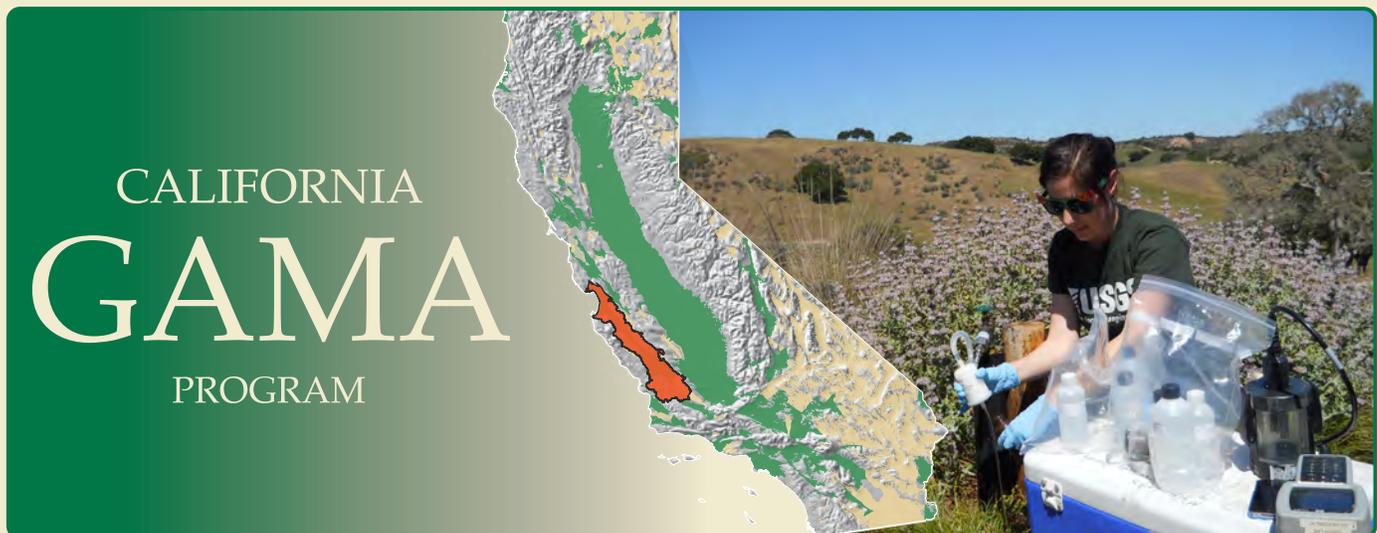


Prepared in cooperation with the California State Water Resources Control Board

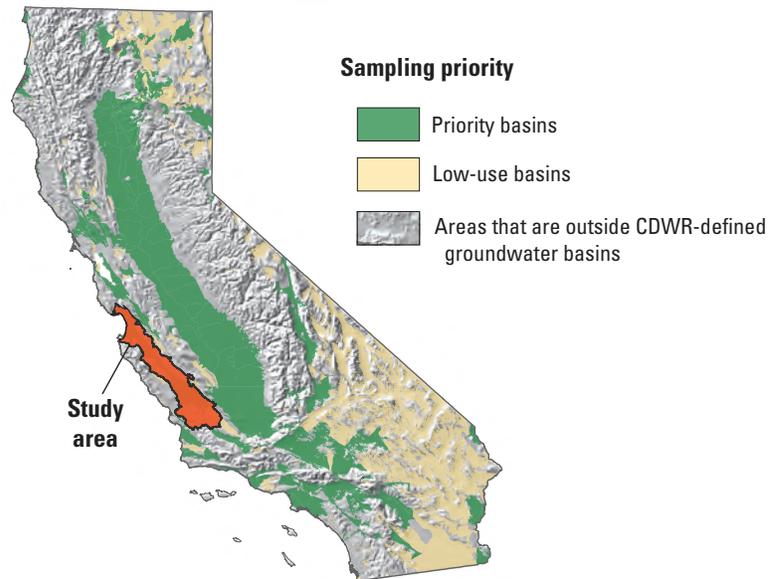
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Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13: California GAMA Priority Basin Project



Scientific Investigations Report 2018–5057

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



Cover photographs:

Front cover: Sampling near Salinas, California. (Photograph taken by Christine Lawrence, U.S. Geological Survey).

Back cover: Vinyard near Paso Robles, California. (Photograph taken by Tyler Johnson, U.S. Geological Survey).

Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13: California GAMA Priority Basin Project

By Carmen A. Burton and Michael T. Wright

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

Prepared in cooperation with the California State Water Resources Control Board

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

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Contents

Abstract.....	1
Introduction.....	2
Previous Gama Priority Basin Project Study.....	4
Purpose and Scope	6
Hydrogeologic Setting of the Monterey-Salinas Shallow Aquifer Study Unit.....	7
Santa Cruz Study Area	9
Pajaro Valley Study Area.....	9
Salinas Valley Study Area	9
Highlands Study Area.....	11
Methods.....	11
Relative Concentrations and Water-Quality Benchmarks	12
Datasets and Methods for Status Assessment	12
Grid Sites	12
Tap Sites	13
Calculation of Aquifer-Scale Proportions.....	13
Selection of Constituents for Status Assessment.....	22
Understanding-Assessment Methods	25
Study-Unit Comparison Assessment Methods.....	25
Potential Explanatory Factors.....	26
Land-Use Characteristics.....	26
Measures of Location	29
Geologic Factors.....	29
Groundwater Age.....	30
Geochemical Condition.....	31
Other Explanatory Factors.....	34
Correlations Between Explanatory Factors	34
Status and Understanding of Water Quality.....	36
Inorganic Constituents.....	36
Salinity Indicators.....	36
Understanding Assessment for Total Dissolved Solids	36
Understanding Assessment for Chloride	54
Understanding Assessment for Sulfate	54

Contents—Continued

Trace Elements.....	54
Understanding Assessment for Arsenic	55
Understanding Assessment for Boron	55
Understanding Assessment for Manganese and Iron	64
Understanding Assessment for Molybdenum	64
Understanding Assessment for Selenium	66
Understanding Assessment for Strontium	66
Uranium and Radioactive Constituents.....	67
Nitrate and Other Nutrients	69
Organic and Special-Interest Constituents.....	70
Understanding Assessment for Trihalomethanes	79
Understanding Assessment for Pesticides	79
Constituents of Special Interest.....	79
Understanding <i>N</i> -Nitroso-Dimethylamine	80
Understanding Perchlorate.....	80
Comparison of Water Quality of the Shallow and Public Drinking-Water Aquifer Systems.....	81
Comparison of Study-Unit Characteristics.....	81
Comparison of Inorganic Constituents.....	83
Comparison of Organic Constituents.....	88
Summary.....	92
References Cited.....	94
Appendix 1. Ancillary Datasets.....	102

Figures

1. Map showing the California hydrogeologic provinces and the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project.....	4
2. Map showing the boundaries of the Monterey-Salinas Shallow Aquifer study unit, the Santa Cruz, Pajaro Valley, Salinas Valley, and Highlands study areas and the location of major cities, topographic and hydrologic features, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.....	5
3. Map showing land use in the Monterey-Salinas Shallow Aquifer study unit, 1992, California Groundwater Ambient Monitoring Assessment Priority Basin Project	8
4. Simplified geologic map of the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project	10
5. Maps showing study-area grid cells, grid and tap wells in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	14
6. Ternary diagrams showing the percentage of urban, agricultural, and natural land use in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, for the study unit and study areas and the 500-meter buffer area surrounding each grid or tap site.....	27

Figures—Continued

7.	Boxplots showing well depths, depths to top of perforation, and perforation lengths for grid and tap sites, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.....	30
8.	Maps showing location of sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	32
9.	Boxplots showing groundwater-age classification in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, relative to depth to top of perforations and well depth.....	35
10.	Graph showing maximum relative concentration of constituents detected in samples from grid sites, by constituent class, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	37
11.	Graphs showing relative concentrations of inorganic constituents in samples from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	38
12.	Maps showing concentrations of salinity indicators for samples collected from grid and tap sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	44
13.	Graph showing stable isotope ratios of water and total dissolved solids concentrations in samples for grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	47
14.	Piper diagrams showing major-ion content of grid and tap samples by total dissolved solids concentration range category for the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	52
15.	Maps showing concentrations of selected trace elements in water samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	56
16.	Graph showing boron concentrations in relation to the water temperature in samples for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	63
17.	Graph showing relations of manganese and iron to dissolved oxygen in samples collected from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	64
18.	Graphs showing relation of molybdenum concentrations in samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, to dissolved oxygen and pH under oxic redox conditions for grid sites.....	65

Figures—Continued

19. Graph showing relation of selenium to dissolved oxygen and land use for water samples from grid and tap sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201366
20. Boxplots showing strontium concentrations by the dominate anion water type in samples from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201367
21. Map showing concentrations of uranium in water samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201368
22. Graph showing uranium concentrations in relation to agricultural land use and bicarbonate concentrations for water samples from grid and tap sites in the Santa Cruz, Pajaro Valley, and Salinas Valley study areas of the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201369
23. Graph showing nitrate concentrations in relation to the percentage of modern carbon-14 and oxidation-reduction conditions in water samples from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201369
24. Map showing concentrations of nitrate plus nitrite as nitrogen in samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201371
25. Graph showing detection frequency and maximum relative concentration of organic and special-interest constituents detected in water samples from U.S. Geological Survey grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201372
26. Graphs showing results for selected organic and special-interest constituents in water samples from U.S. Geological Survey grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201372
27. Maps showing the distribution of sites with organic constituents detected in water samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201373
28. Graph showing predicted probability of detecting perchlorate in groundwater as a function of aridity index and observed detection frequency and average aridity index for sites grouped by aridity index, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 201381
29. Graphs showing the comparison of the study-unit characteristics for the shallow and public drinking-water aquifer systems for the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project82

Figures—Continued

30.	Diagrams showing the comparison of aquifer-scale proportions having high, moderate, and low relative concentrations of inorganic constituents with health-based benchmarks in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer-system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project	83
31.	Maps showing concentrations of selected inorganic constituents with health-based benchmarks for samples collected from grid sites in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project	84
32.	Diagrams showing the comparison of aquifer-scale proportions having high, moderate, and low relative concentrations of inorganic constituents with secondary maximum concentration level benchmarks in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project.....	88
33.	Maps showing the concentrations of selected salinity indicators for samples collected from grid sites in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project	89
34.	Graphs showing organic constituents detected frequently in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project, allowing comparison of relative concentrations and detection frequency	91

Tables

1.	Study areas with number of cells, grid sites, tap sites, and dominant land use, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project	7
2.	Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	16
3.	Number of sites sampled by the U.S. Geological Survey for grid and tap sampling schedules and number of constituents sampled in each constituent class for the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	22
4A.	Benchmark types and values and reporting limits for constituents that were detected at high or moderate concentration or, for organic constituents, were detected in more than 10 percent of the grid samples, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	23
4B.	Constituents detected in samples collected by the U.S. Geological Survey that have no benchmarks, were present only at low relative concentrations, or, for organics, were detected in less than 10 percent of the grid samples, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	24

Tables—Continued

5.	Results of nonparametric analysis for differences among categories for selected potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	28
6.	Results of nonparametric analysis for correlations (Spearman's rho method) between selected potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	35
7A.	Aquifer-scale proportions for constituent classes in the Monterey-Salinas shallow aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	39
7B.	Aquifer-scale proportions for constituent classes for each study area in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	40
8A.	Aquifer-scale proportions and raw detection frequencies for constituents detected in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) that had (1) high or moderate values in samples collected from grid or tap sites or (2) organic or special-interest constituents detected in more than 10 percent of the grid sites sampled, California Groundwater Ambient Monitoring Assessment Priority Basin Project	41
8B.	Aquifer-scale proportions for constituents detected in the four study areas that had (1) high or moderate values in samples collected from grid sites, or (2) organic or special-interest constituents detected in more than 10 percent of the grid sites sampled, California Groundwater Ambient Monitoring Assessment Priority Basin Project	42
9.	Results of non-parametric (Spearman's rho method) analysis for correlations between selected water-quality constituents and potential explanatory factors for grid sites, Monterey Salinas Shallow Aquifer study area, 2010, California Groundwater Ambient Monitoring Assessment Priority Basin Project.....	48
10.	Results of non-parametric analysis (Kruskal-Wallis and multiple comparison tests) for differences in selected water-quality constituents among categories of potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	50
11.	Results of non-parametric (Spearman's rho method) tests for correlations between concentrations of selected water-quality constituents for grid sites, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013	53
1-1.	Data for explanatory factors used for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013	102
1-2.	Tritium, percentage of modern carbon, and age classification for samples collected from grid sites in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) and the Monterey Bay and Salinas Valley Groundwater Basins study unit (2005), California Groundwater Ambient Monitoring and Assessment Priority Basin Project.....	106

Tables—Continued

- 1–3. Oxidation-reduction constituents, redox classification, and pH values for samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013110
- 1–4. Information for other explanatory factors evaluated but not used for samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013114

Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
Radioactivity		
picocurie per liter (pCi/L)	0.313	Tritium units (TU)

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

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

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

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8.$$

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$) or nanograms per liter (ng/L). One milligram per liter is equivalent to 1 part per million (ppm); 1 microgram per liter is equivalent to 1 part per billion (ppb); 1 nanogram per liter (ng/L) is equivalent to 1 part per trillion (ppt); 1 per mil is equivalent to 1 part per thousand.

Abbreviations

1,2-DCP	1,2-dichloropropane
AL-US	U.S. Environmental Protection Agency action level
CDWR	California Department of Water Resources
DDW	State Water Resources Control Board Division of Drinking Water (California Department of Public Health prior to July 1, 2014)
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
GAMA	Groundwater Ambient Monitoring and Assessment program
GAMA-PBP	GAMA Priority Basin Project
HAL-US	U.S. Environmental Protection Agency lifetime health advisory level
HBSL	health-based screening level
LLNL	Lawrence Livermore National Laboratory
MCL	maximum contaminant level
MCL-CA	California's maximum contaminant level
MCL-US	U.S. Environmental Protection Agency maximum contaminant level
MS-PA	Monterey Bay and Salinas Valley Groundwater Basins GAMA Priority Basin Project study unit
MS-SA	Monterey-Salinas Shallow Aquifer GAMA Priority Basin Project study unit
MS-SA3	Monterey-Salinas Shallow Aquifer study areas used for comparison with the MS-PA study unit
MTBE	methyl <i>tert</i> -butyl ether
NDMA	<i>N</i> -nitrosodimethylamine
PCE	tetrachloroethene
pmc	percent modern carbon
SMCL	secondary maximum contaminant level
SMCL-CA	California's secondary maximum contaminant level
SWRCB	State Water Resources Control Board (California)
TDS	total dissolved solids
TEAP	terminal electron acceptor processes
THM	trihalomethane
USGS	U.S. Geological Survey
VOC	volatile organic compound

Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13: California GAMA Priority Basin Project

By Carmen A. Burton and Michael T. Wright

Abstract

Groundwater quality in the approximately 7,820-square-kilometer (km²) Monterey-Salinas Shallow Aquifer (MS-SA) study unit was investigated from October 2012 to May 2013 as part of the second phase of the Priority Basin Project of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. The study unit is in the central coast region of California in the counties of Santa Cruz, Monterey, and San Luis Obispo. The GAMA Priority Basin Project is being conducted by the California State Water Resources Control Board in cooperation with the U.S. Geological Survey and the Lawrence Livermore National Laboratory.

The MS-SA study was designed to provide a statistically robust assessment of untreated-groundwater quality in the shallow aquifer systems. The assessment was based on water-quality samples collected by the U.S. Geological Survey from 100 groundwater sites and 70 household tap sites, along with ancillary data such as land use and well-construction information. The shallow aquifer systems were defined by the depth interval of wells associated with domestic supply. The MS-SA study unit consisted of four study areas—Santa Cruz (210 km²), Pajaro Valley (360 km²), Salinas Valley (2,000 km²), and Highlands (5,250 km²).

This study had two primary components: the *status assessment* and the *understanding assessment*. The first primary component of this study—the *status assessment*—assessed the quality of the groundwater resource indicated by data from samples analyzed for volatile organic compounds (VOCs), pesticides, and naturally present inorganic constituents, such as major ions and trace elements. The *status assessment* is intended to characterize the quality of groundwater resources in the shallow aquifer system of the MS-SA study unit, not the treated drinking water delivered to consumers by water purveyors. As opposed to the public wells, however, water from private wells, which often tap the shallow aquifer, is usually consumed without any treatment. The second component of this study—the *understanding assessment*—identified the natural and human factors that potentially affect groundwater quality by evaluating land-use characteristics, measures of location, geologic factors, groundwater age, and geochemical conditions of the shallow aquifer. An additional component of this study was a

comparison of MS-SA water-quality results to those of the GAMA Monterey Bay and Salinas Valley Groundwater Basins study unit. This study unit covered much of the same areal extent as the MS-SA, but assessed the deeper, public drinking-water aquifer system.

Relative concentrations (sample concentration divided by the benchmark concentration) were used to evaluate concentrations of constituents in groundwater samples relative to water-quality benchmarks for those constituents that have Federal or California benchmarks, such as maximum contaminant levels. For organic and special-interest constituents, relative concentrations were classified as high, greater than 1.0; moderate, greater than 0.1 and less than or equal to 1.0; or low, less than or equal to 0.1. For inorganic constituents, relative concentrations were classified as high, greater than 1.0; moderate, greater than 0.5 and less than or equal to 1.0; or low, less than or equal to 0.5. A relative concentration greater than 1.0 indicates that the concentration was greater than a benchmark. Aquifer-scale proportions were used to quantify regional-scale groundwater quality. The aquifer-scale proportions are the areal percentages of the shallow aquifer system where relative concentrations for a given constituent or class of constituents were high, moderate, or low.

Inorganic constituents were measured at high and moderate relative concentrations more frequently than organic constituents. In the MS-SA study unit, inorganic constituents with benchmarks were detected at high relative concentrations in 51 percent of the study unit. The greatest proportions of high relative concentrations of trace elements and radioactive constituents were in the Highlands and Santa Cruz study areas, whereas high relative concentrations of nutrients were most often detected in the Salinas Valley and Pajaro Valley study areas and salinity indicators were most often detected in the Highlands and Salinas Valley study areas. The trace elements detected at high relative concentrations were arsenic, boron, iron, manganese, molybdenum, selenium, and strontium. The radioactive constituents detected at high relative concentrations were adjusted gross alpha radioactivity and uranium. The nutrient detected at high relative concentrations was nitrate plus nitrite. The salinity indicators detected at high relative concentrations were chloride, sulfate, and total dissolved solids.

2 Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13

Organic constituents (VOCs and pesticides) were not detected at high relative concentrations in any of the study areas. The fumigant 1,2-dichloropropane was detected at moderate relative concentrations. The VOC chloroform and the pesticide simazine were the only organic constituents detected in more than 10 percent of samples. The constituents of special interest NDMA (*N*-nitrosodimethylamine) and perchlorate were detected at high relative concentrations in the MS-SA study unit.

Selected constituents were evaluated with explanatory factors to identify potential sources or processes that could explain their presence and distribution. Trace elements and radioactive constituents came from natural sources and were not elevated by anthropogenic sources or processes, except for selenium and the radioactive constituent uranium. Arsenic, manganese, iron, selenium, and uranium concentrations were all influenced by oxidation-reduction conditions.

Unlike other trace elements and radioactive constituents, uranium and selenium can be affected by agricultural practices. Uranium and selenium can be released from aquifer sediments as a result of irrigation recharge water interacting with bicarbonate systems.

Nitrate can be strongly affected by anthropogenic sources. Nitrate concentrations were significantly higher in modern groundwater, indicating recent inputs of nitrate to the shallow aquifer system. Nitrate was positively correlated with agricultural land use, indicating that irrigation-return water could be leaching nitrogen fertilizer and naturally present nitrate to elevate nitrate concentrations in shallow groundwater.

The salinity indicators total dissolved solids, chloride, and sulfate all had natural sources in the MS-SA study unit, primarily marine sediments. Concentrations of the constituents were elevated as a result of evaporative concentration of irrigation water or precipitation. Sulfate concentrations were significantly correlated to agricultural land use, indicating that agricultural land-use practices are a contributing source of sulfate to groundwater.

The samples with most of the detections of VOCs were from sites in the Pajaro Valley and northern part of the Salinas Valley. Most of the samples with pesticide detections were from sites in the Salinas Valley study area. The herbicide simazine was positively correlated to the percentage of agricultural land use, and its concentrations were higher in modern groundwater than in pre-modern groundwater.

Perchlorate, similar to nitrate, has natural and anthropogenic sources. Correlations of perchlorate to dissolved oxygen, nitrate, and percentage of agricultural land use indicated that the irrigation-return water could be leaching naturally present perchlorate, as well as perchlorate from historical applications of Chilean nitrate fertilizer, to increase perchlorate concentrations in groundwater.

The quality of the water in the shallow aquifer system from this study was compared with the quality of water in the public drinking-water aquifer in a previous GAMA

(MS-PA) study in the same area. The shallow system was more oxic and had more sites with modern groundwater than the public drinking-water aquifer, which was more anoxic and had sites with more pre-modern groundwater. Arsenic and selenium were found at high relative concentrations in a greater proportion of the shallow system. Manganese and iron were found at high relative concentrations in a greater proportion of the public drinking-water aquifer. Uranium was found at higher relative concentrations in a greater proportion of the shallow system. Concentrations of arsenic, iron, manganese, and molybdenum are not likely to change much as groundwater percolates from the shallow system to the public drinking-water aquifer because there are no anthropogenic sources affecting these constituents. Uranium and selenium concentrations in the public drinking-water aquifer could be affected by the higher concentrations in the shallow system because of irrigation-return water, however.

Nitrate and salinity indicators had concentrations that were much higher in the shallow system than the deeper public drinking-water aquifer. High concentrations of these constituents in the shallow system could lead to increased concentrations in the public drinking-water aquifer in parts of the study units because of land-use practices, such as irrigated agriculture.

Organic constituents were detected more frequently in the public drinking-water aquifer than in the shallow system, possibly because more of the sites sampled in the public drinking-water aquifer were in urban areas compared to the sites sampled for the shallow system or because sources of contamination have decreased as a result of changes in use at the land surface.

Introduction

About one-half of the water used for public and domestic drinking-water supply in California is groundwater (Kenny and others, 2009). To assess the quality of ambient groundwater in shallow aquifers used for drinking-water supply and to establish a baseline groundwater-quality monitoring program, the California State Water Resources Control Board (SWRCB), in cooperation with the U.S. Geological Survey (USGS) and Lawrence Livermore National Laboratory (LLNL), implemented the Groundwater Ambient Monitoring and Assessment (GAMA) Program (<http://www.waterboards.ca.gov/gama/>). The SWRCB initiated the GAMA Program in 2000 in response to Legislative mandates (State of California, 1999, 2001a). The program consists of four projects: (1) the GAMA Priority Basin Project (GAMA-PBP), carried out by the USGS (<http://ca.water.usgs.gov/gama/>); (2) the GAMA Domestic Well Project, carried out by the SWRCB; (3) the GAMA Special Studies, carried out by the LLNL; and (4) the GeoTracker GAMA online groundwater information system, led by the SWRCB (<http://geotracker.waterboards.ca.gov/>

[gama/](#)). The SWRCB's Domestic Well Project sampled private domestic wells on a voluntary, first-come-first-serve basis in six counties between 2002 and 2011. From 2004 to 2012, the GAMA-PBP did water-quality assessments for groundwater resources used for public drinking water. These resources typically are deeper than the groundwater resources used for domestic drinking water. In 2012, the GAMA-PBP began water-quality assessments of shallow aquifers typically used by private domestic wells.

The GAMA-PBP was initiated in response to the Groundwater Quality Monitoring Act of 2001 to assess and monitor the quality of groundwater in California, to help understand and identify risks to groundwater resources, and to increase the availability of information about groundwater quality to the public (State of California, 2001b).

For the first phase of the GAMA-PBP, the USGS, in cooperation with the SWRCB, developed a monitoring plan to assess groundwater resources used for public drinking-water supply through statistically reliable sampling approaches (Belitz and others, 2003; California State Water Resources Control Board, 2003). Hydrologic and geologic conditions and land-use patterns in California were considered in this statewide assessment of groundwater quality. Belitz and others (2003) partitioned the State into 10 hydrogeologic provinces, each with distinctive hydrologic, geologic, and land-use characteristics: Cascades and Modoc Plateau, Klamath Mountains, Northern Coast Ranges, Central Valley, Sierra Nevada, Basin and Range, Southern Coast Ranges, Transverse Ranges and selected Peninsular Ranges, Desert, and San Diego Drainages (fig. 1). These 10 hydrogeologic provinces include groundwater basins designated by the California Department of Water Resources (CDWR; California Department of Water Resources, 2003). Groundwater basins generally consist of relatively permeable, unconsolidated deposits of alluvial origin. Areas outside of basins generally consist of fractured hard-rock aquifers and are an important source of drinking water in some hydrogeologic provinces.

The first phase of the GAMA-PBP assessed approximately 95 percent of the groundwater resource used for public supply. Basins were prioritized for sampling on the basis of the number of public-supply wells, with secondary consideration given to municipal groundwater use, agricultural pumping, the number of historically leaking underground fuel tanks, and the number of Public Land Survey sections having registered pesticide applications (Belitz and others, 2003). The State agency responsible for regulation of public drinking water maintains a database of public-supply wells and water-quality data collected for regulatory compliance purposes. On July 1, 2014, this responsibility moved from the California Department of Public Health Drinking Water Program to the SWRCB Division of Drinking Water (DDW; http://www.waterboards.ca.gov/drinking_water/programs/DW_PreJuly2014.shtml).

For the second phase of the GAMA-PBP, a different method of prioritization was required because shallow aquifer

systems typically are used by private domestic wells, and no statewide database of these wells was available. The State was divided into 938 groundwater units, corresponding to the 463 alluvial groundwater basins defined by the CDWR and 475 areas outside of the basins (referred to as highland areas; Johnson and Belitz, 2014). The estimated number of households relying on domestic wells in each groundwater unit was calculated from U.S. Census data (U.S. Census Bureau, 1990), and water-use information was compiled from drillers' logs submitted to the CDWR (Johnson and Belitz, 2015). The groundwater units were prioritized for sampling on the basis of the number and density of households relying on domestic wells. Groundwater units were grouped into study units designed to facilitate comparison of groundwater quality between the shallow aquifer systems assessed during this second phase of the GAMA-PBP and the deeper aquifer systems assessed during the first phase.

