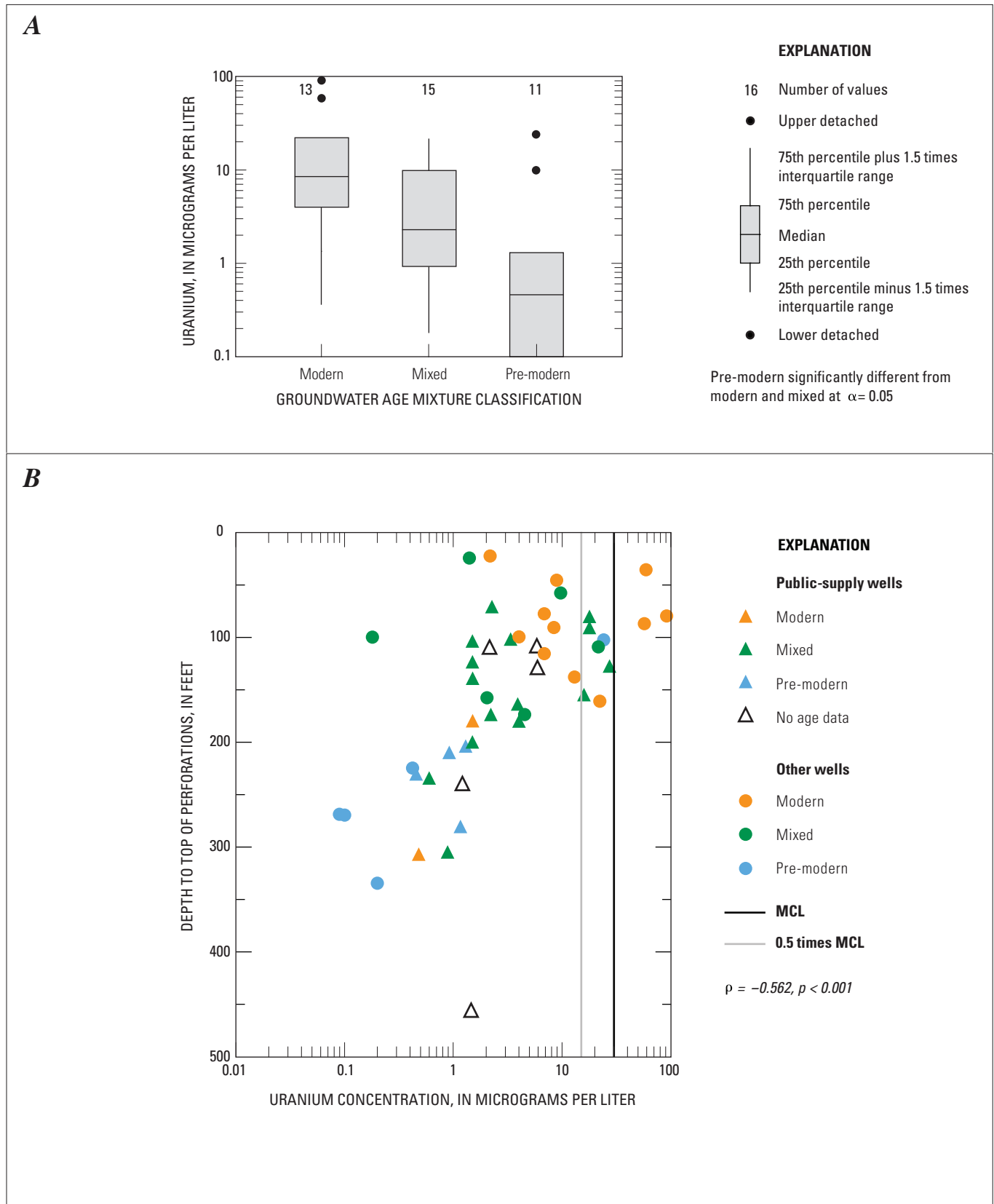


Figure 18. Relation of uranium concentrations to (A). groundwater-age classification, (B). depth to top of perforations, and (C). normalized lateral position, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

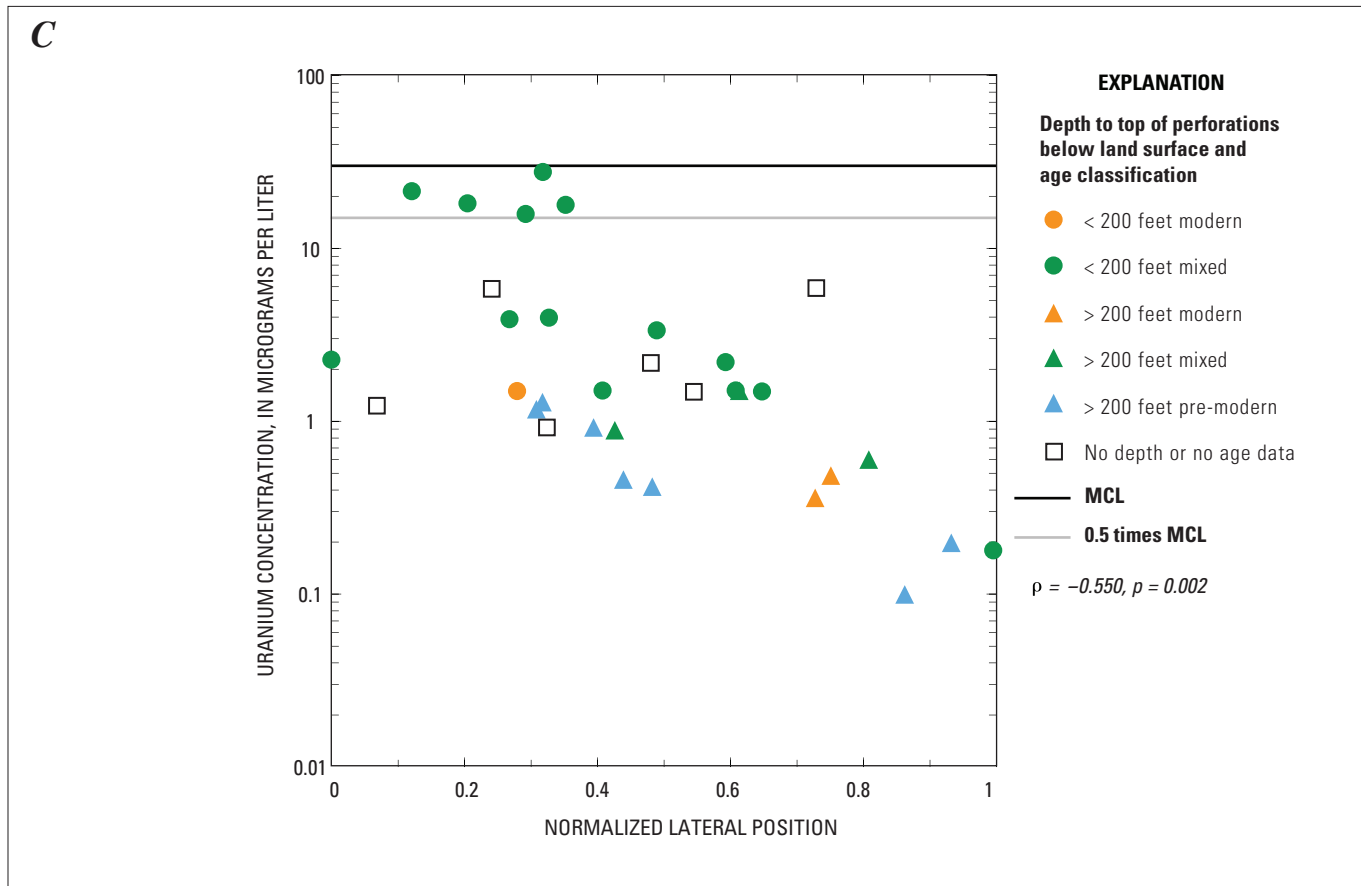


Figure 18. Continued.

Nutrients

For nutrients as a class, 2.1 percent of the aquifer had high relative-concentrations of at least one nutrient having human-health benchmarks, 14.6 percent had moderate relative-concentrations of at least one nutrient, and 83.3 percent had low relative-concentrations of all nutrients (table 8). As a class, nutrients had aquifer-scale proportions that were dominated by the occurrence of nitrate (table 7A). Nitrite was detected in one well at a high relative-concentration in the CDPH database during the current period but not in the most recent sample from that well (table 7B).

Status Assessment for Nutrients

Nitrate had high relative-concentrations in 2.1 percent of the aquifer, moderate relative-concentrations in 14.6 percent of the aquifer, and low relative-concentrations in 83.3 percent (table 7A). High relative-concentrations of nitrate primarily occur in the west-central Turlock, central Modesto, and

northern Merced study areas (fig. 15D). Moderate relative-concentrations of nitrate are distributed widely across the study unit (figs. 14 and 15D).

Understanding Assessment for Nitrate

Nitrate concentrations were significantly greater in wells having modern, compared to mixed and pre-modern, ages (table 4, fig. 19A). Nitrate also was correlated significantly (negatively) with depth to the tops of the perforations (fig. 19B) and correlated significantly (positively) with dissolved oxygen (fig. 19C) and percent orchard and vineyard land use (fig. 19D; table 9). Some of the explanatory factors related to nitrate are themselves related—dissolved oxygen, groundwater age, and depth to the top of perforations (tables 4 and 5). Nitrate in groundwater has been studied extensively in the eastern San Joaquin Valley (for example, Dubrovsky and others, 1998; Burow and others, 2008b).

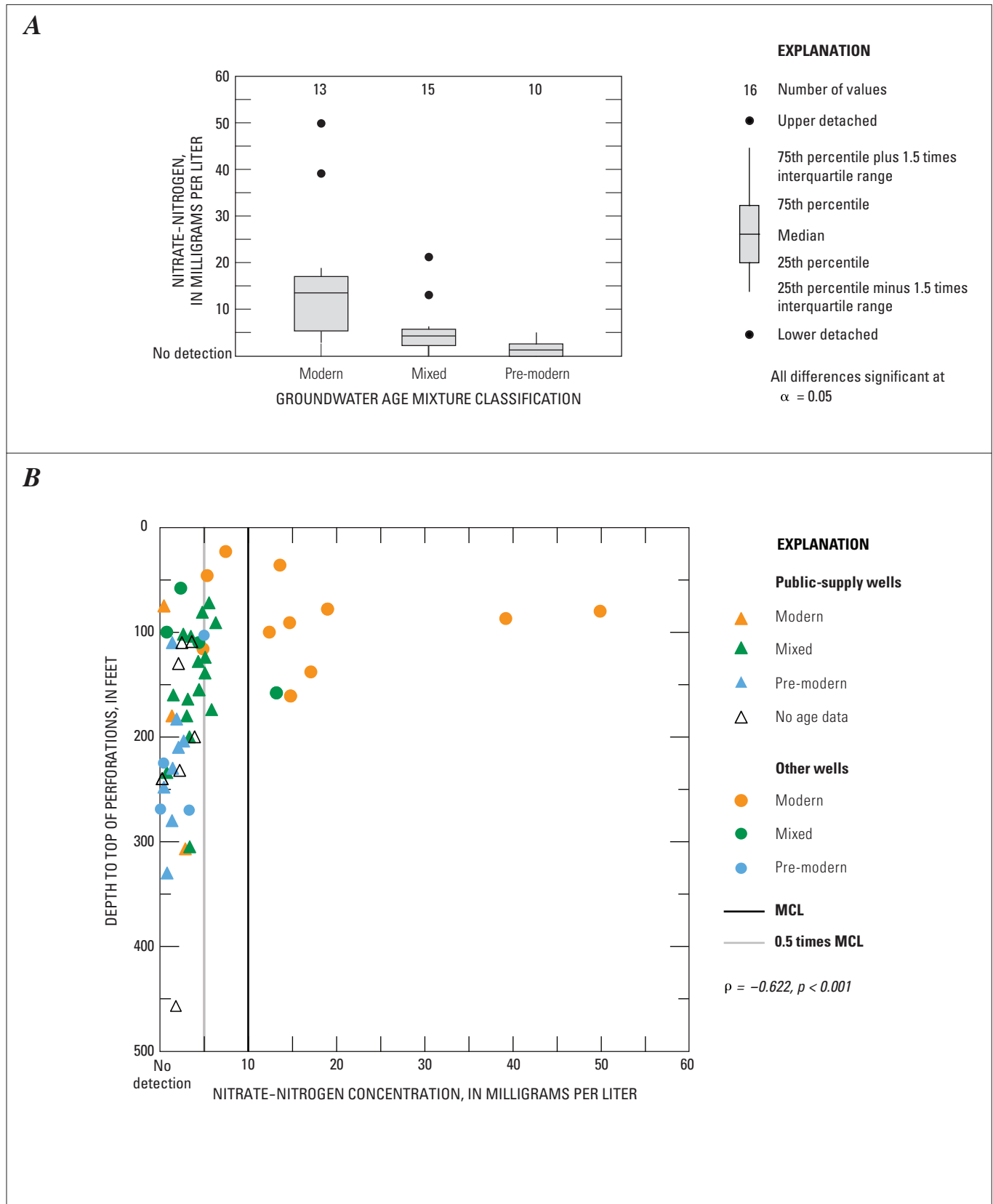


Figure 19. Plots relating nitrate (as nitrogen) to explanatory factors. (A) Boxplots showing relation to classified groundwater age, and graphs showing (B) relation to depth to top of perforations, (C) relation to dissolved oxygen, (D) graph showing relation of orchard and vineyard land use and depth to the top of perforations to detection frequency of nitrate (as nitrogen) >5 mg/L, (E) graph showing nitrogen and oxygen isotopic values of nitrate, classified by dissolved oxygen concentration, with nitrate (as nitrogen) concentration and dissolved excess nitrogen gas concentration shown for those samples suspected of being affected by denitrification, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

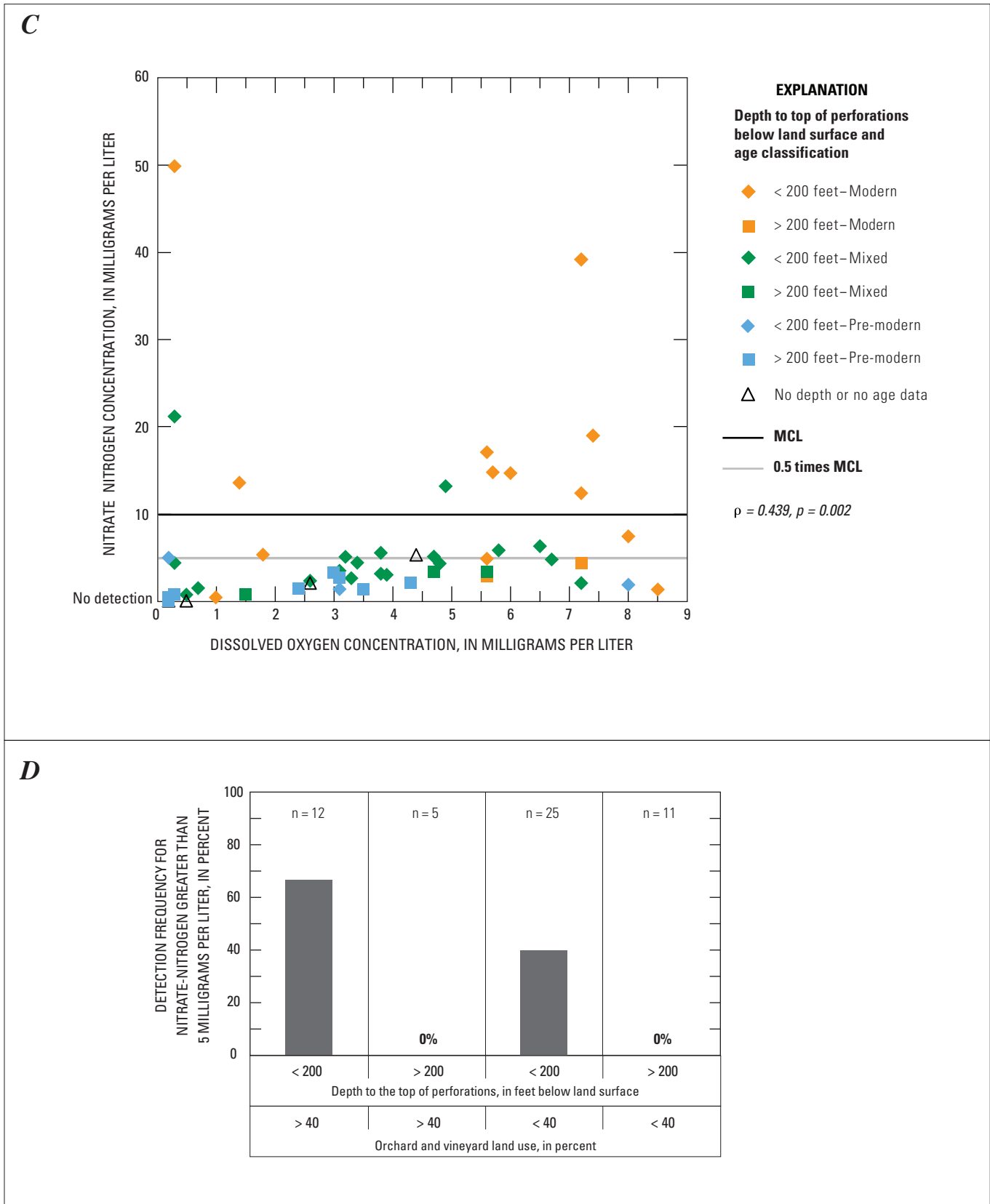


Figure 19. Continued.

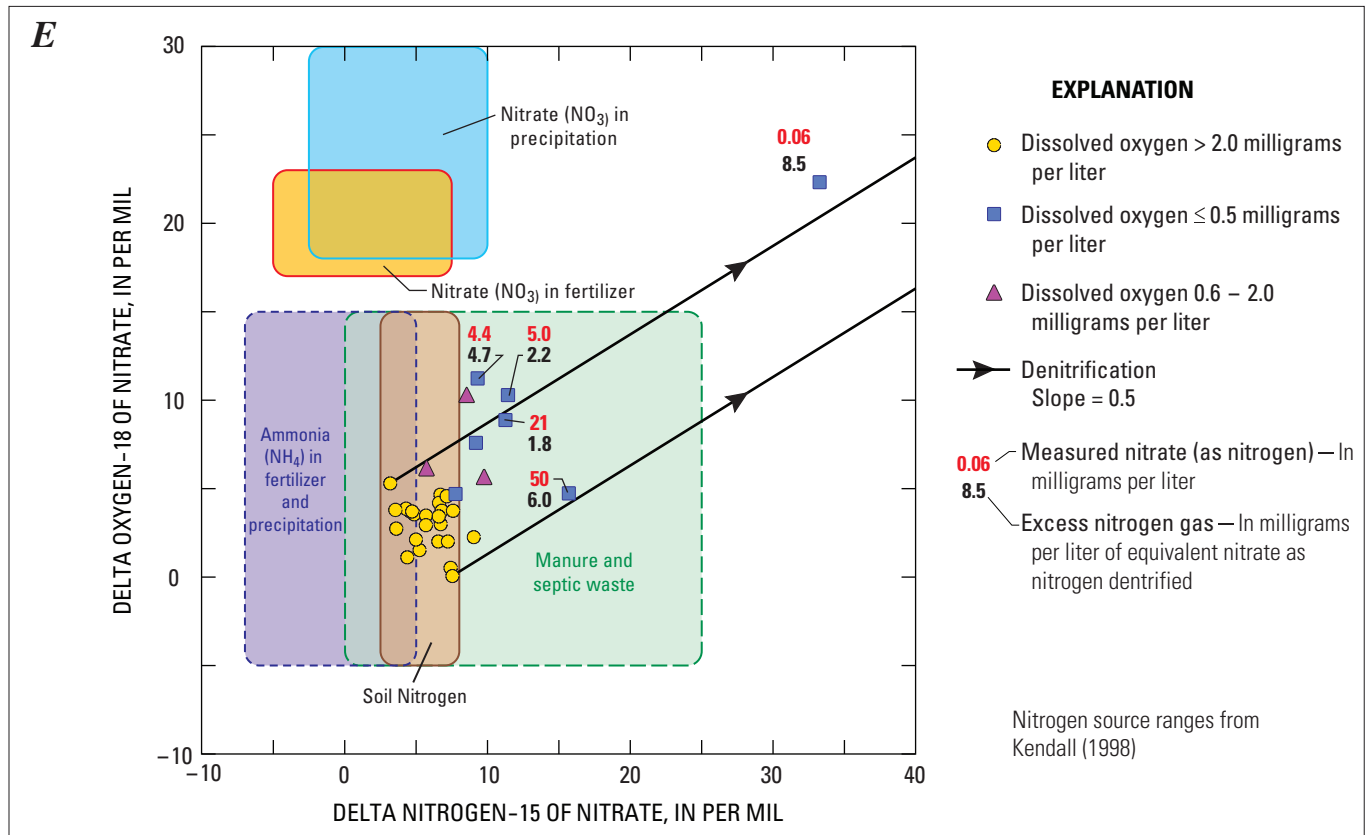


Figure 19. Continued.