This report discusses the Monterey-Salinas Shallow Aquifer (MS-SA) study unit (fig. 1), which was the second study unit sampled in the second phase of the GAMA-PBP. The MS-SA study unit is in the Southern Coast Ranges hydrogeologic province. The study unit has four study areas—Santa Cruz, Pajaro Valley, Salinas Valley, and Highlands—that consist of the groundwater basins included in the GAMA Priority Basin Project assessment of groundwater resources used for public supply in the Monterey-Salinas region (Kulongoski and Belitz, 2007, 2011) and highland areas around the groundwater basins.

The GAMA Priority Basin Project was designed to assess the status of the quality of the groundwater resources, identify natural and human factors likely affecting groundwater quality, and monitor changes in groundwater quality. These three objectives were modeled after those of the USGS National Water Quality Assessment (NAWQA) Program (Hirsch and others, 1988). The sample collection protocols used in this study were designed to obtain representative samples of groundwater.

In groundwater basins, domestic and small-system wells typically are shallower than public-supply wells listed in the DDW database. In the first phase of the GAMA-PBP, the groundwater resources used for public drinking water were defined by the depths of the screened or open intervals of public-supply wells in the study unit. The shallow aquifer system assessed during the second phase of the GAMA-PBP was defined as the aquifers generally shallower than the groundwater resources used for public drinking water. In highland areas, the differences between depth zones used by public-supply wells and by domestic and small-system wells can be less distinct.

All published and quality-assured data collected for the GAMA Program are available through the USGS National Water Information System (NWIS) web interface (<http://waterdata.usgs.gov/ca/nwis/>) and the SWRCB GeoTracker groundwater information system (<https://geotracker.waterboards.ca.gov/gama/>).



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

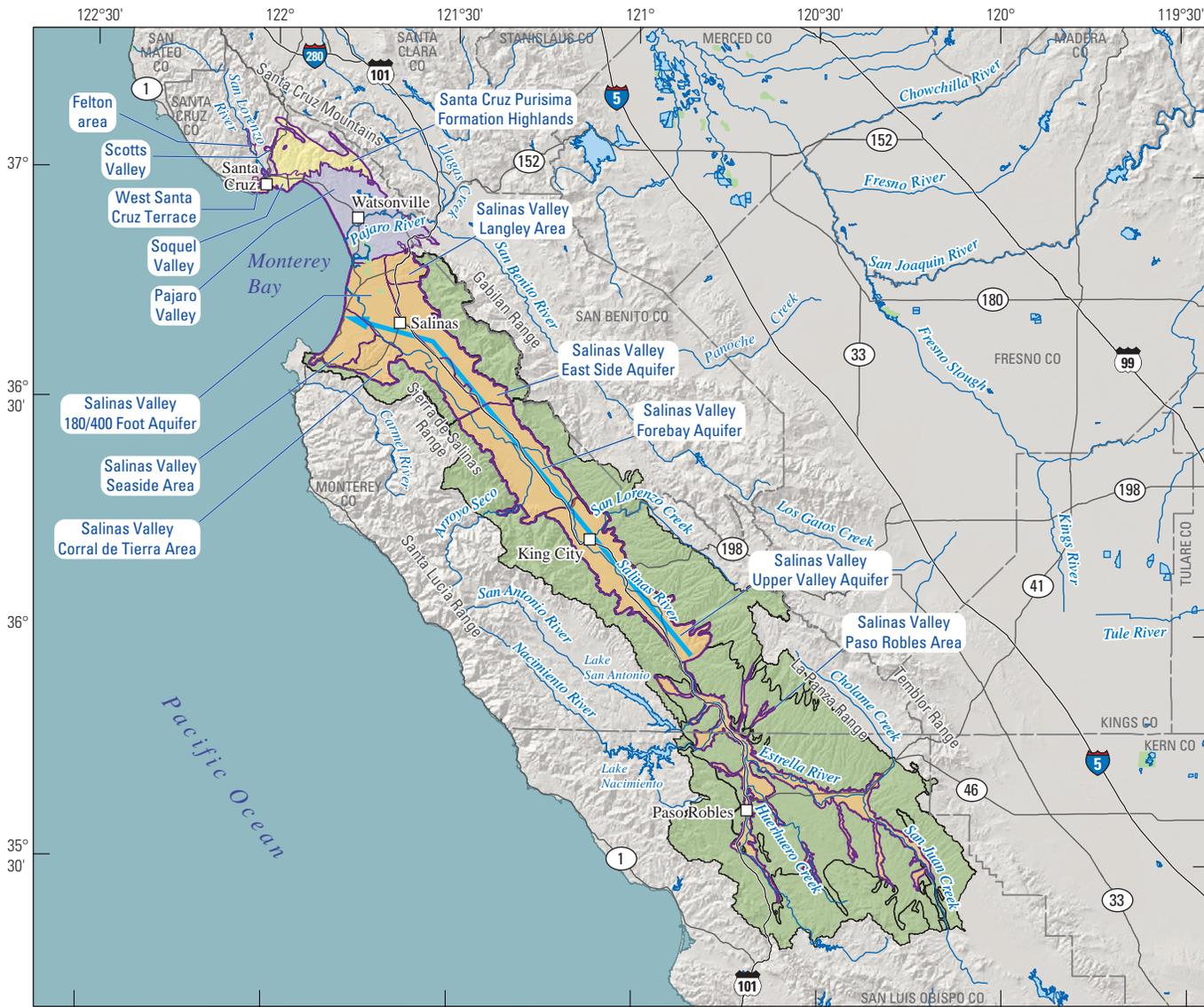
Provinces from Belitz and others, 2003.

Figure 1. California hydrogeologic provinces and the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Program Priority Basin Project.

Previous GAMA Priority Basin Project Study

As part of the first phase of GAMA-PBP, the Monterey Bay and Salinas Valley Groundwater Basins (MS-PA) study unit was sampled in 2005 (Kulongoski and Belitz, 2007, 2011). The groundwater resources primarily used for public drinking water in the CDWR-defined groundwater basins

and subbasins from Santa Cruz to Paso Robles were studied (fig. 2). The groundwater resources used for public drinking water for the MS-PA study were defined by the perforation intervals of sites listed in the DDW water-quality database for the MS-PA study unit. The MS-PA study unit covers approximately the same area as the Santa Cruz, Pajaro Valley, and Salinas Valley study areas in the MS-SA study unit.



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

0 15 30 MILES
0 15 30 KILOMETERS

EXPLANATION

- Santa Cruz study area
- Pajaro Valley study area
- Salinas Valley study area
- Highlands study area
- Groundwater basins and subbasins
- County boundary
- Generalized direction of groundwater flow

Figure 2. Boundaries of the Monterey-Salinas Shallow Aquifer study unit, the Santa Cruz, Pajaro Valley, Salinas Valley, and Highlands study areas and the location of major cities, topographic and hydrologic features, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

The MS-PA study found that inorganic constituents with health-based benchmarks were at high concentrations in 14.5 percent of the primary aquifer. Inorganic constituents detected at high concentrations included nitrate, molybdenum, arsenic, boron, and gross alpha radioactivity. Organic constituents were detected in high concentrations in 0.2 percent of the primary aquifer because of tetrachloroethene

(PCE) and methyl *tert*-butyl ether (MTBE). The herbicide simazine was the only organic constituent detected in more than 10 percent of the primary aquifer. Land use, geochemical conditions, groundwater age, and depth to the top of perforations of the well were the factors that most strongly correlated with groundwater quality in the MS-PA (Kulongoski and Belitz, 2011).

Purpose and Scope

The purposes of this report are to provide a description of the hydrogeologic setting of the MS-SA study unit, an assessment of the status of quality in the shallow aquifer system in the MS-SA study unit, a general identification of natural and anthropogenic factors that could be affecting groundwater quality, and a comparison between the quality of groundwater in the shallow aquifer system (MS-SA study unit) and the quality of groundwater resources used for public drinking water (MS-PA study unit). Temporal trends in groundwater quality in the shallow and primary aquifer systems are not discussed in this report. Water-quality data from samples collected by the USGS for the GAMA program in the MS-SA study unit, as well as details about sample collection, analysis, and quality-assurance procedures, are provided in Goldrath and others (2016).

Features of the hydrogeologic setting for the four study areas are described; features of specific alluvial basins and delineated hard-rock aquifers are not discussed. Geology, land-use patterns, and hydrology of the study unit are summarized. Characteristics of groundwater resources used for domestic drinking water, including overlying land-use characteristics, depth and hydrologic conditions, geologic characteristics, groundwater age, and geochemical conditions, are described by using ancillary data compiled for the groundwater sites in the MS-SA study unit sampled by the USGS.

The *status assessment* is designed to provide a statistically representative characterization of groundwater resources used for domestic drinking water at the study-area scale for the period of the assessment (Belitz and others, 2003, 2010, 2015). This report describes methods used to design the sampling network for the status assessment and to estimate aquifer-scale proportions having specified ranges of relative concentrations for constituents. Aquifer-scale proportion is defined as the areal proportion of the groundwater resource having groundwater of defined quality (Belitz and others, 2010). The *status assessment* uses water-quality data from 100 sites selected by the USGS at a spatial coverage of one site per grid cell (referred to as grid sites) across the MS-SA study unit. Samples were collected for analysis of anthropogenic constituents, such as volatile organic compounds (VOCs) and pesticides, and of naturally present inorganic constituents, that can be affected by anthropogenic activities, such as major ions and trace elements. Data from 70 other sites also were collected at households supplied by domestic wells (referred to as tap sites) in 2 of the 4 study

areas in the MS-SA study unit. Tap sites were used to increase the spatial density of data for selected inorganic constituents in the Salinas Valley and Pajaro Valley study areas. The resulting set of water-quality data from USGS-grid and tap sites was considered to be representative of the shallow aquifer systems in the MS-SA study unit.

To provide context, the water-quality data discussed in this report were compared to the California and Federal regulatory and non-regulatory benchmarks for treated drinking water (California State Water Resources Control Board, 2016, 2018a,b; U.S. Environmental Protection Agency, 2012) and non-regulatory health-based drinking-water benchmarks known as health-based screening levels (HBSLs) developed by the USGS (Toccalino and others, 2012). The assessments in this report are intended to characterize the quality of untreated groundwater resources in the shallow aquifers in the study unit. Grid-site samples used for this study were collected before any treatment or storage. Most tap-site samples were collected after storage or pressure tanks used to store water from wells. The quality of groundwater can differ from the quality of drinking water because water chemistry can change as a result of contact with plumbing systems or the atmosphere or because of treatment, disinfection, or blending with water from other sources. The State of California does not regulate the quality of drinking water provided by domestic wells.

The evaluation of natural and human factors that could affect groundwater quality in the study unit is based primarily on relations between groundwater quality and potential explanatory factors. These relations are examined with statistical tests and graphical analyses and are discussed in the context of the hydrogeologic setting of the study unit. Potential explanatory factors included land use; geology; well depth; indicators of groundwater age; distance or density of possible sources of contamination, such as septic systems; and geochemical conditions.

Comparisons between groundwater resources used for domestic drinking water (MS-SA) and those used for public drinking water (MS-PA) were made using results from the Santa Cruz, Pajaro Valley, and Salinas Valley study areas of the MS-SA study unit and from the GAMA-PBP sampling of the MS-PA in 2005 (Kulongoski and Belitz, 2007, 2011). Study-unit characteristics, such as well construction and land use around each site, as well as the results of water-quality analyses in each study unit are compared and discussed in the “[Comparison of Water Quality of the Shallow and Public Drinking-Water Aquifer Systems](#)” section.

Hydrogeologic Setting of the Monterey-Salinas Shallow Aquifer Study Unit

The MS-SA study unit is in the Southern Coast Ranges hydrogeologic province (fig. 1) described by Belitz and others (2003) and the Central Coast Hydrologic Region defined by the CDWR (California Department of Water Resources, 2003). More than three-quarters of the water used for public and domestic drinking-water supply in the Central Coast Hydrologic Region of California is groundwater, and there are over 8,000 well drilling logs for domestic wells (California Department of Water Resources, 2013). The study unit covers approximately 7,820 square kilometers (km²) in Santa Cruz, Monterey, and San Luis Obispo Counties in the central coast region of California (fig. 2). Groundwater provides 99 percent of water for agricultural and urban use in Monterey County, 92 percent in San Luis Obispo County, and 79 percent in Santa Cruz County (California Department of Water Resources, 2013).

The MS-SA study unit was divided into four study areas based on the CDWR basin delineations, geology, and geography. The Santa Cruz, Pajaro Valley, and Salinas Valley study areas cover approximately the same area as a previous study unit in the first phase of the GAMA-PBP—the Monterey Bay and Salinas Valley Basins (MS-PA) study unit (Kulongoski and Belitz, 2011). A fourth study area in the MS-SA study unit, the Highlands study area, consists of areas that primarily are served by domestic wells bordering the Salinas Valley study area (fig. 2), but are partly outside of CDWR defined basins. General information about the study areas is given in table 1.

The climate in the MS-SA study unit is characterized by warm, dry summers and cool, moist winters. Based on an

80-year average of climate records from 1931 to 2015 from the National Climatic Data Center station at the Salinas airport (station USW00023233), the average annual temperature was 14 degrees Celsius (°C), and the average annual precipitation was 331 millimeters (mm) falling as rain during the winter and early spring (accessed October 24, 2016, <http://www.ncdc.noaa.gov/cdo-web/datatools/findstation>). The distribution of precipitation across the area is dependent on the topography and the prevailing winds, such that precipitation increases concomitantly with increasing altitude.

The MS-SA study unit has several rivers and creeks including the Salinas River, the Pajaro River, and the San Lorenzo River (fig. 2). The direction of groundwater flow generally follows the topography of the basins, going from the mountain ranges, down to the Salinas Valley and then flowing towards Monterey Bay and the Pacific Ocean. Sources of groundwater recharge include percolation of precipitation, streamflow infiltration, and agricultural irrigation and return flow. Groundwater discharge primarily is through the pumping of wells.

Land use in the MS-SA study unit primarily is natural in the Santa Cruz study area (fig. 3). The land use in the Pajaro Valley study area primarily is a mix of agricultural and urban. The Salinas Valley study area is primarily agricultural with some urban land use present in the northern part of the study area. The Highlands study area primarily is natural (fig. 3).

Previous studies have indicated water-quality issues in the study unit. These issues include seawater intrusion in the Pajaro and Salinas Valley study areas near Monterey Bay (Hanson, 2003); elevated nitrate concentrations in several parts of the Salinas Valley study area (Kulongoski and Belitz, 2011; Harter and others, 2012); and high concentrations of trace elements such as arsenic, boron, molybdenum, and gross alpha radioactivity in parts of the study unit (Kulongoski and Belitz, 2011).

Table 1. Study areas with number of cells, grid sites, tap sites, and dominant land use, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

[km², square kilometers]

Study area	Study-area abbreviation	Size of study area (km ²)	Number of grid cells	Average size of grid cell (km ²)	Number of grid sites sampled	Number of tap sites sampled	Predominant land use
Santa Cruz	MS-SC	210	15	13	15	0	Natural
Pajaro Valley	MS-P	360	15	18	15	15	Natural
Salinas Valley	MS-SV	2,000	40	49	40	55	Agricultural
Highlands	MS-H	5,250	30	174	30	0	Natural

8 Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13

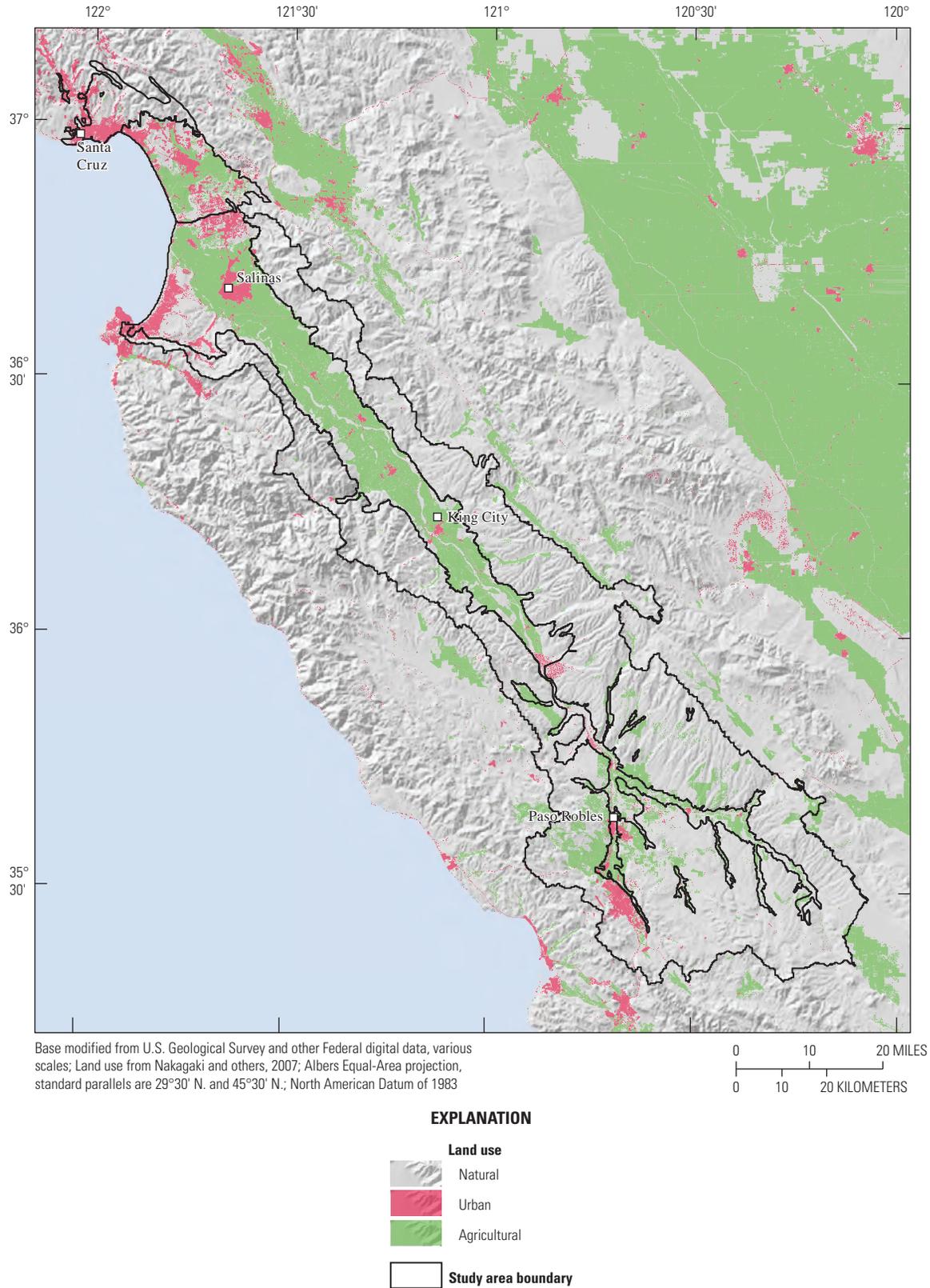


Figure 3. Land use in the Monterey-Salinas Shallow Aquifer study unit, 1992, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

Santa Cruz Study Area

The Santa Cruz study area covers approximately 210 km² and includes the following groundwater basins: Santa Cruz Purisima Formation Highlands, Felton Area, Scotts Valley, Soquel Valley, and West Santa Cruz Terrace as defined in Bulletin 118 by the California Department of Water Resources (2003). The Santa Cruz study area is bounded to the north, east, and west by the Santa Cruz Mountains, where altitudes are as high as 880 meters (m), and to the south by the Monterey Bay and the Pajaro Valley groundwater basin (fig. 2).

In the northern part of the Santa Cruz study area, the Santa Cruz Purisima Formation Highlands groundwater basin (fig. 2) is defined by the geologic boundary of the Purisima Formation. The Purisima Formation is a Pliocene deposit that is the primary water-bearing unit and consists of poorly consolidated, silty to very fine- to medium-grained sandstone interbedded with siltstone. The formation ranges in thickness from 183 m in the north to 305 m in the south near Soquel (Muir, 1980). These formations are primarily of marine origin (fig. 4).

The West Santa Cruz Terrace and Soquel Valley groundwater basins are south of the Santa Cruz Purisima Formation Highlands groundwater basin and primarily are composed of alluvial deposits (fig. 4). In the Soquel Valley groundwater basin, the water-bearing sediments consist of the Pliocene Purisima Formation, overlain by the Pleistocene Aromas Sand and by Quaternary terrace deposits. The Purisima Formation and Quaternary terrace deposits have been incised locally by streams, and these channels have been filled with Quaternary alluvium (Muir, 1980). To the southeast, the Purisima Formation is overlain by the hydraulically unconfined Aromas Sand. The Aromas Sand is brown to red, poorly consolidated, fine- to coarse-grained sandstone containing lenses of silt and clay (California Department of Water Resources, 2003). The West Santa Cruz Terrace groundwater basin contains water-bearing sediments derived from the Purisima Formation, Quaternary terrace deposits, and alluvium along the San Lorenzo River and other streams (figs. 2, 4). The Purisima Formation, the main water-bearing formation, is a thick sedimentary sequence with a fossiliferous marine-rock base that grades to continental deposits in its upper part. The thin terrace deposits and alluvium are poorly cemented, moderately permeable gravel, sands, silts and silty clays that yield only minor quantities of groundwater to wells (Greene, 1970).

The Scotts Valley and Felton area groundwater basins are small alluvial valleys in the Santa Cruz Mountains (fig. 2). The Felton area and Scotts Valley groundwater basins include the following formations from oldest to youngest: granitic basement, Tertiary Lompico Sandstone, Monterey Formation,

Santa Margarita Sandstone, and Quaternary alluvium. The principal water-bearing formation is the unconfined Santa Margarita Sandstone, which is as much as 107 m thick. The underlying Lompico Sandstone also yields water, but to a lesser extent, and is as much as 183 m thick.

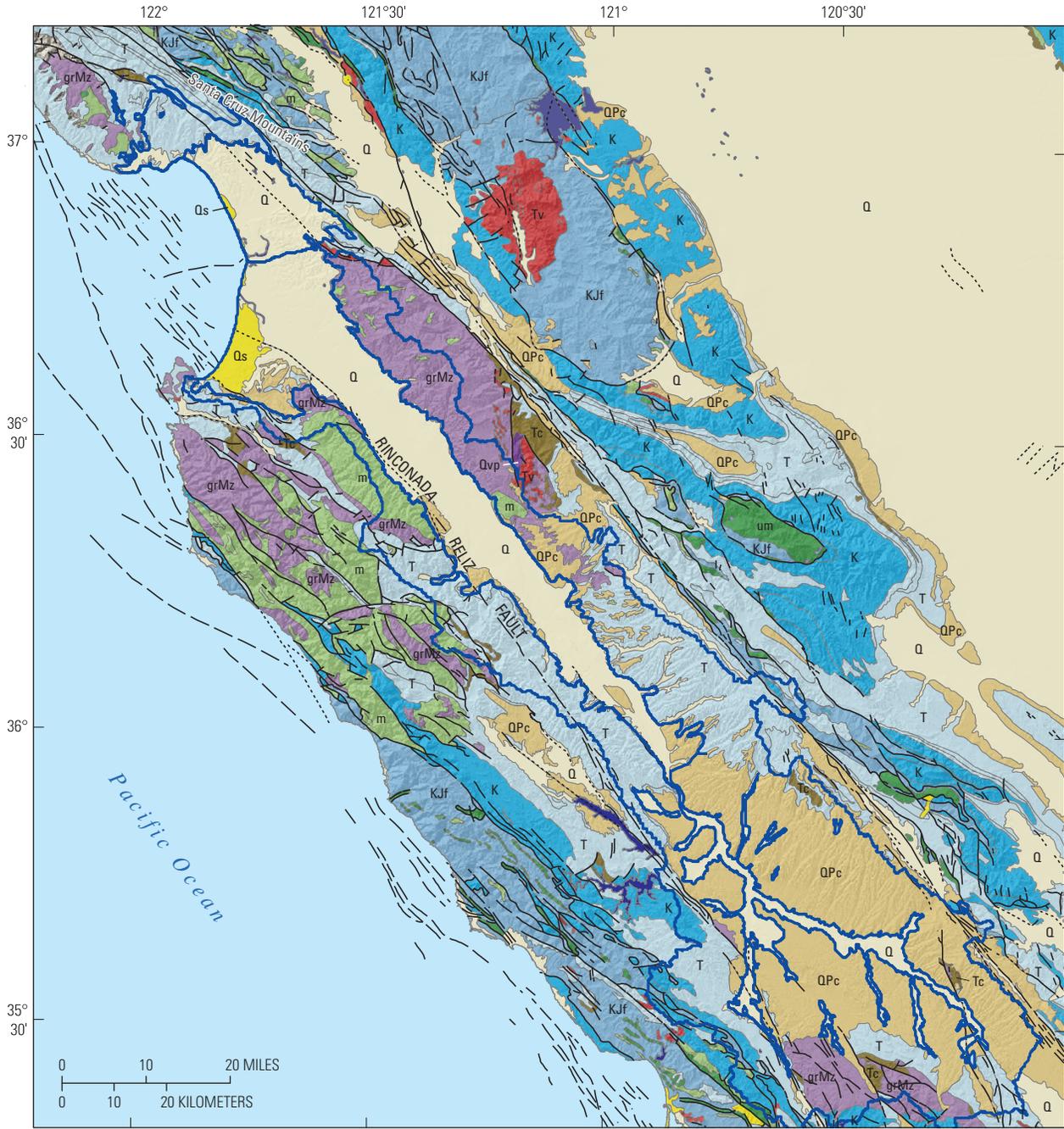
Pajaro Valley Study Area

The Pajaro Valley study area covers about 360 km² and consists of the Pajaro Valley groundwater basin (fig. 2). The Pajaro Valley study area is bounded to the west by the Monterey Bay, to the east and north by the Santa Cruz Mountains, and to the south by the Salinas Valley. The water-bearing geologic units in the Pajaro Valley include, from oldest to youngest, the Purisima Formation, the Aromas Sand, terrace deposits, alluvium, and dune deposits (Johnson and others, 1988). The Aromas Sand is the primary freshwater-bearing unit in the Pajaro Valley study area. It consists of upper eolian and lower fluvial sand units that are separated by confining layers of interbedded clays and silty clay, and it ranges in thickness from 30 m in the foothills to more than 250 m near the mouth of the Pajaro River (Johnson and others, 1988). The terrace deposits consist of unconsolidated gravel, sand, silt, and clay overlain by alluvium. The basal gravel has good hydraulic continuity with the underlying Aromas Sand and is a major source of water for shallow wells in the Pajaro River floodplain. The alluvium is composed of Pleistocene materials, which are overlain by Holocene alluvium consisting of sand, gravel, and clay deposited by the Pajaro River and by dune deposits consisting of dune sands with an average thickness of 15–90 m (Johnson and others, 1988).

Salinas Valley Study Area

The Salinas Valley study area covers approximately 2,000 km² and includes the following CDWR-defined groundwater subbasins of the Salinas Valley (California Department of Water Resources, 2003): 180/400 Foot Aquifer, Seaside Area, Corral de Tierra Area, Langley Area, Eastside Aquifer, Forebay Aquifer, Upper Valley Aquifer, and the Quaternary alluvium part of the Paso Robles Area groundwater subbasin (figs. 2, 4). The part of the Paso Robles Area subbasin mapped as having Plio-Pleistocene alluvium as the surficial geologic unit was considered part of the Highlands study area (see the following section). The Salinas Valley study area is bounded by the Monterey Bay, Sierra de Salinas, and Santa Lucia Range along the west and southwest; the Pajaro Valley to the north; the Gabilan Range to the east; and the Temblor Range and La Panza Range to the southeast and south, respectively (fig. 2).

10 Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

Geology modified from Saucedo and others (2000), GIS data for the Geologic Map of California

Geologic units		EXPLANATION		
Holocene alluvium		KJf Franciscan complex	Tc Tertiary—non-marine sediment	 Study unit and area boundary
Q Recent alluvium, landslide	K Metasediment	Tv Tertiary mafic volcanics	grMz Granitic rocks	 Fault —Dashed where approximately located,
Qs Other deposits	Qvp Quarternary—pyroclastic volcanics	m Metamorphic rocks	um Ultramafic and mafic rocks	 dotted where concealed
Marine sediments and metasediments		T Tertiary marine sediments	QPc Plio-Pleistocene and Pliocene nonmarine	

Figure 4. Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

The Salinas Valley is the largest of the intermontane valleys of the southern Coast Ranges, and it extends southeastward 193 km from Monterey Bay to Paso Robles (fig. 2). The Salinas Valley was formed, in part, as a result of normal faulting along the Rinconada-Reliz fault along the western margin of the valley from King City in the south to Monterey Bay in the north (figs. 2, 4; California Department of Water Resources, 2003). Normal movement along the fault, valley-side down, resulted in the deposition of a westward thickening alluvial wedge (Showalter and others, 1984). The Salinas Valley is filled by as much as 3,048 m on the east and by as much as 4,572 m on the west with Tertiary and Quaternary marine and terrestrial sediments that include as much as 609 m of saturated alluvium (Showalter and others, 1984). Water-bearing units, which lie above mostly non-water-bearing and consolidated granitic basement, include the Miocene Monterey Formation, Pliocene Purisima Formation, Pliocene-to-Pleistocene Paso Robles Formation, and Pleistocene to Holocene alluvium (Hanson and others, 2002). The main water-bearing units in the northern and eastern parts of the Salinas Valley study area are unconsolidated to semi-consolidated sediments with interbedded gravel sand and silt, alluvial-fan, and river deposits (Durbin and others, 1978). The 180-Foot Aquifer is likely to be an important source of water to shallow domestic wells in the area of the 180/400 Foot Aquifer subbasin in the north and the Forebay Aquifer subbasin in the south (fig. 2). The deeper 400-Foot and 900-Foot Aquifers are likely the main source of water for public-supply wells. Water-bearing units in the southern part of the Salinas Valley study area, the area surrounding the city of Paso Robles, include Pleistocene alluvium that consists of unconsolidated fine-to-coarse-grained sand and Holocene alluvium that consists of pebbles and boulders as much as 40 m thick near the Salinas River, which convey limited amounts of water to shallow wells in the area.

Highlands Study Area

The Highlands study area covers about 5,250 km² that surround the Salinas Valley study area on three sides. Surface and groundwater generally flow out of the Highlands and toward the Salinas Valley study area. The Highlands study area is underlain by fractured rocks in the north and Plio-Pleistocene sediments in the south that compose the hills and mountains bordering the Highlands study area (figs. 2, 3). Elevations in the study area ranged from 300 to more than 1,200 m above sea level. The Highlands study area is underlain by the Franciscan Complex and the Salinian block basement complexes as a result of transverse movement along the San Andreas Fault (Compton, 1966; Alt and Hyndman,

2000). The Cretaceous Franciscan basement complex generally is composed of accreted ocean-floor sediments and rocks formed during subduction; the Mesozoic Salinian block basement complex generally is composed of rocks formed when the continental crust was intruded by granitic plutons (Harden, 2004).

The northwestern part of the Highlands study area is underlain by the Sierra de Salinas, which is composed of schist that was formed when sandstone was intruded by granitic magma that formed the Salinian block (Compton, 1966; Alt and Hyndman, 2000). The southwestern part of the Highlands study area includes part of the Santa Lucia Range, which is composed of the Franciscan Complex that has intensely sheared sediments and serpentine (Compton, 1966; Alt and Hyndman, 2000). Other sedimentary rocks in the Franciscan Complex include sandstone, shale, and limestone. The southern and southeastern part of the Highlands study area is in the 80-million-year-old La Panza Range, which is part of the granitic Salinian block. The southern part of the Highlands study area also includes the Plio-Pleistocene alluvium of the Paso Robles Area groundwater basin that is not included in the Salinas Valley study area. This is underlain by the Monterey Formation (Durham, 1974). The eastern part of the Highlands study area includes the Gabilan Range, which is generally composed of granite that is also part of the Salinian block complex. A layer of the Monterey Formation lies between the surficial Paso Robles Formation and the underlying granitic rocks (Durham, 1974).

Groundwater in the Highlands study area comes from aquifers in granitic, metamorphic, or lithified sedimentary rocks, rather than from sediment deposits in groundwater basins. These rocks typically have low permeability, except where they are extensively fractured. The three-dimensional complexity and variability of fracture systems can cause well yields and water quality to vary widely on a local scale. These hard-rock aquifers are recharged by infiltration of precipitation, snow melt, and water from lakes and streams (California Department of Water Resources, 2011).

Methods

This section describes the methods used for (1) defining groundwater quality, (2) assembling the datasets used for the assessments, (3) selecting constituents for evaluation, (4) calculating aquifer-scale proportions, (5) providing statistical analyses for the *understanding assessment*, and (6) comparing the groundwater quality of the MS-SA and MS-PA study units.

Relative Concentrations and Water-Quality Benchmarks

In this study, groundwater-quality data are presented as relative concentrations, which are defined as the ratio of a constituent's concentration measured in a groundwater sample to the concentration of a constituent's regulatory or non-regulatory benchmark used to evaluate drinking-water quality. A relative-concentration value less than 1 indicates that the sample concentration was less than the benchmark concentration, and a relative-concentration value greater than 1 indicates that the sample concentration was greater than the benchmark concentration. The use of relative concentrations permits comparison on a single scale for constituents that can be present at a wide range of concentrations. Relative concentrations can only be computed for constituents with water-quality benchmarks; therefore, constituents without water-quality benchmarks were not included in the *status assessment*.

The use of relative concentration is similar to the approaches used by other studies to place the concentrations of constituents in groundwater in a toxicological context. Toccalino and others (2004), Toccalino and Norman (2006), and Rowe and others (2007) previously used the ratio of measured sample concentration to the benchmark concentration—either the U.S. Environmental Protection Agency (EPA) maximum contaminant levels (MCLs) or health-based screening levels (HBSL)—and defined this ratio as the benchmark quotient. The ratio is called the relative concentration in this report rather than benchmark quotient because the two ratios may be calculated with benchmarks from different sources and therefore can have different values.

The benchmarks used for each constituent in this study were selected in the following order of priority:

Regulatory, health-based: California and EPA maximum contaminant levels (MCL-CA and MCL-US), action levels (AL-US), and treatment technique levels (TT-US; California State Water Resources Control Board, 2015; U.S. Environmental Protection Agency, 2016).

Non-regulatory, health-based: HBSL, EPA lifetime health-advisory levels (HAL-US), EPA risk-specific doses for 1:100,000 (RSD5-US), and California notification levels (NL-CA; California State Water Resources Control Board, 2015; U.S. Environmental Protection Agency, 2016).

Non-regulatory: California and EPA secondary maximum contaminant levels (SMCL-CA and SMCL-US; California State Water Resources Control Board, 2015). For constituents with recommended and upper SMCL-CA levels, the values for the upper levels were used.

For constituents with multiple types of benchmarks, this hierarchy may not result in selection of the benchmark with the lowest concentration. Additional information about the types of benchmarks and listings of the benchmarks for all constituents analyzed is provided by Goldrath and others (2016).

For ease of discussion, relative concentrations of constituents were classified into low, moderate, and high categories. Relative concentrations greater than 1.0 indicate groundwater concentrations greater than the benchmark concentrations and were defined as “high” for all constituents. For inorganic constituents (trace elements, nutrients, radioactive constituents, and inorganic constituents having SMCL benchmarks) relative concentrations greater than 0.5 and less than or equal to 1.0 (groundwater concentration greater than half of the benchmark concentration, but less than the benchmark) were defined as “moderate,” and relative concentration less than or equal to 0.5 (groundwater concentration less than half the benchmark concentration) were defined as “low.” For organic and special-interest constituents, relative concentration greater than 0.1 and less than or equal to 1.0 were defined as “moderate,” and relative concentration less than or equal to 0.1 were defined as “low.”

A larger threshold value for inorganic constituents was used because in the MS-SA study unit, and elsewhere in California, naturally present inorganic constituents tend to be more prevalent and have higher background levels than organic constituents in groundwater (Belitz and others, 2015). Although more complex classifications based on the properties and sources of individual constituents could be devised, use of a single moderate/low threshold value for each of the two major groups of constituents provided a consistent, objective criteria for distinguishing constituents at moderate, rather than low, concentrations.

Datasets and Methods for Status Assessment

Groundwater-quality data used for the status assessment came from 100 grid and 70 tap sites sampled by the USGS in the MS-SA study unit between October 2012 and May 2013.

Grid Sites

Detailed descriptions of the methods used to identify sites for sampling are given in Goldrath and others (2016). Briefly, each study area was divided into equal-area grid cells (Scott, 1990), but the size and number of grid cells were not the same for the different areas. The Santa Cruz study area was divided into 15 cells (13-km² each), the Pajaro Valley study area was divided into 15 cells (18-km² each), the Salinas Valley study area was divided into 40 cells (49-km² each), and the Highland study area was divided into 30 cells (174-km² each; [table 1](#)). In each grid cell, one site was randomly selected to represent the groundwater resource used for domestic supply (grid sites). Sites were selected from lists of candidate domestic sites in each grid cell, identified using drillers' log information obtained from the CDWR. The target lists of domestic wells were taken into the field and door-to-door canvassing was done, beginning with the site nearest to a random point in the grid cell to ensure random selection of sites. In cases where limited or no drillers' logs were available for a grid cell, wells

were identified by door-to-door canvassing. The MS-SA study unit contained a total of 100 grid cells, and a sample was collected from each cell (fig. 5). Grid-site samples were named with an alphanumeric GAMA identification (ID) consisting of an alpha prefix identifying the type of GAMA PBP study, the study unit, and the study area and a numeric suffix indicating the cell number of the site (table 2). For example, in the S-MS-SC14 GAMA ID, the S stands for PBP shallow aquifer, MS stands for Monterey-Salinas study unit, SC stands for the Santa Cruz study area, and the number 14 means the site was in cell 14 of the Santa Cruz study area. The following prefixes were used to identify the study area: SC, Santa Cruz study area; P, Pajaro Valley study area; SV, Salinas Valley study area; and H, Highlands study area.

Samples collected from grid wells were analyzed for 208 constituents. The classes of constituents analyzed in samples included volatile organic compounds, pesticides, trace elements, isotopic tracers, and radioactivity (table 3). The collection, analysis, and quality-control data for these analytes are described by Goldrath and others (2016). Water-quality data collected are tabulated in Goldrath and others (2016) and also are available from the SWRCB's database GeoTracker GAMA (http://www.waterboards.ca.gov/gama/geotracker_gama.shtml) and the USGS's database NWISWeb (<http://waterdata.usgs.gov/ca/nwis/>).

Tap Sites

In addition to the water-quality data obtained from samples collected at grid sites, spatially weighted calculations of aquifer-scale proportions of relative concentrations for the MS-SA study unit also used data from water samples collected from household tap sites. Seventy groundwater samples were collected from tap sites, primarily at households supplied by a domestic well. Most tap samples were collected from faucets downstream from storage or pressure tanks used to store water pumped from wells. Tap-site samples were collected in the Salinas Valley and Pajaro Valley study areas to provide a greater spatial density of groundwater data to define the distribution of inorganic constituents (fig. 5). Goldrath and others (2016) provide a more thorough discussion of the tap sampling design. A total of 39 water-quality indicators and inorganic constituents were analyzed in samples collected at tap sites (table 3). Comparison of the data from samples collected at the well head to data from samples at tap sites showed that most water-quality data collected from tap sites may be combined with data from the grid sites for the purposes of calculating aquifer-scale proportions (Justin Kulongoski, U.S. Geological Survey, written commun., 2016).

Calculation of Aquifer-Scale Proportions

Aquifer-scale proportions are defined as the percentage of the area (rather than the volume) of the shallow aquifer system where concentrations are greater than or less than

specified thresholds relative to regulatory or aesthetic water-quality benchmarks. The proportions of those areas with high, moderate, and low relative concentrations of constituents were calculated using the spatially weighted approach of Belitz and others (2010). For ease of discussion, these proportions are referred to as high, moderate, and low aquifer-scale proportions. Aquifer-scale proportions were calculated for individual constituents and for classes of constituents.

Aquifer-scale proportions were computed on a cell-by-cell basis rather than an average of all the sites. The proportion of high values for each study area was computed by (1) calculating the number of sites with high relative concentrations in each grid cell and (2) averaging the grid-cell values computed in step 1 (equation 1; Isaaks and Srivastava, 1989; Belitz and others, 2010). The resulting proportions are spatially unbiased. The aquifer-scale proportion for moderate relative concentrations was calculated similarly.

$$P_s^{high} = \frac{\sum_c \frac{W_c^{high}}{W_c}}{N} \quad (1)$$

where

P_s^{high}	is the high aquifer-scale proportion for the study area,
W_c^{high}	is the number of sites in a particular cell in the study area having high relative concentration for the constituent,
W_c	is the number of sites in a particular cell in the study area having data for the constituent,
\sum_c	is summation over the number of cells in the study area for the constituent, and
N	is the number of cells in the study area having data for the constituent.

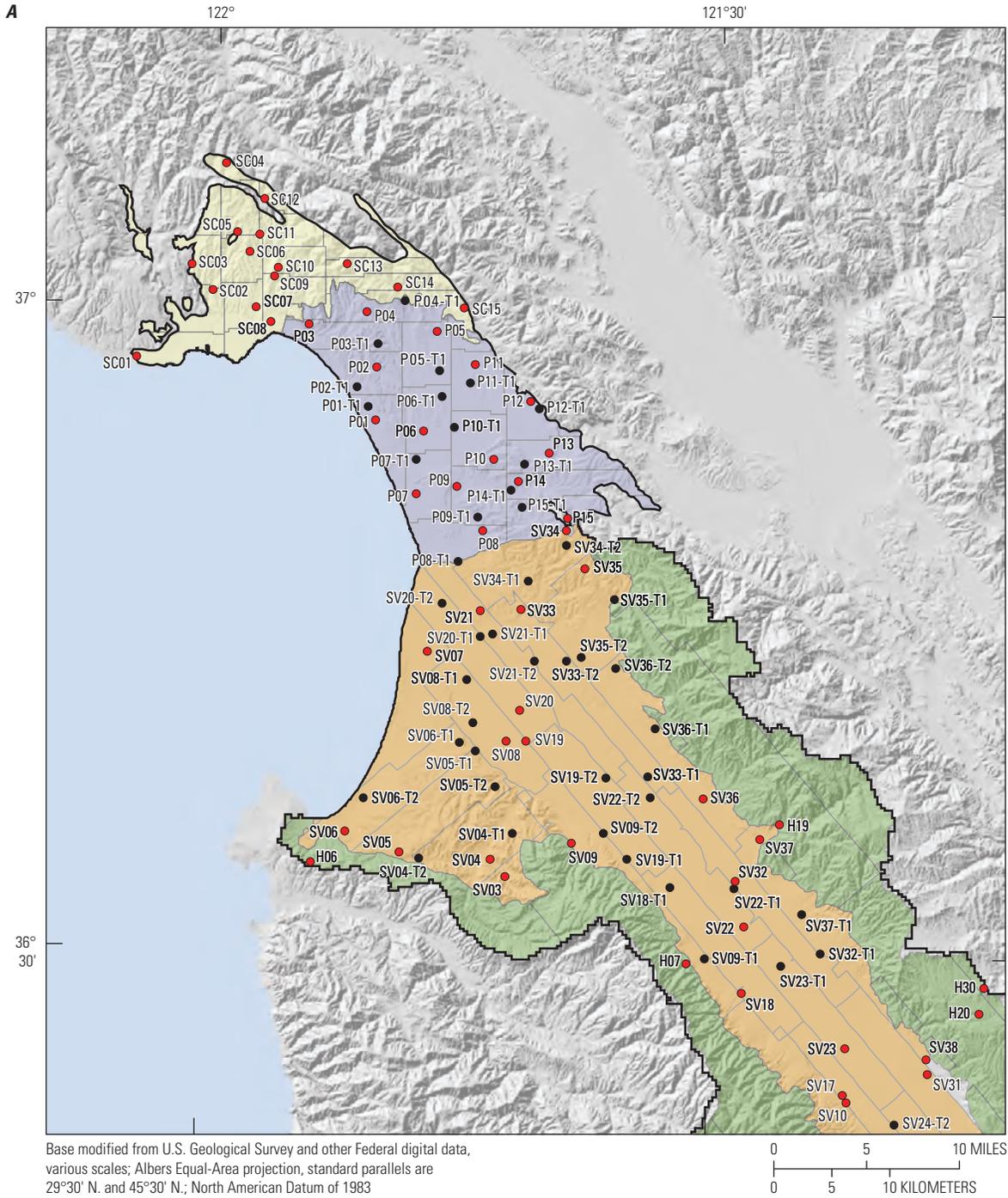
The proportion for each study area was calculated individually because grid-cell sizes are not uniform across the study areas. The proportion for the study unit is determined by calculating the area-weighted sum using the following equation:

$$P_{SU} = \sum P_{SA} F_{SA} \quad (2)$$

where

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

The F_{SA} for each study area of the MS-SA study unit follows: Santa Cruz at 0.03, Pajaro Valley at 0.04, Salinas Valley at 0.26, and Highlands at 0.67. The F_{SA} for the three study areas of the MS-SA study unit used to compare the water quality with the MS-PA study unit follows: Santa Cruz at 0.08, Pajaro Valley at 0.14, and Salinas Valley at 0.78. The Highlands study area was not included because that area was not part of the MS-PA study unit.



EXPLANATION

- | | | |
|---------------------|-------------------|---------------------|
| Study areas | | Grid cell boundary |
| Santa Cruz (SC) | Pajaro Valley (P) | Study unit boundary |
| Salinas Valley (SV) | Highlands (H) | Grid site |
| | | Tap site |

Figure 5. Study-area grid cells, grid and tap wells in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: A, northern part, and B, southern part.

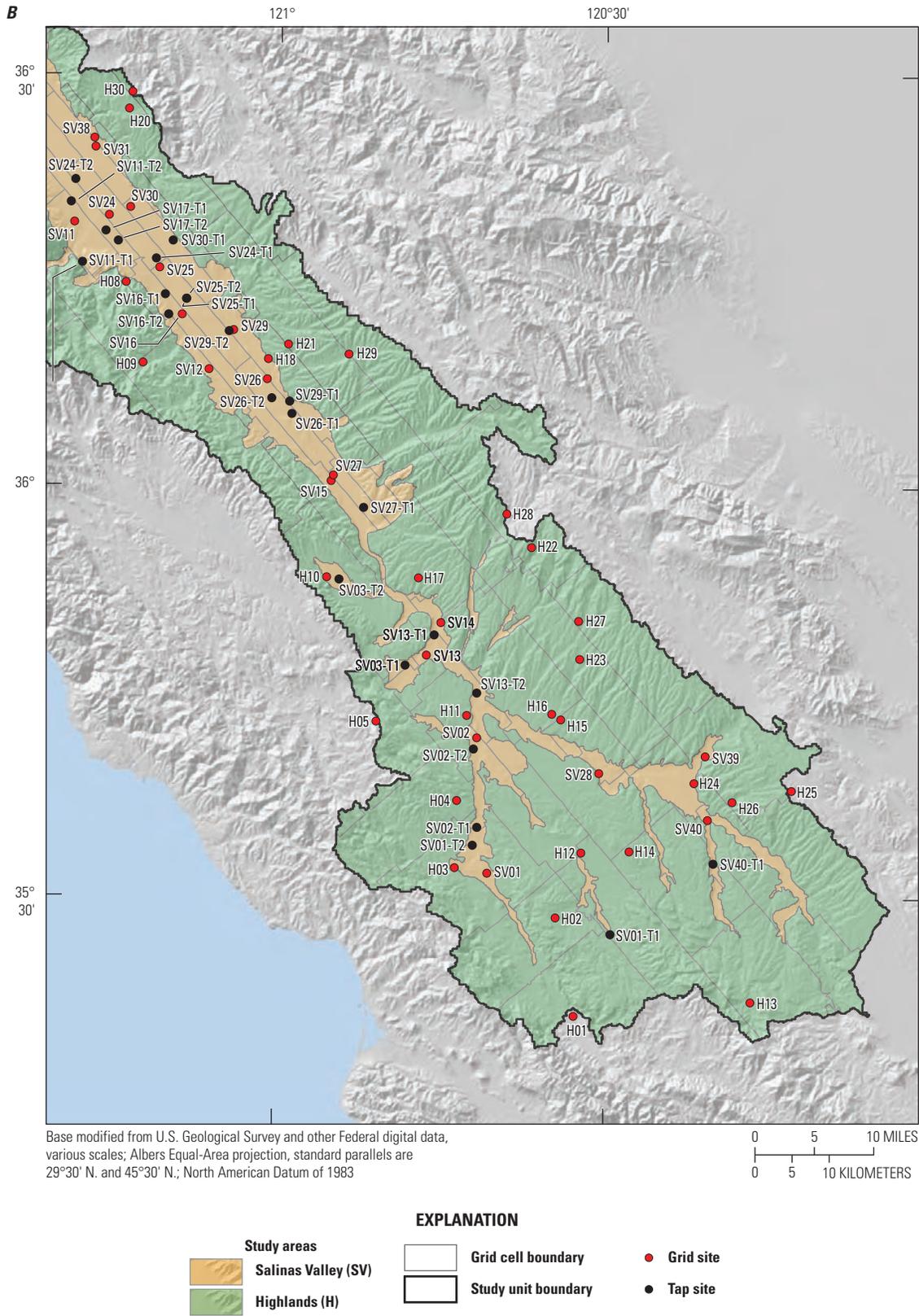


Figure 5. —Continued

16 Status and Understanding of Groundwater Quality in the Monterey-Salinas Shallow Aquifer Study Unit, 2012–13

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Santa Cruz study-area grid sites					
S-MS-SC01	365727122041701	91	na	na	na
S-MS-SC02	370039121594901	159	116	159	43
S-MS-SC03	370150122010601	37	18	37	19
S-MS-SC04	370632121591001	30	10	30	21
S-MS-SC05	370322121582801	155	119	155	37
S-MS-SC06	370226121574301	99	26	99	73
S-MS-SC07	365954121571601	35	18	35	17
S-MS-SC08	365911121562001	46	32	46	13
S-MS-SC09	370120121561501	134	na	na	na
S-MS-SC10	370145121560101	41	35	41	6
S-MS-SC11	370314121570801	52	21	52	30
S-MS-SC12	370456121565301	74	30	74	44
S-MS-SC13	370159121515601	274	152	244	91
S-MS-SC14	370055121485701	73	30	73	43
S-MS-SC15	370000121445601	82	67	82	15
Pajaro Valley study-area grid sites					
S-MS-P01	365443121500701	115	na	na	na
S-MS-P02	365709121500401	61	24	58	34
S-MS-P03	365905121540901	88	55	88	34
S-MS-P04	365943121504101	183	146	180	34
S-MS-P05	365853121463101	na	na	na	na
S-MS-P06	365415121471501	61	49	58	9
S-MS-P07	365117121473601	58	43	49	6
S-MS-P08	364938121433701	55	39	54	15
S-MS-P09	365140121451201	55	43	55	12
S-MS-P10	365259121430101	79	67	79	12
S-MS-P11	365722121441601	91	79	91	12
S-MS-P12	365541121405801	140	104	134	30
S-MS-P13	365318121394601	134	95	131	37
S-MS-P14	365159121413301	159	128	159	30
S-MS-P15	365016121383701	146	na	na	na

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Salinas Valley study-area grid sites					
S-MS-SV01	353151120403801	85	43	85	43
S-MS-SV02	354141120413301	88	52	88	37
S-MS-SV03	363332121415701	140	64	137	73
S-MS-SV04	363418121425001	104	43	104	61
S-MS-SV05	363437121481201	152	49	146	98
S-MS-SV06	363531121512601	84	6	84	78
S-MS-SV07	364356121464701	120	107	120	12
S-MS-SV08	363951121420201	88	79	88	9
S-MS-SV09	363507121380601	213	137	213	77
S-MS-SV10	362314121214401	58	46	58	12
S-MS-SV11	361910121184801	125	113	125	12
S-MS-SV12	360831121061901	79	54	79	24
S-MS-SV13	354745120461101	104	37	101	64
S-MS-SV14	355008120445501	120	na	na	na
S-MS-SV15	360024120550501	55	30	55	24
S-MS-SV16	361227121085501	50	37	49	12
S-MS-SV17	362335121215301	49	30	49	18
S-MS-SV18	362815121275801	26	na	na	na
S-MS-SV19	363953121405001	113	108	111	3
S-MS-SV20	364117121411401	152	na	na	na
S-MS-SV21	364555121434301	73	61	73	12
S-MS-SV22	363100121270002	165	128	165	37
S-MS-SV23	362547121214801	91	na	na	na
S-MS-SV24	361941121153701	204	168	198	30
S-MS-SV25	361552121105701	84	35	67	32
S-MS-SV26	360747121005701	30	18	30	12
S-MS-SV27	360000120540001	40	24	40	15
S-MS-SV28	353908120303101	39	na	na	na
S-MS-SV29	361123121040801	26	21	24	3
S-MS-SV30	362017121134501	61	na	na	na