For grid and understanding wells having construction data, nitrate concentrations in excess of the US-MCL of 10 mg/L (as nitrogen) occurred in some wells having depths to the top of the perforations <200 ft; these wells were not used for public supply. All public-supply wells having well construction data had nitrate (as nitrogen) <10 mg/L. Wells having depths to the top of the perforations >200 ft had nitrate concentrations that were low (<5 mg/L as N) (fig. 19B). Among wells with depths to the top of the perforations <200 ft, lower nitrate concentrations in public-supply wells than other wells may reflect that public-supply wells have longer perforated intervals. Consequently, high nitrate water from shallow depths may be diluted with low nitrate water from deep depths in long-screened public-supply wells.

Decreases in nitrate concentrations with depth primarily may reflect increasing groundwater age. Nitrate concentrations were significantly different between wells having modern, mixed, and pre-modern age distributions (fig. 19A; table 4).

Under the generally widespread oxic conditions in most of the aquifer in the Central Eastside study unit, the distribution of nitrate in the aquifer is not expected to be

controlled by denitrification. Dispersion and mixing of nitrate in modern recharge waters with older waters having low nitrate is expected to influence nitrate distribution, as has been shown to occur in simulation studies in the eastern San Joaquin Valley (Burow and others, 1999; 2008b; Weissman and others, 2002).

Nitrate may be affected by denitrification in reducing groundwaters in the western and deeper parts of the flow system. Nitrate-N concentrations also were correlated significantly (positively) with dissolved oxygen (fig. 19C). Denitrification of nitrate to dissolved nitrogen gas (N_2) and intermediate products in reducing groundwater have been identified in numerous studies (review by Kendall, 1998). Local studies within the Central Eastside study unit have confirmed that denitrification occurs in parts of the aquifer (Singleton and others, 2007; Green and others, 2008; McMahon and others, 2008). Isotopic and geochemical evidence for denitrification in the Central Eastside study unit are described in the following paragraphs.

Values of nitrogen isotopes of nitrate ($\delta^{15}\text{N}$ -nitrate) and oxygen isotopes of nitrate ($\delta^{18}\text{O}$ -nitrate) for samples having reducing groundwaters ($\text{DO} < 0.5$ mg/L), plot along lines that are consistent with denitrification of nitrate (fig. 19E). As denitrification occurs, the $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values of the residual nitrate tend to increase along a line having a slope between about 0.5 and 1.0 on a plot of $\delta^{15}\text{N}$ versus $\delta^{18}\text{O}$ (Böttcher and others, 1990; Mengis and others, 1999).

Excess N_2 (table A3, fig. 19E) in reducing water was consistent with the occurrence of denitrification. Excess N_2 was estimated by comparing measured concentrations of argon (Ar) and N_2 with those expected in water in equilibrium with the atmosphere (Singleton and others, 2005; Singleton and others, 2007). Uncertainties include the recharge temperature and the amount of excess air (Vogel and others, 1981; Böhlke, 2002). Therefore, excess N_2 from denitrification cannot be uniquely determined from measuring Ar and N_2 alone. Excess N_2 was estimated by adjusting the values until the calculated recharge temperatures determined from Ar and N_2 were close to those estimated on the basis of noble-gas concentrations (Michael J. Singleton, Lawrence Livermore National Laboratory, written commun., March 12, 2007). These analyses indicated that eight samples with reducing or mixed redox groundwater had 1.1 to 11.3 mg/L of excess N_2 (table A3). Three of these samples (two samples not shown on fig. 19E because the nitrate-N concentrations were too low for isotopic values to be measured) had nitrate-N at or below detection level, suggesting that complete denitrification had occurred. Four of these samples (MODFP-02, TRLKFP-01, TRLKFP-02, and TRLKMW-01) had nitrate-N of 4.4 to 50 mg/L (table A3); these samples all were located in the western quarter of the study unit (fig. A1, table A1) in an unconfined portion of the aquifer above the Corcoran clay. Data from these four samples are consistent with partial denitrification of nitrate or mixing of waters with differing amounts of denitrification in these wells screened in the unconfined aquifer overlying the Corcoran clay.

Nitrate concentrations were not related strongly to land use in this study. Previous investigations in the eastern San Joaquin Valley have found positive correlations between nitrate-N concentrations and percent agricultural land use (Burow and others, 1998a,b, 2007). These relations reflect that irrigated agricultural land use has been the dominant land use in the eastern San Joaquin Valley for several decades to as much as a century, and increasing quantities of nitrogen fertilizers have been applied on agricultural lands since the 1950s (Burow and others, 2007, 2008b). However, nitrate and agricultural land use were not correlated significantly in this study on the basis of all grid wells (table 9), or grid wells having depths to the top of perforations of < 200 ft. The absence of a relation between agricultural land use and nitrate

in this study probably reflects that the wells included in the analysis were perforated at depths where modern recharge affected by agricultural land use often is mixed with deep pre-modern water unaffected by modern land use. Nitrate was correlated positively with percent urban land use in grid wells (table 9). This relation probably reflects other factors such as differences in well construction and groundwater ages between urban and nonurban areas. A plot of nitrate against urban land use showed no clear visual patterns; the correlation appears to reflect that several wells having nitrate of < 1 mg/L (as nitrogen), depth to the top of perforations > 200 ft, and pre-modern ages, were located in areas with little or no urban land use. The apparent relation of nitrate to urban land use may reflect a relation between the occurrence of mixed ages and urban land use; wells having water of mixed ages had a significantly larger percent urban land use and nitrate than wells having water of pre-modern age (table 4). In previous investigations of shallow young groundwater, nitrate concentrations were lower beneath parts of the Modesto urban area than beneath adjacent agricultural areas (Burow and others, 2008a; Jurgens and others, 2008).

Nitrate was correlated significantly (positively) to percent orchard and vineyard land use on the basis of grid-plus-understanding wells (table 9). The correlation was strongest ($\rho = 0.481$, $p = 0.004$) among wells having depths to the tops of the perforations of < 200 ft; there was not a significant correlation for wells having depths to the tops of the perforations of > 200 ft. Thus, higher nitrate occurs in shallow groundwater beneath orchard and vineyard-land use areas (fig. 19D).

Sources of nitrate in groundwater have been investigated in the literature by comparing nitrogen and oxygen isotopic values of groundwater samples to ranges of values expected from different sources (Kendall, 1998). Most groundwater samples from the Central Eastside study unit have isotopic ratios that plot within the overlap between ammonia fertilizer, soil nitrogen, and animal waste sources (fig. 19E). Therefore, information on nitrate sources to groundwater cannot be determined uniquely from the nitrogen and oxygen isotope values. Samples plotting in the manure and septic waste range primarily are those samples that show evidence of being affected by denitrification, which shifts isotopic values upward and to the right. A few samples with $\delta^{15}\text{N}$ -nitrate values of about 10 to 11 per mil could be consistent with animal waste sources. Although animal waste sources sometimes can be distinguished from fertilizer, soil nitrogen, and precipitation sources using $\delta^{15}\text{N}$ or $\delta^{18}\text{O}$ of nitrate, different animal waste sources, such as human versus livestock, generally cannot be distinguished (Kendall, 1998).

Inorganic Constituents with Secondary Maximum Contaminant Levels

CDPH has established nonenforceable benchmarks (SMCL-CAs) that are based on aesthetic properties rather than on human-health concerns for selected constituents. For TDS and the major ions chloride and sulfate, CDPH defines a “recommended” and an “upper” SMCL-CA. The “upper” SMCL-CA benchmarks were used for computing relative-concentrations in this report; a relative concentration of 0.5 corresponds to concentrations equal to the recommended SMCL-CA for each of these constituents. The minor elements manganese and iron also have SMCL-CA benchmarks.

TDS for USGS–GAMA wells used in the analysis was calculated from specific conductance (SC) using a linear regression equation so that all grid wells would have TDS values determined using the same method. The linear regression equation ($\text{TDS} = 0.6164 \times \text{SC} + 38.9$) was developed from data for 39 USGS grid and understanding wells in the Central Eastside having both measured SC and TDS data. SC, an electrical measure of TDS, was available in all 78 USGS grid and USGS understanding wells, whereas laboratory-measured TDS data (as residue on evaporation) only were available for 39 of these wells. The predicted TDS using the regression equation closely matched measured TDS ($r^2 = 0.999$). Because there were similar numbers of CDPH wells available with both TDS and SC measurements, TDS values from CDPH were used directly and combined with USGS–GAMA-calculated TDS values.

Status Assessment for Inorganic Constituents with Secondary Maximum Contaminant Levels

Manganese had high relative-concentrations in 4.5 percent of the aquifer ([table 7A](#)). Moderate relative-concentrations of manganese occurred in 9.1 percent of the aquifer ([table 7A](#)). Wells having moderate-to-high relative-concentrations of manganese primarily were located in the western and southern parts of the study unit ([fig. 15E](#)) or deeper parts of the aquifer, as indicated by the distribution of reduced groundwater on [figure 11](#). Iron had an aquifer-scale high proportion of 2.2 percent (spatially-weighted), with high relative-concentrations in eight wells in the CDPH database ([table 7A](#)). For the constituent class manganese and iron, the aquifer-scale proportions ([table 8](#)) were determined on the basis of grid-based aquifer proportions for manganese.

TDS had high relative-concentrations in 1.7 percent of the aquifer and moderate relative-concentrations in 8.6 percent ([table 7A](#)). Moderate relative-concentrations of TDS were present in the Merced, Modesto, and Turlock study areas, but not the Uplands study area ([figs. 14](#) and [15F](#)).

Chloride had high relative-concentrations in at least one well in the CDPH database before March 1, 2003, but not during the current period analyzed ([table 7B](#)). These high relative-concentrations represented historic, rather than current, conditions.

Understanding Assessment for Manganese

Manganese was correlated significantly (negatively) with DO ([table 9](#)). DO <0.5 mg/L and manganese >50 mg/L generally are consistent with reducing conditions ([table A3](#)).

Manganese also was correlated significantly (negatively) with percent urban land use ([table 9](#)). However, the correlation probably reflects that high manganese primarily occurs in the western and southern parts of the study unit ([fig. 15E](#)), which has little urban land use. Manganese concentrations in oxic waters in both urban and nonurban land settings were low ([table A3](#)).

Understanding Assessment for Iron

The distribution of iron concentrations were described earlier in the sections describing redox characteristics and arsenic. High concentrations of iron occur in the western portion of the study unit and at large depths in the aquifer ([fig. 11](#)), reflecting the natural distribution of iron-reducing conditions that result from reductive dissolution of iron oxides present in the aquifer sediments.

Understanding Assessment for TDS

TDS was correlated significantly (negatively) with depth to the top of the perforations ([fig. 20A](#)) and well depth, although the former correlation was stronger ([table 9](#)). TDS also was negatively correlated with normalized lateral distance from the valley trough (grid wells only) ([table 9](#), [fig. 20B](#)) and DO ([table 9](#)). The apparent correlation between TDS and DO likely is a result of the correlation of both factors with lateral position.

TDS generally was higher in wells with depths to the tops of the perforations <200 ft ([fig. 20A](#)). Wells with depths to the tops of the perforations >200 ft generally had fairly uniform TDS of about 200 mg/L, with the exception of monitoring well MODFP-01, with a TDS of 5,810 mg/L (relative-concentration of 5.81), discussed below. The higher TDS in the upper 200 ft of the aquifer is similar to the patterns for nitrate ([fig. 19B](#)) and uranium ([fig. 18B](#)). The higher concentrations near the water table imply greater loading of dissolved constituents to groundwater in recent decades, which could reflect several factors, including increases in recharge, changes in soil chemistry due to historical changes in land use, greater chemical use at the land surface, and changes in consumptive water use by plants.

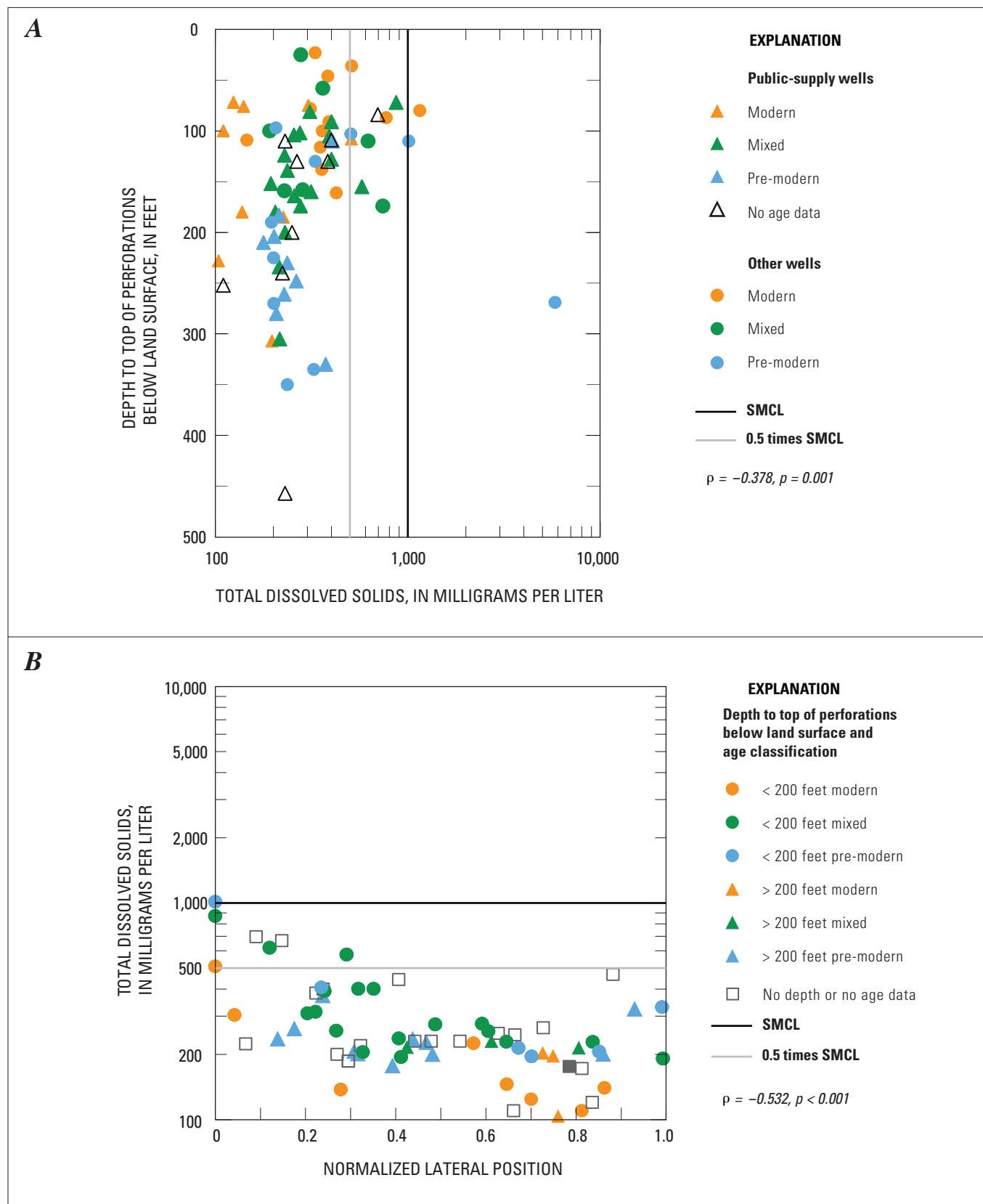


Figure 20. Relations of total dissolved solids to (A). depth to the top of the perforations, and, (B). normalized lateral position, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

TDS significantly increased from east to west across the study unit ([fig. 20B](#)). Moderate to high relative-concentrations primarily occurred in the downgradient part of the flow system having normalized lateral position <0.3 . This pattern was evident for all well depths, as well as modern, mixed, and pre-modern ages. Increases in TDS from east to west across the eastern San Joaquin Valley have been noted previously (Bertoldi and others, 1991). The increase could reflect a variety of factors, both natural and anthropogenic, including: historical groundwater discharge and evapotranspiration patterns, irrigation return and irrigation recycling, addition of salts from anthropogenic activities at or near the land surface, rock/water interaction along regional groundwater-flow paths and upwelling of more saline groundwater influenced by interactions with deep marine or lacustrine sediments near the valley trough. Detailed analysis of the processes accounting for these patterns is beyond the scope of this report.

The high TDS in MODFP-01 most likely results from mixing with deeper saline waters underlying the freshwater aquifer. MODFP-01 is a monitoring well that is not used for public supply. This well is perforated from 269 to 274 ft below land surface, just below the Corcoran clay, and is located in the western part of the Modesto study area ([fig. A1](#)). This well has distinctive chemistry with the highest concentrations of several inorganic constituents measured in the Central Eastside study, including chloride (3,130 mg/L), sodium (1,010 mg/L), iron (1,870 $\mu\text{g/L}$), and manganese (3,940 $\mu\text{g/L}$), as well as the lowest values of sulfate (<0.18 mg/L) and $\delta^{13}\text{C}$ (-44.5 per mil) (Landon and Belitz, 2008). The well is highly reducing, with methanogenic conditions ([table A3](#)). The chloride-to-iodide ratio for MODFP-01 is distinctive from other wells sampled in the Central Eastside and is in the range of groundwater affected by interactions with marine rocks (Izbicki and others, 2006). Although the depth to the base of freshwater, classified as SC $<3,000$ $\mu\text{S/cm}$ (Page, 1973), typically is deeper than 300 ft (Burow and others, 2004), saline water could be present at shallower depths beneath the Corcoran clay, as a result of regional upward hydraulic gradients causing upward flow of deep groundwater.

Organic Constituents

The organic compounds are organized by constituent class, including three classes of VOCs (trihalomethanes, solvents, and other VOCs), fumigants, and two classes of pesticides (herbicides and insecticides). VOCs can be present in paints, solvents, fuels, fuel additives, refrigerants, and can be byproducts of drinking water and other water disinfection, and are characterized by their tendency to evaporate (Ivashenko and Barbash, 2004; Zogorski and others, 2006). Fumigants used to control pests also are a type of VOC, but are discussed separately in this report because their uses and distribution differ from other VOCs. Pesticides are used to

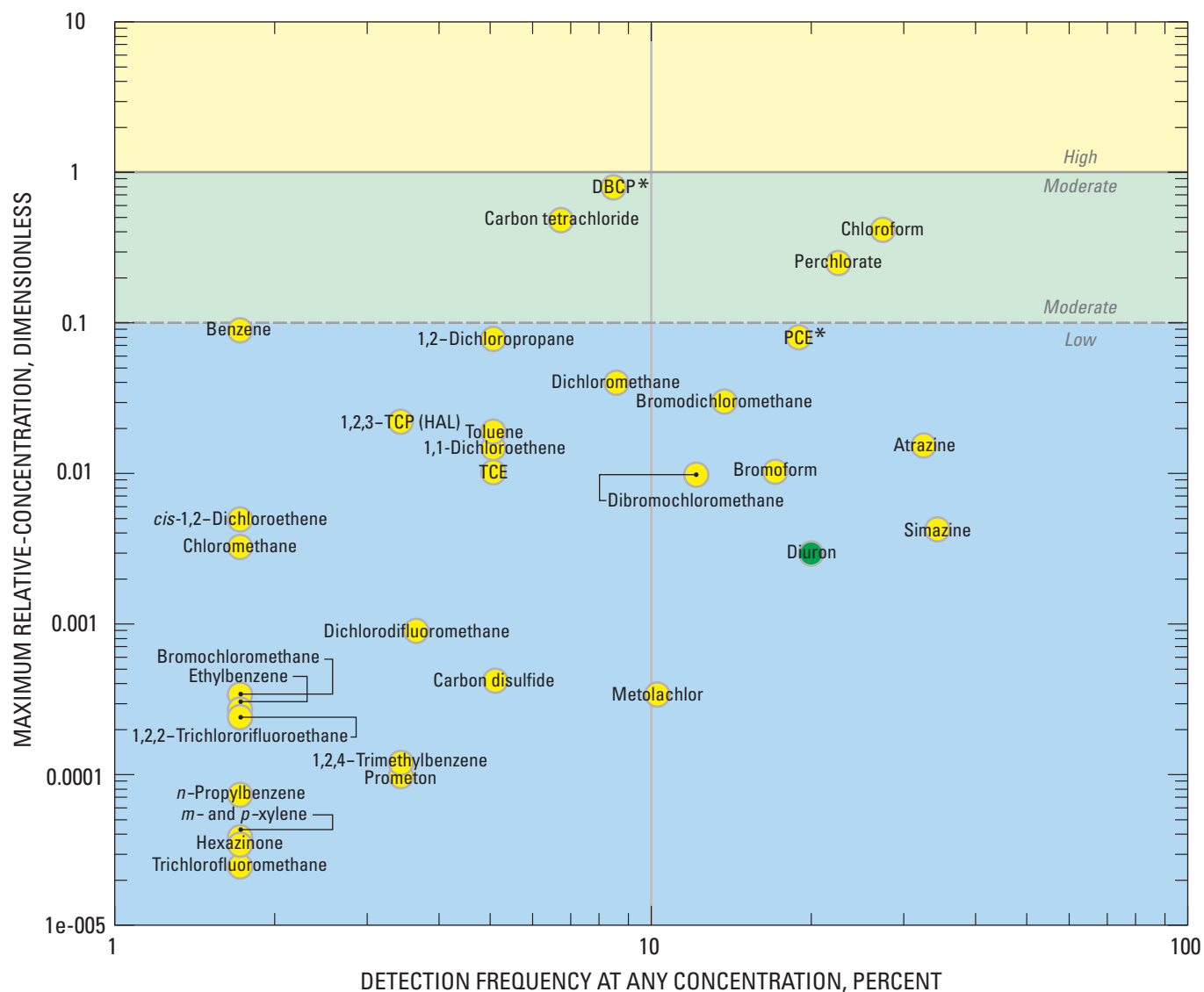
control weeds, insects, fungi, and other pests in agricultural, urban, and suburban settings.