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Salinas Valley study-area grid sites—Continued					
S-MS-SV31	362438121165801	38	na	na	na
S-MS-SV32	363329121282401	87	na	na	na
S-MS-SV33	364601121411901	79	67	79	12
S-MS-SV34	364944121384101	192	51	186	134
S-MS-SV35	364757121373301	144	132	144	12
S-MS-SV36	363718121302001	213	146	207	61
S-MS-SV37	363527121270001	101	49	98	49
S-MS-SV38	362517121170401	61	34	51	16
S-MS-SV39	354027120204901	98	46	95	49
S-MS-SV40	353547120203701	89	na	na	na
Highlands study-area grid sites					
S-MS-H01	352125120324101	146	55	146	91
S-MS-H02	352838120341901	110	49	110	61
S-MS-H03	353212120433101	na	na	na	na
S-MS-H04	353707120432001	72	35	72	37
S-MS-H05	354251120504701	na	na	na	na
S-MS-H06	363403121532701	122	61	116	55
S-MS-H07	362938121311201	7	na	na	na
S-MS-H08	361449121140301	30	na	na	na
S-MS-H09	360856121122301	43	24	43	18
S-MS-H10	355325120552201	36	na	na	na
S-MS-H11	354321120423401	125	na	na	na
S-MS-H12	353322120320101	42	na	na	na
S-MS-H13	352230120163701	146	na	na	na
S-MS-H14	353327120273901	226	183	226	43
S-MS-H15	354302120335501	143	125	143	18
S-MS-H16	354327120344601	98	79	98	18
S-MS-H17	355322120470201	122	61	122	61
S-MS-H18	360919121005501	122	na	na	na
S-MS-H19	363608121255101	46	na	na	na
S-MS-H20	362727121135701	38	15	38	23

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Highlands study-area grid sites—Continued					
S-MS-H21	361020120590501	122	116	122	6
S-MS-H22	355538120364001	47	na	na	na
S-MS-H23	354731120321801	212	159	212	53
S-MS-H24	353830120215001	152	91	152	61
S-MS-H25	353753120125301	na	na	na	na
S-MS-H26	353707120181601	154	32	123	91
S-MS-H27	355018120322301	152	na	na	na
S-MS-H28	355803120390001	18	na	na	na
S-MS-H29	360939120533101	27	10	15	16
S-MS-H30	362841121134201	130	116	na	45
Pajaro Valley study-area tap sites					
S-MS-P01-T1	365519121502901	78	60	na	na
S-MS-P02-T1	365613121511301	na	na	na	na
S-MS-P03-T1	365816121500101	213	na	na	na
S-MS-P04-T1	370017121482301	107	na	na	na
S-MS-P05-T1	365704121462201	na	na	na	na
S-MS-P06-T1	365552121461001	72	na	na	na
S-MS-P07-T1	365253121473901	na	na	na	na
S-MS-P08-T1	364811121450501	na	na	na	na
S-MS-P09-T1	365017121435701	na	na	na	na
S-MS-P10-T1	365425121452201	54	31	45	13
S-MS-P11-T1	365632121443101	na	na	na	na
S-MS-P12-T1	365522121402401	85	na	na	na
S-MS-P13-T1	365245121411201	na	na	na	na
S-MS-P14-T1	365134121420101	na	na	na	na
S-MS-P15-T1	365047121412201	na	na	na	na
Salinas Valley study-area tap sites					
S-MS-SV01-T1	352725120292101	na	na	na	na
S-MS-SV01-T2	353351120415801	na	9	17	8
S-MS-SV02-T1	353510120413301	na	na	na	na
S-MS-SV02-T2	354000120410001	51	38	51	12
S-MS-SV03-T1	354659120481001	61	40	55	15
S-MS-SV03-T2	355316120541701	na	na	na	na

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Salinas Valley study-area tap sites—Continued					
S-MS-SV04-T1	363535121413301	na	na	na	na
S-MS-SV04-T2	363420121470401	146	na	na	na
S-MS-SV05-T1	363920121434901	104	91	104	12
S-MS-SV05-T2	363745121423901	122	101	113	12
S-MS-SV06-T1	363945121444701	149	87	na	na
S-MS-SV06-T2	363700121500001	70	57	66	9
S-MS-SV08-T1	364242121442401	na	na	na	na
S-MS-SV08-T2	364042121435801	105	93	105	12
S-MS-SV09-T1	362951121300801	180	146	177	30
S-MS-SV09-T2	363538121361101	na	na	na	na
S-MS-SV11-T1	361615121180401	na	na	na	na
S-MS-SV11-T2	362037121190801	na	na	na	na
S-MS-SV13-T1	354911120452701	61	na	na	na
S-MS-SV13-T2	354501120413301	91	27	82	56
S-MS-SV16-T1	361356121102901	na	na	na	na
S-MS-SV16-T2	361228121100801	na	na	na	na
S-MS-SV17-T1	361830121155501	na	na	na	na
S-MS-SV17-T2	361747121144801	na	na	na	na
S-MS-SV18-T1	363310121321301	na	na	na	na
S-MS-SV19-T1	363428121344901	na	na	na	na
S-MS-SV19-T2	363813121360601	na	na	na	na
S-MS-SV20-T1	364441121433801	na	na	na	na
S-MS-SV20-T2	364615121455701	na	na	na	na
S-MS-SV21-T1	364448121425401	na	na	na	na
S-MS-SV21-T2	364337121402601	137	na	na	na
S-MS-SV22-T1	363308121283001	91	37	91	55
S-MS-SV22-T2	363719121332801	na	na	na	na
S-MS-SV23-T1	362934121253901	na	na	na	na

Table 2. Nomenclature and well-construction information for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[H, Highlands study-area well; MS, Monterey-Salinas study unit; na, data not available; P, Pajaro Valley study-area well; S, shallow aquifer assessment; SC, Santa Cruz study-area well; SV, Salinas Valley study-area well; T, tap well; USGS, U.S. Geological Survey]

GAMA site- identification number	USGS site- identification number	Construction information (meters)			
		Well depth	Depth to top of perforations	Depth to bottom of perforations	Length of perforations
Salinas Valley study-area tap sites—Continued					
S-MS-SV24-T1	361631121112001	na	na	na	na
S-MS-SV24-T2	362215122185101	91	51	89	38
S-MS-SV25-T1	361338121083001	na	na	na	na
S-MS-SV25-T2	361335121083101	na	na	na	na
S-MS-SV26-T1	360516120584101	na	na	na	na
S-MS-SV26-T2	360600121000001	43	27	43	15
S-MS-SV27-T1	355827120520601	122	15	122	107
S-MS-SV29-T1	360613120585801	na	na	na	na
S-MS-SV29-T2	361115121043601	56	na	na	na
S-MS-SV30-T1	361753121094801	na	na	na	na
S-MS-SV32-T1	363011121232201	122	na	na	na
S-MS-SV33-T1	363818121334001	201	177	201	24
S-MS-SV33-T2	364337121383501	na	na	na	na
S-MS-SV34-T1	364721121405301	na	na	na	na
S-MS-SV34-T2	364902121384001	85	na	na	na
S-MS-SV35-T1	364633121354801	21	na	na	na
S-MS-SV35-T2	364347121374201	na	na	na	na
S-MS-SV36-T1	364034121331601	na	na	na	na
S-MS-SV36-T2	364317121354001	na	na	na	na
S-MS-SV37-T1	363158121242801	122	na	na	na
S-MS-SV40-T1	353236120200501	na	na	na	na

Table 3. Number of sites sampled by the U.S. Geological Survey for grid and tap sampling schedules and number of constituents sampled in each constituent class for the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[—, no data]

	Schedule	
	Grid	Tap
Total number of sites	100	70
Constituent class	Number of constituents	
Field water-quality indicators		
Dissolved oxygen, temperature, pH, and specific conductance	4	4
Field alkalinity	1	—
Organic constituents		
Volatile organic compounds (VOCs) ¹	85	—
Pesticides and degradates	63	—
Constituents of special interest		
Perchlorate and <i>N</i> -nitrosodimethylamine (NDMA)	2	—
Inorganic constituents		
Trace elements	23	23
Nutrients	5	1
Major and minor ions, silica, and total dissolved solids (TDS)	11	11
Radon-222	1	—
Gross alpha and gross beta radioactivity (72-hour and 30-day) ²	2	—
Isotopic constituents		
Stable isotopes of hydrogen and oxygen in water	2	—
Stable isotopes of carbon in dissolved inorganic carbon and carbon-14 abundance	2	—
Tritium	1	—
Noble gases	6	—
Total	208	39

¹Includes nine fumigants.²Only 72-hour results are used for analyses in this report.

Aquifer-scale proportions of high relative concentrations also were determined for classes of constituents. Aquifer-scale proportions for constituent classes were calculated using the maximum relative concentration for any constituent in the class to represent the class. The classes of organic constituents for which aquifer-scale proportions were calculated included trihalomethanes and pesticides (herbicides, insecticides, and fumigants). The classes of inorganic constituents with human-health benchmarks for which aquifer-scale proportions were calculated include trace elements, radioactive constituents, nutrients, and any inorganic with a health-based benchmark. Classes of inorganic constituents with SMCL benchmarks for which aquifer-scale proportions were calculated were the salinity indicators total dissolved solids, sulfate, and chloride and any inorganic constituent with an aesthetic-based benchmark. Constituents of special interest were considered as a class.

The raw detection frequency of each constituent with high or moderate relative concentrations was calculated for the same dataset as used for the aquifer-scale proportions as well. This approach is not spatially unbiased because tap sites are not uniformly distributed throughout the MS-SA study unit. Consequently, the raw detection frequency of high relative concentrations at sites clustered in a particular area represents a smaller part of the shallow aquifers and could be given a

disproportionately high weight compared to spatially unbiased methods.

Selection of Constituents for Status Assessment

More than 200 constituents were analyzed in samples from the MS-SA study-unit wells; however, only subsets of these constituents are discussed in this report. Criteria used to select constituents for evaluation in the status assessment are as follows:

Constituents present at high or moderate relative concentrations in grid or tap sites.

Organic or special-interest constituents for which study-unit detection frequencies were 10 percent or more in samples from grid sites, regardless of concentration.

These criteria identified 5 organic and special-interest constituents and 20 inorganic constituents for evaluation in the status assessment (table 4A). An additional 18 organic constituents and 21 inorganic constituents were detected, but were not evaluated in the status assessment because either benchmarks were not established or detections were at low relative concentrations (table 4B). Complete tables of the constituents analyzed in samples collected in the MS-SA study unit can be found in Goldrath and others (2016).

Table 4A. Benchmark types and values and reporting limits for constituents that were detected at high or moderate concentration or, for organic constituents, were detected in more than 10 percent of the grid samples, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[**Benchmark types:** *Regulatory, health-based benchmarks:* MCL-CA, California's maximum contaminant level; MCL-US, U.S. Environmental Protection Agency (EPA) maximum contaminant level. *Non-regulatory, health-based benchmarks:* HAL-US, EPA lifetime health-advisory level; HBSL, health-based screening level developed by the U.S. Geological Survey (USGS); NL-CA, California's notification level. *Non-regulatory, aesthetic-based benchmarks:* SMCL-CA, California's secondary maximum contaminant level. **Abbreviations:** mg/L, milligrams per liter; na, not available; pCi/L, picocuries per liter; ssL_c, sample-specific critical level; µg/L, micrograms per liter]

Constituent	Benchmark			Reporting limits	
	Type ¹	Value	Units	USGS	California
Trace and minor elements					
Arsenic	MCL-US	10	µg/L	0.03	2
Beryllium	MCL-US	4	µg/L	0.006	1
Boron	HAL-US	5,000	µg/L	3	100
Chromium	MCL-CA	50	µg/L	0.07	10
Fluoride	MCL-CA	2	µg/L	0.04	0.1
Iron	SMCL-CA	300	µg/L	3.2	100
Manganese	HBSL	300	µg/L	0.13	20
Molybdenum	HBSL	40	µg/L	0.014	na
Selenium	MCL-US	50	µg/L	0.03	2
Strontium	HAL-US	4,000	µg/L	0.2	2
Vanadium	NL-CA	50	µg/L	0.08	3
Radioactive constituents					
Adjusted gross alpha radioactivity, 72-hour count	MCL-US	15	pCi/L	ssL _c ²	3
Gross beta radioactivity, 72-hour count	MCL-CA	50	pCi/L	ssL _c ²	1
Radon-222	Proposed MCL-US	4,000	pCi/L	ssL _c ²	100
Uranium	MCL-US	30	µg/L	0.003	1 (pCi/L)
Nutrients					
Ammonia, as nitrogen	HAL-US	25	mg/L	0.01	na
Nitrate plus nitrite, as nitrogen	MCL-US	10	mg/L	0.04	0.4
Salinity indicators ³					
Chloride	SMCL-CA	500 (250)	mg/L	0.06	na
Sulfate	SMCL-CA	500 (250)	mg/L	0.09	0.5
Total dissolved solids (TDS)	SMCL-CA	1,000 (500)	mg/L	10	na
Trihalomethanes					
Chloroform (trichloromethane) ⁴	MCL-US	80	µg/L	0.03	1
Fumigant					
1,2-Dichloropropane (1,2-DCP)	MCL-US	5	µg/L	0.026	0.5
Herbicides					
Simazine	MCL-US	4	µg/L	0.006	1
Constituents of special interest					
Perchlorate	MCL-CA	6	µg/L	⁵ 0.1	4
<i>N</i> -nitrosodimethylamine	NL-CA	0.01	µg/L	⁵ 0.002	na

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

²Reporting limits vary by sample.

³The SMCL-CA for chloride, sulfate, and TDS have recommended and upper benchmark values. The lower benchmark value is shown in parentheses.

⁴Benchmark value is for the sum of four trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform). Only chloroform was detected in more than 10 percent of the grid sites.

⁵Reporting limits are from Weck Laboratories.

Table 4B. Constituents detected in samples collected by the U.S. Geological Survey that have no benchmarks, were present only at low relative concentrations, or, for organics, were detected in less than 10 percent of the grid samples, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[**Benchmark types:** *Regulatory, health-based benchmarks:* AL-US, U.S. Environmental Protection Agency (EPA) lifetime health-advisory level; MCL-CA, California's maximum contaminant level; MCL-US, EPA maximum contaminant level. *Non-regulatory, health-based benchmarks:* HBSL, health-based screening level developed by the USGS; NL-CA, California's notification level. *Non-regulatory, aesthetic-based benchmarks:* SMCL-CA, California's secondary maximum contaminant level. **Abbreviations:** mg/L, milligrams per liter; na, not applicable; µg/L, micrograms per liter]

Constituent	Benchmark			Reporting limits	
	Type	Value	Units	USGS	California
Trace elements					
Aluminum	MCL-CA	1,000	µg/L	2.2	10
Antimony	MCL-US	6	µg/L	0.027	6
Barium	MCL-CA	1,000	µg/L	0.07	100
Cadmium	MCL-US	5	µg/L	0.016	1
Copper	AL-US	1,300	µg/L	0.08	50
Lead	AL-US	15	µg/L	0.025	5
Lithium	na	na	µg/L	0.22	na
Nickel	MCL-CA	100	µg/L	0.09	2
Silver	HBSL	100	µg/L	0.005	1
Thallium	MCL-US	2	µg/L	0.01	1
Zinc	HBSL	2,000	µg/L	1.4	20
Nutrients					
Nitrite (as nitrogen)	MCL-US	1	mg/L	0.001	0.4
Total nitrogen (ammonia + nitrite + nitrate + organic nitrogen)	na	na	mg/L	0.05	na
Orthophosphate (as phosphorus)	na	na	mg/L	0.004	0.3
Major ions					
Bromide	na	na	mg/L	0.01	na
Calcium	na	na	mg/L	0.022	na
Magnesium	na	na	mg/L	0.011	na
Potassium	na	na	mg/L	0.03	2
Sodium	na	na	mg/L	0.06	na
Silica (as SiO ₂)	na	na	mg/L	0.018	na
Laboratory or field alkalinity (as CaCO ₃) ¹	na	na	mg/L	4.6	na
Volatile organic compound					
<i>tert</i> -Amyl methyl ether (TAME)	na	na	µg/L	0.06	3
Bromodichloromethane	MCL-US	180	µg/L	0.034	na
Bromoform (tribromomethane)	MCL-US	180	µg/L	0.1	1
Carbon disulfide	HBSL	700	µg/L	0.1	0.5
Carbon tetrachloride (tetrachloromethane)	MCL-CA	0.5	µg/L	0.06	0.5
Dibromochloromethane	MCL-US	180	µg/L	0.12	1
Dichlorodifluoromethane (CFC-12)	HBSL	1,000	µg/L	0.1	na
Methyl <i>tert</i> -butyl ether (MTBE)	MCL-CA	13	µg/L	0.1	3
Tetrachloroethene (PCE)	MCL-US	5	µg/L	0.026	0.5
Toluene	MCL-CA	150	µg/L	0.018	0.5
Trichlorofluoromethane (CFC-11)	MCL-CA	150	µg/L	0.06	na
Trichlorotrifluoroethane (CFC-113)	MCL-CA	1,200	µg/L	0.022	na

Table 4B. Constituents detected in samples collected by the U.S. Geological Survey that have no benchmarks, were present only at low relative concentrations, or, for organics, were detected in less than 10 percent of the grid samples, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[**Benchmark types:** *Regulatory, health-based benchmarks:* AL-US, U.S. Environmental Protection Agency (EPA) lifetime health-advisory level; MCL-CA, California's maximum contaminant level; MCL-US, EPA maximum contaminant level. *Non-regulatory, health-based benchmarks:* HBSL, health-based screening level developed by the USGS; NL-CA, California's notification level. *Non-regulatory, aesthetic-based benchmarks:* SMCL-CA, California's secondary maximum contaminant level. **Abbreviations:** mg/L, milligrams per liter; na, not applicable; µg/L, micrograms per liter]

Constituent	Benchmark			Reporting limits	
	Type	Value	Units	USGS	California
Herbicides					
Atrazine	MCL-CA	1	µg/L	0.008	0.5
Deethylatrazine (2-chloro-4-isopropylamino-6-amino-s-triazine)	na	na	µg/L	0.006	na
Hexazinone	HBSL	400	µg/L	0.012	na
Pendimethalin	HBSL	20	µg/L	0.012	na
Insecticides					
Chlorpyrifos	HBSL	2	µg/L	0.0036	1
Dimethoate	HBSL	2	µg/L	0.006	2

¹Benchmark value is for the sum of four trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform).

Understanding-Assessment Methods

The data used in the *understanding assessment* were from grid sites. Constituents discussed in the *status assessment* that had high relative concentrations in greater than 2 percent of the MS-SA study unit or were organic or special-interest constituents detected in greater than 10 percent of the grid-site samples are discussed in the *understanding assessment*. Potential explanatory factors were analyzed in relation to the constituents of interest to help understand the physical and chemical processes affecting groundwater quality in the shallow aquifers of the MS-SA. Statistical tests were used to identify significant correlations between the constituents of interest and potential explanatory factors. The strongest correlations of factors affecting water quality are shown graphically.

Nonparametric statistical methods were used to test the significance of correlations between water-quality variables and potential explanatory factors. Nonparametric statistics are robust techniques that 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 to test hypotheses 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 by using Spearman's method to calculate the rank-order correlation coefficient (ρ) between continuous variables, such as well depth or pH. The values of ρ can range from +1.0 (perfect positive correlation) to 0.0 (no correlation) to -1.0 (perfect negative correlation).

The Kruskal-Wallis analysis of variance on ranks was the statistical test used to compare three or more independent populations (data groups or categories) to determine whether one population contains larger values of a constituent. Examples of independent populations and categorical variables include groundwater age (modern, mixed, or pre-modern) or land-use classification (natural, agricultural, or urban; Helsel and Hirsch, 2002). If a significant difference was found among the groups, a multiple comparison test (Dunn's test; Dunn, 1964) was used to determine which groups were different. The null hypothesis for the Kruskal-Wallis analysis of variance on ranks is that there is no significant difference among the median values of the three independent data groups. The Wilcoxon rank sum test was used if there were only two data groups, for example, redox conditions (oxic and anoxic or mixed).

Study-Unit Comparison Assessment Methods

The comparison between the MS-SA and the MS-PA study units focused on two aspects: study-unit characteristics and results of groundwater-quality analyses. Differences between the MS-SA and MS-PA study-unit characteristics were evaluated to identify dissimilarities that could affect interpretations of comparisons between the study units with respect to the groundwater-quality results. Wilcoxon rank sum tests were used to evaluate differences in categorical and continuous variables between the two study units. If an appropriate statistical test could not be run, qualitative graphical comparisons were used.

Using the framework established in the status and understanding assessments of the MS-SA and MS-PA study units, constituents selected for additional evaluation were the focus of the comparison between the study units with respect to groundwater quality. Individual constituent aquifer proportions and proportions of constituent groups by class presented in the assessments of status and understanding for the MS-SA study unit discussed in this report were recalculated for the comparison with the MS-PA. This was necessary because sites in the MS-SA study outside of the area of comparison were not included in the comparison of the two study units. The MS-PA is equivalent to collapsing the Santa Cruz, Pajaro Valley, and Salinas Valley study areas of the MS-SA study unit into one group (referred to as MS-SA3). A few caveats are important to note when interpreting the results of the comparison: (1) the MS-PA system assessment included two grid sites sampled in the Carmel Valley groundwater basin, which was not sampled in the MS-SA systems assessment; (2) calculation of aquifer proportions for the MS-PA system assessment were redone using benchmarks used for the MS-SA system so constituent classes would be consistent with the MS-SA system assessment; (3) age classification for the MS-PA system was redone so classification would be consistent with the MS-SA system assessment, and carbon-14 data collected from sites as part of the trend sampling in 2008 for the MS-PA were included; (4) special-interest constituents in the MS-PA system assessment were only available for a subset of grid sites and, therefore, were not compared; and (5) because 7 years separated sample collection and analysis between the MS-PA and MS-SA systems assessments, laboratory reporting levels (LRL) had changed for many of the constituents (Kulongoski and Belitz, 2007, 2011; Goldrath and others, 2016). These LRL discrepancies would affect detection frequencies for organics, leading to a biased comparison. For the purpose of this comparison, therefore, VOC and pesticide detections were censored using the higher of the two LRLs as the censoring level.

Not all constituents, primarily inorganic constituents, were collected at all sites for the MS-PA study; therefore, inorganic data were supplemented using data from the DDW database. Details about how the MS-PA data were supplemented are in Kulongoski and Belitz (2011). The data from the DDW database used in the MS-PA understanding assessment were used in the comparison between the two studies.

Potential Explanatory Factors

Characteristics of the shallow aquifer system are described using explanatory factor data compiled for the sites sampled by the GAMA-PBP in the study unit. Several explanatory factors were evaluated, but only the factors with

explanatory value are discussed here: geology, land use, well construction, groundwater age, geochemical conditions, and hydrologic conditions. Groundwater age and geochemical condition explanatory variables were not available for tap sites.

Land-Use Characteristics

Human activities at the land surface can affect groundwater quality because they can be sources of contaminants and because they can alter the groundwater flow system. Fertilizers and amendments applied to agricultural and residential lands, livestock, septic and wastewater systems, runoff from urban and residential areas, industrial activities, leaking fuel and chemical storage tanks, landfill leachates, and other anthropogenic sources can contribute nitrate, salts, pesticides, VOCs, and other constituents to groundwater recharge. Irrigation and groundwater pumping can alter the volume and source of groundwater recharge and can change the rates and directions in which recharge moves through an aquifer system.

Land use was classified by using an enhanced version of the satellite-derived (30-m pixel resolution) USGS National Land Cover Dataset (Nakagaki and others, 2007). This dataset has been used in previous national and regional studies relating land use to water quality (Gilliom and others, 2006; Zogorski and others, 2006). The dataset characterizes land cover during the early 1990s. One pixel in the dataset imagery represents a land area of 900 square meters (m²), calculated from the pixel resolution of 30 m. The imagery was classified into 25 land-cover classes (Nakagaki and Wolock, 2005). These 25 land-cover classes were aggregated into 3 principal land-use classes—urban, agricultural, and natural.

Overall land use (proportions of urban, agricultural, and natural) in the study unit, the study areas, and the areas within a radius of 500 m (1,640 ft) surrounding each site was calculated using a geographic information system, ArcGIS (version 9.2; Johnson and Belitz, 2009). Land use assigned to the area surrounding an individual site ([appendix table 1–1](#)) was calculated from land use in the area surrounding each site (radius of 500 m). Each area was assigned a land-use class if more than 50 percent of the land cover in that area could be associated with a single land use. If no land cover was greater than 50 percent of the pixel area, the classification of “mixed” was assigned.

Of land use in the MS-SA study unit, 76 percent was classified as natural, 19 percent was agricultural, and 5 percent was urban ([fig. 6](#)). Land use within the 500-m radius around all grid sites sampled in the study unit was more evenly distributed among land-use types, with 46 percent classified as natural, 38 percent as agricultural, and 16 percent as urban ([fig. 6](#)). In the MS-SA study unit, natural lands were mostly grasslands and shrub lands, and the primary use of agricultural land was for row crops, pasture, and hay.

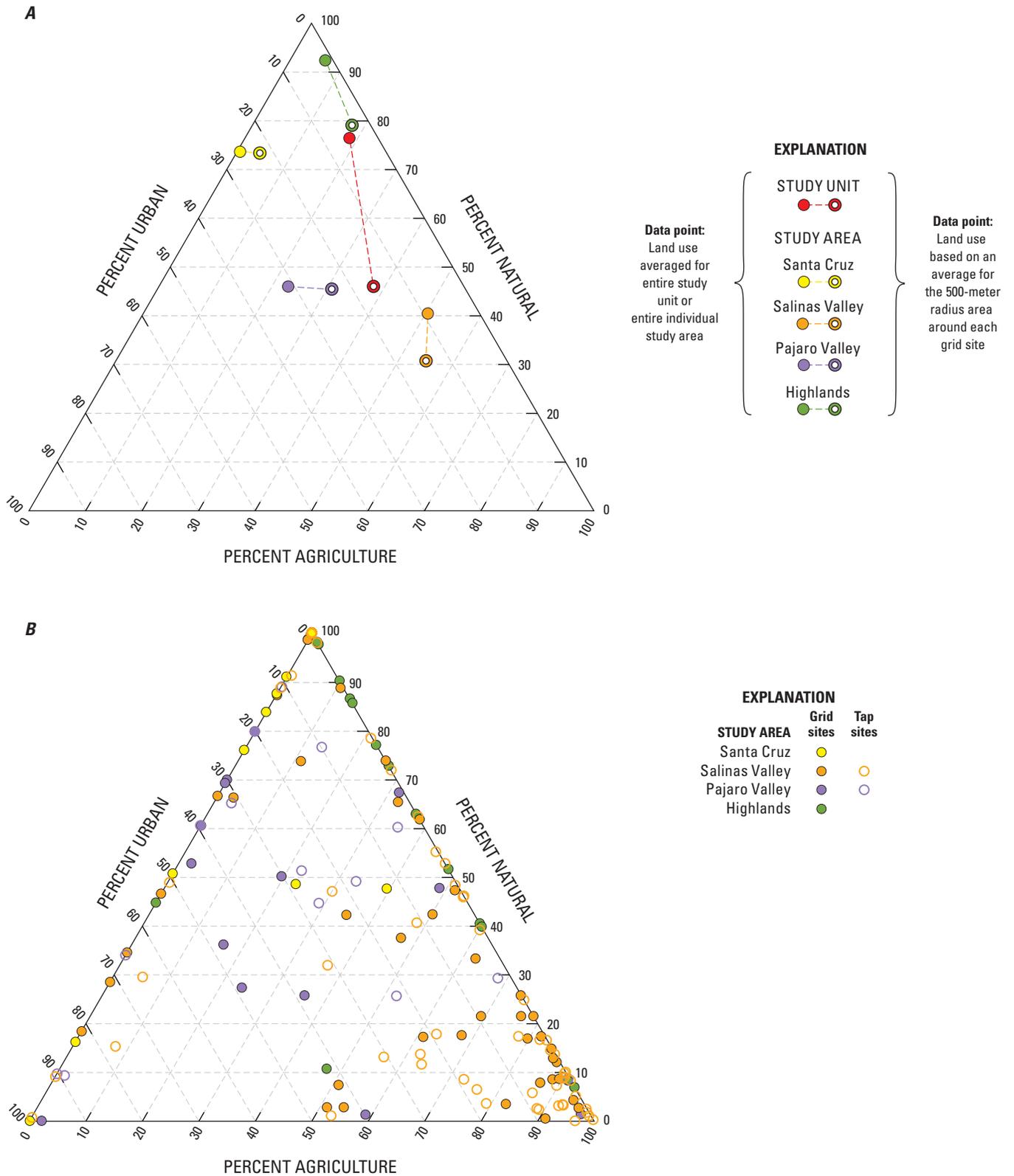


Figure 6. Percentage of urban, agricultural, and natural land use in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, for **A**, the study unit and study areas, and **B**, the 500-meter buffer area surrounding each grid or tap site.