Maximum relative-concentration and detection frequency were used as selection criteria for organic and special-interest constituents and are shown in [figure 21](#). Ten organic constituents analyzed for all USGS grid wells met the selection criteria of having maximum relative-concentrations >0.1 and (or) detection frequency ≥ 10 percent ([figs. 21](#) and [22](#)).

All concentrations of VOCs in USGS–GAMA-collected samples from the Central Eastside study unit were below human-health benchmarks. Of the 22 VOCs detected, two (carbon tetrachloride and chloroform) had moderate relative-concentrations in one or more grid wells ([fig. 22](#)). The other 20 VOCs were detected at low relative-concentrations, some with constituents having maximum relative-concentrations as low as 2.5×10^{-5} ([fig. 21](#)). Five VOCs were detected in more than 10 percent of the grid wells, including: the trihalomethanes (THMs) chloroform, bromoform, bromodichloromethane, and dibromochloromethane; and the solvent tetrachloroethene (PCE, [fig. 22](#)). The other 17 VOCs had detection frequencies of <10 percent. One or more VOCs were detected in 47 percent of the grid wells.

Of the 115 pesticides and pesticide degradates analyzed, 10 were detected (Landon and Belitz, 2008; [table 6](#)). The detected compounds were all herbicides or herbicide degradates; no insecticides were detected. Of the 10 herbicides and herbicide degradates detected, six were parent compounds with benchmarks (atrazine, simazine, diuron, metolachlor, prometon, hexazinone), one was a parent compound without a benchmark (norflurazon), and three were degradates not having a benchmark (de-ethylatrazine, de-isopropylatrazine, and 3,4-dichloroaniline). Results for the herbicide diuron, sampled for 15 of 58 grid wells, are discussed in the section “Constituents Sampled for in a Subset of Wells.” All concentrations of pesticides were below human-health benchmarks. The individual constituents that were not detected, and the wells sampled for different pesticides and pesticide degradates, in the Central Eastside study unit are listed by Landon and Belitz (2008).

For organic constituents having human-health benchmarks, 1.2 percent of the aquifer had high relative-concentrations of at least one constituent, 14.3 percent had moderate relative-concentrations of at least one constituent, and 84.5 percent had low relative-concentrations of all constituents ([table 8](#)). The aquifer-scale high proportion of organic constituents reflected high relative-concentrations of the fumigant DBCP in 1.0 percent of the aquifer, and the solvent PCE in 0.2 percent of the aquifer.



EXPLANATION

- Atrazine** Constituents with >20 grid wells and spatially representative wells sampled—Name and center of symbol is location of data unless indicated by following location line: _____
- Diuron** Constituents with <20 grid wells and wells sampled not spatially representative—Name and center of symbol is location of data unless indicated by following location line: _____

TCE, Trichloroethene; PCE, Tetrachloroethene; DBCP, 1,2-Dibromo-3-chloropropane; 1,2,3-TCP, 1,2,3-Trichloropropane; HAL, U.S. Environmental Protection Agency Lifetime Health Advisory Level

* Detected at relative concentration >1 in one or more wells in the Central Eastside in the California Department of Public Health Data Base for March 1, 2003 to February 28, 2006

Figure 21. Detection frequency and maximum relative-concentration for organic and special interest constituents detected in grid wells, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

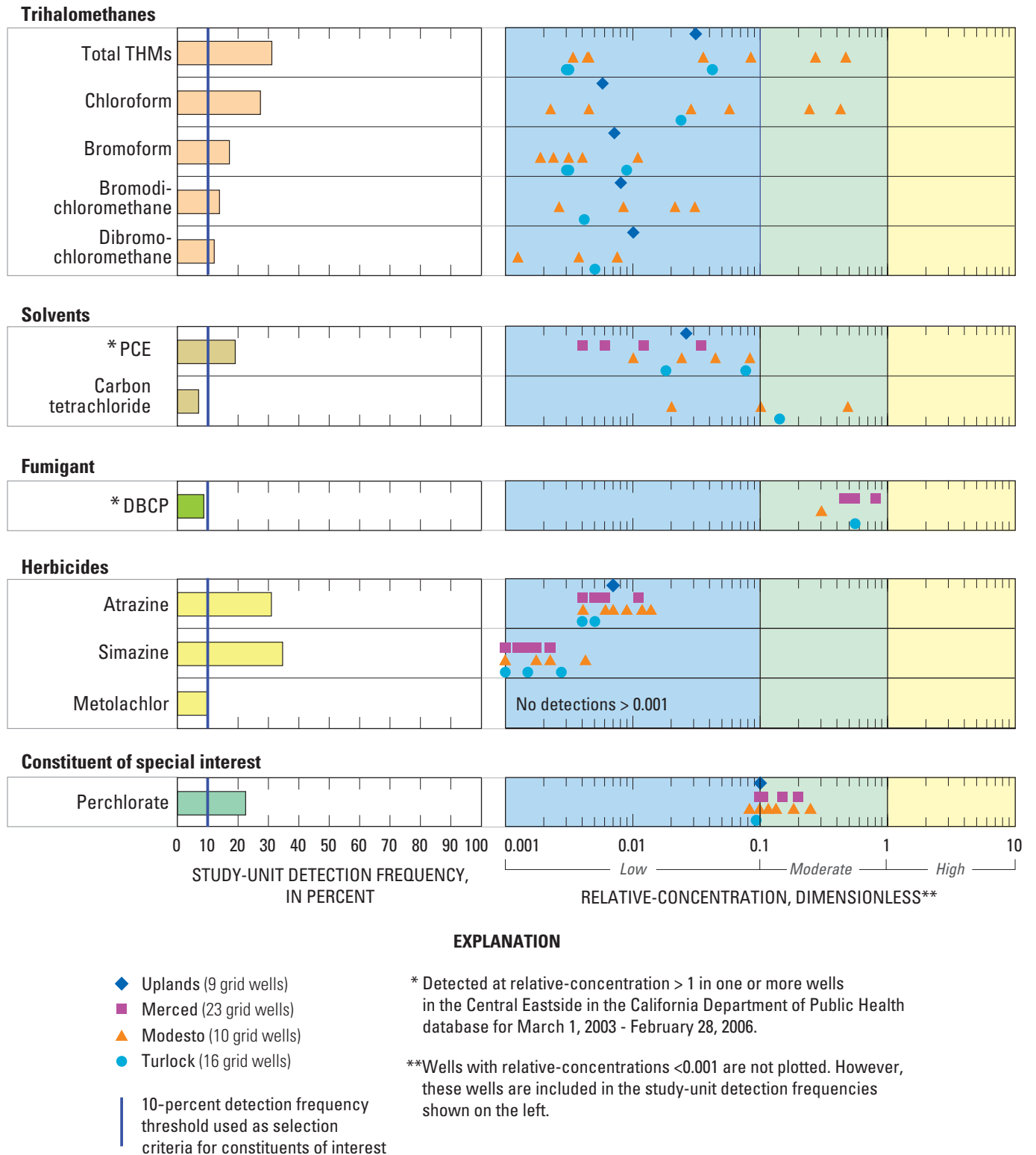


Figure 22. Detection frequency and relative-concentrations in grid wells of selected organic and special interest constituents in the Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit, March–June 2006.

Trihalomethanes

In addition to individual THMs, the detection frequency and relative-concentrations of total THMs (sum of the four individual THMs) are shown on [figure 22](#) because (1) there is an MCL for total THMs, and, (2) all four THM compounds had detection frequencies of 10 percent or higher in grid wells in the study unit. For the purpose of presentation, relative-concentrations of the individual THMs were computed using the MCL-US of 80 µg/L, corresponding to total THM concentrations.

Status Assessment for Trihalomethanes

One or more THMs were detected in 31 percent of the grid wells in the study unit ([fig. 22](#)); no high relative-concentrations were detected. THMs (on the basis of chloroform) had moderate relative-concentrations in 3.4 percent of the aquifer ([tables 7B](#) and [8](#)). THMs had low relative-concentrations or were not detected in 96.6 percent of the aquifer. Comparison of the relative-concentrations for total THMs and chloroform illustrates that chloroform accounted for most of the total THMs in most samples (17 of 21; Landon and Belitz, 2008). Nationally, chloroform was the most detected frequently VOC in aquifers as indicated by the USGS National Water Quality Assessment (NAWQA) program (Zogorski and others, 2006). THMs were more prevalent in the Modesto study area (detection frequency of 80 percent) than other study areas (detection frequency <25 percent, Landon and Belitz, 2008).

Understanding Assessment for Trihalomethanes

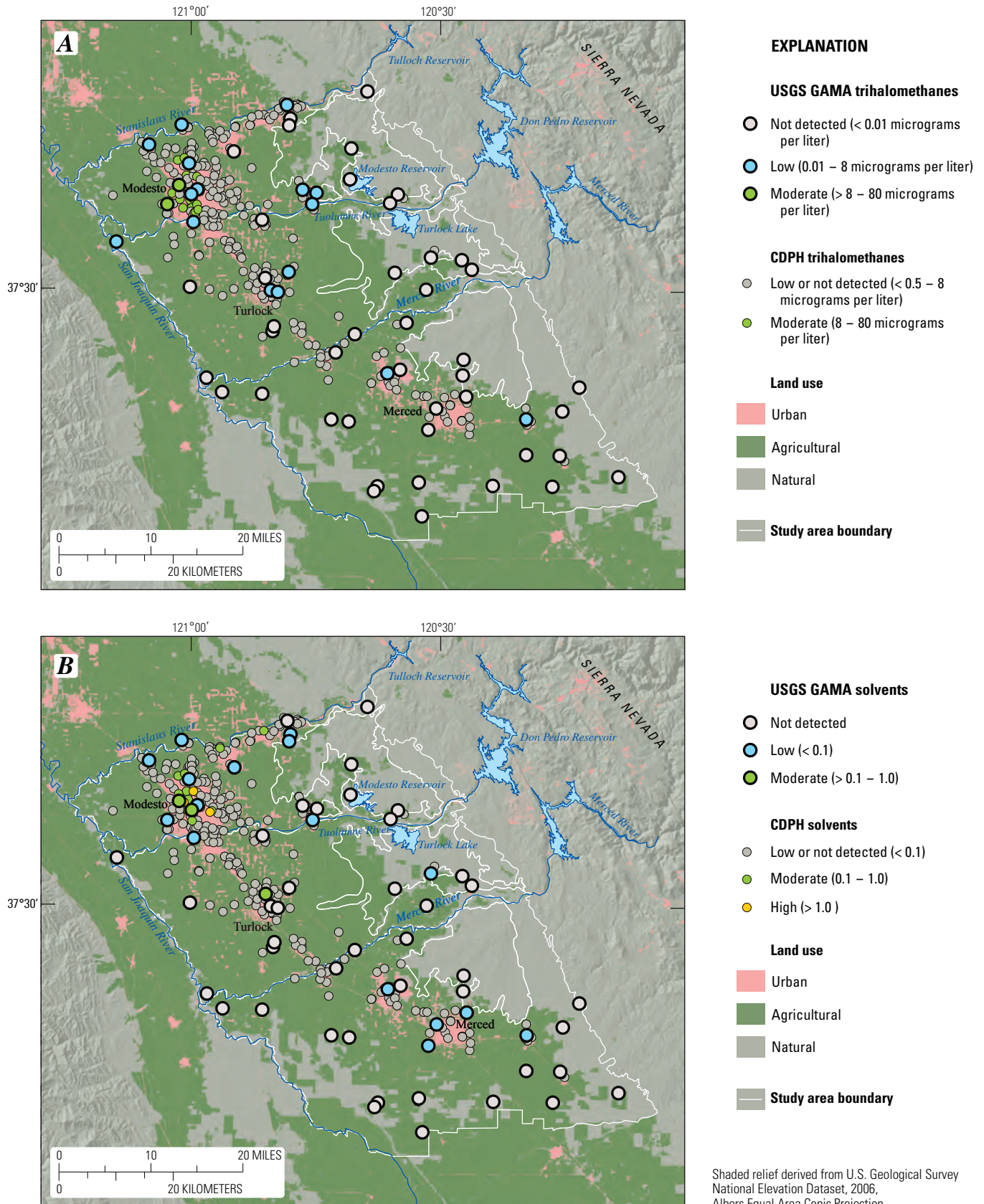
The sum of THM concentrations was correlated significantly (positively) with percent urban land use ([table 9](#), [figs. 23A](#) and [24](#)). The detection frequency of THMs in grid wells having >40 percent urban land use was about 82 percent, compared with about 10 percent for wells having <40 percent urban land use. Nationally, THM concentrations also have been correlated strongly with percent urban land use (Zogorski and others, 2006). Potential urban sources of THMs include recharge from landscape irrigation that uses disinfected water, leakage from distribution or sewer systems, as well as industrial and commercial sources (Ivahnenko and Barbash, 2004). THMs also were significantly negatively correlated with percent agricultural land use and percent natural land use ([table 9](#)), further indicating the strong relation with urban land use.

Although THM concentrations were not directly correlated with depth ([table 9](#)), most of the wells with detections of THMs had depths to the tops of the perforations

of <200 ft ([fig. 24](#)). Detection frequencies for four categories of wells classified by depths to the top of the perforations and urban land use were determined: shallow-urban (<200 ft, >40 percent urban, 11 wells), deep-urban (>200 ft, >40 percent urban, 6 wells), shallow-less-urban (<200 ft, <40 percent urban, 24 wells), and deep-less-urban (>200 ft, <40 percent urban, 11 wells) ([fig. 24](#)). Detection frequencies were higher in shallow-urban (91 percent), than in deep-urban (67 percent), and shallow-less-urban (13 percent), or deep-less-urban wells (9 percent).

THM concentrations were correlated significantly (positively) with DO ([table 9](#)). THMs were not detected in wells having DO <3 mg/L. The relation between THMs and DO could reflect a combination of degradation processes of THMs in reducing groundwater, or sources of THMs co-located with localized areas of high recharge from urban return flows that also might promote relatively high DO. THMs usually are considered to be resistant to degradation, except in parts of the aquifer that have sulfate-reduction or more highly reducing conditions (Barbash, 2007); however, THM degradation under more oxic conditions has been noted and has been attributed to degradation in reduced microenvironments within aquifers that receive artificial recharge (Pavelic and others, 2006). Positive correlations of THMs and DO also have been noted in nationwide analysis (Squillace and others, 2004; Zogorski and others, 2006).

THM concentrations were not significantly different between wells having different groundwater-age classifications ([table 4](#)), even for wells having DO >0.5 mg/L and urban land use >40 percent. However, most of the THM detections (11 of 16) occurred in wells both with mixed ages and depths to the tops of the perforations <200 ft. Two wells had detections of THMs but had pre-modern ages and depths to the tops of the perforations >200 ft. Because the practice of disinfection of water supplies using chlorination predates atmospheric nuclear testing, THMs could occur in relatively deep wells without the apparent presence of modern recharge water (from the last 50 years). However, the age classifications do not exclude the possibility that a very small amount of modern water could be mixed into a sample. The presence of THMs with the absence of modern-age water could reflect short-circuit mechanisms owing to well construction or well operation practices (Jurgens and others, 2008; Landon and others, 2009); investigating these mechanisms is beyond the scope of this report.



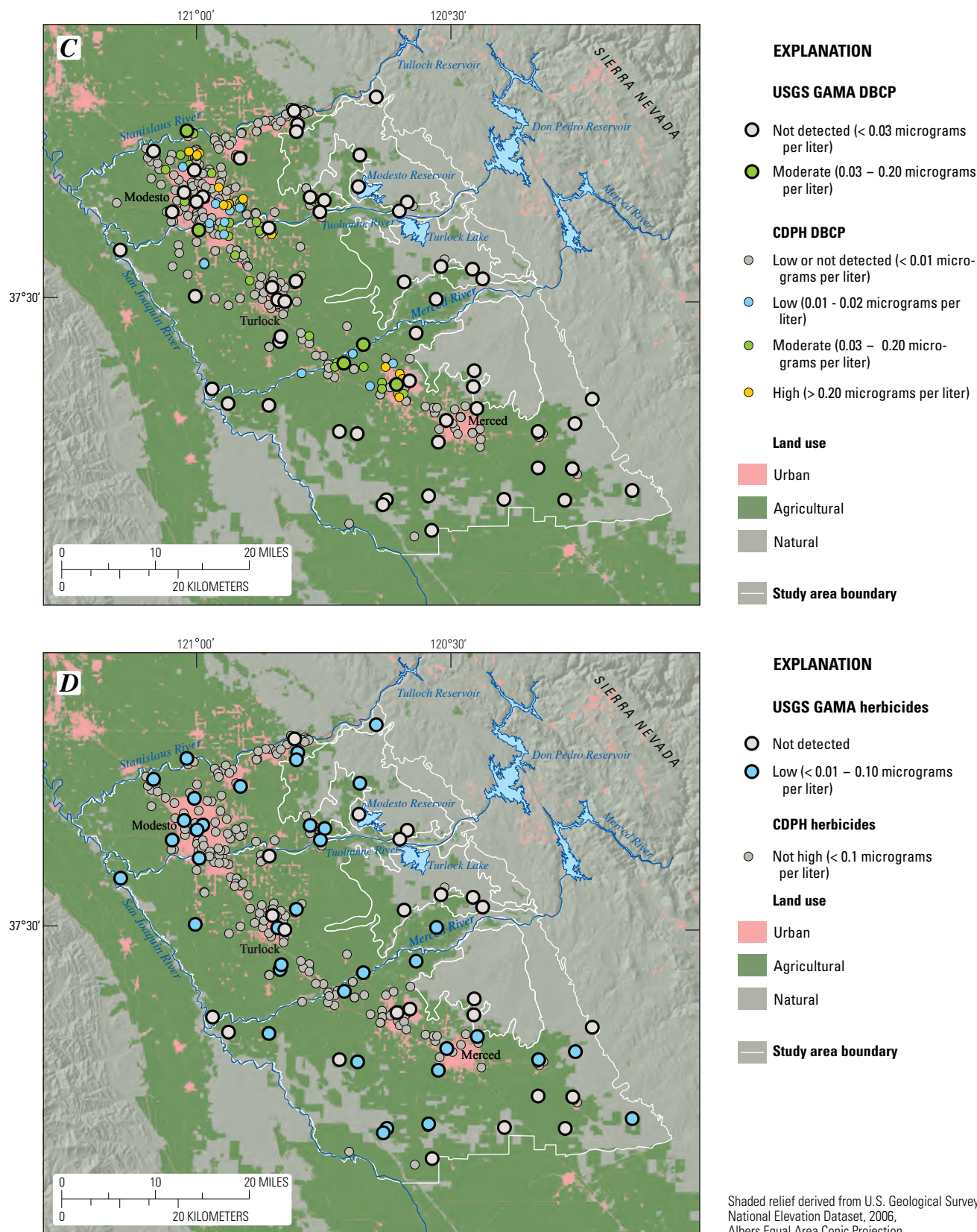


Figure 23. Continued.