Land use in the Santa Cruz, Pajaro Valley, and Highlands study areas was predominately natural, and land use in the Salinas Valley study area was predominately agricultural (fig. 6A). The Santa Cruz and Pajaro Valley study areas both had more than 25 percent of their area classified as urban, whereas the Salinas Valley and Highlands study area only had 9 and 1 percent, respectively, classified as such. Land use within the 500-m buffer surrounding each study-area grid site generally followed the same land-use patterns as observed at the study-area scale, with natural land use predominating at all study-area grid sites, except the grid sites in the Salinas Valley study area where agricultural land use was the predominate land-use type (figs. 6A, B). Land use in the 500-m buffer surrounding tap sites was similar to grid sites in their respective study areas.

Septic tanks also are markers of land-use patterns. The density of septic tanks in the 500-m radius area around a site can be an indicator of potential sources of anthropogenic contaminants from the land surface. Septic-tank density was determined from housing characteristics data from the 1990 U.S. Census (U.S. Census Bureau, 1990). The density of septic tanks in each housing census block was calculated from the number of tanks and block area. The density of septic tanks around each site was calculated from the area-weighted mean of the block densities for blocks within a 500-m buffer around the site location (Tyler Johnson, U.S. Geological Survey, written commun., 2009). The density of septic tanks around grid sites ranged from 0 to 67 tanks per square kilometer (tanks/km²), and the median density was 1.2 tanks/km² (appendix table 1–1). The Santa Cruz and Pajaro Valley study areas had the highest density of septic tanks (table 5).

Table 5. Results of nonparametric analysis for differences among categories for selected potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[Results are shown only for those correlations with a *p* value is less than or equal to (\leq) 0.05 (significant correlation). **Abbreviations:** Ag, agricultural; An-mix, anoxic or mixed oxidation-reduction classifications; grMz-m, Mesozoic granitic rocks and metamorphic rocks; H, Highlands; Mix, groundwater having both modern and pre-modern groundwater; Mod, modern groundwater primarily recharged after 1953; Nat, natural; ns, not significant; P, Pajaro Valley; preM, pre-modern groundwater primarily recharged before 1953; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; SC, Santa Cruz; SV, Salinas Valley; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments; Urb, urban; <, less than; >, greater than; —, not applicable]

Potential explanatory factor	Kruskal-Wallis with Dunn's multiple comparison test				
	Land-use category (Ag, Nat, Urb)	Study area	Geology (Q, Qpc, TK, grMz-m)	Oxidation-reduction class (Oxic, An-mix)	Age class (Mod, Mix, preM)
Percentage of urban land use	—	<0.001 P,SV,SC>H	<0.001 Q>Qpc	ns	ns
Percentage of agricultural land use	—	<0.001 SV>SC,H	<0.001 Q>Qpc,TK,grMz-m	<0.001 Oxic>An-mix	0.005 Mod>preM
Percentage of natural land use	—	<0.001 H>SV,P; SC>SV	<0.001 grMz-m,Qpc,TK>Q	<0.001 An-mix>Oxic	0.011 PreM>Mod
Depth of well	ns	ns	ns	ns	0.006 preM> Mod
Depth to top of perforation	ns	ns	ns	ns	ns
Dissolved oxygen	ns	<0.001 P,SV,H>SC	<0.001 grMz-m,Qpc,Q>TK	<0.001 Oxic>An-mix	0.007 Mod>Mix, preM
pH	ns	ns	ns	ns	<0.001 preM>Mix,Mod
Density of septic tanks	<0.001 Urb>Ag,Nat	<0.001 SC,P>SV,H	0.002 TK>Qpc	ns	ns
Distance to nearest geothermal site	0.006 Nat>Ag,Urb	<0.001 SC>SV,P,H	0.002 TK>Q,Qpc	0.046 An-mix >Oxic	ns
Aridity index	<0.001 Urb,Nat>Ag	<0.001 SC,P>SV,H	<0.001 TK>Q,Qpc	<0.001 An-mix >Oxic	ns
Percentage of modern carbon-14	0.005 Ag>Nat	0.004 P,SV>H	0.001 Q>Qpc,TK	0.035 Oxic>An-mix	<0.001 Mod>Mix>preM

Measures of Location

Four potential explanatory factors were used to represent the locations of sites in the MS-SA study-unit hydrologic system: study area, climate index, well depth, and depth to top of perforations in well.

There are many differences between study areas in the MS-SA study unit discussed in the section on the hydrogeologic setting. The factor “study area” combines all of those differences in one variable. By using study area as a potential explanatory factor, the differences and similarities among the component study areas in the study unit could be evaluated.

The aridity index was used as an indicator of climate. Aridity index is defined as average annual precipitation divided by average annual evapotranspiration, and it is equal to the United Nations Educational, Scientific, and Cultural Organization Aridity Index (United Nations Educational, Scientific, and Cultural Organization, 1979; United Nations Environment Programme, 1997). Average annual precipitation for each grid site was extracted from the PRISM average annual precipitation for 1971–2009 GIS coverage (PRISM Group, Oregon State University, 2010). Average annual evapotranspiration for each grid site was extracted from a GIS coverage modified from Flint and Flint (2007). The modification consisted of calibrating the evapotranspiration values to the measured California Irrigation Management Information System reference evapotranspiration values (California Irrigation Management Information System, 2012; A.L. Flint, U.S. Geological Survey, oral commun., 2009). Greater values of aridity index correspond to wetter conditions. Values less than 0.05 are defined as hyper-arid, 0.05 to less than 0.20 as arid, 0.20 to less than 0.50 as semi-arid, 0.50 to less than 0.65 as dry subhumid, 0.65 to less than 1.00 as humid, and 1.00 or greater as wet.

Aridity-index values at grid sites ranged from 0.21 to 0.89 (appendix table 1–1). Of the 100 grid sites sampled in the MS-SA study unit, 10 had an aridity index in the humid or wet category (aridity index greater than 0.65), all of which were in the Santa Cruz study area. The grid sites in the Salinas Valley and Highlands study areas had aridity index values less than 0.50, or semi-arid. In general, the Santa Cruz and Pajaro Valley study areas were less arid than the Salinas Valley and Highlands study areas (table 5).

Well-construction information was available for 96 of the 100 grid sites sampled in the MS-SA study unit. Most of the well-construction data were from driller’s logs and are given in table 2. Other sources were ancillary records from well owners and the USGS National Water Information System database. Grid-site identification verification procedures are described by Goldrath and others (2016). Well depths of

grid sites ranged from 7 to 275 m below land surface (bls), with a median of 89 m bls (fig. 7; table 2). Depths to the top of perforation ranged from 6 to 183 m bls, with a median of 50 m bls. The perforation length of well casings ranged from 3 to 134 m, with a median of 30 m. Well-construction information was available for 28 of 70 tap sites that had similar depths and opening lengths as grid sites. Well depths of tap sites ranged from 21 to 213 m bls, with a median of 91 m bls (fig. 7; table 2). Depths to the top of perforation ranged from 9 to 177 m bls, with a median of 51 m bls. The perforation length of tap well casings ranged from 8 to 107 m, with a median of 15 m. Well depths and depths to top of perforations were not significantly different among study areas (table 5).

Geologic Factors

Geologic factors were represented by two variables: aquifer lithology and distance to nearest geothermal site. Aquifer lithology was classified on the basis of lithologic information from the CDWR well-completion reports and the surficial geology on the California state geologic map (Jennings and others, 1977; Saucedo and others, 2000). For the purpose of examining broad relations between geology and groundwater quality in the MS-SA study unit, the lithology was simplified into four groups (fig. 4; appendix table 1–1):

Q: Q, mostly Holocene alluvial deposits with some Pleistocene of marine and non-marine origin; Qs, sand dune deposits.

QPc: Plio-Pleistocene and Pliocene non-marine sediments.

TK: T, Tertiary marine sediments (Miocene and Pliocene marine sediments); K, Upper Cretaceous metasediment and Paleocene marine sediments; FJf, Franciscan Complex.

grMz-m: grMz, Mesozoic granitic rocks; m, undivided Mesozoic, Paleozoic, and Precambrian metamorphics.

The Pajaro and Salinas Valley study areas were composed almost entirely of alluvial deposits. The Santa Cruz study area was composed primarily of marine sediments, with some alluvial deposits in the southwestern part of the study area. The Highlands study area is composed of marine sediments and non-marine rocks (fig. 4).

Some constituents are naturally elevated as a result of geothermal activity. Distance to the nearest geothermal site was used to evaluate the influence of geothermal activity on water quality. Data for geothermal sites (appendix table 1–1) were obtained from a list compiled by the National Oceanic and Atmospheric Administration (Berry and others, 1980) and the USGS Mineral Resources Data System (<http://tin.er.usgs.gov/mrds/>).

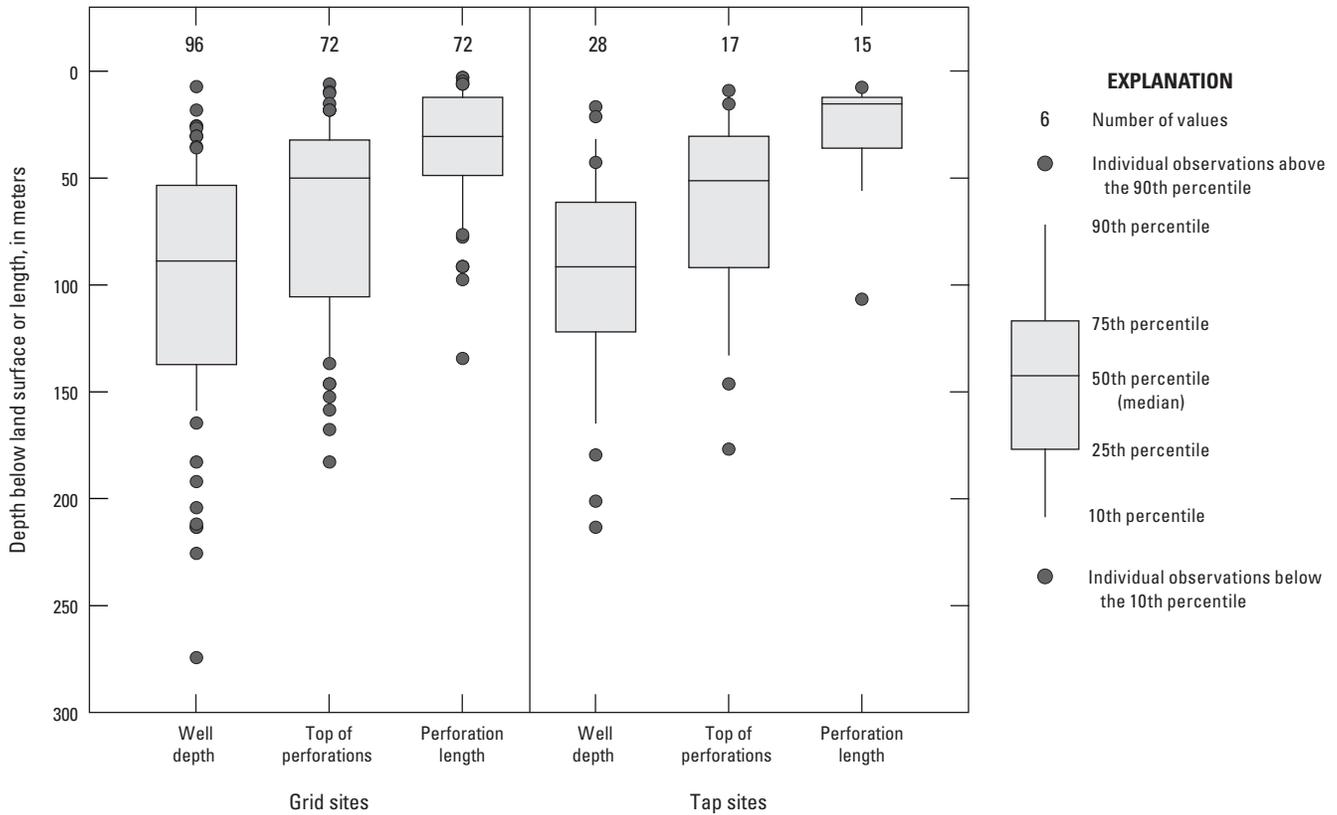


Figure 7. Well depths, depths to top of perforation, and perforation lengths for grid and tap sites, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Groundwater Age

Groundwater age was selected as a potential explanatory factor because a longer contact time between groundwater and aquifer sediments generally provides a greater opportunity for reactions that can alter the groundwater quality. Groundwater “age” refers to the length of time that the water has resided in the aquifer system, which is the amount of time elapsed since the water was last in contact with the atmosphere. Carbon-14 dating was used as an explanatory factor representing the age of groundwater samples. In addition, data for the age-dating tracers tritium and carbon-14 were used to classify groundwater ages among three categories: modern, mixed, and pre-modern.

Groundwater samples with tritium activities less than 0.3 tritium units (TU) and carbon-14 values less than 90-percent modern carbon (pmc) were classified as “pre-modern” groundwater; samples with tritium activities greater than or equal to 0.3 TU and carbon-14 values greater than or equal to 90 pmc were classified as “modern” groundwater. Samples with tritium activities greater than or equal to 0.3 TU and carbon-14 values less than 90 pmc, or with tritium activities less than 0.3 TU and carbon-14 values greater than or equal to 90 pmc, were classified as “mixed” groundwater. Samples classified as modern consist primarily of water recharged after 1953; samples classified as pre-modern

consist primarily of water recharged before 1953; and samples classified as mixed contain substantial amounts of modern and pre-modern groundwater. Practically speaking, pre-modern groundwater could contain a fraction of modern water, and modern water could contain a fraction 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-1953 from post-1953 water (Michel, 1989; Plummer and others, 1993; Michel and Schroeder, 1994; Clark and Fritz, 1997; Manning and others, 2005). By using a tritium value of 0.3 TU for the threshold in this study, the age-classification scheme allows for samples with a slightly greater fraction of pre-modern water to be classified as modern.

Background tritium values in California precipitation at the latitudes and longitudes corresponding to the southern Coast Ranges are approximately 4 TU (Michel, 1989; Jurgens and others, 2012). Aboveground nuclear testing greatly increased tritium values in precipitation beginning in about 1952; tritium values peaked in the northern hemisphere in 1963 at more than 1,000 TU (Michel, 1989). Radioactive decay of tritium in water is such that 4 TU in 1952 would be 0.14 TU in 2012. The lower threshold for modern groundwater was defined as 0.3 TU because most of the samples with tritium values between 0.14 and 0.30 TU also had carbon-14 values less than 90 pmc, indicating dominance by old groundwater.

Aboveground nuclear testing also increased carbon-14 values in atmospheric carbon dioxide and dissolved inorganic carbon in precipitation. Radioactive decay of carbon-14 in the dissolved inorganic carbon in precipitation at a background value of 100 pmc in 1952 would result in a carbon-14 value of 99 pmc in 2010. The upper threshold for pre-modern groundwater was defined as 90 pmc because the carbon-14 values in this study are “uncorrected,” meaning they have not been adjusted to consider exchanges with sedimentary sources of carbon (Fontes and Garnier, 1979). Bexfield and others (2012) corrected carbon-14 values of groundwater samples from Albuquerque, New Mexico, by using geochemical modeling to account for reactions with sedimentary carbonates and oxidation of sedimentary organic matter, yielding corrected values of carbon-14 that were from 1 to 9 pmc greater than the measured values. It was assumed that corrected carbon-14 values for MS-SA samples would be similar to the higher corrections for the Albuquerque samples because the Coast Ranges alluvium contains some carbonate minerals.

Tritium, carbon-14, and sample-age classifications are reported in [appendix table 1–2](#). Although more sophisticated lumped parameter models to analyze age distributions that incorporate mixing are available (Cook and Böhlke, 2000), use of these models to characterize age mixtures was beyond the scope of this report. Rather, classification into modern (recharged after 1953), mixed, or pre-modern (recharged before 1953) was sufficient to provide an appropriate and useful characterization for the purposes of examining groundwater quality.

Age classifications were assigned to 99 out of 100 grid sites sampled, such that 25 samples were classified as modern, 31 as mixed, and 43 as pre-modern age ([appendix table 1–2](#)). Most samples classified as pre-modern groundwater were in and near the Pajaro Valley study area or in the southern part of the study unit. Most of the modern-age groundwater samples were in the Salinas Valley ([fig. 8A](#)). The Highlands study area has some of the oldest groundwater on the basis of carbon-14 dating ([table 5](#)).

Geochemical Condition

Geochemical conditions investigated as potential explanatory factors in this report include oxidation-reduction characteristics, dissolved oxygen (DO), and pH. Geochemical conditions influence the mobility of many inorganic and organic constituents (McMahon and Chapelle, 2007). A modified classification of oxidation-reduction (redox) conditions was adapted from the framework presented by McMahon and Chapelle (2007) based on dissolved oxygen (DO), nitrate-nitrogen (N), manganese, iron, and sulfate concentrations.

Of 100 grid sites, 98 had sufficient data for redox classification ([appendix table 1–3](#)). Tap sites were not assigned a redox classification because sufficient data for classification were not available. An automated Excel workbook program was used to assign redox classification to each sample (Jurgens and others, 2009). This workbook uses the framework proposed by McMahon and Chapelle (2007) to

classify samples according to redox conditions in groundwater. Samples were classified as oxic, anoxic, or mixed. Anoxic conditions were further subdivided into suboxic, nitrate-reducing, manganese-reducing, iron-reducing, or sulfate-reducing conditions. Constituent concentrations used to classify samples and the resulting redox classifications are shown in [appendix table 1–3](#).

Redox conditions generally evolve along a well-documented sequence of terminal electron acceptor processes (TEAP), where one TEAP predominates at a particular time and aquifer location (Chapelle and others, 1995; Chapelle, 2001). The predominant TEAPs are oxygen-reduction, nitrate-reduction, manganese-reduction, iron-reduction, sulfate-reduction, and carbon dioxide-reduction or methanogenesis. The presence of redox-sensitive chemical species characteristic of more than one TEAP can indicate mixed water from different redox zones upgradient of the site, a site screened across more than one redox zone, or spatially heterogeneous microbial activity in the aquifer. Different redox elements (for example, iron) tend not to reach overall equilibrium in most natural water systems (Lindberg and Runnels, 1984); therefore, a single redox measurement usually cannot represent the system, further complicating the assessment of redox conditions.

Of groundwater samples collected in the MS-SA study unit, 67 percent were classified as oxic, 26 percent as anoxic, and 7 percent as mixed ([appendix table 1–3](#)). The Pajaro Valley study area had the highest frequency of samples classified as oxic (73 percent), and the Santa Cruz study area had the highest frequency of samples classified as anoxic (67 percent). Many samples classified as anoxic also were in the southern part of the study unit ([fig. 8B](#)). The DO concentrations were available for 98 of the 100 grid-site samples. The DO concentrations ranged from less than 0.2 to 9.5 milligrams per liter (mg/L), with a median DO concentration of 2.15 mg/L. Redox classifications and DO were used to help explain the distribution and concentrations of selected inorganic constituents in the shallow aquifer systems of the MS-SA.

The pH of groundwater influences the behavior of dissolved constituents by altering the charge characteristics of molecules and the variably charged surfaces of minerals and amorphous phases that compose aquifer matrices. As groundwater increases in pH (becomes more alkaline), the variable surface charge of aquifer matrices becomes increasingly negative (Stumm, 1992). A particle that has a predominantly negatively charged surface inhibits the adsorption and promotes desorption of dissolved anionic constituents in groundwater, such as arsenic (HAsO_4^{2-}), while promoting the adsorption of dissolved cationic constituents, such as copper (Cu^{2+}). Values of pH were available for samples from all grid sites and 68 of the 70 tap sites. Values of pH in samples from the MS-SA study unit ranged from 6.0 to 8.2, with a median value of 7.2 ([appendix table 1–3](#)). The median pH values for samples from all the study areas were 7.2, except for samples from the MS-P study area, which had a median value of 7.4. Only two grid samples and one tap sample had a pH value greater than or equal to 8.0. The pH values for samples collected in the MS-SA study unit are shown in [appendix table 1–3](#).

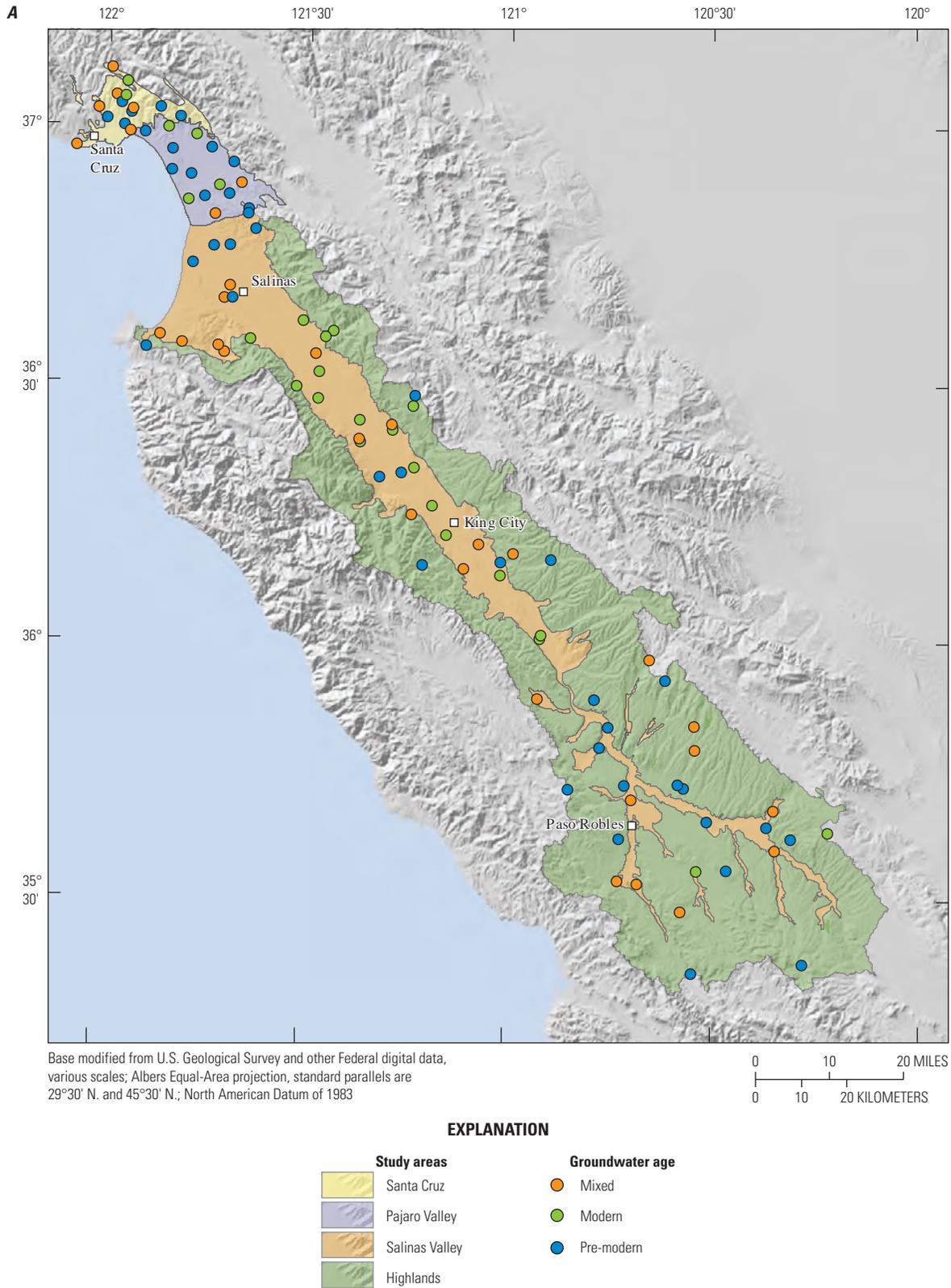
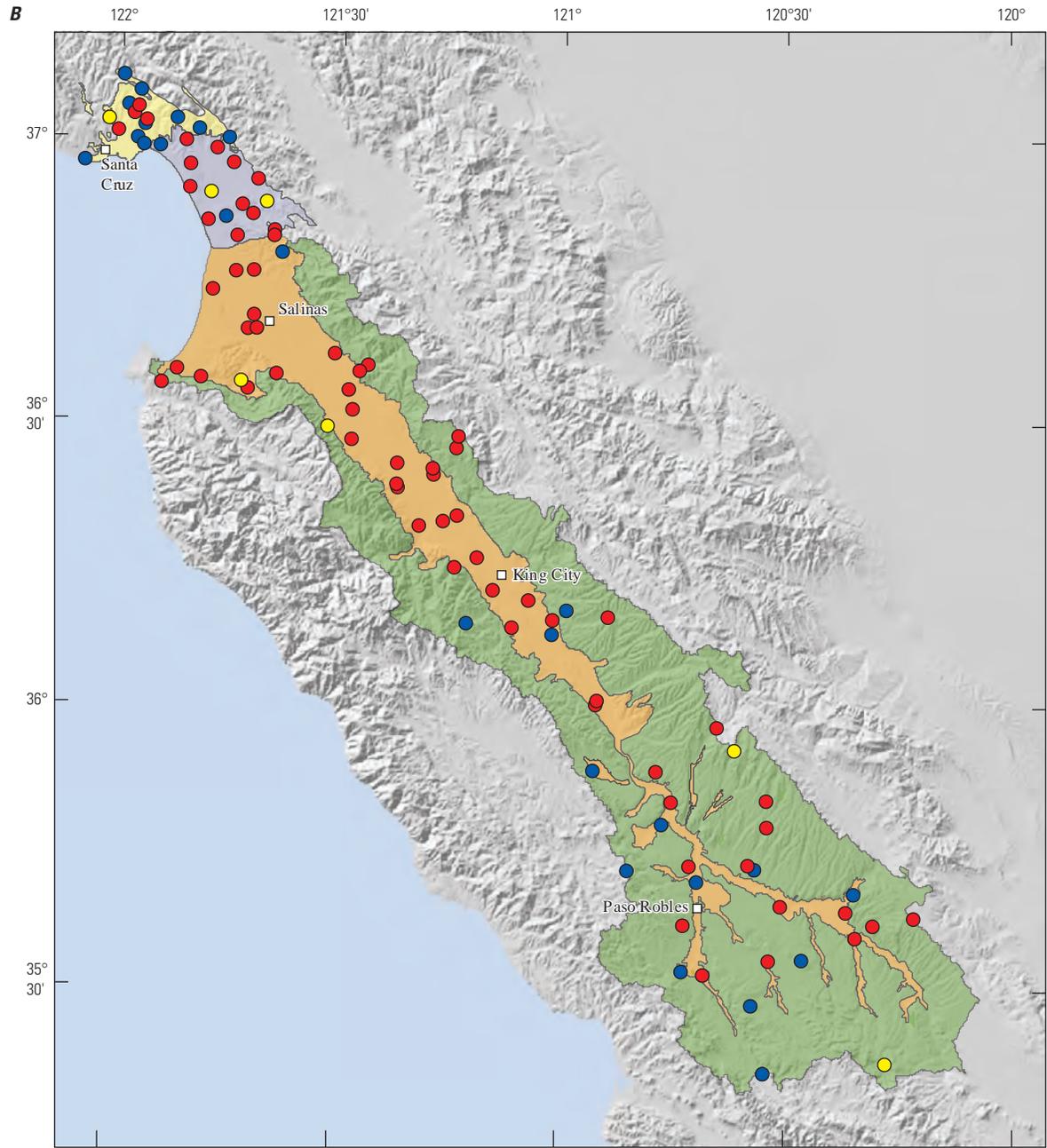


Figure 8. Location of sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, by *A*, groundwater-age classification, and *B*, oxidation-reduction classification.