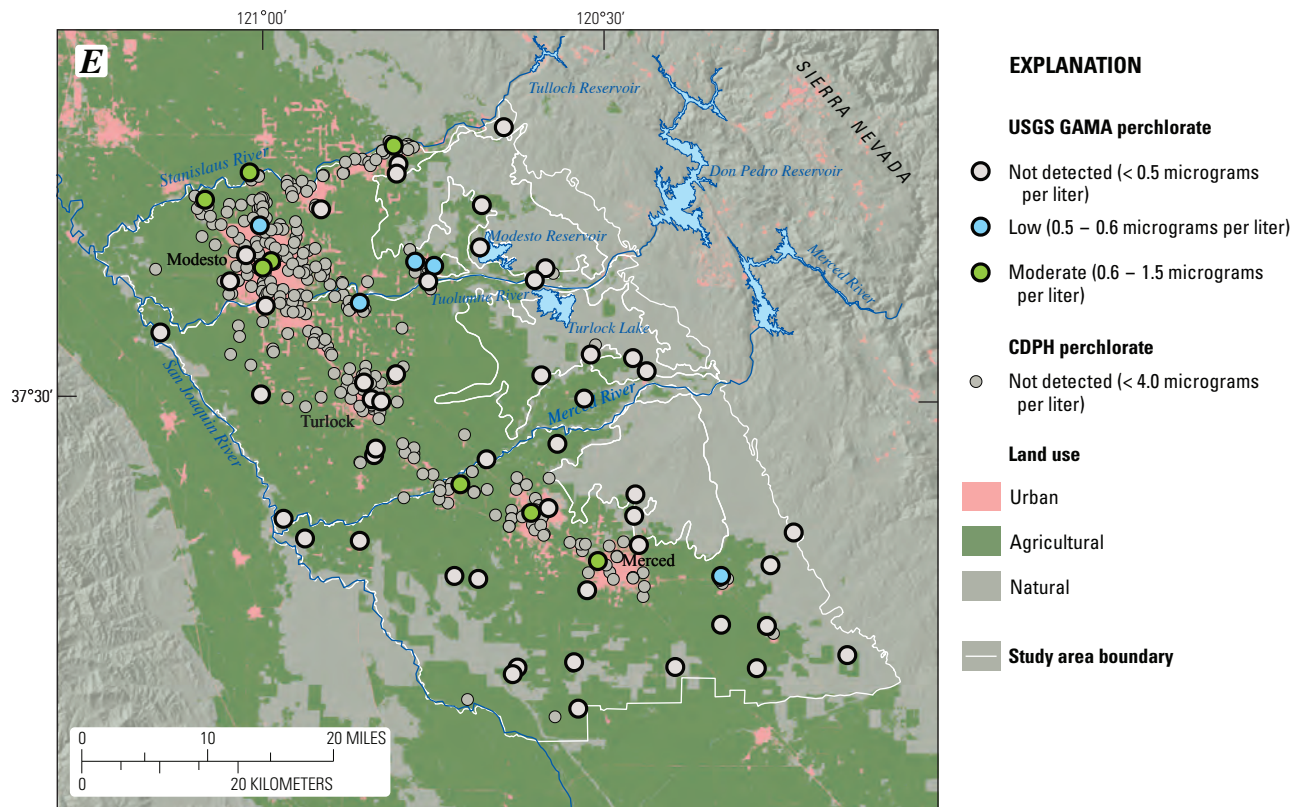


Figure 23. Continued.

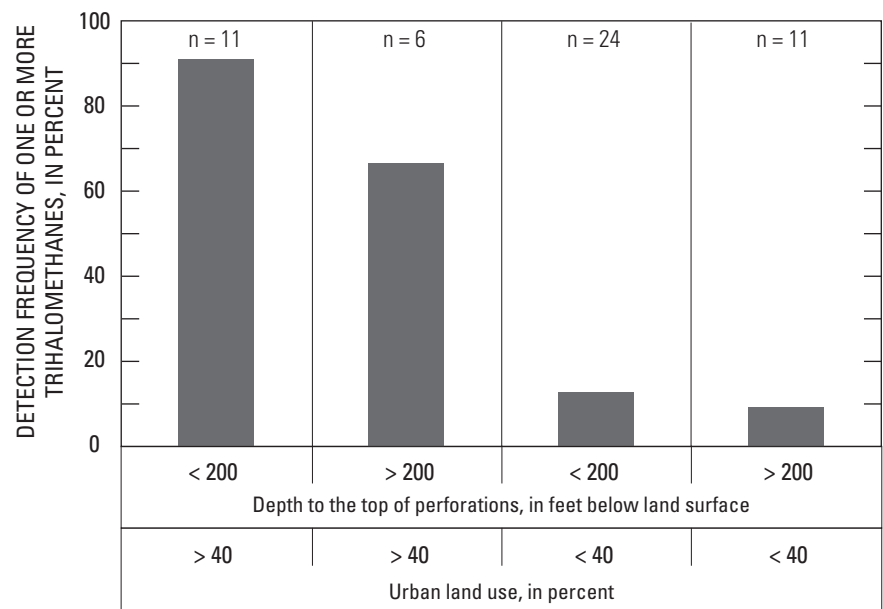


Figure 24. Relation of detection frequency of trihalomethanes to percent urban land use and depth to the top of perforations, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Solvents

Solvents are used for a variety of industrial, commercial, and domestic purposes (Zogorski and others, 2006). Solvents meeting the selection criteria were PCE and carbon tetrachloride (figs. 21 and 22).

Status Assessment for Solvents

As a class, 0.2 percent of the aquifer had high relative-concentrations (spatially-weighted) of at least one solvent, and 3.4 percent had moderate relative-concentrations of at least one solvent (table 8). Solvents had low relative-concentrations, or were not detected, in 96.4 percent of the aquifer.

Moderate relative-concentrations of solvents in 3.4 percent of the aquifer reflected the grid-based moderate aquifer-scale proportions for carbon tetrachloride (3.4 percent).

The solvent PCE was detected in 19 percent of grid wells in the study unit, with all detections at low relative-concentrations (fig. 22). PCE had an aquifer-scale high proportion of 0.2 percent (spatially-weighted value, table 7A). As with THMs, the detection frequency of PCE was highest in the Modesto study area, 40 percent, as compared with detection frequencies of <17 percent in other study areas (Landon and Belitz, 2008). PCE was the second most frequently detected VOC in aquifers on the basis of national assessments by the USGS NAWQA program (Zogorski and others, 2006) and analysis of CDPH data across California (Williams and others, 2002).

Carbon tetrachloride was detected in 6.8 percent of grid wells in the study unit (Landon and Belitz, 2008). Carbon tetrachloride was not detected at high relative-concentrations, had moderate relative-concentrations in 3.4 percent of the aquifer, and had low relative-concentrations in 3.4 percent. The detection frequency of carbon tetrachloride in the Modesto study area was 30 percent, larger than detection frequencies of 0 to 6 percent for other study areas (Landon and Belitz, 2008). Carbon tetrachloride has been used as a solvent in a variety of manufacturing and commercial applications in addition to historical use as a fumigant at grain storage facilities (Zogorski and others, 2006). Nationally, carbon tetrachloride was detected in 1.3 percent of wells sampled by the USGS NAWQA program; concentrations always were less than the USEPA MCL (Zogorski and others, 2006).

The solvent trichloroethene (TCE) had a high value in one well within the current period but no high relative-concentrations were detected in the most recent analyses (table 7B). The solvents dichloromethane and 1,2-dichloroethane had high relative-concentrations in at least one well in the CDPH data before March 1, 2003, but not during the current period analyzed (table 7B). These high values represented historic rather than current conditions.

Understanding Assessment for Solvents

Similar to THMs, the sum of solvent concentrations was correlated significantly (positively) with percent urban land use (table 9, fig. 25). The sum of solvents was calculated by summing the concentrations of all seven solvents detected: PCE, carbon tetrachloride, TCE, dichloromethane, dibromomethane, *cis*-1,2-dichloroethene, and *n*-propylbenzene. The detection frequency of solvents in wells having >40 percent urban land use was about 65 percent, significantly larger than the detection frequency of about 15 percent for wells having <40 percent urban land use. Solvents were detected in samples from wells primarily in the Modesto, Turlock, and Merced urban areas (fig. 23B).

Similar to THMs, solvent concentrations were not correlated directly with depth (table 9), but most of the wells with detections of solvents had depths of <200 ft to the tops of the perforations and urban land use of >40 percent (fig. 25). Detection frequencies were higher in shallow-urban wells (82 percent), than in deep-urban wells (33 percent), shallow less-urban (13 percent), or deep less-urban (0 percent) wells.

Solvent concentrations were not correlated significantly with any other factors, suggesting that the distribution of sources in urban land-use settings is the dominant explanatory factor affecting solvent distribution. Nationally, solvent concentrations also have been correlated strongly with percent urban land use (Zogorski and others, 2006; Moran and others, 2007). A previous investigation in the Modesto area found urban land use to be the best predictor for the detection of VOCs (Wright and others, 2004).

Although solvent concentrations were not significantly different between different age classes (table 4), detection frequencies for solvents were less in pre-modern waters (5 percent, 1 of 20 wells) than in mixed wells (44 percent, 12 of 27 wells) and modern wells (21 percent, 5 of 24). Because some solvents were used before 1950, solvents could be present in pre-modern water without invoking mixing of small amounts of modern water in the predominantly pre-modern age distribution. Similar to THMs, solvents in pre-modern water could reflect short-circuit mechanisms due to well construction or well operation processes or other nonadvective transport processes.

Other VOCs

For the class “other VOCs”, there were no grid-based moderate or high aquifer-scale proportions (table 7B). There also were no high relative-concentrations of constituents in this class in the CDPH database during the current period analyzed. Other VOCs vinyl chloride and naphthalene had high concentrations in at least one well in the CDPH data before March 1, 2003, but represented historic values rather than current conditions.

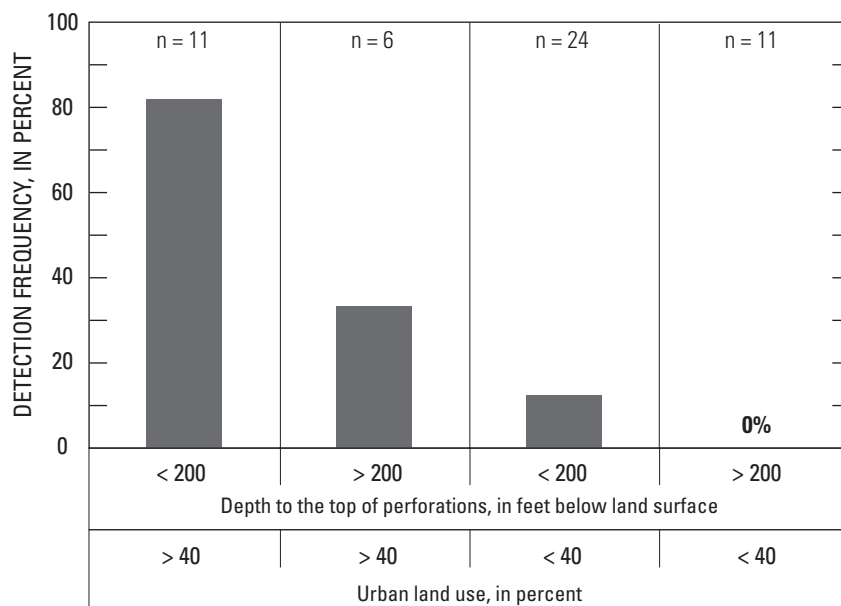


Figure 25. Relation of detection frequency of solvents to percent urban land use and depth to the top of perforations, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study.

Fumigants

Ten VOCs used primarily as fumigants to control pests in agriculture and in households, or synthesis byproducts included in fumigant mixtures, were grouped into the constituent class of fumigants. The classification of nine of these constituents as fumigants was determined by the USGS National Water Quality Assessment Program (Zogorski and others, 2006; listed by Landon and Belitz, 2008, table 3A). Although classified as having a primary use as a solvent and in the synthesis of some organic compounds (Zogorski and others, 2006), 1,2,3-trichloropropane (1,2,3-TCP) has been identified as synthesis byproduct in fumigant mixtures in use from the 1950s until the early 1980s (Oki and Giambelluca, 1987; Zearth and others, 1998), including use in the San Joaquin Valley (Domagalski and Dubrovsky, 1991), and has been detected in groundwater in areas where fumigants have been used (Zogorski and others, 2006). Consequently, 1,2,3-TCP was included in the fumigants category in this report, but actually represents a fumigant synthesis byproduct. Results of low-level analyses of 1,2,3-TCP in a subset of wells are discussed in “Constituents Sampled for in a Subset of Wells.”

Status Assessment for Fumigants

One fumigant, DBCP, met the selection criteria (fig. 21). Moderate relative-concentrations of DBCP occurred in 8.6 percent of the aquifer (table 7A). Relative-concentrations of DBCP ranged from 0.30 to 0.80 in grid wells (fig. 22). Detection frequencies of DBCP were similar in three of the four study areas: 6 percent in Turlock, 10 percent in Modesto,

and 13 percent in Merced. DBCP was not detected in the Uplands study area. DBCP was used as a soil fumigant to control nematodes, primarily on orchards and vineyards but also some row crops, in California approximately between 1955 and 1977 (Domagalski, 1997; Peoples and others, 1980). Use of DBCP was discontinued by the California Department of Food and Agriculture in 1977 because of its detection in groundwater and toxicity (California State Water Resources Control Board, 2002). DBCP was the most frequently detected fumigant or pesticide detected in groundwater samples collected from the San Joaquin Valley during 1971–88 (Domagalski, 1997) and in California as a whole up to 1999 (Troiano and others, 2001). Detection frequencies of DBCP in groundwater in the Central Valley have been higher than most other parts of the country because of its historical use on orchards and vineyards (Dubrovsky and others, 1998; Zogorski and others, 2006).

DBCP had an aquifer-scale high proportion of 1.0 percent (spatially-weighted), the highest proportion of any organic constituent (table 7A). Although high relative-concentrations were not detected in grid wells, the spatially-weighted aquifer-scale high proportion fell within the 90-percent confidence interval for the grid-based aquifer-scale high proportion (table 7A).

High relative-concentrations of DBCP occurred in parts of the north-central Merced, north-central Turlock, and central Modesto study areas (fig. 23C). Moderate relative-concentrations of DBCP occur in the north-central Merced, south-central and north-central Turlock, and central Modesto study areas.

Because DBCP was the only fumigant having moderate and high relative-concentrations, the aquifer-scale proportions for fumigants as a class were equivalent to those for DBCP (table 8). The moderate aquifer-scale proportion for fumigants (7.6 percent) was calculated from the grid-based moderate aquifer-scale proportion for DBCP (8.6 percent) minus the spatially-weighted aquifer-scale high proportion of 1.0 percent.

The fumigant EDB had high relative-concentrations in at least one well in the CDPH data before March 1, 2003, but not during the current period analyzed (table 7B). These high values represented historic values rather than current conditions.

Understanding Assessment for DBCP

DBCP was correlated significantly (positively) with orchard and vineyard land use (table 9) despite being detected in only 10 percent of the grid plus understanding wells. Detection frequencies of DBCP were higher (25 percent) in shallower (depth to top of perforations <200 ft) wells having orchard and vineyard land use >40 percent than in deeper wells (depth to the top of the perforations >200 ft) or orchard and vineyard land <40 percent (fig. 26). The relation between orchard and vineyard land use and DBCP also may partially reflect a relation between explanatory factors—a significant negative correlation between orchard and vineyard land use and well depth (but not depth to top of perforations) (table 5). DBCP was not correlated significantly with depth to top of perforations or well depth (table 9), even for wells having >40 percent orchard and vineyard land use. Relatively low detection frequencies of DBCP may mask relations with depth.

However, 6 of the 7 wells with known well construction where DBCP was detected had a depth to the top of the perforations <200 ft.

DBCP was not correlated significantly with other explanatory factors. DBCP was correlated positively with nitrate (as nitrogen) concentrations ($p = 0.338$, $p=0.015$), although nitrate was detected much more widely.

Herbicides

All detections of herbicides in samples from the Central Eastside study unit were at low relative-concentrations (figs. 21 and 22). At least one herbicide was detected in 57 percent of the 58 grid wells sampled. The highest maximum relative-concentration of 0.014 was for atrazine.

Status Assessment for Herbicides

Three herbicides, simazine, atrazine, and metolachlor, were detected in 10 percent or more of the grid wells (figs. 21 and 22). Simazine, atrazine, and metolachlor also were among the most commonly detected herbicides in groundwater in major aquifers across the United States (Gilliom and others, 2006). Four additional herbicides or herbicide degradates, de-ethylatrazine (2-chloro-4-isopropylamino-6-amino-*s*-triazine), 3,4-dichloroaniline, prometon, and hexazinone, analyzed for all grid wells, were detected in <10 percent of the primary aquifer, all at low relative-concentrations. Concentrations of these four constituents were summed with simazine, atrazine, and metolachlor to calculate the sum of herbicide concentrations.

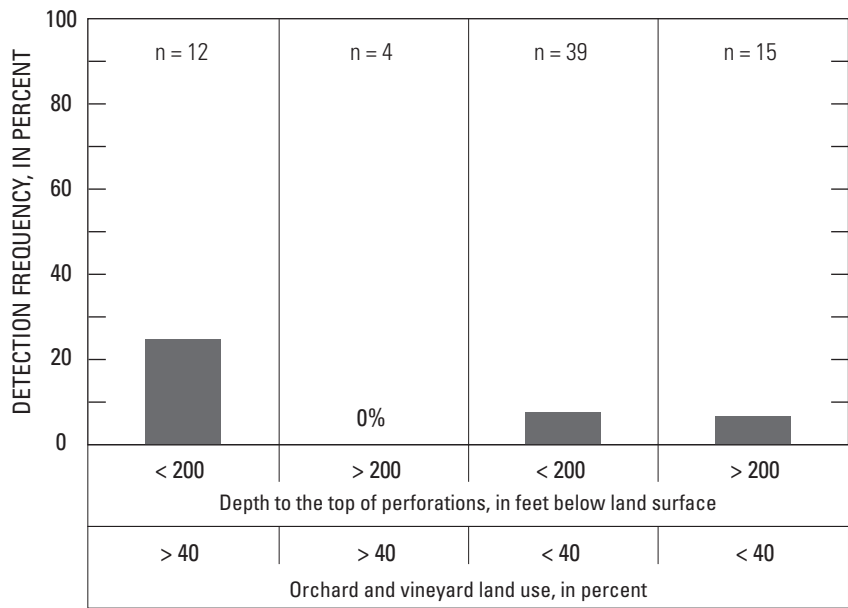


Figure 26. Relation of detection frequency of DBCP to percent orchard and (or) vineyard land use and depth to top of perforations, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Simazine was the most commonly detected herbicide (detected in 34 percent of the 58 grid wells), with detection frequencies varying by study area: 60 percent in Modesto, 48 percent in Merced, 19 percent in Turlock, and 0 percent in the Uplands study area. Simazine historically has had the highest use on vineyards and orchards in the study unit, but also has been used on right-of-ways for weed control (Domagalski and Dubrovsky, 1991). Simazine was the most frequently detected triazine herbicide in groundwater in California (Troiano and others, 2001) and in a regional survey of 183 wells of the San Joaquin Valley in 1985–87 (Domagalski and Dubrovsky, 1991).

Atrazine was detected in 31 percent of the 58 grid wells. Detection frequencies of atrazine were highest in the Modesto study area (70 percent), with comparatively lower values of <30 percent in the other three study areas (Landon and Belitz, 2008). Registered use of atrazine has been discontinued nearly entirely in the study unit since at least the late 1980s, but historically was used for weed control along roadsides and in row crops such as corn and has been detected widely in the San Joaquin Valley (Domagalski and Dubrovsky, 1991; Burow and others, 1998a; Troiano and others, 2001). Atrazine had high relative-concentrations in at least one well in the CDPH data before 2001, but not during the current period analyzed (table 7B). These high values represented historic rather than current conditions.

Metolachlor was detected in 10 percent of the 58 grid wells. Metolachlor was detected in 19 percent of grid wells in Turlock and 13 percent of grid wells in Merced, but was not detected in the Modesto or Uplands study areas. Metolachlor is an herbicide used primarily on corn in the study unit (Burow and others, 1998a).

For the class herbicides, there were no grid-based moderate or high aquifer-scale proportions (table 7B). Similarly, there were no current high relative-concentrations of constituents in these classes in the CDPH database.

Understanding Assessment for Herbicides

Concentrations of herbicides were significantly lower in pre-modern than modern- or mixed-age waters (fig. 27A, table 4). However, herbicides were detected in 6 of 20 wells (30 percent) classified as having pre-modern ages. Concentrations of herbicides were not significantly different between modern and mixed-age waters.

Herbicides primarily were detected in wells with depths to the tops of the perforations <200 ft (fig. 27B). However, herbicides were detected in some wells with depths to the tops of perforations as large as 335 ft. The detection frequency of herbicides for wells with the depths to the top of the perforations <200 ft was 75 percent, whereas for wells with depths to the top of perforations >200 ft, the detection frequency was 32 percent. Herbicides also were correlated positively with DO (table 9), but this relation may result from the correlation of DO and depth (table 5).

Herbicide concentrations were not correlated significantly with percent agricultural land use, but were correlated significantly (negatively) with percent natural land use (figs. 23D and 27C, table 9) and were correlated (positively) with percent urban land use (figs. 27D, table 9). Atrazine (along with its degradation product de-ethylatrazine) and simazine are the herbicides with the largest detection frequencies and concentrations in the Central Eastside; both herbicides have been used in agricultural and urban settings (Gilliom and others, 2006). The detection frequency of herbicides was 69 percent in wells with natural land use ≤40 percent, implying >60 percent agricultural and urban land use, and 31 percent in wells with natural land use >40 percent. The correlation of urban land use with herbicides was weaker than the relation with percent natural land use. However, detection frequencies of herbicides were higher for urban land use >40 percent than for urban land use ≤40 percent, although the relation of herbicide detection frequency to urban land use was weaker than the relation to depth of top of perforations (fig. 27D).

The detection of low concentrations of herbicides in 30 percent of wells classified as having a pre-modern age probably reflects the presence of modern water (containing herbicides) in quantities too small to detect with ³H and He tracers, given the mixing of waters of widely varying age in long-screened production wells. The age tracers indicate that these wells predominantly are pre-modern. The presence of pesticides can be used to constrain the age of the young fraction of groundwater mixtures (Plummer and others, 1993). Atrazine first was registered for use in the United States in 1958 (U.S. Environmental Protection Agency, 2003), and simazine first was introduced in 1956 (Gunasekara, 2004). The presence of atrazine or de-ethylatrazine in two pre-modern samples and simazine in two pre-modern samples indicates that some fraction of the water sample was recharged after the late 1950s. Metolachlor was first registered in 1976 (U.S. Environmental Protection Agency, 1995). The presence of metolachlor in two wells with a pre-modern age implies a fraction of the water was recharged after 1976. The higher detection frequency of herbicides (30 percent), as compared to THMs (10 percent) and solvents (5 percent) in pre-modern water, may reflect a wider areal extent of herbicide use than disinfected water use or solvent use in the Central Eastside. It also is possible that the LRLs for herbicides, which are lower than for THMs or solvents, could result in a larger number of detections and thus, higher detection frequencies of herbicides than THMs and solvents. The THMs, solvents, and herbicides are related to urban sources, as indicated by the positive correlation with urban land use and results of previous investigations (Zogorski and others, 2006). However, herbicides also are used widely in agricultural areas (Gilliom and others, 2006).

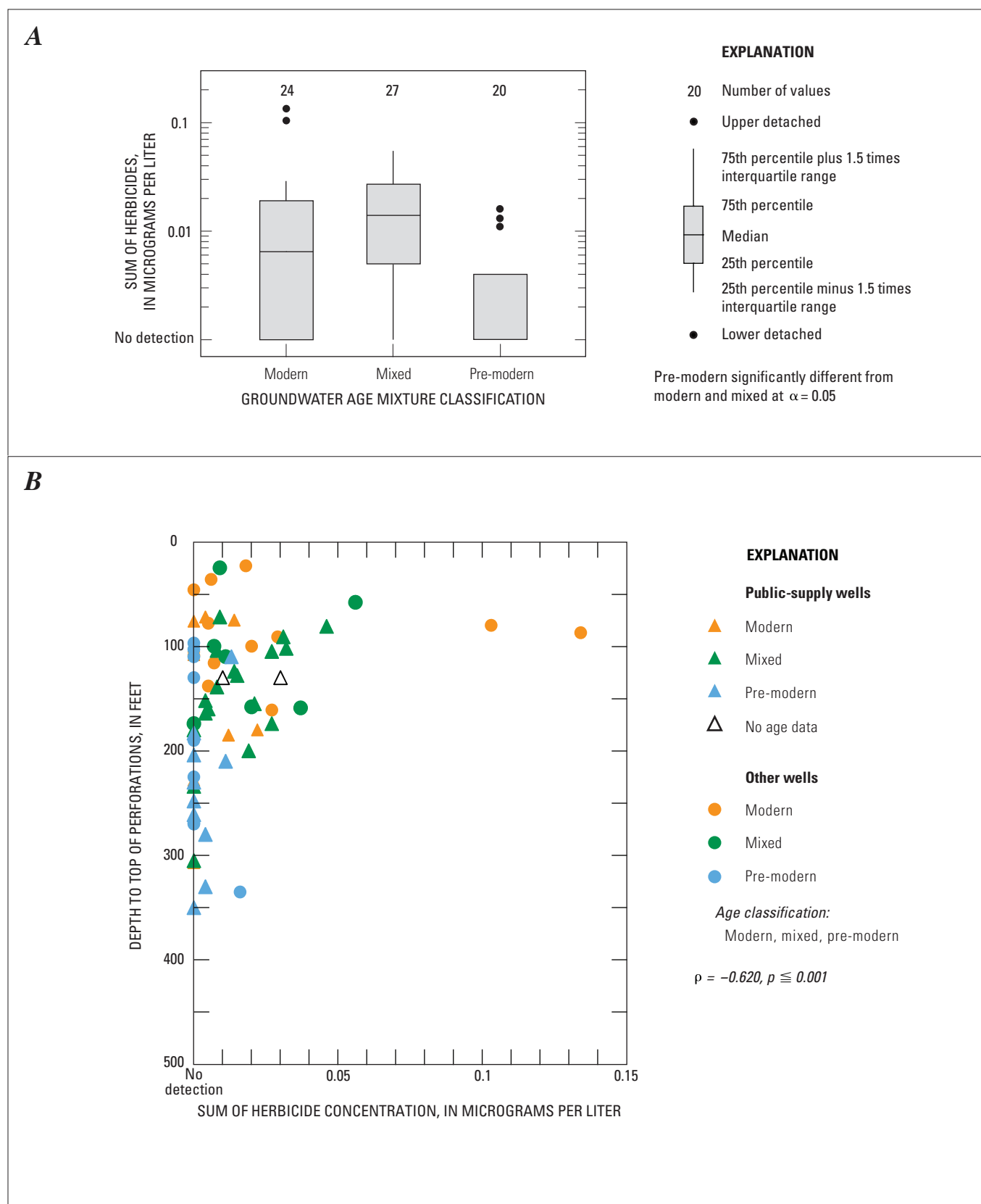


Figure 27. Relations of sum of herbicides to (A) groundwater-age classification, (B) depth to top of perforations, and (C) percent natural land use, and (D) pesticide detection frequency to percent urban land use and depth to the top of perforations, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

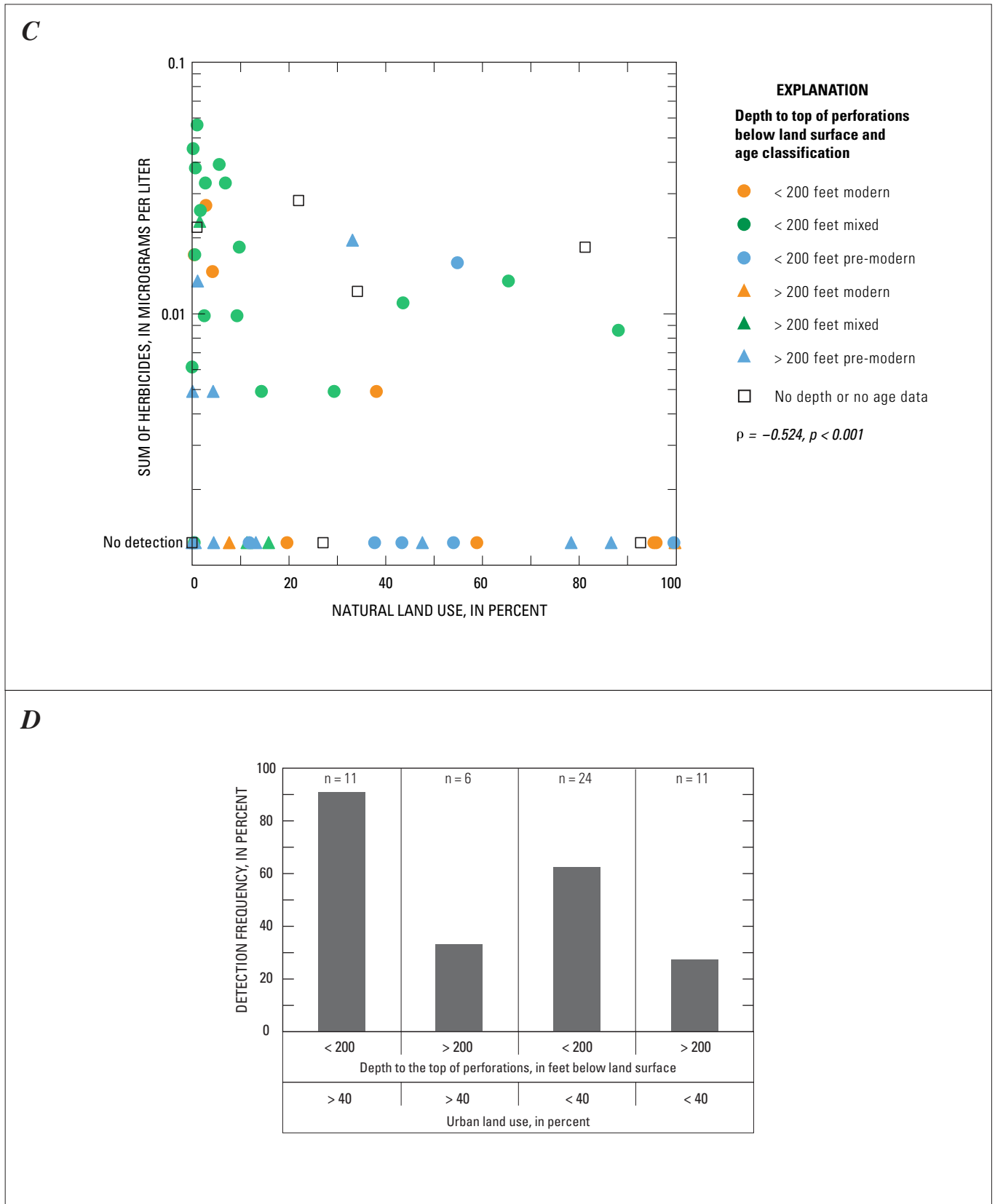


Figure 27. Continued.

The detections of herbicides in relatively deep wells having pre-modern ages potentially could be influenced by short-circuiting mechanisms that allow small quantities of modern water with dissolved herbicides to enter the wells, although most of the water extracted from the wells has pre-modern ages. For example, in a local study in Modesto, Jurgens and others (2008) found evidence of movement of waters from the shallow aquifer, with higher concentrations of many constituents, including herbicides, down the well bore of a public-supply well and into storage in the aquifer adjacent to the deepest part of the well under decreased pumping conditions during the winter. It is possible that these or other short-circuiting processes could account for the presence of trace amounts of herbicides in groundwater having an apparently pre-modern age. Also, increased pumping from a deeper aquifer will increase the downward hydraulic gradient between shallow and deeper aquifer zones, resulting in increased downward migration of water from the shallow aquifer.

Although organic constituents mostly had low or moderate relative-concentrations (except for some high relative-concentrations of DBCP and PCE), these constituents can serve as tracers of groundwater influenced by modern recharge and land-use activities and their relation to potential explanatory factors contributes to understanding factors affecting concentrations of constituents that have high concentrations.

Insecticides

Insecticides were not detected at moderate or high relative-concentrations ([table 7B](#)). Also, there were no current high relative-concentrations of constituents in this class in the CDPH database.

Special Interest Constituents

Constituents of special interest analyzed for the Central Eastside study unit were NDMA, 1,2,3-TCP, and perchlorate. These constituents were selected because recently they have been found in, or are considered to have the potential to reach, drinking-water supplies (California Department of Public Health, 2008a,b,c). NDMA was not detected in the 15 grid wells sampled (Landon and Belitz, 2008). Results of low-level analyses of 1,2,3-TCP are discussed in the Constituents Sampled for in a Subset of Wells section of this report.

Perchlorate met the selection criteria of having a maximum relative-concentration ≥ 0.1 and a detection frequency ≥ 10 percent ([fig. 21](#)). Perchlorate was included in explanatory factor analysis because it is the only constituent of special interest having moderate relative-concentrations.

Status Assessment for Special Interest Constituents

The maximum relative-concentration of perchlorate in grid wells from the Central Eastside study unit was 0.25 (MCL-CA of 6 $\mu\text{g/L}$) ([fig. 22](#)). The MRL (minimum reporting level) for perchlorate of 0.5 $\mu\text{g/L}$ corresponds with a relative-concentration of 0.083, a value close to the distinction between moderate and low values. Moderate relative-concentrations of perchlorate occurred in 20.7 percent of the aquifer and low relative-concentrations or nondetects occurred in 79.3 percent. Perchlorate had the highest detection frequency of 70 percent in the Modesto study area ([fig. 23E](#); Landon and Belitz, 2008). Detection frequencies were lower in the other three study areas, ranging from 6 to 17 percent. Perchlorate was not detected historically in the Central Eastside CDPH database above the LRL of 4 $\mu\text{g/L}$, which is considerably higher than the LRL of 0.5 $\mu\text{g/L}$ for the PBP.

Understanding Assessment for Perchlorate

Concentrations of perchlorate were significantly higher in modern and mixed-age waters than in pre-modern age waters ([table 4](#), [fig. 28A](#)). Perchlorate was not significantly different between water having modern or mixed ages. One shallow monitoring well sampled for the purposes of understanding had a concentration of 8.8 $\mu\text{g/L}$; this well was not included in aquifer proportion calculations because it did not represent the primary aquifer. Perchlorate concentrations in all other wells were 0.5 to 1.6 $\mu\text{g/L}$. Perchlorate concentrations were not correlated with depth to the top of the perforations or bottom of the well but were correlated significantly (positively) with dissolved oxygen concentrations ([table 9](#)). While perchlorate biodegrades under anoxic conditions in some aquifers (Sturchio and others, 2007), the apparent relation between perchlorate and DO in the Central Eastside may result from relations of both DO and perchlorate with modern-age and mixed-age groundwater.

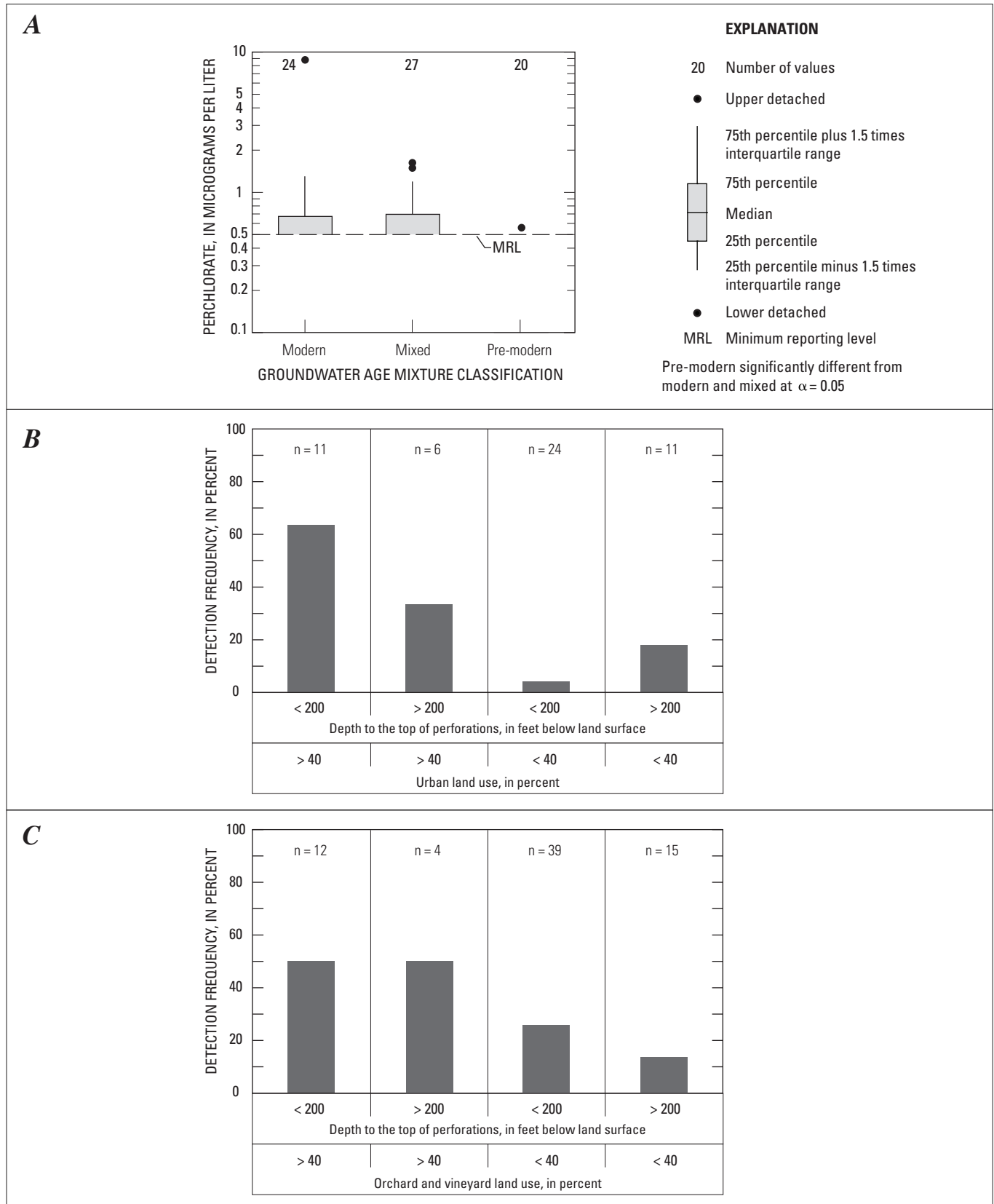


Figure 28. Relations of (A) perchlorate concentrations to groundwater-age classification, (B) perchlorate detection frequency to percent orchard and (or) vineyard land use and depth to the top of perforations below land surface, and (C) perchlorate detection frequency to percent urban land use and depth to the top of perforations below land surface, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Perchlorate was correlated significantly (positively) with orchard and vineyard land use, and urban land use ([table 9](#)). Perchlorate detection frequencies were higher in wells having high proportions of either urban land use or orchard and (or) vineyard land use than in wells having small fractions of either of these land uses ([fig. 28B,C](#)). The distribution of detections of perchlorate in modern- and mixed-age waters beneath disparate land-use areas suggests multiple potential sources. Possible anthropogenic sources of perchlorate could include nitrate fertilizers mined from the Atacama Desert of Chile that have been used historically on some orchard crops (Dasgupta and others, 2006) or industrial, manufacturing, or commercial uses such as explosives, road flares, automobile air-bag systems, and other products (Parker and others, 2008). Perchlorate derived from natural atmospheric and soil processes has been detected in groundwater in some highly arid desert environments (Dasgupta and others, 2005; Plummer and others, 2006); the influence of natural processes on perchlorate concentrations in groundwater in the Central Eastside study unit is currently unknown and beyond the scope of this investigation.

Constituents Sampled for in a Subset of Wells

For 62 constituents, including polar pesticides, selected trace elements, and selected radioactive constituents, data were available for only a subset of grid wells (<20 wells) (Landon and Belitz, 2008). Of these, two organic constituents, diuron and 1,2,3-TCP, met the selection criteria of having detection frequencies >10 percent in the samples collected. None of the constituents analyzed for a subset of wells met the selection criteria of having moderate or high relative-concentrations ([fig. 13](#)).

Diuron was detected in 20 percent of the 15 grid wells sampled for polar pesticides in the study unit ([fig. 21](#)). It was detected in two wells in the Merced study area and one well in the Modesto study area. Diuron has been used extensively throughout the San Joaquin Valley on orchards, particularly oranges, but has also been used for nonagricultural purposes such as weed control on roadways (Domagalski, 1997). Nationally, the detection frequency of diuron was <1 percent (Gilliom and others, 2006), but in California it has been detected in about 6 percent of well samples (Troiano and others, 2001).

For the fumigant synthesis byproduct 1,2,3-TCP, samples analyzed with a MRL of 0.005 µg/L (Montgomery Watson Harza Laboratories) indicated detections in 3 of the 15 grid wells (20 percent detection frequency). In comparison, in samples analyzed with an LRL of 0.18 µg/L (USGS NWQL), 1,2,3-TCP was detected in 2 of 58 grid wells (3 percent

detection frequency). In two wells, 1,2,3-TCP was detected using both methods. 1,2,3-TCP was detected in the Merced and Turlock study areas. The maximum relative-concentration of 1,2,3-TCP was 0.022. The HAL-US of 40 µg/L was used as the water-quality benchmark instead of the NL-CA of 0.005 µg/L, resulting in relative-concentrations for 1,2,3-TCP that were on a similar scale to other organic constituents. Nationally, the detection frequency of 1,2,3-TCP above 0.20 µg/L was <1 percent (Zogorski and others, 2006).

For radon-222, there are two benchmarks, a proposed MCL of 300 pCi/L and a proposed alternative MCL-US of 4,000 pCi/L. The alternative MCL-US will apply if the State or local water agency has an approved multimedia mitigation program to address radon in indoor air (U.S. Environmental Protection Agency, 1999). This alternative MCL-US is anticipated to represent the most common benchmark and was used for computing relative-concentrations for this study. Compared to this benchmark, all relative-concentrations of radon-222 were low.

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 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 water-quality conditions in study units of the GAMA Priority Basin Project (PBP).

The 1,695-square-mile Central Eastside GAMA study unit lies in the Central Valley Hydrogeologic province and contains three groundwater subbasins (Modesto, Turlock, and Merced). The Central Eastside study unit was divided into four study areas: Merced, Modesto, Turlock, and Uplands. The purposes of this report are to (1) briefly describe the hydrogeologic setting of the Central Eastside study unit, (2) assess the current status of untreated-groundwater quality in the primary aquifer in the Central Eastside study unit, and (3) assess the relations between water quality and selected potential explanatory factors for the purpose of understanding.

The GAMA PBP is designed to provide a statistically robust characterization of untreated-groundwater quality in the primary aquifer at the basin-scale. Fifty-eight grid wells were selected randomly within spatially distributed grid cells across the Central Eastside study unit. Samples were collected from these USGS grid wells for analysis of 175 to 335 constituents. Data from the most recent 3-year period available at the time of analysis (March 1, 2003,–February 28, 2006) meeting ionic charge balance criteria were selected from the CDPH database to supplement USGS grid wells for inorganic constituents not sampled for by the USGS in each grid cell (CDPH grid wells). In addition, the most recent analyses from all wells in the in the CDPH database (CDPH other wells) were incorporated in the analysis. Using these data, grid-based and spatially-weighted approaches were used to assess proportions (aquifer-scale proportions) of high, moderate, and low relative-concentrations of constituents and constituent classes in the primary aquifer.