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

0 10 20 MILES
0 10 20 KILOMETERS

EXPLANATION

Study areas		Oxidation-reduction class	
	Santa Cruz		Anoxic
	Pajaro Valley		Mixed
	Salinas Valley		Oxic
	Highlands		

Figure 8. —Continued

Other Explanatory Factors

Some potential explanatory factors evaluated did not have any statistically significant relation with concentrations of water-quality constituents in this study unit. These factors included the distance to nearest sources of halite, oil and gas fields, faults, and anthropogenic perchlorate as well as the density of leaky underground fuel tanks (LUFTs; [appendix table 1–4](#)). Data for halite sources was obtained January 10, 2012, from the USGS Mineral Resources Data System website (<http://tin.er.usgs.gov/mrds/>). Oil and gas information was obtained September 1, 2005, from the California Division of Oil, Gas, and Geothermal Resources (<http://www.consrv.ca.gov/DOG>). Fault data were extracted from the California State geologic map (Jennings and others, 1977; Saucedo and others, 2000). The LUFT data were obtained from the California Environmental Protection Agency (2001). Sources of perchlorate were compiled in 2007 from data obtained from the SWRCB's GeoTracker database (<http://geotracker.waterboards.ca.gov/>), a 2005 draft report from the California Department of Toxic Substances Control workshop on Perchlorate Best Management Practices (https://www.dtsc.ca.gov/HazardousWaste/Perchlorate/BMP_Workshops.cfm), and a list of perchlorate manufacturers and users, obtained from the U.S. Environmental Protection Agency.

Correlations Between Explanatory Factors

Apparent correlations between an explanatory factor and a water-quality constituent could be erroneous, resulting from correlations between two explanatory factors, rather than a causative relation between the explanatory factor and the water-quality constituent. For example, detections of VOCs could be inversely correlated to urban land use in a given area because well depths in urban areas tend to be deeper and the water tapped pre-modern, not because of a low incidence of VOCs in urban settings. For this reason, it is important to identify significant correlations among explanatory variables. Relations among explanatory factors are shown in [tables 5 and 6](#).

Several potential explanatory factors used in this report had a significant correlation with another explanatory factor. Land use around grid sites was related to geology because most of the urban and agricultural land uses were in alluvial deposits, and natural land uses were primarily in non-alluvial

deposits. Samples collected from sites in agricultural areas were correlated to oxic redox conditions and modern groundwater ages, whereas samples collected from sites in natural areas were correlated to anoxic and mixed redox conditions and to pre-modern groundwater ages ([table 5](#)). In addition, the percentage of agricultural land use was positively correlated to DO concentration and the percentage of modern carbon-14 ([table 6](#)). Agricultural land use was negatively correlated and urban land use was positively correlated with the density of septic tanks and with the aridity index ([table 6](#)).

As might be expected, well depth was significantly correlated with the depth to the top of the uppermost opening ([table 6](#)). Because of the strong correlation between these depth variables, only well depth, for which there were more measurements, is discussed in the *understanding assessment* section of this report. Well depth was negatively correlated with the percentage of modern carbon-14, and sites with pre-modern age groundwater were generally deeper than sites with modern-age groundwater ([fig. 9](#)). Samples collected from sites classified with pre-modern groundwater age had lower DO concentrations and higher pH values; conversely, samples classified with modern groundwater had higher DO concentrations and lower pH values. As the contact time between groundwater and the aquifer materials increases, pH values generally rise as acid is consumed by weathering reactions of silicate minerals and dissolution of carbonate minerals, if present (Stumm and Morgan, 1996). Similarly, the percentage of modern carbon-14 was positively correlated with DO concentrations and negatively with pH values. Groundwater from alluvial deposits (Q) had a higher percentage of modern carbon-14 than that from non-marine (Qpc) and marine (TK) sediments. Septic tank density was greater in areas of marine sediments (TK) than in areas of non-marine sediments (Qpc).

The aridity index was negatively correlated to the percentage of agricultural land use and positively correlated to urban land-use percentages. These correlations reflect that urban land use is primarily in the northern part of the study unit, where the climate is wetter, rather than a causative relation. The positive correlation of the aridity index to the density of septic tanks was most likely a result of the correlation of septic systems with urban land use. The aridity index was negatively correlated to pH and DO concentrations, and a higher aridity index was associated with anoxic redox conditions. A higher aridity index was also associated with marine geology (TK) compared to non-marine and alluvial deposits (Qpc, Q).

Table 6. Results of nonparametric analysis for correlations (Spearman’s rho method) between selected potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[Results are given only for those correlations with a *p* value less than or equal to (\leq) 0.05 (significant correlation). **Abbreviations:** ns, correlation not significant; <, less than]

Potential explanatory factor	Depth to top of perforation	Density of septic tanks	Distance to nearest geothermal site	Aridity index	pH	Dissolved oxygen	Percentage of modern carbon-14	Percentage of agricultural land use	Percentage of natural land use	Percentage of urban land use
Depth of well	0.835 <0.001	ns	ns	ns	ns	ns	-0.264 0.010	ns	ns	ns
Depth to top of perforation		ns	ns	ns	ns	ns	ns	ns	ns	ns
Density of septic tanks			ns	0.755 <0.001	ns	ns	ns	-0.292 0.003	ns	0.511 <0.001
Distance to nearest geothermal site				0.348 <0.001	ns	ns	ns	-0.255 0.011	0.242 0.015	ns
Aridity index					ns	-0.218 0.031	ns	-0.525 <0.001	0.236 0.018	0.268 0.007
pH						ns	-0.304 0.002	ns	ns	ns
Dissolved oxygen							0.334 0.001	0.239 0.018	ns	ns
Percentage modern carbon-14								0.372 <0.001	-0.340 <0.001	ns

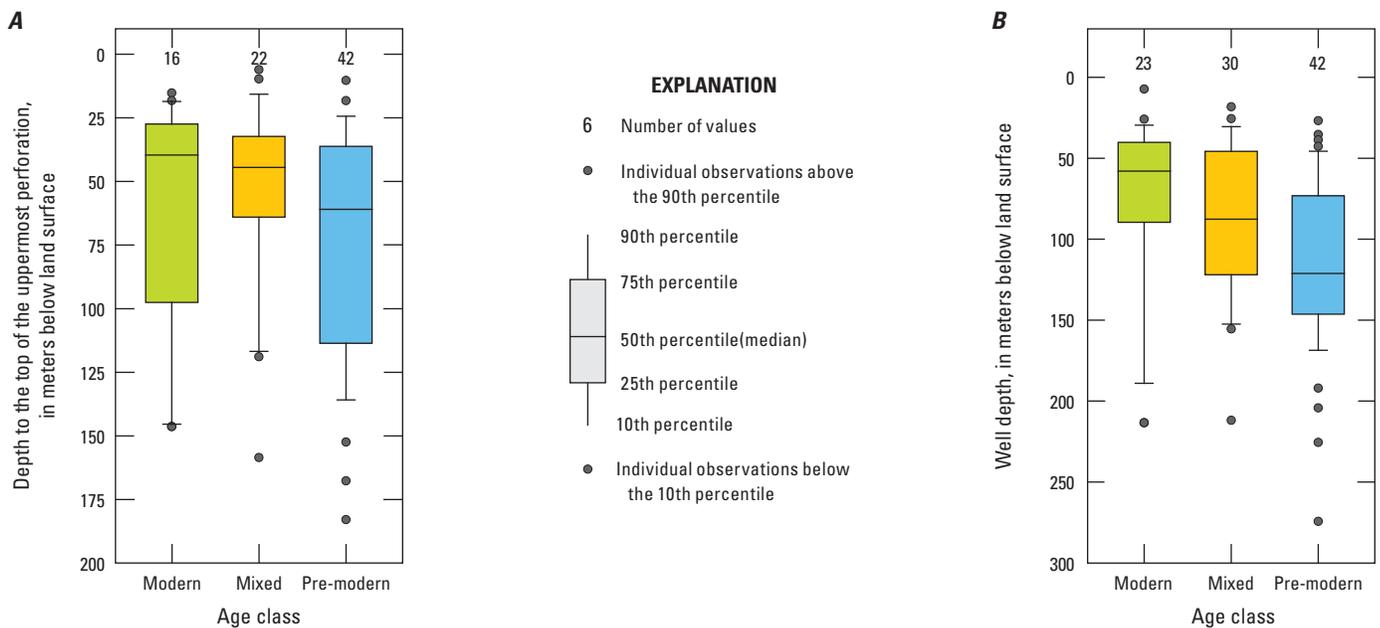


Figure 9. Groundwater-age classification in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, relative to *A*, depth to top of perforations, and *B*, well depth.

Status and Understanding of Water Quality

The following discussion of the *status* and *understanding assessment* results is divided into inorganic, organic, and special-interest constituents. The status assessment begins with a survey of how many constituents were detected at any concentration compared to the number analyzed and with a graphical summary of the relative concentrations of constituents detected in the grid-site samples. Aquifer-scale proportions are presented for constituent classes and the subset of constituents that were present at high or moderate relative concentrations. Finally, results of statistical tests for relations between water quality and potential explanatory factors are presented for constituents that met criteria for selection for additional evaluation based on relative concentration or, for organic or special-interest constituents, detection frequency.

Inorganic Constituents

Inorganic constituents generally are natural in groundwater, although the concentrations can be influenced by human activities. Of the 42 inorganic constituents analyzed by the GAMA-PBP, 27 had regulatory or non-regulatory health-based benchmarks, 4 had non-regulatory aesthetic-based secondary maximum contaminant level (SMCL) benchmarks, and 11 had no established benchmarks. Of the 41 constituents detected, 16 inorganic constituents with health-based benchmarks and 4 inorganic constituents with secondary maximum contaminant levels (SMCLs) were detected at moderate or high relative concentrations in one or more grid sites sampled in the MS-SA study unit (figs. 10, 11; table 4A). The other 21 inorganic constituents detected either had no established benchmarks or were only detected at low RCs (table 4B).

Aquifer-scale proportions for inorganic constituent classes with health-based benchmarks and SMCLs are summarized in table 7A for the MS-SA study unit and the three study areas that coincide with the MS-PA study unit. Aquifer-scale proportions for inorganic constituent classes are summarized in table 7B for the four study areas. Aquifer-scale proportions for individual inorganic constituents are summarized in table 8A for the MS-SA study unit and in table 8B for each study area. Inorganic constituent classes include trace elements, radioactive constituents, nutrients, and salinity indicators.

Inorganic constituents with health-based benchmarks, as a group, were present at high relative concentrations in 51 percent of the shallow aquifer system and at moderate relative concentrations in 19 percent (table 7A). The proportion of the shallow aquifer system having high relative concentrations of inorganic constituents with health-based benchmarks was highest for the Highlands study area and lowest for the Pajaro Valley study area (table 7B).

Inorganic constituents with SMCL benchmarks (metals and salinity indicators), as a group, were present at high relative concentrations in 40 percent of the primary aquifer system and at moderate relative concentrations in 33 percent (table 7A).

Salinity Indicators

The class of constituents with SMCL benchmarks included salinity indicators (TDS, sulfate, and chloride) and the trace element iron. These constituents can affect the aesthetic properties of water, such as taste, color, and odor, or can create technical problems, such as scaling and staining. The SMCL benchmarks are based on these aesthetic and technical concerns and are not health-based benchmarks. Iron is discussed in the “Trace Elements” section. One or more salinity indicators with SMCLs were detected at high relative concentrations in 38 percent of the MS-SA study unit and at moderate relative concentrations in 36 percent (table 7A). The Highlands and Salinas Valley study areas, had the highest proportions of high relative concentrations at 43 and 31 percent, respectively (table 7B; fig. 11B). Total dissolved solids, chloride, and sulfate were detected at high relative concentrations in more than 6 percent of the study unit (table 8A).

Understanding Assessment for Total Dissolved Solids

Total dissolved solids (TDS) were detected at high relative concentrations in 38 percent of the MS-SA study unit and at moderate relative concentrations in 36 percent (table 8A); the SMCL-CA for TDS is 1,000 mg/L. High relative concentrations were detected in all study areas, but the Highlands study area had the greatest aquifer proportions of high relative concentrations at 43 percent, followed by the Salinas Valley study area at 31 percent (figs. 11B, 12A; table 8B). Aquifer proportions for moderate relative concentrations also were greatest in the Highlands and Salinas Valley study areas (table 8B). Correlation of TDS with potential explanatory variables indicated natural and anthropogenic sources could both be primary contributors to elevated TDS in groundwater.

Natural sources of TDS include mixing of groundwater with deep saline groundwater (connate water) that is influenced by interactions with deep marine or lacustrine sediments, concentration of salts by evaporation in discharge areas, or water-rock interactions. Stable isotopes of water, $\delta^2\text{H}$ and $\delta^{18}\text{O}$ (Goldrath and others, 2016), can be used to determine whether there has been fractionation through evaporation. Isotopic values plotting to the right of the global meteoric water line are indicative of evaporative processes. Several samples from the MS-SA study unit showed evidence of evaporative processes (fig. 13). These samples were primarily from the Highlands and Salinas Valley study areas. Evaporative processes were indicated throughout the range of TDS concentrations, although most of the high concentrations plot to the right of the global meteoric water line.

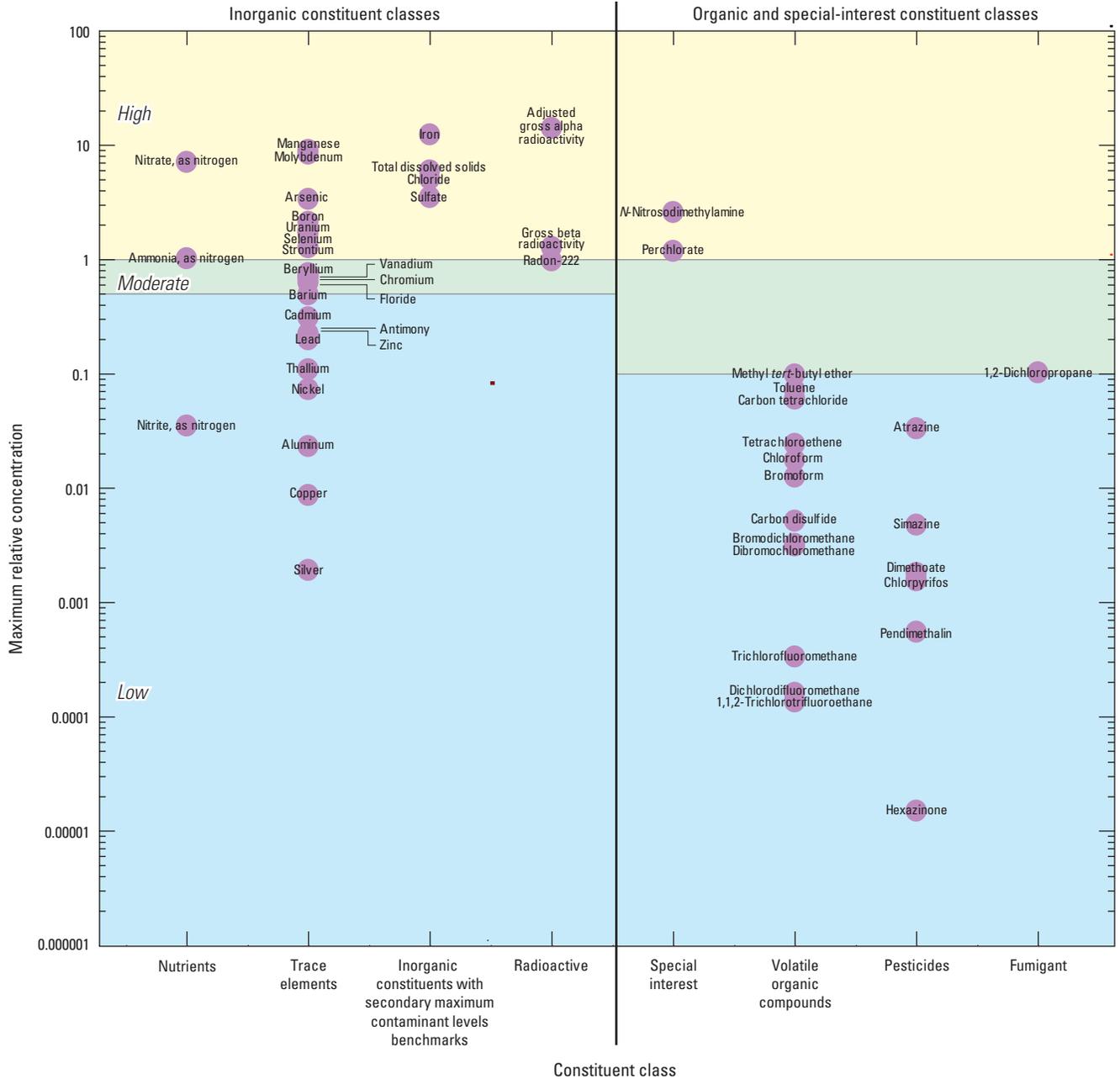


Figure 10. Maximum relative concentration of constituents detected in samples from grid sites, by constituent class, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

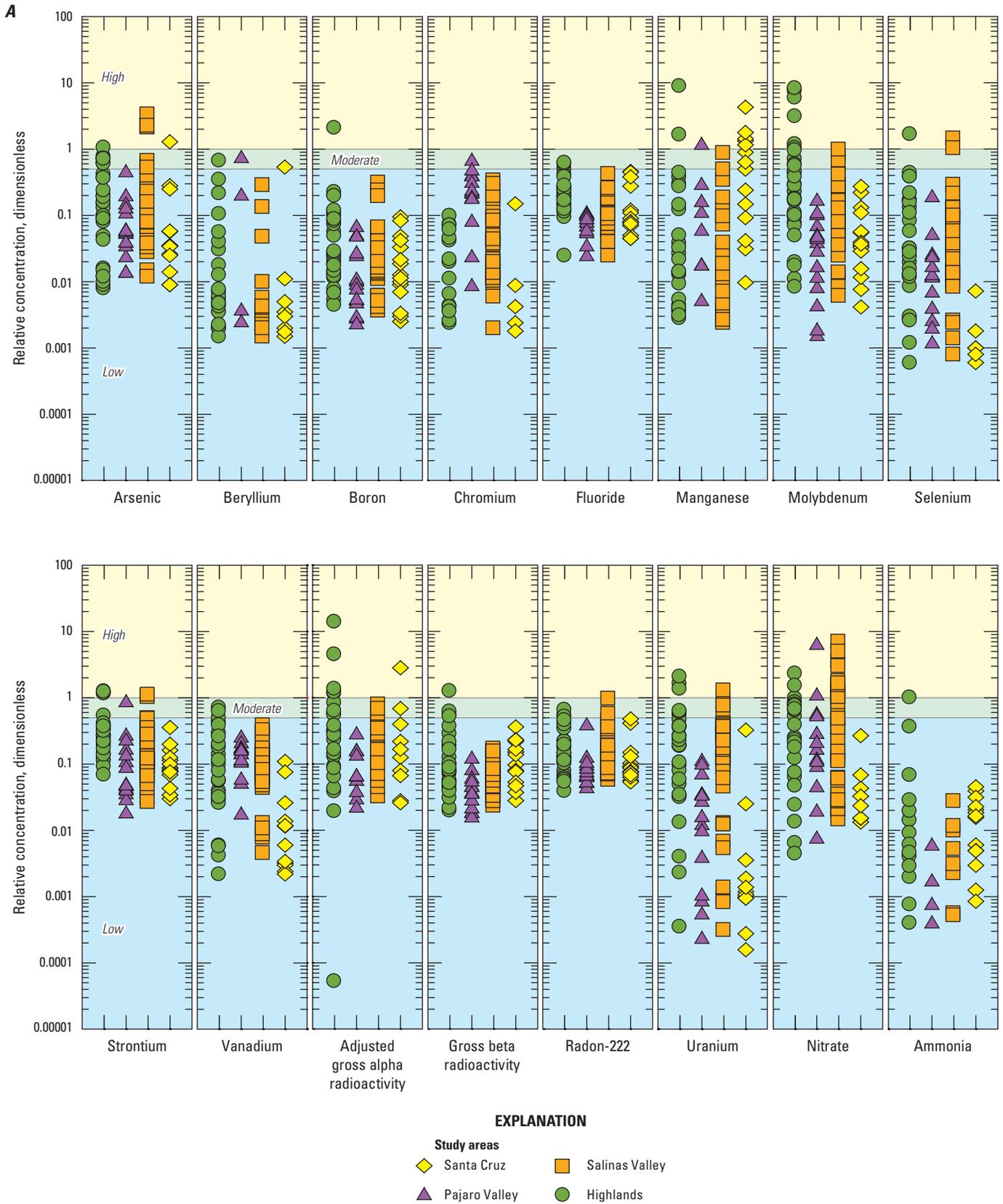


Figure 11. Relative concentrations of inorganic constituents in samples from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: A, with health-based benchmarks, and B, with secondary maximum contaminant levels.

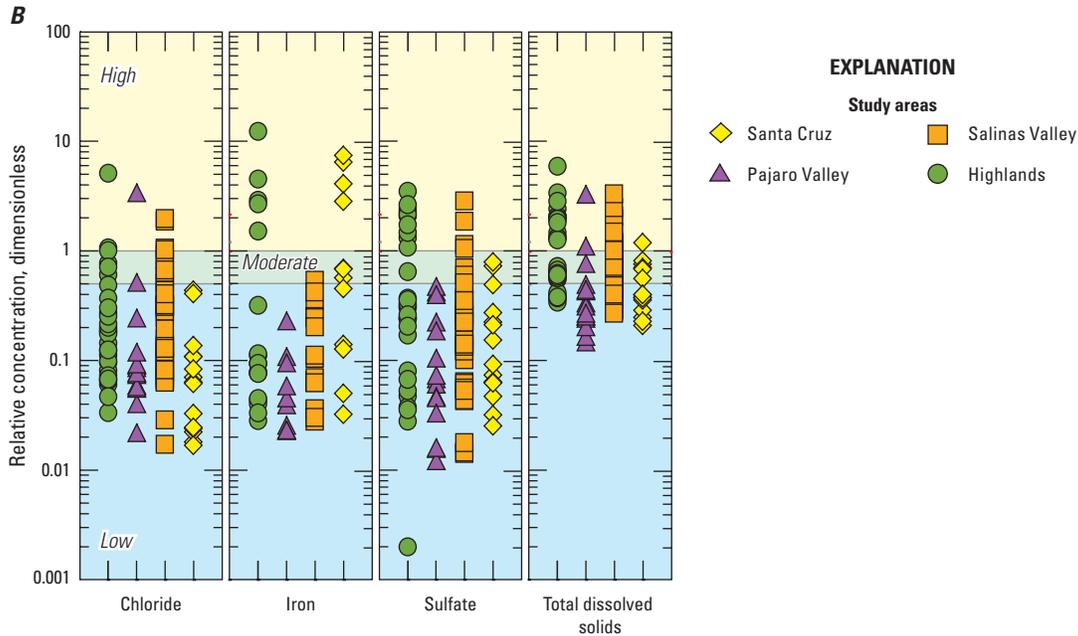


Figure 11. —Continued

Table 7A. Aquifer-scale proportions for constituent classes in the Monterey-Salinas shallow aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[Aquifer-scale proportions are based on samples collected at 100 grid and 70 tap sites from October 2012 to May 2013. The benchmarks are given in tables 4A and 4B. **Abbreviations:** High, concentrations greater than the water-quality benchmark; moderate, concentrations greater than or equal to 0.1 of the benchmark, but less than or equal to the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark); low, concentrations less than or equal to 0.1 of the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark); SMLC, secondary maximum contaminant level; TDS, total dissolved solids]

Constituent class	Aquifer-scale proportion for the MS-SA study unit ¹ (percent)			Aquifer-scale proportion for the Santa Cruz, Pajaro Valley, and Salinas Valley study areas ² (percent)		
	High	Moderate	Low	High	Moderate	Low
Inorganics with health-based benchmarks						
Trace elements	37	13	51	16	11	73
Radioactive	19	20	61	2.5	14	83
Nutrients	16	19	65	28	11	60
Any inorganic with health-based benchmarks	51	19	30	39	24	37
Inorganics with SMCL benchmarks						
Salinity indicators (TDS, sulfate, chloride)	38	36	27	25	34	40
Any inorganic with SMCL benchmarks	40	33	26	27	33	39
Organics with health-based benchmarks						
Trihalomethanes ³	0	0	100	0.0	0.0	100
Pesticides (including fumigants)	0	0.7	99	0.0	2.0	98
Any organic with health-based benchmarks	0	0.7	99	0.0	2.0	98
Constituents of special interest						
<i>N</i> -nitrosodimethylamine and (or) perchlorate	2.0	36	62	5.9	42.2	52.0

¹Aquifer-scale proportion is calculated by summing the area-weighted average for each individual study area. Area weights for each study area are Santa Cruz = 0.03, Pajaro Valley = 0.04, Salinas Valley = 0.26, and Highlands = 0.67.