The status assessment is intended to characterize the quality of untreated-groundwater resources in the primary aquifer within the study unit. To provide context, concentrations of constituents measured in the untreated groundwater were compared with regulatory and nonregulatory human-health and aesthetic benchmarks.

Given the large number of analytes, an objective algorithm was used to select those constituents of greatest importance to water quality in the primary aquifer for discussion in the report. 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. Those constituents with maximum relative-concentrations >1 were classified as high. For inorganic constituents, maximum relative-concentrations ≤ 1 and >0.5 were classified as moderate, and maximum relative-concentrations ≤ 0.5 were classified as low. For organic and special-interest constituents, maximum relative-concentrations ≤ 1 and >0.1 were classified as moderate, and maximum relative-concentrations ≤ 0.1 were classified as low.

Selected constituents and constituent classes having high or moderate relative-concentrations or organic and special-interest constituents with detection frequencies >10 percent were selected for additional analysis. These constituents or classes were tested for relations to a finite set of potential explanatory factors that included land use, depth, lateral position in the flow system, groundwater-age classification, and geochemical-condition indicators.

On the basis of ^3H (tritium), noble gas, and ^{14}C data, groundwater ages were classified into modern, mixed, and pre-modern categories. Of the wells for which sufficient data were available for classification, samples from 24 wells were modern, 27 were mixed, and 21 were pre-modern. Most samples from wells perforated entirely within the upper 200 ft of the aquifer were modern. Most samples from wells perforated entirely at depths ≥ 200 ft were pre-modern.

Samples from wells with the top of the perforation <200 ft, but with the bottom of the well ≥ 200 ft mostly were mixed.

Groundwater in the Central Eastside primarily was oxic (81 percent of sampled wells), but became more reducing with depth and near the western (distal or downgradient) end of the study area. pH values increased with larger depths and older groundwater ages.

The status assessment showed that one or more inorganic constituents were high, relative to human-health benchmarks, in 18.0 percent of the primary aquifer, moderate in 44.0 percent, and low in 38.0 percent. Aquifer-scale high proportions of inorganic constituents reflected high relative-concentrations of trace elements in 17.4 percent of the aquifer, radioactive constituents in 3.6 percent of the aquifer, and nutrients in 2.1 percent of the aquifer. Inorganic constituents with aquifer-scale high proportions were arsenic (15.6 percent), vanadium (3.6 percent), lead (2.4 percent), uranium (3.6 percent), gross alpha radioactivity (5.9 percent), and nitrate (2.1 percent). Inorganic constituents with moderate aquifer-scale proportions were arsenic (28.9 percent), boron (4.2 percent), lead (2.4 percent), vanadium (21.4 percent), uranium (15.2 percent), gross alpha radioactivity (10.8 percent), and nitrate (14.6 percent). Spatially-weighted aquifer-scale high proportions nearly always fell within the 90-percent confidence interval of grid-based aquifer-scale high proportions, indicating that the grid-based approach yielded statistically equivalent results to the spatially-weighted approach incorporating CDPH data.

The status assessment for organic and special-interest constituents showed that one or more of these constituents were high, relative to human-health benchmarks, in a smaller proportion of the primary aquifer (1.2 percent) than inorganic constituents (18.0 percent). Organic constituents had moderate relative-concentrations in 14.3 percent of the primary aquifer and low relative-concentrations in 84.5 percent. The proportion of the primary aquifer with high relative-concentrations of organic constituents reflected aquifer-scale high proportions of the discontinued soil fumigant 1,2-dibromo-3-chloropropane (DBCP, 1.0 percent) and the solvent tetrachloroethene (PCE, 0.2 percent). Four organic and special-interest constituents were detected at moderate relative-concentrations in grid wells, including: chloroform (3.4 percent), carbon tetrachloride (3.4 percent), DBCP (8.6 percent), and perchlorate (20.7 percent).

The status assessment for organic constituents indicated that 22 of the 78 VOCs (not including fumigants) and 10 of the 115 pesticides and pesticide degradates analyzed in grid wells were detected. All detections of VOCs and pesticides in grid-well samples from the Central Eastside study unit were below human-health benchmarks. Of the 22 VOCs detected, 20 had low maximum relative-concentrations. Of the 22 VOCs detected, 17 had detection frequencies of <10 percent. Five VOCs were detected in ≥ 10 percent of the grid wells—the THMs chloroform, bromoform, bromodichloromethane, and dibromochloromethane, and the solvent PCE. For the six parent herbicides with benchmarks,

all had low relative-concentrations. Of the five herbicide parent compounds detected, analyzed in all 58 grid wells, and having benchmarks, three had detection frequencies ≥ 10 percent. Atrazine, simazine, and metolachlor were detected in 31 percent, 34 percent, and 10 percent of grid wells, respectively. Perchlorate was detected in 22 percent of grid wells.

The understanding assessment indicated that the concentrations of many constituents were related to depth and groundwater age. However, concentrations of individual constituents or constituent classes also were sometimes related to geochemical conditions, lateral position in the flow system, or land use.

Nitrate, uranium, and total dissolved solids concentrations had higher concentrations in the upper 200 ft than in the deeper parts of the aquifer system. There was a similar contrast in concentrations for a number of constituents that did not have human-health benchmarks or that were detected only at low relative-concentrations (such as sum of herbicides). Constituents with these vertical profiles included most major ions (calcium, magnesium, sodium, bicarbonate, chloride, and sulfate), and several trace elements (strontium, barium, cobalt, and lithium). Isotopic values of boron, sulfate, strontium, carbon, and uranium also had contrasting values between the upper 200 ft and greater depths. A detailed discussion of the processes affecting these additional constituents and tracers is beyond the scope of this report.

The concentration profiles for multiple constituents suggests that water chemistry generally differs between the upper 200 ft of the aquifer and depths >200 ft. The zonation of water chemistry with depth is consistent with the hydrogeologic setting, in which return flows from agricultural and urban land use are the major source of recharge, and withdrawals for irrigation are the major source of discharge, resulting in substantial vertical components of groundwater flow.

The decrease in concentrations of many constituents with depth reflects, in part, that groundwater generally gets older with depth in the Central Eastside study unit. Uranium, nitrate, herbicide, and perchlorate concentrations were significantly larger in groundwater having modern and mixed ages than pre-modern ages, indicating that these constituents may be affected by anthropogenic activities in the last 50 years.

Other patterns in the distribution of nitrate, uranium, and TDS were evident. Nitrate concentrations were correlated positively with dissolved oxygen. Nitrate concentrations and percent orchard and vineyard land use were correlated in groundwater sampled from <200 ft below land surface. Additional isotopic and geochemical data are consistent with partial denitrification of nitrate in some reducing groundwaters in the western and deeper parts of the flow system. Geochemical and isotopic patterns for this study are similar to those of a local-scale study in Modesto and a regional-scale study in the eastern San Joaquin Valley in which elevated uranium in shallow groundwater was attributed to desorption of uranium from sediments by irrigation and urban recharge.

Uranium and TDS increase from east to west across the valley, along the direction of regional lateral groundwater flow.

Mobilization of the trace element arsenic by reductive dissolution of manganese or iron oxides and desorption by high pH waters explains high-to-moderate arsenic concentrations in the Central Eastside study unit. The primary variable influencing moderate-to-high concentrations of the trace element vanadium appears to be high pH, particularly in oxic waters. The pattern of increasing arsenic with increasing groundwater age and depth was opposite to the pattern for uranium, which decreased with depth and groundwater age. These divergent patterns with depth reflect different mobilization processes. High concentrations of another trace element, manganese (SMCL), occurred in reduced groundwater located in the western and deep parts of the aquifer in the study unit.

For organic and special interest constituents, THMs and solvents are significantly and positively correlated with percent urban land use. THM concentrations also were significantly and positively correlated with DO. DBCP, although detected infrequently, primarily was detected in areas with a high proportion of orchard and vineyard land use and at depths <200 ft. Herbicide concentrations were negatively correlated with percent natural land use and positively correlated with percent urban land use. Perchlorate was significantly and positively correlated with two land uses—percent orchard/vineyard land use and percent urban land use.

Generally, there were many similarities in groundwater quality areally across the study unit. However, some variations in groundwater quality between study areas were evident, most likely as a result of differences in land use, lateral position, redox, and pH. The Modesto study area had higher detection frequencies of THMs, solvents, and perchlorate than other study areas; these constituents were positively correlated with urban land use and the higher detection frequencies in Modesto are consistent with greater percentages of urban land use than in the other study areas. The grid wells, particularly in the Modesto study area, had more urbanized land use than the study areas as a whole; therefore, the grid well data may reflect greater urban influence than might be expected on the basis of the average land use of the study areas. Detection frequencies of herbicides generally were lower in the Uplands study area than in the Modesto, Turlock, and Merced study areas; herbicides were correlated negatively with natural land use and the lower detection frequencies in the uplands study area may reflect greater amounts of natural land use in the uplands study area compared to the other study areas. High concentrations of arsenic and manganese occurred in the western Modesto, Turlock, and Merced study areas but did not occur in the Uplands study area located in the eastern portion of the study unit; this pattern reflects that groundwater becomes more reducing in the western part of the study unit. Concentrations of uranium and TDS also increased from east to west across the study unit, probably reflecting several processes that vary with valley position, and concentrations of these constituents were lower in the Uplands study area than in the Modesto, Turlock, and Merced study areas.

At the low concentrations at which they generally were present, VOCs, pesticides, and perchlorate primarily are tracers of groundwater that has recharged in the decades since these compounds began to be used for industrial and commercial purposes. Low-level analyses provide an early awareness of constituents whose presence in groundwater at low concentrations may be important for prioritization of monitoring of water quality in the future.

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Appendix A. Attributes of USGS–GAMA and CDPH Grid Wells

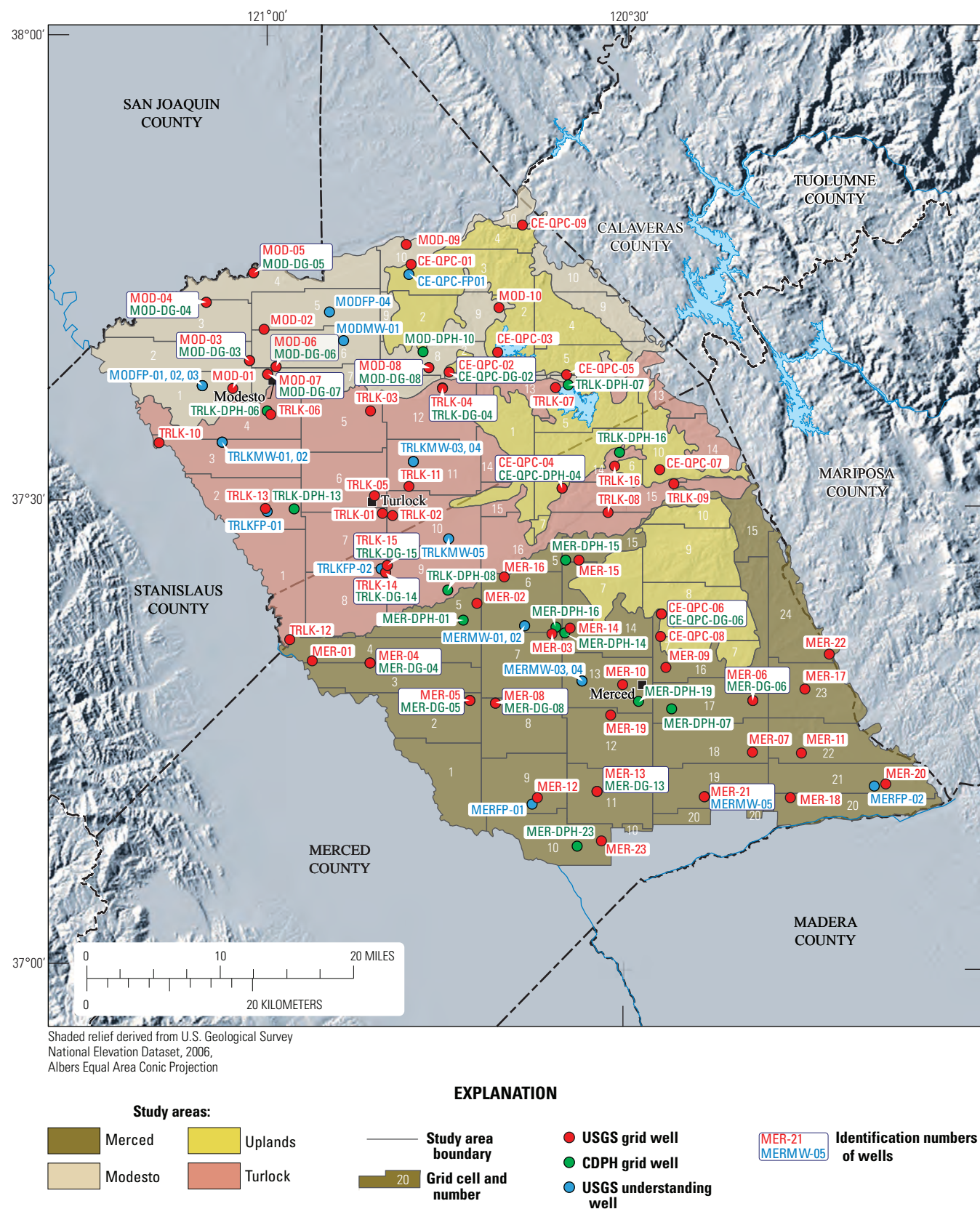


Figure A1. Identification numbers and locations of grid and understanding wells sampled during March–June, 2006, and grid wells at which data for inorganic constituents from the California Department of Public Health were used, Central Eastside, California, Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

Table A1. Identifiers and explanatory factor attributes of grid and understanding wells sampled during March–June, 2006, and grid wells at which data for inorganic constituents from the California Department of Public Health were used, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study.

[CDPH, California Department of Public Health; CE-QPC, Uplands study area well; MER, Merced study area well; MOD, Modesto study area well; TRLK, Turlock study area well; FP, flow-path well; MW, monitoring well; ft, feet; m, meter; LSD, land surface datum; na, not available; nc, not calculated; USGS, U.S. Geological Survey; MER-##, naming convention for USGS-grid well; MER-DG-##, naming convention for CDPH data from a USGS-grid well; MER-DPH-##, naming convention for CDPH-data from a CDPH-grid well; PSW, public supply well; COM, commercial well; DOM, domestic well; IRR, irrigation well; MON, monitoring well; DRAIN, drainage well; USGS, U.S. Geological Survey; age-tracer data reported in [table A2](#); oxidation-reduction data reported in [table A3](#)]

USGS GAMA well identification number	CDPH GAMA well identification number	Well type	Agricultural land use within 500-m of the well (percent)	Natural land use within 500-m of the well (percent)	Urban land use within 500-m of the well (percent)	Construction information			Length from top of uppermost perforated interval to bottom of well (ft below LSD)	Normalized lateral position (dimension- less)
						Well depth (ft below LSD)	Top of perforations (ft below LSD)	Bottom of perforations (ft below LSD)		
Grid wells										
CE-QPC-01	none	PSW	46.8	34.1	19.0	280	na	na	na	0.73
CE-QPC-02	CE-QPC-DG-02	PSW	40.9	0.6	58.5	300	124	na	176	0.65
CE-QPC-03	none	PSW	0.2	99.7	0.1	285	228	na	57	0.76
CE-QPC-04	none	COM	7.4	92.6	0.0	336	252	na	84	0.66
CE-QPC-05	none	DOM	44.3	54.0	1.7	117	97	117	20	0.85
CE-QPC-06	CE-QPC-DG-06	PSW	59.6	37.7	2.7	358	183	na	175	0.67
CE-QPC-07	none	COM	21.8	78.2	0.0	380	270	380	110	0.86
CE-QPC-08	none	DOM	1.4	95.3	3.3	109	na	na	na	0.65
CE-QPC-09	none	DOM	12.0	88.0	0.0	100	na	na	na	1.00
MER-01	none	DOM	56.7	43.3	0.0	130	110	130	20	0.00
MER-02	none	PSW	89.2	1.0	9.7	na	na	na	na	0.32
MER-03	none	PSW	4.0	11.3	84.7	526	305	515	221	0.43
MER-04	MER-DG-04	PSW	65.2	0.5	34.4	75	na	na	na	0.04
MER-05	MER-DG-05	PSW	52.5	47.5	0.0	268	248	268	20	0.18
MER-06	MER-DG-06	PSW	44.9	0.1	55.0	178	130	150	48	0.73
MER-07	none	PSW	99.7	0.0	0.3	na	na	na	na	0.67
MER-08	MER-DG-08	PSW	99.1	0.8	0.1	380	130	380	250	0.22
MER-09	none	PSW	61.4	2.7	35.9	266	174	249	92	0.59
MER-10	none	PSW	10.2	5.6	84.2	294	102	294	192	0.49
MER-11	none	PSW	48.0	15.8	36.2	630	234	620	396	0.81
MER-12	none	IRR	34.6	65.3	0.1	210	110	210	100	0.12
MER-13	MER-DG-13	PSW	45.2	54.8	0.0	355	110	350	245	0.24
MER-14	none	PSW	17.3	13.2	69.5	734	261	730	473	0.47
MER-15	none	PSW	95.6	4.2	0.1	185	na	185	na	0.57
MER-16	none	PSW	64.1	14.3	21.5	167	152	167	15	0.41
MER-17	none	DOM	16.3	81.1	2.6	na	na	na	na	0.88
MER-18	none	DOM	88.2	11.8	0.0	200	na	na	na	0.70
MER-19	none	DOM	74.8	22.0	3.2	na	na	na	na	0.41
MER-20	none	IRR	66.9	33.1	0.0	923	335	909	588	0.93
MER-21	none	MON	13.5	86.5	0.0	345	225	345	120	0.48
MER-22	none	DOM	0.0	99.4	0.6	130	na	na	na	0.99
MER-23	none	COM	100.0	0.0	0.0	485	350	475	135	0.14
MOD-01	none	PSW	87.3	1.0	11.7	81	81	na	0	0.21
MOD-02	none	PSW	0.0	0.7	99.3	395	91	366	304	0.35
MOD-03	MOD-DG-03	PSW	1.3	2.9	95.9	255	180	255	75	0.28
MOD-04	MOD-DG-04	PSW	34.0	29.3	36.7	304	164	276	140	0.27
MOD-05	MOD-DG-05	PSW	35.3	9.3	55.4	292	139	271	153	0.41

Table A1. Identifiers and explanatory factor attributes of grid and understanding wells sampled during March–June, 2006, and grid wells at which data for inorganic constituents from the California Department of Public Health were used, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study.—Continued

[CDPH, California Department of Public Health; CE-QPC, Uplands study area well; MER, Merced study area well; MOD, Modesto study area well; TRLK, Turlock study area well; FP, flow-path well; MW, monitoring well; ft, feet; m, meter; LSD, land surface datum; na, not available; nc, not calculated; USGS, U.S. Geological Survey; MER-##, naming convention for USGS-grid well; MER-DG-##, naming convention for CDPH data from a USGS-grid well; MER-DPH-##, naming convention for CDPH-data from a CDPH-grid well; PSW, public supply well; COM, commercial well; DOM, domestic well; IRR, irrigation well; MON, monitoring well; DRAIN, drainage well; USGS, U.S. Geological Survey; age-tracer data reported in [table A2](#); oxidation-reduction data reported in [table A3](#)]

USGS GAMA well identification number	CDPH GAMA well identification number	Well type	Agricultural land use within 500-m of the well (percent)	Natural land use within 500-m of the well (percent)	Urban land use within 500-m of the well (percent)	Construction information			Length from top of uppermost perforated interval to bottom of well (ft below LSD)	Normalized lateral position (dimension- less)
						Well depth (ft below LSD)	Top of perforations (ft below LSD)	Bottom of perforations (ft below LSD)		
MOD-06	MOD-DG-06	PSW	0.0	9.7	90.3	216	128	192	88	0.32
MOD-07	MOD-DG-07	PSW	0.3	1.7	97.9	231	155	231	76	0.29
MOD-08	MOD-DG-08	PSW	65.3	1.6	33.1	296	200	292	96	0.61
MOD-09	none	PSW	49.6	7.7	42.7	338	307	338	31	0.75
MOD-10	none	IRR	99.8	0.2	0.0	815	159	815	656	0.84
TRLK-01	none	PSW	0.5	4.4	95.2	348	280	348	68	0.31
TRLK-02	none	PSW	48.2	0.5	51.3	272	180	252	92	0.33
TRLK-03	none	PSW	75.4	4.5	20.2	497	230	460	267	0.44
TRLK-04	TRLK-DG-04	PSW	39.2	2.5	58.3	332	104	na	228	0.61
TRLK-05	none	PSW	0.0	0.7	99.3	472	204	457	268	0.32
TRLK-06	none	PSW	50.6	6.9	42.5	221	105	213	116	0.24
TRLK-07	none	PSW	0.0	95.8	4.2	200	100	196	100	0.81
TRLK-08	none	PSW	62.0	38.0	0.0	128	72	na	56	0.70
TRLK-09	none	PSW	54.5	19.6	25.9	338	76	na	262	0.87
TRLK-10	none	PSW	46.5	43.5	10.0	116	72	112	44	0.00
TRLK-11	none	PSW	21.6	1.1	77.2	410	210	400	200	0.39
TRLK-12	none	PSW	40.1	58.8	1.1	158	108	na	50	0.00
TRLK-13	none	PSW	91.6	1.0	7.3	104	84	104	20	0.09
TRLK-14	TRLK-DG-14	PSW	100.0	0.0	0.0	360	160	355	200	0.22
TRLK-15	TRLK-DG-15	PSW	99.9	0.1	0.0	400	330	390	70	0.24
TRLK-16	none	COM	73.0	27.0	0.0	na	na	na	na	0.79
none	CE-QPC- DPH-04	PSW	7.4	92.6	0.0	340	232	336	108	0.66
none	MER-DPH-01	PSW	58.8	8.6	32.6	na	na	na	na	0.27
none	MER-DPH-07	PSW	58.1	10.9	31.0	672	457	672	215	0.54
none	MER-DPH-14	PSW	nc	nc	nc	na	na	na	na	0.45
none	MER-DPH-15	PSW	99.9	0.1	0.0	na	na	na	na	0.55
none	MER-DPH-16	PSW	23.0	4.8	72.2	na	na	na	na	0.44
none	MER-DPH-19	PSW	12.7	9.6	77.7	198	110	176	88	0.48
none	MER-DPH-23	PSW	nc	nc	nc	315	240	300	na	0.07
none	MOD-DPH-10	PSW	81.9	14.4	3.7	260	200	260	60	0.63
none	TRLK-DPH-06	PSW	nc	nc	nc	266	109	221	157	0.24
none	TRLK-DPH-07	PSW	nc	nc	nc	na	na	na	na	0.84
none	TRLK-DPH-08	PSW	74.3	12.8	12.8	na	na	na	na	0.30
none	TRLK-DPH-13	PSW	nc	nc	nc	na	na	na	na	0.15
none	TRLK-DPH-16	PSW	nc	nc	nc	na	na	na	na	0.82

Table A1. Identifiers and explanatory factor attributes of grid and understanding wells sampled during March–June, 2006, and grid wells at which data for inorganic constituents from the California Department of Public Health were used, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study.—Continued

[CDPH, California Department of Public Health; CE-QPC, Uplands study area well; MER, Merced study area well; MOD, Modesto study area well; TRLK, Turlock study area well; FP, flow-path well; MW, monitoring well; ft, feet; m, meter; LSD, land surface datum; na, not available; nc, not calculated; USGS, U.S. Geological Survey; MER-##, naming convention for USGS-grid well; MER-DG-##, naming convention for CDPH data from a USGS-grid well; MER-DPH-##, naming convention for CDPH-data from a CDPH-grid well; PSW, public supply well; COM, commercial well; DOM, domestic well; IRR, irrigation well; MON, monitoring well; DRAIN, drainage well; USGS, U.S. Geological Survey; age-tracer data reported in [table A2](#); oxidation-reduction data reported in [table A3](#)]

USGS GAMA well identification number	CDPH GAMA well identification number	Well type	Agricultural land use within 500-m of the well (percent)	Natural land use within 500-m of the well (percent)	Urban land use within 500-m of the well (percent)	Construction information			Length from top of uppermost perforated interval to bottom of well (ft below LSD)	Normalized lateral position (dimension- less)
						Well depth (ft below LSD)	Top of perforations (ft below LSD)	Bottom of perforations (ft below LSD)		
USGS-Understanding Wells										
CE-QPC-FP01	none	IRR	97.1	1.5	1.4	611	315	606	296	0.71
MERFP-01	none	IRR	24.1	75.9	0.0	368	na	na	na	0.10
MERFP-02	none	DOM	14.0	86.0	0.0	na	na	na	na	0.91
MERMW-01	none	MON	97.4	0.1	2.5	88	78	83	10	0.38
MERMW-02	none	MON	97.4	0.1	2.5	148	138	143	10	0.38
MERMW-03	none	MON	97.8	2.2	0.0	56	46	51	10	0.43
MERMW-04	none	MON	97.8	2.2	0.0	168	158	163	10	0.43
MERMW-05	none	MON	17.3	79.2	3.6	68	23	68	45	0.48
MODFP-01	none	MON	100.0	0.0	0.0	280	269	274	11	0.15
MODFP-02	none	MON	100.0	0.0	0.0	183	174	179	9	0.15
MODFP-03	none	MON	100.0	0.0	0.0	35	25	30	10	0.15
MODFP-04	none	IRR	98.9	1.1	0.0	275	116	275	159	0.50
MODMW-01	none	MON	94.6	3.2	2.2	260	100	260	160	0.48
TRLKFP-01	none	DRAIN	92.1	1.4	6.5	80	na	na	na	0.09
TRLKFP-02	none	DRAIN	100.0	0.0	0.0	58	na	na	na	0.22
TRLKMW-01	none	MON	99.9	0.1	0.0	113	103	108	10	0.11
TRLKMW-02	none	MON	99.9	0.1	0.0	46	36	41	10	0.11
TRLKMW-03	none	MON	98.1	1.7	0.2	171	161	166	10	0.44
TRLKMW-04	none	MON	98.1	1.7	0.2	101	91	96	10	0.44
TRLKMW-05	none	MON	100.0	0.0	0.0	97	87	92	10	0.39

Table A2. Summary of groundwater age data and classification into modern, mixed, and pre-modern age categories for samples collected during March–June, 2006, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.[°C, degrees celsius; $^3\text{H}/^4\text{He}$, Helium-3/Helium-4; ^{14}C , carbon-14; pmc, percent modern carbon; <, less than; >, greater than; na, not applicable; blank field, no data; —, not detected; e, estimated]

GAMA well identification number	Recharge temperature (°C)	Recharge temperature uncertainty, (°C)	Terrigenic				³ H/ ³ He _{tr} age uncertainty (years)	¹⁴ C (pmc)	¹⁴ C counting uncertainty (pmc)	¹⁴ C age (uncorrected) (years)	¹⁴ C age uncertainty (uncorrected) (years)	Age classifi- cation
			Tritium (tritium units)	Tritium uncertainty (tritium units)	helium (percent of total helium)	³ H/ ³ He _{tr} age (years)						
Grid Wells												
CE-QPC-01	18.3	<0.1	10.85	0.60	0.0	32.7	1.0	110.0	0.6	<1,000	na	Modern
CE-QPC-02	17.8	<0.1	2.79	0.13	82.8	>50	na					Mixed
CE-QPC-03	15.3	<0.1	8.50	0.38	0.0	32.1	0.9					Modern
CE-QPC-04	19.6	<0.1			5.2	>50	na					Mixed/Pre-modern
CE-QPC-05	19.6	<0.1	0.31	0.17	8.6	>50	na					Pre-modern
CE-QPC-06	21.0	<0.1	0.85	0.11	23.6	>50	na					Pre-modern
CE-QPC-07	24.1	0.7	—	0.31	59.4	>50	na	48.7	0.2	5,900	1	Pre-modern
CE-QPC-08	18.0	0.2	4.81	0.23	0.3	29.9	0.9					Modern
CE-QPC-09	16.6	0.8	3.32	0.31	28.2	16.3	2.2	110.3	0.5	<1,000	na	Mixed
MER-01	16.2	<0.1	0.75	0.09	98.7	>50	na					Pre-modern
MER-02	21.7	0.1	5.20	0.41	79.0	41.9	1.6		0.4	1,500	87	Mixed
MER-03	17.5	<0.1	1.60	0.19	95.0	>50	na	82.1	0.3	8,700	97	Mixed
MER-04	22.6	0.6	3.65	0.19	0.0	10.9	0.5	34.4				Modern
MER-05	16.5	0.1	0.55	0.07	89.0	>50	na					Pre-modern
MER-06	19.1	0.2			96.9	>50	na					Mixed/ Pre-modern
MER-07	18.5e	2.7e			24.9	>50	na					Pre-modern
MER-08												Pre-modern
MER-09	18.8	<0.1	5.20	0.41	28.6	32.1	1.6	105.2	0.4	<1,000	na	no data
MER-10	16.8	0.3	4.70	0.41	39.6	36.6	1.7	96.6	0.4	<1,000	na	Mixed
MER-11	15.7	<0.1	4.83	0.31	41.4	32.4	1.6	94.9	0.4	<1,000	na	Mixed
MER-12	12.1	<0.1	1.60	0.31	44.9	16.5	6.7	100.8	0.4	<1,000	na	Mixed
MER-13	18.6	<0.1	0.34	0.19	23.0	>50	na					Pre-modern
MER-14	17.6	0.1	0.97	0.13	97.8	>50	na					Pre-modern
MER-15	18.9	<0.1	8.47	0.35	0.0	24.7	0.8					Modern
MER-16	20.6	0.1	4.66	0.21	90.5	>50	na					Mixed
MER-17	20.6	0.2	5.02	0.27	0.0	2.3	0.1					Modern
MER-18	20.5	<0.1	0.51	0.09	16.6	>50	na					Pre-modern
MER-19	18.8	<0.1	11.44	0.47	6.0	14.9	1.0					Mixed

Table A2. Summary of groundwater age data and classification into modern, mixed, and pre-modern age categories for samples collected during March–June, 2006, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.—Continued

GAMA well identification number	Recharge temperature (°C)	Recharge temperature uncertainty, (°C)	Tritium, (tritium units)	Tritium uncertainty (tritium units)	Terrigenic helium (percent of total helium)	$^3\text{H}/^3\text{He}_{\text{tri}}$ age (years)	$^3\text{H}/^3\text{He}_{\text{tri}}$ age uncertainty (years)	^{14}C (pmc)	^{14}C counting uncertainty (pmc)	^{14}C age uncertainty (uncorrected) (years)	^{14}C age uncertainty (uncorrected) (years)	Age classifi- cation
MER-20	10.4	8.9	0.50	0.31	77.6	>50	na	27.0	0.2	10,800	15	Pre-modern
MER-21	20.7	<0.1	—	0.19	27.1	>50	na	51.2	0.3	5,400	87	Pre-modern
MER-22	23.1	1.0	0.56	0.10	97.6	>50	na					Pre-modern
MER-23	15.6	<0.1	0.11	0.05	64.5	>50	na					Pre-modern
MOD-01	17.9	<0.1	5.61	0.41	77.1	30.5	1.5	91.4	0.4	<1,000	na	Mixed
MOD-02	19.7	<0.1	4.01	0.41	58.2	39.9	1.9	97.0	0.4	<1,000	na	Mixed
MOD-03	13.1	0.3	4.11	0.20	1.8	Not Datable						Modern
MOD-04	15.6	<0.1	1.55	0.10	18.9	37.2	2.0					Mixed
MOD-05	15.9	<0.1	4.82	0.20	53.4	36.2	1.2					Mixed
MOD-06	18.2	<0.1	2.40	0.13	80.6	>50	na					Mixed
MOD-07	16.7	<0.1	4.62	0.32	95.7	>50	na					Mixed
MOD-08	17.5	<0.1	5.32	0.22	68.1	45.8	1.1					Mixed
MOD-09	15.4	1.8	1.00	0.31	0.0	36.8	4.9	93.4	0.5	<1,000	na	Modern
MOD-10	20.6	0.2	1.52	0.13	29.7	>50	na					Mixed
TRLK-01	16.8	0.1	—	0.19	95.5	>50	na					Pre-modern
TRLK-02	18.8	<0.1	1.69	0.19	77.1	46.9	2.3	14.0	0.2	16,200	96	Mixed
TRLK-03	17.3	<0.1	0.46	0.07	83.9	>50	na	55.4	0.3	4,800	40	Pre-modern
TRLK-04	18.1	<0.1	8.02	0.33	66.0	33.0	1.1	19.0	0.2	13,700	56	Mixed
TRLK-05	17.8	<0.1	0.41	0.19	88.8	>50	na	26.7	0.2	10,800	118	Pre-modern
TRLK-06	20.7	<0.1	9.21	0.36	58.5	33.1	1.1					Mixed
TRLK-07	16.1	<0.1	5.42	0.39	0.0	19.5	1.0					Modern
TRLK-08	19.8	<0.1	4.52	0.32	0.0	17.6	0.9					Modern
TRLK-09	18.4	<0.1	4.04	0.21	0.0	18.5	0.7					Modern
TRLK-10	16.9	<0.1	2.51	0.31	44.2	25.0	2.6	90.8	0.5	<1,000	na	Mixed
TRLK-11	17.9	0.1	0.50	0.19	69.6	>50	na	39.4	0.3	7,600	88	Pre-modern
TRLK-12	19.8	0.2	6.12	0.61	4.4	42.3	1.7					Modern
TRLK-13			12.73	0.56								Modern/ Mixed
TRLK-14	18.5e	2.7e	1.64	0.68	97.4	>50	na					Mixed
TRLK-15	18.6	0.3	0.51	0.07	98.4	>50	na					Pre-modern
TRLK-16	22.8	0.1	1.08	0.11	0.0	6.4	0.5					Modern

[°C, degrees celsius; $^3\text{H}/^4\text{He}$, Helium-3/Helium-4; ^{14}C , carbon-14; pmc, percent modern carbon; <, less than; >, greater than; na, not applicable; blank field, no data; —, not detected; e, estimated]

Table A2. Summary of groundwater age data and classification into modern, mixed, and pre-modern age categories for samples collected during March–June, 2006, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.—Continued

[°C, degrees celsius; ³ He/ ⁴ He, Helium-3/Helium-4; ¹⁴ C, carbon-14; pmc, percent modern carbon; <, less than; >, greater than; na, not applicable; blank field, no data; —, not detected; e, estimated]														
GAMA well identification number	Recharge temperature (°C)	Recharge temperature uncertainty, (°C)	Tritium			Terrigenous helium		³ H/ ³ He _{tr} age (years)	³ H/ ³ He _{tr} age uncertainty (years)	¹⁴ C (pmc)	¹⁴ C counting uncertainty (pmc)	¹⁴ C age (years)	¹⁴ C age uncertainty (uncorrected) (years)	Age classifi- cation
			Tritium, (tritium units)	Tritium uncertainty (tritium units)	helium (percent of total helium)									
Understanding Wells														
CE-QPCFP-01			1.74	0.13										Modern/ Mixed
MERFP-01	14.2	<0.1	0.91	0.31	57.5	>50	na	80.2	0.3	1,700	71	Pre-modern		
MERFP-02	21.0	<0.1	—	0.31	35.6	>50	na	3.2	0.1	28,400	369	Pre-modern		
MERMW-01	19.7	1.0	4.70	0.41	0.0	10.0	0.7	116.5	0.6	<1,000	na	Modern		
MERMW-02	19.4	<0.1	8.03	0.50	0.0	33.0	1.1	128.7	0.6	<1,000	na	Modern		
MERMW-03	22.8	<0.1	9.72	0.60	0.0	37.7	1.1	111.4	0.5	<1,000	na	Modern		
MERMW-04	20.4	0.3	4.33	0.41	18.0	32.7	1.8	92.0	0.5	<1,000	na	Mixed		
MERMW-05	24.5	<0.1	2.10	0.31	0.0	4.2	0.6	94.5	0.4	<1,000	na	Modern		
MODFP-01	14.1	4.3	—	0.19	99.4	>50	na	0.9	0.1	39,000	1,042	Pre-modern		
MODFP-02	16.3	0.1	2.92	0.31	95.6	44.3	3.3	72.7	0.3	2,600	7	Mixed		
MODFP-03	21.7	0.2	3.20	0.31	5.9	>50	na	88.6	0.4	<1,000	na	Mixed		
MODFP-04	17.8	0.1	10.94	0.60	0.0	35.5	1.0	119.2	0.6	<1,000	na	Modern		
MODMW-01	21.8	<0.1	9.34	0.60	0.0	15.2	0.8	122.1	0.6	<1,000	na	Modern		
TRLKFP-01	18.8	<0.1	4.61	0.41	0.0	6.1	0.5	107.5	0.4	<1,000	na	Modern		
TRLKFP-02	18.8	0.1	3.82	0.31	13.9	19.5	2.1	105.8	0.4	<1,000	na	Mixed		
TRLKMW-01	17.8	<0.1	0.91	0.19	86.2	>50	na	67.2	0.3	3,200	49	Pre-modern		
TRLKMW-02	17.9	<0.1	9.44	0.60	0.0	29.7	1.1	114.5	0.5	<1,000	na	Modern		
TRLKMW-03	18.8	<0.1	6.11	0.41	0.0	33.4	1.2	103.0	0.5	<1,000	na	Modern		
TRLKMW-04	18.8	<0.1	5.61	0.41	0.0	26.8	1.1	99.7	0.4	<1,000	na	Modern		
TRLKMW-05	21.1	<0.1	7.62	0.50	0.0	12.5	0.7	113.7	0.6	<1,000	na	Modern		

[°C, degrees celsius; $^3\text{H}/^4\text{He}$, Helium-3/Helium-4; ^{14}C , carbon-14; pmc, percent modern carbon; <, less than; >, greater than; na, not applicable; blank field, no data; —, not detected; e, estimated]

Table A3. Concentrations of constituents used to classify oxidation-reduction conditions in groundwater, nitrogen and oxygen isotopic values of nitrate, and excess nitrogen gas concentrations, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.

[Redox, oxidation-reduction; mg/L, milligram per liter; µg/L, microgram per liter; oxic, dissolved oxygen > 0.5; anoxic, dissolved oxygen < 0.5 but no other redox indicators available; suboxic, dissolved oxygen < 0.5 but redox status cannot be further discerned because multiple indicators are below thresholds; NO3-red, nitrate reducing; Mn-red, manganese reducing; Fe-red, iron reducing; >, greater than; <, less than; Mix – Y/Z, mixture of waters with different redox ranging from most oxidized (Y) to most reduced (Z); —, no detection (values reported as zero) in CDPH database, method detection limit variable; blank values, no data; CDPH, California Department of Public Health; USGS, U.S. Geological Survey]

USGS GAMA well identification number	CDPH GAMA well identification number	Redox constituents					Redox classifi- cation	δ ¹⁵ N of nitrate (per mil)	δ ¹⁸ O of nitrate (per mil)	Excess N ₂ (mg/L)
		Dissolved oxygen ¹	Nitrate plus nitrite nitrogen ²	Manga- nese ²	Iron ²	Sulfate ^{2,3}				
Redox threshold value ⁴		>0.5	>0.5	>50	>100	4				
Units		mg/L	mg/L	µg/L	µg/L	mg/L				
Grid wells										
CE-QPC-01	none	7.2	4.4	0.3	8	7.6	oxic	6.6	3.4	<0.4
CE-QPC-02	CE-QPC-DG-02	4.7	4.1	—	—	8.0	oxic			
CE-QPC-03	none						no data			
CE-QPC-04	none	6.0					oxic			
CE-QPC-05	none	8.0					oxic			
CE-QPC-06	CE-QPC-DG-06	8.0					oxic			
CE-QPC-07	none	3.0	3.3	<0.2	<6	16.0	oxic	4.6	3.7	1.4
CE-QPC-08	none	4.5					oxic			
CE-QPC-09	none	7.2	2.1	0.2	E5	10.5	oxic	4.3	3.9	<0.4
MER-01	none	0.3					anoxic			
MER-02	none	4.4	5.3	2.2	<6	21.7	oxic	5.0	2.1	2.7
MER-03	none	4.7	3.4	<0.2	<6	12.2	oxic	5.7	3.5	0.6
MER-04	MER-DG-04	1.0					oxic			
MER-05	MER-DG-05	0.2	—	—	<100	10.7	suboxic			
MER-06	MER-DG-06	2.6	2.8	—	<100	19.7	oxic			
MER-07	none	5.7					oxic			
MER-08	MER-DG-08	<0.2					anoxic			
MER-09	none	5.8	5.9	<0.2	<6	10.6	oxic	4.7	3.7	0.4
MER-10	none	3.3	2.7	<0.2	<6	11.6	oxic	6.6	4.2	<0.4
MER-11	none	1.5	0.8	26	17	19.0	oxic	5.8	6.2	0.5
MER-12	none	0.5	0.8	8	8	70.6	oxic	9.2	7.6	<0.4
MER-13	MER-DG-13	3.1	2.8	—	< 100	17.7	oxic			
MER-14	none	1.1					oxic			
MER-15	none	7.7					oxic			
MER-16	none	5.1					oxic			
MER-17	none	3.2					oxic			
MER-18	none	5.3					oxic			
MER-19	none	2.6					oxic			
MER-20	none	<0.2		109	122	79.6	Fe-red	33.3	22.3	8.5
MER-21	none	0.2	0.4	46	20	12.9	suboxic	7.8	4.7	1.3
MER-22	none	1.8					oxic			
MER-23	none	<0.2					anoxic			

Table A3. Concentrations of constituents used to classify oxidation-reduction conditions in groundwater, nitrogen and oxygen isotopic values of nitrate, and excess nitrogen gas concentrations, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.—Continued