²Aquifer-scale proportion is calculated by summing the area-weighted average for each of the alluvial fill study areas. Area weights for each study area are Santa Cruz = 0.08, Pajaro Valley = 0.14, Salinas Valley = 0.78.

³The MCL-US threshold for trihalomethanes is the sum of chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

Table 7B. Aquifer-scale proportions for constituent classes for each study area in the Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[Aquifer-scale proportions are based on samples collected at 100 grid and 70 tap sites from October 2012 to May 2013. The benchmarks are given in tables 4A and 4B. **Abbreviations:** High, concentrations greater than the water-quality benchmark; Moderate, concentrations greater than or equal to 0.1 of the benchmark, but less than or equal to the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark); Low, concentrations less than or equal to 0.1 of the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark); MCL-US, U.S. Environmental Protection Agency maximum contaminant level; TDS, total dissolved solids]

Constituent class	Aquifer-scale proportion (percent)											
	Highlands			Santa Cruz			Pajaro Valley			Salinas Valley		
	High	Moderate	Low	High	Moderate	Low	High	Moderate	Low	High	Moderate	Low
Inorganics with health-based benchmarks												
Trace elements	47	13	40	40	13	47	3.3	6.7	90	15	12	73
Radioactive	27	23	50	6.7	6.7	87	0	0	100	2.5	18	80
Nutrients	10	23	66	0.0	0.0	100	20	17	63	33	11	56
Any inorganic with health-based benchmarks	57	17	27	40	13	47	20	27	53	43	25	33
Inorganics with aesthetic benchmarks												
Salinity indicators (TDS, sulfate, chloride)	43	37	20	6.7	33	60	6.7	17	77	31	37	32
Any inorganic with aesthetic-based benchmarks	47	33	20	27	27	47	6.7	17	77	31	37	32
Organics with health-based benchmarks												
Trihalomethanes ¹	0.0	0.0	100	0.0	0.0	100.0	0.0	0.0	100	0.0	0.0	100
Pesticides (including fumigants)	0.0	0.0	100	0.0	0.0	100.0	0.0	0.0	100	0.0	2.5	98
Any organic with health-based benchmarks	0.0	0.0	100	0.0	0.0	100.0	0.0	0.0	100	0.0	2.5	98
Constituents of special interest												
<i>N</i> -nitrosodimethylamine and (or) perchlorate	0.0	33	67	0.0	6.7	94	0.0	33	67	7.5	48	45

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

Table 8A. Aquifer-scale proportions and raw detection frequencies for constituents detected in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) that had (1) high or moderate values in samples collected from grid or tap sites or (2) organic or special-interest constituents detected in more than 10 percent of the grid sites sampled, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

[Aquifer-scale proportions are based on samples collected at 100 grid and 70 tap sites from October 2012 to May 2013. The benchmarks are given in tables 4A and 4B. **Abbreviations:** High, concentrations greater than the water-quality benchmark; Moderate, concentrations greater than or equal to 0.1 of the benchmark, but less than or equal to the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of benchmark); MCL-US, U.S. Environmental Protection Agency maximum contaminant level]

Constituent	Raw detection frequency ¹ (percent)			Aquifer-scale proportion for the MS-SA study unit ¹ (percent)			Aquifer-scale proportion for the Santa Cruz, Pajaro Valley, and Salinas Valley study areas ² (percent)		
	Number of sites	High	Moderate	Number of cells	High	Moderate	Number of cells	High	Moderate
Trace and minor elements									
Arsenic	170	4.1	8.2	100	3.9	15	70	4.9	6.3
Beryllium	170	0.0	2.8	100	0.0	2.9	70	0.0	1.9
Boron	170	2.2	0.0	100	2.2	0.0	70	0.0	0.0
Chromium	170	0.0	1.8	100	0.0	0.4	70	0.0	1.4
Fluoride	165	0.0	7.2	98	0.0	7.1	69	0.0	0.7
Iron	170	8.8	3.5	100	13	1.2	70	6.0	3.4
Manganese	170	7.1	4.7	100	6.4	1.7	70	5.7	5.1
Molybdenum	170	14	11	100	14	11	70	2.6	7.5
Selenium	170	2.8	0.5	100	3.2	0.5	70	2.9	1.6
Strontium	170	9.5	3.2	100	9.5	3.1	70	1.6	2.7
Vanadium	170	0.0	2.4	100	0.0	6.9	70	0.0	0.6
Radioactive constituents									
Adjusted gross alpha radioactivity, 72-hour count	93	13	20	93	13	14	67	0.5	11
Gross beta radioactivity, 72-hour count	93	2.6	7.7	93	2.5	7.7	67	0.0	0.0
Radon-222	96	0.0	8.0	96	0.0	8.1	66	0.0	4.1
Uranium	170	7.5	6.7	100	7.6	6.7	70	2.6	6.8
Nutrients									
Nitrate	170	14	20	100	14	19	70	28	11
Ammonia	100	1.0	0.0	100	2.2	0.0	70	0	0.0
Salinity indicators									
Chloride	170	7.0	12.1	100	6.6	12	70	6.3	9.2
Sulfate	170	26	5	100	26	4.7	70	12	7.4
Total dissolved solids (TDS)	170	37	36	100	38	36	70	26	33
Trihalomethanes									
Chloroform (trichloromethane) ³	100	0.0	0.0	100	0.0	0.0	70	0.0	0.0
Fumigant									
1,2-Dichloropropane (1,2-DCP)	100	0.0	0.7	100	0.0	0.7	70	0.0	2.0
Herbicides									
Simazine	100	0.0	0.0	100	0.0	0.0	70	0.0	0.0
Constituents of special interest									
Perchlorate	100	1.0	33.0	100	0.7	35	70	2.0	37.8
<i>N</i> -nitrosodimethylamine (NDMA)	100	3.0	3.0	100	2.0	1.5	70	5.9	4.4

¹Raw detection frequency and aquifer-scale proportions for the study unit are calculated by summing the area-weighted average for each individual study area. Area weights for each study area are Santa Cruz = 0.03, Pajaro Valley = 0.04, Salinas Valley = 0.26, and Highlands = 0.67.

²The aquifer-scale proportion is calculated by summing the area-weighted average for each alluvial fill study area. The area weights for each study area are Santa Cruz = 0.08, Pajaro Valley = 0.14, and Salinas Valley = 0.78.

³The MCL-US threshold for trihalomethanes is the sum of chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

Table 8B. Aquifer-scale proportions for constituents detected in the four study areas that had (1) high or moderate values in samples collected from grid sites, or (2) organic or special-interest constituents detected in more than 10 percent of the grid sites sampled. Aquifer-scale proportions were based on samples collected in each study area from October 2012 to May 2013, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

[Aquifer-scale proportions are based on samples collected at 100 grid and 70 tap sites from October 2012 to May 2013. The benchmarks are given in tables 4A and 4B. **Abbreviations:** High, concentrations greater than the water-quality benchmark; Moderate, concentrations greater than or equal to 0.1 of the benchmark but less than or equal to the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark)]

Constituent	Aquifer-scale proportion (percent)													
	Santa Cruz			Pajaro Valley				Salinas Valley				Highlands		
	Number of sites	High	Moderate	Number of cells	Number of sites	High	Moderate	Number of cells	Number of sites	High	Moderate	Number of sites	High	Moderate
Trace and minor elements														
Arsenic	15	6.7	0.0	15	30	3.3	3.3	40	95	5.0	7.5	30	3.3	20
Beryllium	15	0.0	6.7	15	30	0.0	3.3	40	95	0.0	1.2	30	0.0	3.3
Boron	15	0.0	0.0	15	30	0.0	0.0	40	95	0.0	0.0	30	3.3	0.0
Chromium	15	0.0	0.0	15	30	0.0	10.0	40	95	0.0	0.0	30	0.0	0.0
Fluoride	15	0.0	0.0	15	30	0.0	0.0	39	91	0.0	0.9	29	0.0	10
Iron	15	27	20	15	30	6.7	3.3	40	95	3.8	1.7	30	17	0.0
Manganese	15	33	13	15	30	10.0	3.3	40	95	2.1	4.6	30	6.7	0.0
Molybdenum	15	0.0	0.0	15	30	0.0	0.0	40	95	3.3	9.6	30	20	13
Selenium	15	0.0	0.0	15	30	0.0	0.0	40	95	3.8	2.1	30	3.3	0.0
Strontium	15	0.0	0.0	15	30	0.0	3.3	40	95	2.1	2.9	30	13	3.3
Vanadium	15	0.0	0.0	15	30	0.0	0.0	40	95	0.0	0.8	30	0.0	10.0
Radioactive constituents														
Adjusted gross alpha radioactivity, 72-hour count	15	6.7	6.7	14	14	0.0	0.0	38	38	0.0	13.2	26	19	15
Gross beta radioactivity, 72-hour count	15	0.0	0.0	14	14	0.0	0.0	38	38	0.0	0.0	26	3.8	12
Radon-222	14	0.0	0.0	14	14	0.0	0.0	38	38	0.0	5.3	30	0.0	10.0
Uranium	15	0.0	0.0	15	30	0.0	0.0	40	95	3.3	8.8	30	10.0	6.7
Nutrients														
Nitrate	15	0.0	0.0	15	30	23.3	16.7	40	95	32.1	11.2	30	6.7	23
Ammonia	15	0.0	0.0	15	15	0.0	0.0	40	40	0.0	0.0	30	3.3	0.0
Salinity indicators														
Chloride	15	0.0	0.0	15	30	3.3	3.3	40	95	7.5	11	30	6.7	13
Sulfate	15	0.0	13	15	30	0.0	3.3	40	95	16	7.5	30	33	3.3
Total dissolved solids (TDS)	15	6.7	33	15	30	6.7	13	40	95	31	37	30	43	37

Table 8B. Aquifer-scale proportions for constituents detected in the four study areas that had (1) high or moderate values in samples collected from grid sites, or (2) organic or special-interest constituents detected in more than 10 percent of the grid sites sampled. Aquifer-scale proportions were based on samples collected in each study area from October 2012 to May 2013, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project.—Continued

[Aquifer-scale proportions are based on samples collected at 100 grid and 70 tap sites from October 2012 to May 2013. The benchmarks are given in tables 4A and 4B. **Abbreviations:** High, concentrations greater than the water-quality benchmark; Moderate, concentrations greater than or equal to 0.1 of the benchmark but less than or equal to the benchmark for organic constituents (the threshold for inorganic constituents is 0.5 of the benchmark)]

Constituent	Aquifer-scale proportion (percent)														
	Santa Cruz			Pajaro Valley				Salinas Valley				Highlands			
	Number of sites	High	Moderate	Number of cells	Number of sites	High	Moderate	Number of cells	Number of sites	High	Moderate	Number of sites	High	Moderate	
Trihalomethanes															
Chloroform (trichloromethane) ¹	15	0.0	0.0	15	15	0.0	0.0	40	40	0.0	0.0	30	0.0	0.0	
Fumigant															
1,2-Dichloropropane (1,2-DCP)	15	0.0	0.0	15	15	0.0	0.0	40	40	0.0	2.5	30	0.0	0.0	
Herbicides															
Simazine	15	0.0	0.0	15	15	0.0	0.0	40	40	0.0	0.0	30	0.0	0.0	
Constituents of special interest															
Perchlorate	15	0.0	0.0	15	15	0.0	33	40	40	2.5	42.5	30	0.0	33	
<i>N</i> -nitrosodimethylamine	15	0.0	6.7	15	15	0.0	0.0	40	40	7.5	5.0	30	0.0	0.0	

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

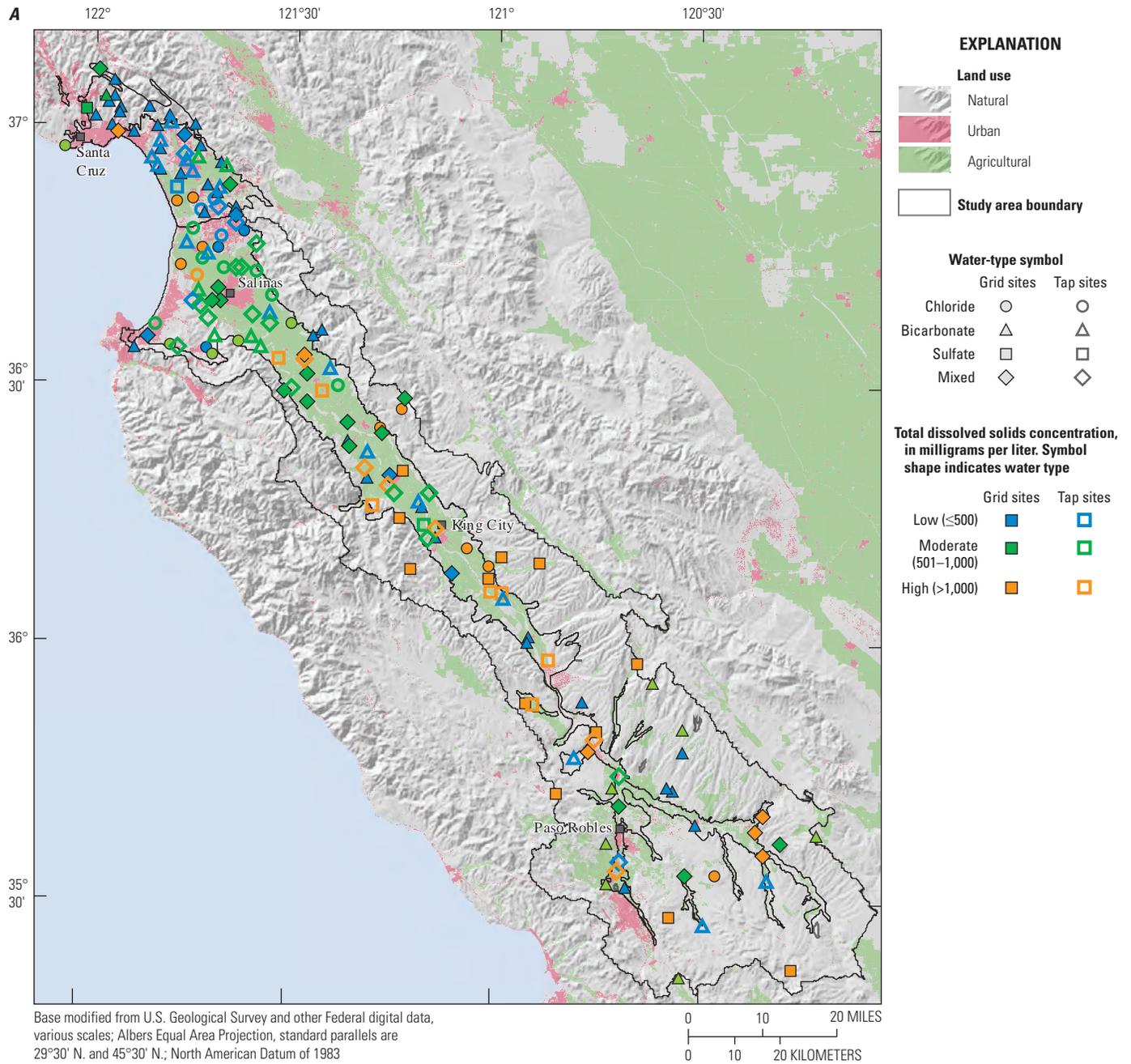
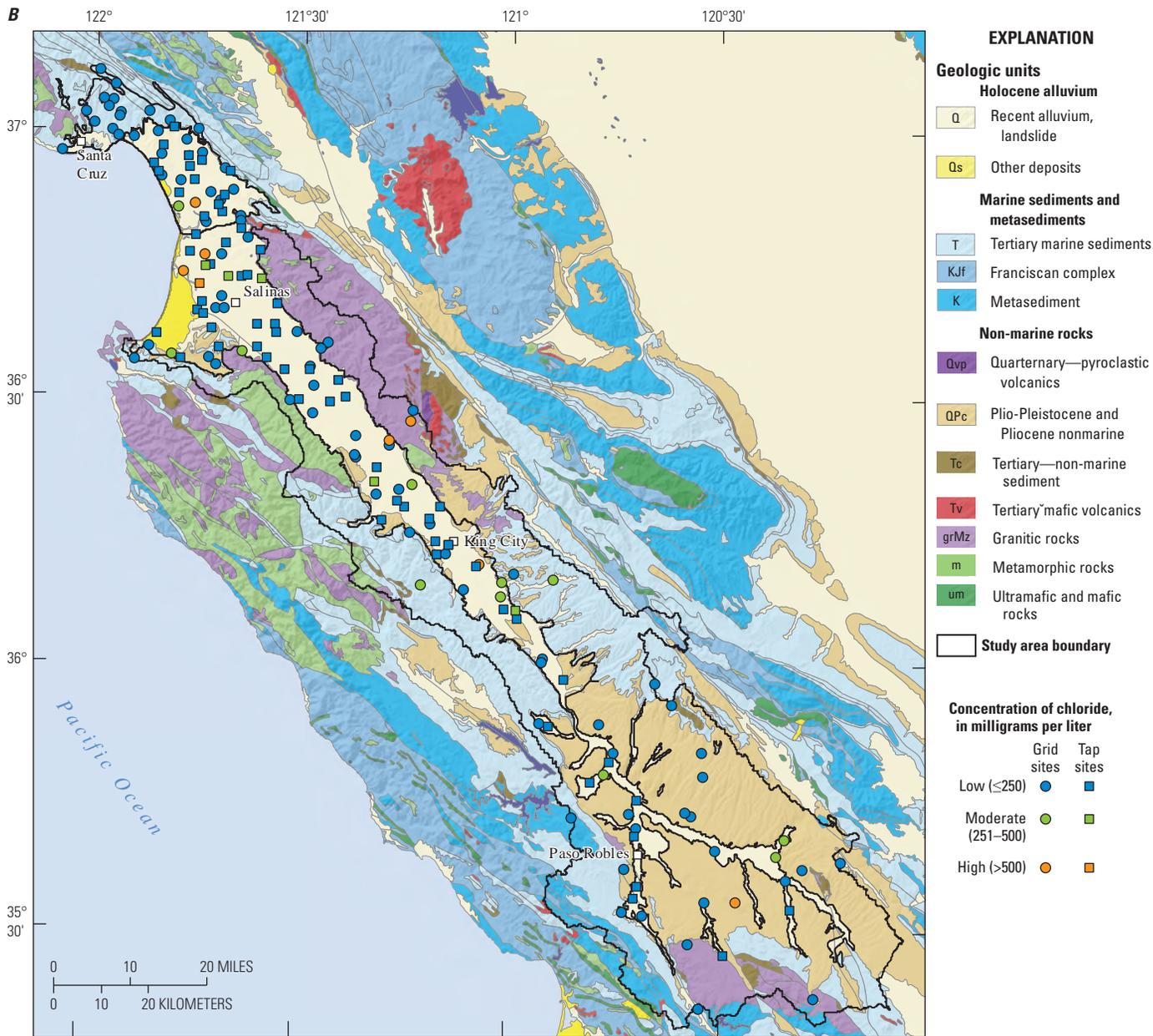


Figure 12. Concentrations of salinity indicators for samples collected from grid and tap sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: *A*, total dissolved solids; *B*, chloride; and *C*, sulfate.



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983

Geology modified from Saucedo and others (2000), GIS data for the Geologic Map of California

Figure 12. —Continued

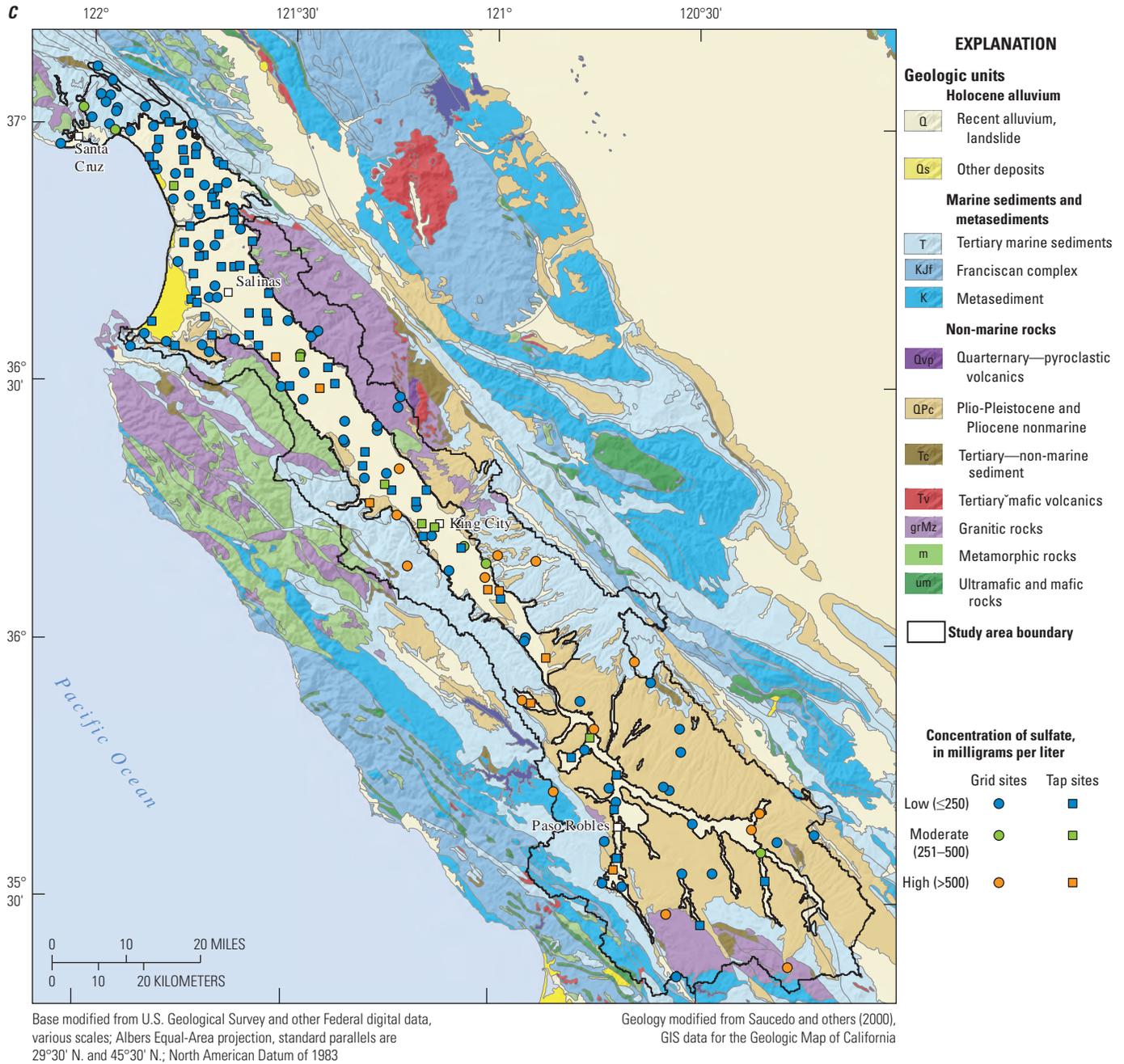


Figure 12. —Continued

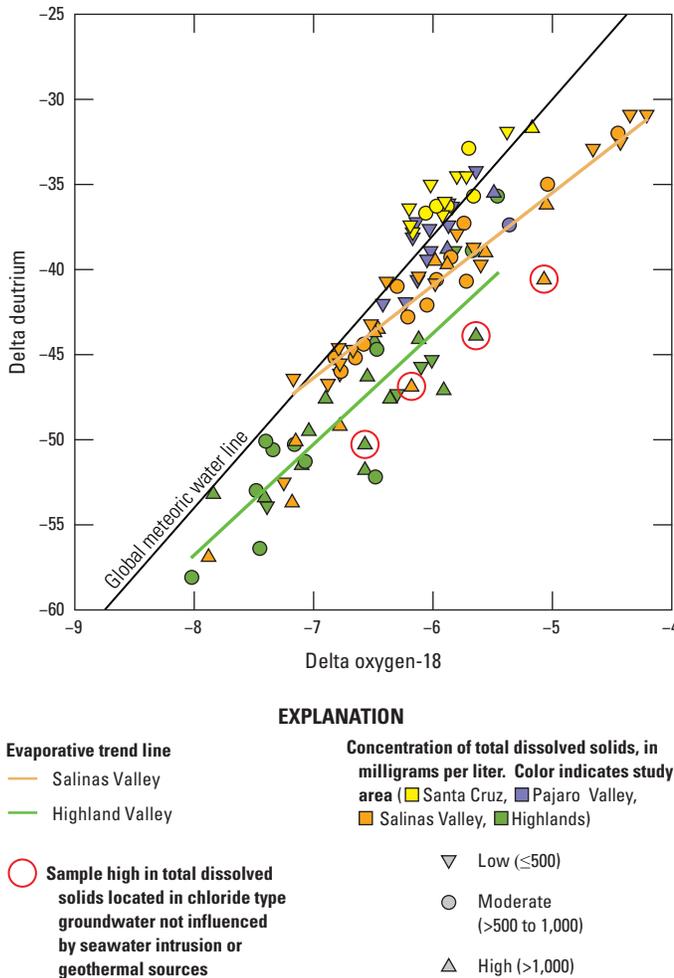


Figure 13. Stable isotope ratios of water and total dissolved solids concentrations in samples for grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Potential anthropogenic sources of TDS to groundwater in the MS-SA study unit include evaporation residues from agricultural and urban irrigation, disposal of wastewater and industrial effluent, seawater intrusion induced by pumping of production wells, and leaking water and sewer pipes. Despite a positive correlation to the percentage of agricultural land use and a negative correlation to the percentage of urban land use (table 9), concentrations of TDS in samples from agricultural land were not significantly different from those in samples from areas of urban land use (table 10). This indicates that factors other than land use could have contributed TDS to groundwater. The TDS concentrations also were negatively correlated to the aridity index, indicating that higher concentrations of TDS were found in drier climates, where evaporative processes could be a cause of elevated TDS concentrations. The correlation of TDS concentrations to agricultural land use could be a result of the covariance of the aridity index with agricultural land use (table 6).