[Redox, oxidation-reduction; mg/L, milligram per liter; µg/L, microgram per liter; oxic, dissolved oxygen > 0.5; anoxic, dissolved oxygen < 0.5 but no other redox indicators available; suboxic, dissolved oxygen < 0.5 but redox status cannot be further discerned because multiple indicators are below thresholds; NO3-red, nitrate reducing; Mn-red, manganese reducing; Fe-red, iron reducing; >, greater than; <, less than; Mix – Y/Z, mixture of waters with different redox ranging from most oxidized (Y) to most reduced (Z); —, no detection (values reported as zero) in CDPH database, method detection limit variable; blank values, no data; CDPH, California Department of Public Health; USGS, U.S. Geological Survey]

USGS GAMA well identification number	CDPH GAMA well identification number	Redox constituents					Redox classifi- cation	δ ¹⁵ N of nitrate (per mil)	δ ¹⁸ O of nitrate (per mil)	Excess N ₂ (mg/L)
		Dissolved oxygen ¹	Nitrate plus nitrite nitrogen ²	Manga- nese ²	Iron ²	Sulfate ^{2,3}				
Redox threshold value ⁴		>0.5	>0.5	>50	>100	4				
Units		mg/L	mg/L	µg/L	µg/L	mg/L				
MOD-01	none	6.7	4.8	<0.2	<6	12.3	oxic	7.6	3.7	1.6
MOD-02	none	6.5	6.3	<0.2	<6	23.8	oxic	6.2	1.7	1.6
MOD-03	MOD-DG-03	8.5					oxic			
MOD-04	MOD-DG-04	3.8	3.8	—	—	8.0	oxic	7.2	4.6	
MOD-05	MOD-DG-05	3.2	3.8	—	—	21.0	oxic			
MOD-06	MOD-DG-06	4.8	3.2	—	—	14.0	oxic			
MOD-07	MOD-DG-07	3.4					oxic			
MOD-08	MOD-DG-08	5.6	4.3	—	—	9.0	oxic			
MOD-09	none	5.6	2.9	<0.2	<6	5.0	oxic			
MOD-10	none	5.7					oxic			
TRLK-01	none	3.5	1.4	<0.2	<6	3.7	oxic	5.3	1.5	2.9
TRLK-02	none	3.9	3.0	0.2	<6	6.1	oxic	6.8	3.7	1.5
TRLK-03	none	2.4	1.4	9.4	101	2.2	oxic	4.9	3.5	
TRLK-04	TRLK-DG-04	3.1					oxic			
TRLK-05	none	3.1	2.7	<0.2	<6	5.1	oxic	6.7	4.7	<0.4
TRLK-06	none	3.8	8.1	—	—	27.0	oxic			
TRLK-07	none	5.6					oxic			
TRLK-08	none	5.2					oxic			
TRLK-09	none	3.5					oxic			
TRLK-10	none	3.8	5.6	<0.2	<6	170.0	oxic	4.4	1.1	1.3
TRLK-11	none	4.3	2.1	<0.2	<6	5.9	oxic	6.6	2.0	0.9
TRLK-12	none	0.8					oxic			
TRLK-13	none	0.2					anoxic			
TRLK-14	TRLK-DG-14	0.7	0.8	—	70	1.4	oxic			
TRLK-15	TRLK-DG-15	0.3					anoxic			
TRLK-16	none	2.0					oxic			
none	CE-QPC- DPH-04		2.1	—	<20	3.2	oxic to NO3-red			
none	MER-DPH-01		2.8	—	<100	23.3	oxic to NO3-red			
none	MER-DPH-07		2.0	—	—	15.0	oxic to NO3-red			

Table A3. Concentrations of constituents used to classify oxidation-reduction conditions in groundwater, nitrogen and oxygen isotopic values of nitrate, and excess nitrogen gas concentrations, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.—Continued

[Redox, oxidation-reduction; mg/L, milligram per liter; µg/L, microgram per liter; oxic, dissolved oxygen > 0.5; anoxic, dissolved oxygen < 0.5 but no other redox indicators available; suboxic, dissolved oxygen < 0.5 but redox status cannot be further discerned because multiple indicators are below thresholds; NO3-red, nitrate reducing; Mn-red, manganese reducing; Fe-red, iron reducing; >, greater than; <, less than; Mix – Y/Z, mixture of waters with different redox ranging from most oxidized (Y) to most reduced (Z); —, no detection (values reported as zero) in CDPH database, method detection limit variable; blank values, no data; CDPH, California Department of Public Health; USGS, U.S. Geological Survey]

USGS GAMA well identification number	CDPH GAMA well identification number	Redox constituents					Redox classifi- cation	δ ¹⁵ N of nitrate (per mil)	δ ¹⁸ O of nitrate (per mil)	Excess N ₂ (mg/L)
		Dissolved oxygen ¹	Nitrate plus nitrite nitrogen ²	Manga- nese ²	Iron ²	Sulfate ^{2,3}				
		Redox threshold value ⁴	>0.5	>0.5	>50	>100				
Units		mg/L	mg/L	µg/L	µg/L	mg/L				
none	MER-DPH-14		1.1	—	—	9.0	oxic to NO3-red			
none	MER-DPH-15		0.6	—	<100	2.6	oxic to NO3-red			
none	MER-DPH-16		4.1	40	—	12.0	oxic to NO3-red			
none	MER-DPH-19		2.7	—	—	11.0	oxic to NO3-red			
none	MOD-DPH-03		7.9	—	—	28.0	oxic to NO3-red			
none	MOD-DPH-07		3.6	—	—	19.0	oxic to NO3-red			
none	MOD-DPH-10		3.9	—	<100	5.8	oxic to NO3-red			
none	TRLK-DPH-04		—	30	<20	3.0	oxic to suboxic			
none	TRLK-DPH-08		—	—	<100	5.3	oxic to suboxic			
none	TRLK-DPH-13		15.5	91	<100	48.3	oxic to Mn-red			
none	TRLK-DPH-15		0.7	10	<20	3.5	oxic to NO3-red			

Table A3. Concentrations of constituents used to classify oxidation-reduction conditions in groundwater, nitrogen and oxygen isotopic values of nitrate, and excess nitrogen gas concentrations, Central Eastside Groundwater Ambient Monitoring and Assessment (GAMA) study unit.—Continued

[Redox, oxidation-reduction; mg/L, milligram per liter; µg/L, microgram per liter; oxic, dissolved oxygen > 0.5; anoxic, dissolved oxygen < 0.5 but no other redox indicators available; suboxic, dissolved oxygen < 0.5 but redox status cannot be further discerned because multiple indicators are below thresholds; NO3-red, nitrate reducing; Mn-red, manganese reducing; Fe-red, iron reducing; >, greater than; <, less than; Mix – Y/Z, mixture of waters with different redox ranging from most oxidized (Y) to most reduced (Z); —, no detection (values reported as zero) in CDPH database, method detection limit variable; blank values, no data; CDPH, California Department of Public Health; USGS, U.S. Geological Survey]

USGS GAMA well identification number	CDPH GAMA well identification number	Redox constituents					Redox classifi- cation	$\delta^{15}\text{N}$ of nitrate (per mil)	$\delta^{18}\text{O}$ of nitrate (per mil)	Excess N ₂ (mg/L)
		Dissolved oxygen ¹	Nitrate plus nitrite nitrogen ²	Manga- nese ²	Iron ²	Sulfate ^{2,3}				
		Redox threshold value ⁴	>0.5	>0.5	>50	>100				
Units		mg/L	mg/L	µg/L	µg/L	mg/L				
USGS-understanding wells										
CE-QPC-FP01	none	3.6					oxic			
MERFP-01	none	<0.2	<0.06	443	189	108.0	Fe-red			1.1
MERFP-02	none	0.5	<0.06	84	20	74.3	Mix oxic/ Mn-red			11.3
MERMW-01	none	7.4	19.0	1.2	<6	32.1	oxic	3.6	3.8	<0.4
MERMW-02	none	5.6	17.1	<0.2	<6	30.9	oxic	7.6	0.1	0.4
MERMW-03	none	1.8	5.4	0.6	<6	24.8	oxic	9.8	5.7	1.3
MERMW-04	none	2.6	2.4	<0.2	<6	9.6	oxic	6.7	3.0	1.0
MERMW-05	none	8.0	7.5	2.9	E4	19.2	oxic	3.2	5.3	1.7
MODFP-01	none	<0.2	<0.06	3940	1870	<0.18	Methano- genic			9.3
MODFP-02	none	0.3	4.4	216	13	46.1	Mix NO3- red/Mn-red	9.3	11.2	4.7
MODFP-03	none	4.9	13.2	E0.1	E5	28.1	oxic	7.4	0.5	0.5
MODFP-04	none	5.6	4.9	0.5	E3	10.9	oxic			
MODMW-01	none	7.2	12.4	E0.1	<6	53.0	oxic	9.1	2.3	1.4
TRLKFP-01	none	0.3	49.9	1130	<6	84.9	Mix NO3- red/Mn-red	15.7	4.7	6.0
TRLKFP-02	none	0.3	21.2	22	<6	32.4	NO3-red	11.3	8.9	1.8
TRLKMW-01	none	0.2	5.0	9.4	<6	12.4	NO3-red	11.4	10.3	2.2
TRLKMW-02	none	1.4	13.6	10	<6	47.8	oxic	8.6	10.3	1.6
TRLKMW-03	none	5.7	14.8	E0.2	<6	35.7	oxic	5.7	2.9	1.0
TRLKMW-04	none	6.0	14.7	E0.1	<6	27.8	oxic	7.2	2.0	1.3
TRLKMW-05	none	7.2	39.2	E0.1	<6	161.0	oxic	3.6	2.7	0.4

¹ Dissolved oxygen values measured by USGS.

² Values for wells with CDPH GAMA identification are from CDPH database. Values for wells with no CDPH GAMA identification were measured in samples collected by USGS for GAMA.

³ Hydrogen sulfide odor, an indicator of sulfate-reducing conditions, was not detected in any of wells sampled by USGS for GAMA.

⁴ Redox classification and thresholds based on McMahon and Chapelle (2008).

Appendix B. Comparison of CDPH and USGS–GAMA Data

Comparisons of CDPH and GAMA data were done to assess the validity of using data from these different sources in combination. Because LRLs for most organic constituents and trace elements were substantially lower for USGS GAMA-collected data than the MDLs used for CDPH data (table 2), it generally was not possible to meaningfully compare concentrations of these constituent types in individual wells. However, concentrations of major ions and nitrate, which generally are prevalent at concentrations substantially above LRLs, were compared for each well having data from both sources. Thirteen wells had some major-ion and nitrate data in common between the data sets. Wilcoxon signed rank tests of paired analyses for eight different constituents (calcium, magnesium, sodium, alkalinity, chloride, sulfate, TDS, nitrate-N) having concentrations above the LRL in both databases indicated no significant differences between USGS–GAMA and CDPH data for these constituents. Because of concerns that the small number of wells prevented a statistically robust analysis for each individual constituent, the data for these eight constituents also were combined into one

data set so that there was a large enough data set (97 pairs) for meaningful statistical comparison. A nonparametric signed rank test indicated no significant differences between the paired USGS–GAMA and CDPH data ($z = 0.74$, $p = 0.410$). While differences between the paired data sets occurred for a few wells, most sample pairs plotted close to a 1 to 1 line (fig. B1). The relative percent difference (RPD) was calculated for each data pair. The median RPD was 6.1 percent; 75 percent of the RPD values were <20 percent. These direct comparisons indicated that the GAMA and CDPH inorganic data were not significantly different.

Combined GAMA and CDPH major ion data for grid wells were plotted on piper diagrams (Piper, 1944) with all CDPH major ion data to determine whether the grid wells represented the range of groundwater types that have historically been observed in the study unit. Piper diagrams show the relative abundance of major cations and anions (on a charge equivalent basis) as a percentage of the total ion content of the water (fig. B2). Piper diagrams often are used to define groundwater type (Hem, 1985). All CDPH data having cation/anion data and a cation/anion balance of <10 percent were retrieved and plotted on these piper diagrams for comparison with grid well data.

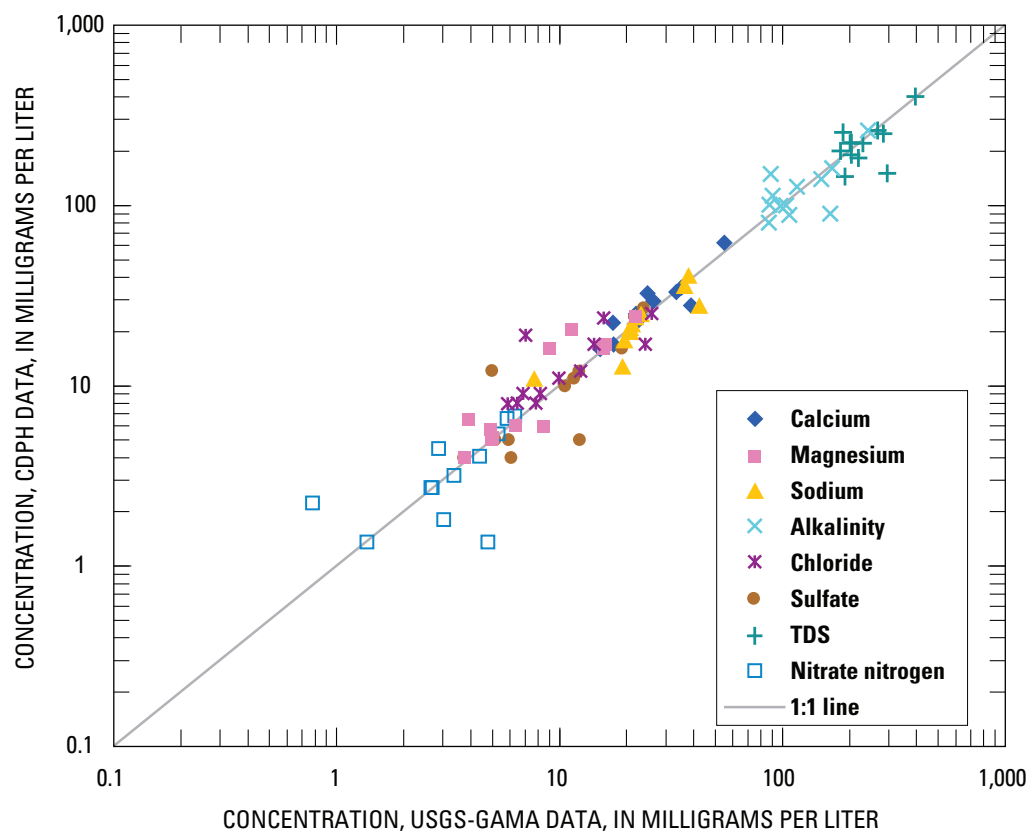
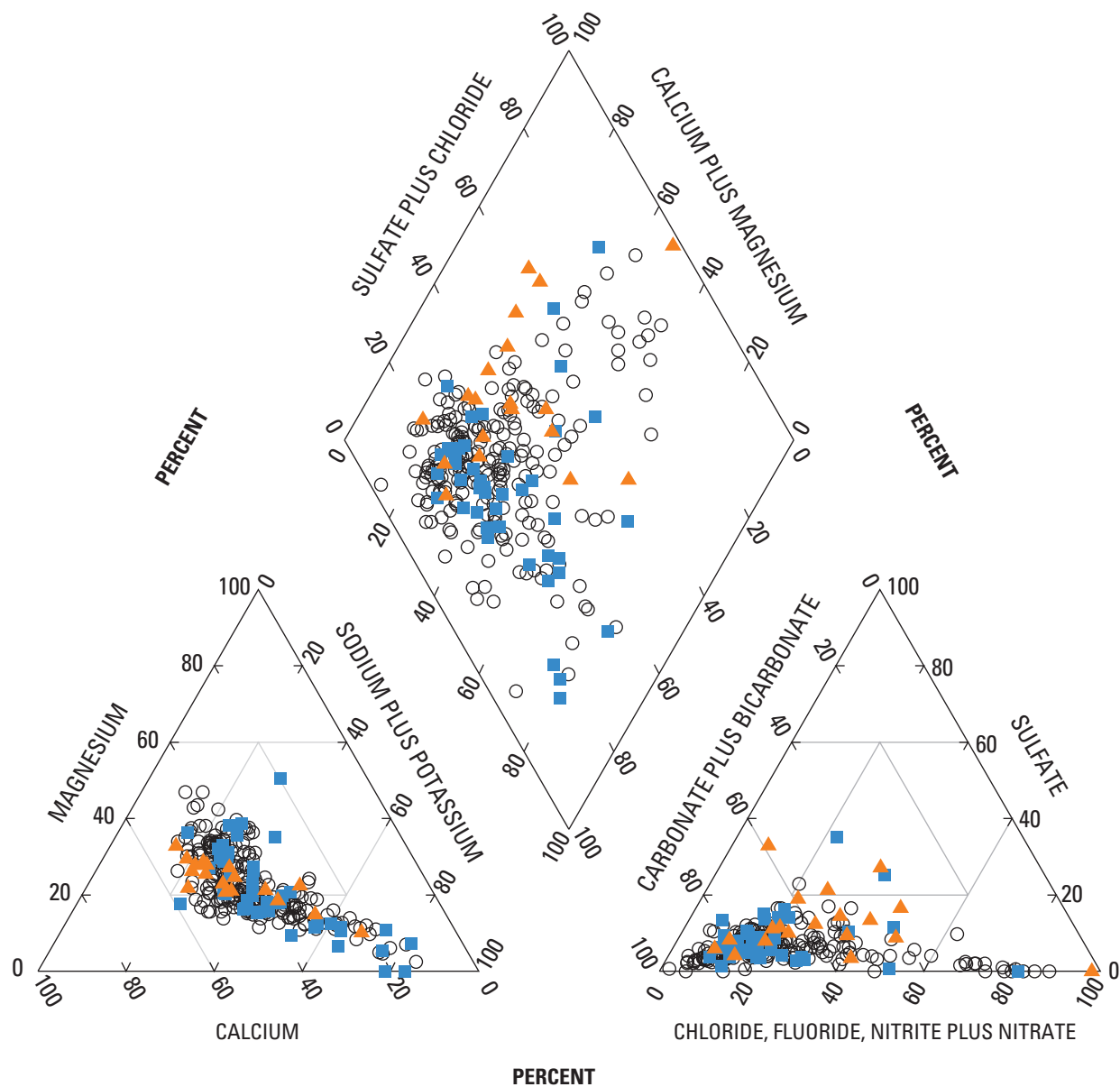


Figure B1. Paired major-ion and nitrate concentrations from wells sampled by the Groundwater Ambient Monitoring and Assessment (GAMA) program in March–June 2006 and the most recent available analysis in the California Department of Health Services, for the Central Eastside, California, study unit.



EXPLANATION

- CDPH well (most recent analysis with charge imbalance less than 10 percent)
- ▲ USGS understanding well
- USGS grid well

Figure B2. Piper diagram for U.S. Geological Survey (USGS) grid and understanding wells and all wells in the California Department of Public Health (CDPH) database that have a charge imbalance of less than 10 percent, Central Eastside, California, study unit.

A similar range of water types were evident from grid wells and historical CDPH data ([fig. B2](#)). In most wells, no single cation accounted for more than 60 percent of the total cations, and bicarbonate accounted for more than 60 percent of the total anions; these samples are described as *mixed cation-bicarbonate* type waters. There also were many wells that were *mixed cation-mixed anion* type waters, indicating that no single cation and no single anion accounted for more than 60 percent of the total. A minority of wells are classified as sodium-chloride type waters, indicating that sodium and chloride accounted for more than 60 percent of the total cations and anions, respectively.

The similarity of the range of relative abundance of major cations and anions in grid wells to the set of all CDPH wells indicates that the grid wells represent most of the diversity of water types present within the Central Eastside study unit. Two minor differences between grid data and CDPH data were evident, as described in the paragraphs below.

First, a minority of CDPH wells (14 of 222, 6.3 percent) had chloride as a dominant anion (lower right of anion diagram, [fig. B2](#)). One of 44 grid wells (2.3 percent) had this water type; the upper limit of the 90-percent confidence interval of the grid-based estimate was 7.3 percent. The CDPH wells having ≥ 60 percent chloride, nitrate, and fluoride (chloride is dominant) are located in parts of three cells located in the northern Turlock and southern Modesto

study areas, along the Tuolumne River and within the Modesto urban area. The cumulative area of this cluster of chloride-type waters is less than that of one grid cell. The one grid well having ≥ 60 percent chloride was within this chloride-type cluster. However, the grid wells in the other two cells overlapping with the chloride-type cluster did not fall within the area with these waters. Considering the localized distribution of these chloride-type waters within parts of three cells, it is not surprising that only one grid well had chloride-type water.

Second, there were two GAMA grid wells having higher sulfate percentages than any CDPH wells ([fig. B2](#)). These GAMA grid wells were located in the southeastern Merced and western Turlock study areas. There were no CDPH wells within the cell or the part of the cell where these wells resided. Thus, it is likely that these two relatively high sulfate grid well samples represent water types not represented in the CDPH database due to the nonuniform distribution of CDPH wells across the study unit.

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