The TDS concentrations were not greater for marine sediments, which indicates that connate marine water had been replaced by fresh water in most of the shallow aquifer. The TDS concentrations also were negatively correlated to DO concentrations and pH, indicating that concentrations of TDS were higher where conditions were anoxic or pH was lower.

Water type was examined to help explain the distribution of TDS observed in the MS-SA study unit. Groundwater samples were classified by major-ion content according to whether or not an ion composed greater than 50 percent of the total cations or anions, on a milliequivalent basis, in a sample; if no single ion was greater than 50 percent of the total, the groundwater was classified as mixed. A Piper diagram (Piper, 1944) categorized by TDS concentration (fig. 14) showed sample water types were primarily demarcated by anionic composition. Samples with low TDS concentrations (less than or equal to 500 mg/L) were primarily classified as a mixed cationic and bicarbonate-type water, whereas the samples with moderate concentrations (501–1,000 mg/L) were classified primarily as mixed cationic and mixed anionic-type water. Samples with high concentrations (more than 1,000 mg/L) of TDS were primarily mixed cationic and sulfate-type water.

Total dissolved solids concentrations were strongly correlated to sulfate, chloride, and bicarbonate (table 11); sulfate anionic water types generally had higher concentrations of TDS, whereas bicarbonate water types generally had lower concentrations of TDS (Kruskal-Wallis and Dunn’s multiple comparison tests, $p < 0.001$). Samples with sulfate-type water were mostly collected from sites in the interior parts of the Salinas Valley and Highland study areas (21 of 23). Of the sulfate-type samples, 45 percent were collected from domestic sites in primarily natural areas (the rest were from areas of agricultural land use), where sewer systems do not exist, indicating that septic-tank discharge could be contributing TDS to groundwater in these areas. Concentrations of TDS were negatively correlated to septic-tank density (table 9); however, this would be expected in the natural land uses, where houses, and the associated septic systems, are separated by long distances.

Chloride-type water composed 24 percent of samples with high concentrations of TDS. Almost half of these samples (four of nine) were collected from sites along the coastal parts of the Pajaro Valley and Salinas Valley study areas. Samples from these sites had high calcium and low sodium concentrations (fig. 14) and were likely groundwater that had been affected by older (connate) seawater (Hanson, 2003; Brown and Caldwell, 2014). Other samples consisting of chloride-type water and high concentrations of TDS were collected from sites in the interior of the Salinas Valley study area or in the Highlands study area and, thus, were not likely to have been affected by seawater intrusion. High TDS concentrations in these samples could be due to evaporative concentration of salts in recharge water, leaching of built-up salts in soil by irrigation-return water, or both (fig. 13).

Table 9. Results of non-parametric (Spearman's rho method) analysis for correlations between selected water-quality constituents and potential explanatory factors for grid sites, Monterey Salinas Shallow Aquifer study area, 2010, California Groundwater Ambient Monitoring Assessment Priority Basin Project.

[All tests were done on dataset consisting of the 100 grid sites sampled by the U.S. Geological Survey for the study unit. Tabled values are the test results, as Spearman's rho above the associated *p* value; results are given only for those correlations with a *p* value less than or equal to (\leq) 0.05 (significant correlation). **Abbreviations:** ns, correlation not significant; <, less than]

Constituent	Depth of well	Depth to top of perforation	pH	Density of septic tanks	Distance to nearest geothermal site	Aridity index	Dissolved oxygen	Percentage of modern carbon-14	Percentage of agricultural land use	Percentage of natural land use	Percentage of urban land use
Inorganic constituents											
Trace elements											
Arsenic	ns	ns	0.204 0.042	-0.247 0.013	-0.295 0.003	-0.354 <0.001	0.224 0.027	ns	ns	ns	ns
Boron	ns	ns	ns	-0.443 <0.001	ns	-0.488 <0.001	-0.279 0.006	-0.236 0.019	ns	ns	-0.312 0.002
Iron	ns	ns	-0.237 0.017	ns	0.213 0.034	0.383 <0.001	-0.372 <0.001	-0.227 0.024	-0.340 <0.001	0.222 0.027	ns
Manganese	ns	ns	ns	0.230 0.022	ns	0.383 <0.001	-0.605 <0.001	-0.251 0.012	-0.410 <0.001	0.270 0.007	ns
Molybdenum	ns	ns	ns	-0.505 <0.001	-0.232 0.020	-0.477 <0.001	ns	-0.220 0.029	0.220 0.028	ns	-0.212 0.035
Selenium	ns	ns	ns	-0.538 <0.001	-0.356 <0.001	-0.610 <0.001	0.417 <0.001	0.220 0.029	0.518 <0.001	-0.265 0.009	ns
Strontium	ns	ns	ns	-0.542 <0.001	ns	-0.393 <0.001	ns	-0.217 0.031	ns	ns	-0.289 0.004
Radioactive constituents											
Adjusted gross alpha radioactivity, 72-hour count	ns	ns	ns	-0.310 0.003	ns	-0.281 0.006	ns	-0.286 0.006	ns	ns	ns
Uranium	ns	0.257 0.029	ns	-0.592 <0.001	-0.276 0.006	-0.678 <0.001	0.247 0.014	ns	0.504 <0.001	ns	-0.273 0.006
Nutrients											
Nitrate	ns	ns	ns	-0.245 0.014	ns	-0.411 <0.001	0.610 <0.001	0.506 <0.001	0.467 <0.001	-0.333 <0.001	ns
Salinity indicators											
Chloride	ns	ns	-0.388 <0.001	-0.301 0.002	ns	-0.336 <0.001	ns	ns	ns	ns	ns
Sulfate	-0.256 0.012	ns	ns	-0.433 <0.001	ns	-0.368 <0.001	-0.277 0.006	ns	0.311 0.002	ns	-0.206 0.040
Total dissolved solids (TDS)	ns	ns	-0.360 <0.001	-0.454 <0.001	ns	-0.361 <0.001	-0.221 0.029	ns	0.210 0.036	ns	-0.228 0.023

Table 9. Results of non-parametric (Spearman’s rho method) analysis for correlations between selected water-quality constituents and potential explanatory factors for grid sites, Monterey Salinas Shallow Aquifer study area, 2010, California Groundwater Ambient Monitoring Assessment Priority Basin Project.—Continued

[All tests were done on dataset consisting of the 100 grid sites sampled by the U.S. Geological Survey for the study unit. Tabled values are the test results, as Spearman’s rho above the associated *p* value; results are given only for those correlations with a *p* value less than or equal to (\leq) 0.05 (significant correlation). **Abbreviations:** ns, correlation not significant; <, less than]

Constituent	Depth of well	Depth to top of perforation	pH	Density of septic tanks	Distance to nearest geothermal site	Aridity index	Dissolved oxygen	Percentage of modern carbon-14	Percentage of agricultural land use	Percentage of natural land use	Percentage of urban land use
Organic constituents											
Number of volatile organic compound (VOC) detects	ns	ns	ns	0.208 0.038	ns	ns	ns	ns	ns	ns	ns
Chloroform (trichloromethane)	ns	ns	ns	0.203 0.043	ns	ns	ns	ns	ns	ns	ns
Number of pesticide detects	ns	ns	ns	-0.203 0.043	-0.220 0.028	-0.426 <0.001	ns	0.322 0.001	0.431 <0.001	-0.337 <0.001	ns
Simazine	-0.249 0.015	ns	ns	-0.286 0.004	-0.209 0.037	-0.463 <0.001	ns	0.327 <0.001	0.386 <0.001	-0.240 0.016	ns
Special interest constituents											
<i>N</i> -nitrosodimethylamine (NDMA)	ns	ns	ns	ns	ns	-0.227 0.023	ns	ns	ns	-0.234 0.019	ns
Perchlorate	ns	ns	ns	-0.290 0.004	ns	-0.347 <0.001	0.608 <0.001	0.285 0.004	0.292 0.003	ns	ns

Table 10. Results of non-parametric analysis (Kruskal-Wallis and multiple comparison tests) for differences in selected water-quality constituents among categories of potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[Results are shown only for those correlations with a p value less than ($<$) 0.05. Only results with p values less than or equal to (\leq) 0.05 are considered significant in this study. A positive value indicates positive correlations; negative values indicate negative correlations. **Abbreviations:** Ag, agricultural; An-mix, anoxic and mixed oxidation-reduction classifications; grMz-m, Mesozoic granitic rocks and metamorphic rocks; H, Highlands; Mix, groundwater having both modern and pre-modern groundwater; Mod, modern groundwater primarily recharged after 1953; Nat, natural; ns, not significant; P, Pajaro Valley; preM, pre-modern groundwater primarily recharged before 1953; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; SC, Santa Cruz; SV, Salinas Valley; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments; Urb, urban; $>$, greater than; —, not applicable]

Constituent	Kruskal-Wallis with Dunn's multiple comparison test p value significant differences				
	Land-use category (Ag, Nat, Urb) ¹	Study area (SC, P, SV, H)	Geology (Q, Qpc, TK, grMz-m)	Oxidation-reduction class (Oxic, An-mix)	Groundwater-age class (Mod, Mix, PreM)
Inorganic constituents					
Trace elements					
Arsenic	ns	0.007 SV,H>SC	0.001 Qpc>TK,Q	<0.001 Oxic>An-mix	ns
Boron	0.025 Nat>Urb	0.018 H>P	ns	ns	ns
Iron	0.038 Urb,Nat>Ag	0.006 SC>SV,P	0.004 TK>Q	<0.001 An-mix>Oxic	ns
Manganese	0.027 Nat,Urb>Ag	<0.001 SC>SV,P,H	<0.001 TK>Q,Qpc	<0.001 An-mix>Oxic	0.013 preM,Mix>Mod
Molybdenum	ns	<0.001 H>SV>P,SC	0.048 Qpc>grMz-m	ns	ns
Selenium	<0.001 Ag>Urb,Nat	<0.001 SV,H,P>SC	<0.001 Qpc,Q>TK	<0.001 Oxic>An-mix	ns
Strontium	ns	<0.001 H>SV,P,SC	ns	ns	ns
Radioactive constituents					
Adjusted gross alpha radioactivity, 72-hour count	ns	0.015 H>P	ns	ns	0.047 Mix>Mod
Uranium	<0.001 Ag>Nat>Urb	<0.001 SV,H>SC,P	0.001 Qpc,Q>TK	<0.001 Oxic>An-mix	ns
Nutrients					
Nitrate	<0.001 Ag>Nat	<0.001 SV,P,H>SC	<0.001 Q,Qpc, grMz-m>TK	<0.001 Oxic>An-mix	<0.001 Mod>preM,Mix
Salinity indicators					
Chloride	ns	<0.001 SV,H>SC: SV>P	ns	ns	ns
Sulfate	0.009 Ag>Urb	0.016 H>P	ns	0.028 An-mix>Oxic	ns
Total dissolved solids (TDS)	ns	<0.001 H, SV>P; H>SC	ns	0.020 An-mix>Oxic	0.035 Mix>preM

Table 10. Results of non-parametric analysis (Kruskal-Wallis and multiple comparison tests) for differences in selected water-quality constituents among categories of potential explanatory factors for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[Results are shown only for those correlations with a *p* value less than (<) 0.05. Only results with *p* values less than or equal to (≤) 0.05 are considered significant in this study. A positive value indicates positive correlations; negative values indicate negative correlations. **Abbreviations:** Ag, agricultural; An-mix, anoxic and mixed oxidation-reduction classifications; grMz-m, Mesozoic granitic rocks and metamorphic rocks; H, Highlands; Mix, groundwater having both modern and pre-modern groundwater; Mod, modern groundwater primarily recharged after 1953; Nat, natural; ns, not significant; P, Pajaro; preM, pre-modern groundwater primarily recharged before 1953; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; SC, Santa Cruz; SV, Salinas Valley; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments; Urb, urban; >, greater than; —, not applicable]

Constituent	Kruskal-Wallis with Dunn's multiple comparison test				
	<i>p</i> value significant differences				
	Land-use category (Ag, Nat, Urb) ¹	Study area (SC, P, SV, H)	Geology (Q, Qpc, TK, grMz-m)	Oxidation-reduction class (Oxic, An-mix)	Groundwater-age class (Mod, Mix, PreM)
Organic constituents					
Number of volatile organic compound (VOC) detects	ns	ns	ns	ns	ns
Chloroform (trichloromethane)	ns	ns	ns	ns	ns
Number of pesticide detects	<0.001 Ag>Urb, Nat	<0.001 SV>SC, P, H	0.005 Q>TK	ns	0.010 Mod>PreM
Simazine	0.001 Ag>Nat	0.001 SV>SC	0.028 Q>TK	ns	0.001 Mod>preM
Special interest constituents					
<i>N</i> -nitrosodimethylamine (NDMA)	ns	ns	ns	ns	ns
Perchlorate	ns	<0.001 SV, H, P>SC	<0.001 Qpc, grMz-m, Q>TK	<0.001 Oxic>An-mix	ns

¹ Land-use percentages are within a radius of 500-meters from each well included in analysis.

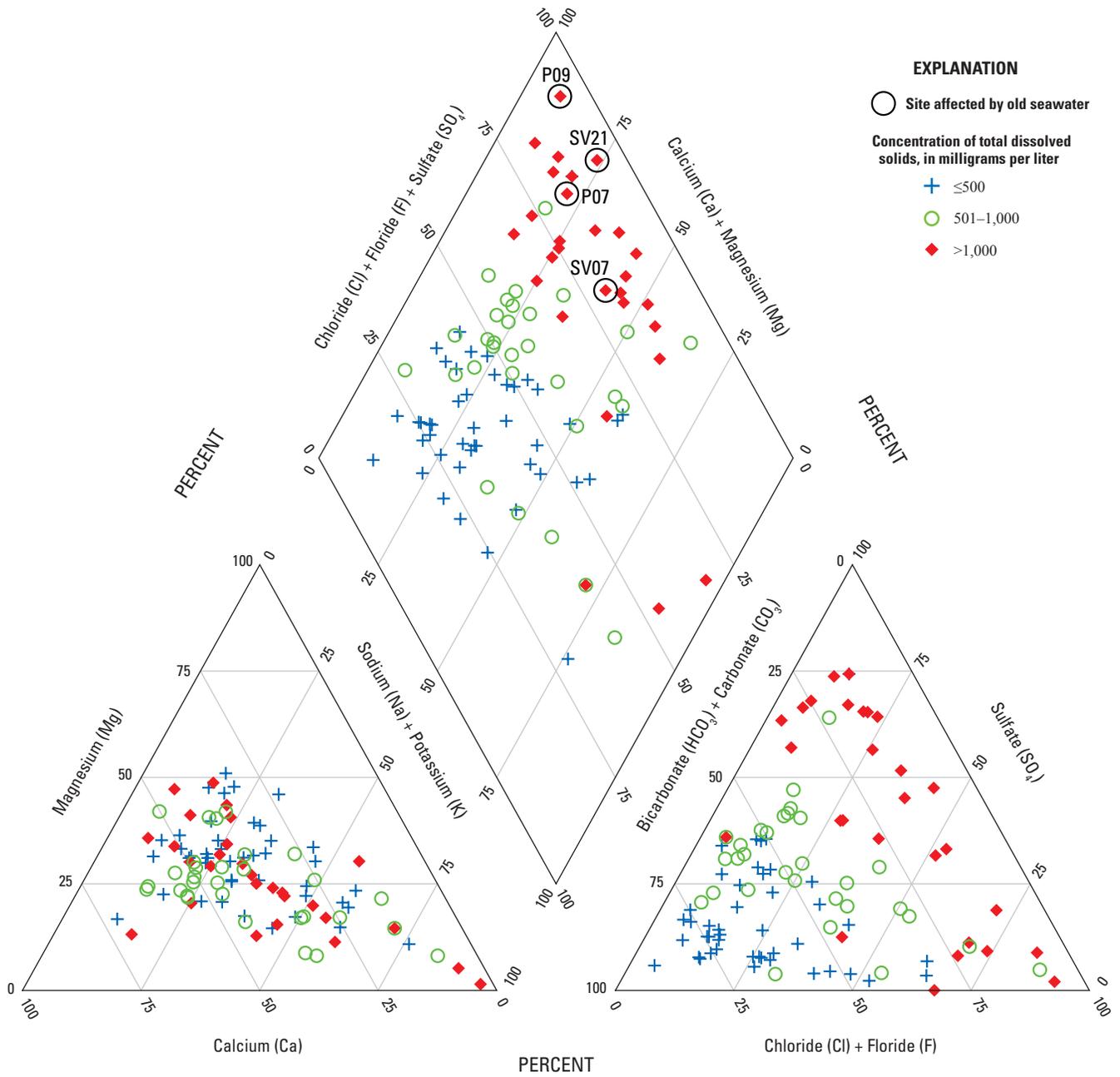


Figure 14. Major-ion content of grid and tap samples by total dissolved solids concentration range category for the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Table 11. Results of non-parametric (Spearman’s rho method) tests for correlations between concentrations of selected water-quality constituents for grid sites, Monterey-Salinas Shallow Aquifer assessment study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

[All tests were done on dataset consisting of the 100 grid sites sampled by the U.S. Geological Survey for the study unit. Tabled values are the test results, as Spearman’s rho above the associated *p* value; results are given only for those *p* values less than threshold value (α) of 0.05 are considered significant: black text, positive correlation; red text, negative correlation. **Abbreviations:** ns, not significant; <, less than]

Constituent	Boron	Iron	Manganese	Molybdenum	Selenium	Strontium	Adjusted gross alpha radioactivity, 72-hour count	Uranium	Nitrate	Chloride	Sulfate	Total dissolved solids (TDS)	Bicarbonate	Perchlorate
Arsenic	ns	-0.407 <0.001	-0.316 0.001	0.430 <0.001	0.467 <0.001	ns	ns	0.450 <0.001	0.252 0.012	ns	ns	ns	ns	0.305 0.002
Boron		ns	ns	0.480 <0.001	0.250 0.012	0.531 <0.001	0.330 0.001	0.430 <0.001	ns	0.368 <0.001	0.495 <0.001	0.536 <0.001	0.413 <0.001	ns
Iron			0.691 <0.001	ns	-0.449 <0.001	ns	ns	-0.348 <0.001	-0.545 <0.001	ns	ns	ns	ns	-0.450 <0.001
Manganese				ns	-0.532 <0.001	ns	ns	-0.392 <0.001	-0.649 <0.001	ns	ns	ns	0.221 0.027	-0.589 <0.001
Molybdenum					0.374 <0.001	0.315 0.001	0.216 0.037	0.553 <0.001	ns	ns	0.342 <0.001	0.243 0.015	0.240 0.016	ns
Selenium						0.319 0.001	ns	0.654 <0.001	0.690 <0.001	0.272 0.006	ns	0.252 0.012	ns	0.681 <0.001
Strontium							0.486 <0.001	0.467 <0.001	ns	0.615 <0.001	0.687 <0.001	0.842 <0.001	0.479 <0.001	ns
Adjusted gross alpha radioactivity, 72-hour count								0.307 0.003	ns	0.404 <0.001	0.395 <0.001	0.434 <0.001	ns	ns
Uranium									0.445 <0.001	ns	0.414 <0.001	0.349 <0.001	0.281 0.004	0.395 <0.001
Nitrate										0.209 0.037	ns	ns	-0.238 0.018	0.840 <0.001
Chloride											0.341 <0.001	0.777 <0.001	ns	0.354 <0.001
Sulfate												0.764 <0.001	0.433 <0.001	ns
Total dissolved solids													0.450 <0.001	ns

Understanding Assessment for Chloride

Chloride was detected at high relative concentrations in 6.6 percent of the MS-SA study unit and at moderate relative concentrations in 12 percent (table 8A); the SMCL-CA for chloride is 500 mg/L. High relative concentrations were detected in samples from all except the Santa Cruz study area (table 8B; figs. 11B, 12B). The Salinas Valley study area had the greatest proportion of the shallow aquifer with high relative concentrations of chloride at 7.5 percent, followed by the Highlands study area at 6.7 percent (table 8B). Moderate relative concentrations were detected in all study areas, except Santa Cruz. Chloride is likely to have natural and anthropogenic sources in the study unit.

Despite the lack of correlation with marine geology, the Pliocene and Miocene marine sediments in the Coast Ranges are likely sources of chloride in the interior of the Salinas Valley study area and the Highlands study area (fig. 12B). Natural sources of chloride include the dissolution of sedimentary rocks, particularly evaporates, and the dissolution of fine grained marine shale (Hem, 1985). Chloride is also present in precipitation as a result of entrainment of marine salts into the air at the ocean's surface. Similar to TDS, chloride was negatively correlated to the aridity index, indicating higher concentrations generally in drier climates (table 9). Concentration of chloride as a result of evaporative concentration, similar to TDS, could also partially explain elevated chloride in the interior of the Salinas Valley study area.

Potential anthropogenic sources include agricultural practices, where irrigation-return water can leach chloride salts in soils into groundwater, and seawater intrusion induced by pumping near the coast. As discussed in the TDS understanding section, elevated concentrations of chloride in samples collected from sites in the coastal areas of the Salinas Valley and Pajaro Valley study areas could be due to older seawater intrusion (fig. 12B).

Understanding Assessment for Sulfate

Sulfate was detected at high relative concentrations in 26 percent of the MS-SA study unit and at moderate relative concentrations in 4.7 percent (table 8A); the SMCL-CA for sulfate is 500 mg/L. High relative concentrations were detected only in the Highlands and Salinas Valley study areas (figs. 11B, 12C). The Highlands study area had the greatest proportion of the shallow aquifer with high relative concentrations, at 33 percent, and the Salinas Valley study area had 16 percent (table 8B). Moderate relative concentrations were detected in all study areas. Natural and anthropogenic sources are likely to have contributed to elevated sulfate concentrations in the study unit.

Natural sources of sulfate include the dissolution of natural sulfur and its oxidation to the anion sulfate, the

biochemical oxidation of sulfide minerals and pyrites, atmospheric deposition from volcanic activity, or entrained from sea water (Hem, 1985; Drever, 1997; Fenn and others, 2013). Sulfate was negatively correlated to DO (table 9), and sulfide was detected in some samples (Goldrath and others, 2016), providing evidence for sulfur dissolution and oxidation in the study unit. Sulfate is in evaporites, such as gypsum or anhydrite, and in soils in arid and semi-arid environments, and it commonly exceeds concentrations of 1 mg/L in rainfall (Hem, 1985). Sulfate was negatively correlated to the aridity index, which indicated that sulfate concentrations, similar to those of TDS and chloride, were higher in drier climates (table 9). Similar to chloride, the Pliocene and Miocene marine sediments in the Coast Ranges are likely sources of sulfate in the interior portions of the Salinas Valley study area and the Highlands study area (fig. 12C).

Sulfate concentrations were positively correlated to the percentage of agricultural land use and negatively correlated to well depth (table 9). These correlations indicate that agricultural practices could be contributing to sulfate concentrations in groundwater and that shallow wells were most likely to have concentrations above the benchmarks. Anthropogenic sources include sulfuric acid used to lower the pH of irrigation water to assist with nutrient uptake in some agriculture and atmospheric deposition of sulfuric oxides from combustion of fossil fuels. A study by Oren and others (2004) identified sulfate as a primary constituent contributing to increased groundwater salinity in irrigated fields in an arid environment. Ammonium sulfate is used on a wide variety of crops in the Monterey and San Luis Obispo Counties (California Department of Pesticide Regulation, 2014). Excess sulfate can be leached to the groundwater through irrigation recharge.

Trace Elements

The trace elements constituent class included a variety of metallic and non-metallic constituents that typically are present in groundwater at concentrations less than 1 mg/L (Hem, 1985). Trace elements with health-based benchmarks, as a class, were detected at high relative concentrations (for one or more constituents) in 37 percent of the MS-SA study unit, moderate relative concentrations in 13 percent, and low relative concentration in 51 percent (table 7A). Trace elements were most frequently detected at high relative concentrations in the Highlands and Santa Cruz study areas (table 7B).

Trace elements detected at high relative concentrations in more than 2 percent of the shallow aquifer included arsenic, boron, iron, manganese, molybdenum, selenium, and strontium (table 8A). These seven trace elements are discussed in more detail in following sections. Four other trace elements only detected at moderate relative concentrations included beryllium, chromium, fluoride, and vanadium.

Understanding Assessment for Arsenic

Arsenic was detected at high relative concentrations in 3.9 percent of the MS-SA study unit and at moderate relative concentrations in 15 percent of the shallow aquifer (table 8A); the MCL-US for arsenic is 10 micrograms per liter ($\mu\text{g/L}$). High relative concentrations were detected in at least one sample collected from each of the study areas, but were detected most frequently at high and moderate relative concentrations in samples from the Salinas Valley and Highlands study areas (fig. 11A, 15A; tables 8B, 10). The MCL-US for arsenic was lowered from 50 $\mu\text{g/L}$ to 10 $\mu\text{g/L}$ in 2002, and chronic exposure to arsenic concentrations between 10 and 50 $\mu\text{g/L}$ in drinking water has been linked to increased cancer risk and to non-cancerous effects including skin damage and circulatory problems (National Research Council, 2001; U.S. Environmental Protection Agency, 2007). Sources of arsenic in the shallow aquifer are likely to be natural.

Arsenic is a semi-metallic trace element that is found naturally in the environment. Potential sources of arsenic to groundwater are natural and anthropogenic. Natural sources include the dissolution of arsenic-rich minerals such as arsenopyrite (FeAsS), a common constituent of shales, and apatite, a common constituent of phosphorites. Arsenic is used as a wood preservative and a pesticide, in glass production, paints, dyes, metals, drugs, soaps, semi-conductors, and the mining of copper and gold (Welch and others, 2000). The MS-SA study unit has had relatively little mining activity compared to other areas of the State (<http://tin.er.usgs.gov/mrds/>); thus, arsenic concentrations were not likely to be elevated because of mining activities.

Previous investigations and literature reviews of arsenic have indicated two mechanisms that increase arsenic concentrations in groundwater: (1) release of arsenic by reductive dissolution of iron or manganese oxyhydroxides under anoxic conditions and (2) desorption of arsenic from these oxyhydroxides under high-pH, oxic conditions (Welch and others, 2000; Smedley and Kinniburgh, 2002; Stollenwerk, 2003). Arsenic concentrations were significantly higher in samples classified as oxic than in samples classified as anoxic or mixed, were positively correlated to DO concentrations, and were negatively correlated to manganese concentrations (tables 9, 10, 11). Arsenic concentrations also had a significant positive correlation with pH. Under oxic redox conditions, arsenic likely exists in an oxyanionic form (for example, HAsO_4^{2-}). In this form, arsenic would be more mobile in alkaline (higher pH) groundwater because the predominately negative surface charge of particles would promote desorption, and inhibit adsorption, of negatively charged molecules (Stumm, 1992). This indicates that the mechanism of desorption from iron and manganese oxyhydroxides under high-pH, oxic conditions could be one

source of arsenic in groundwater. This does not fully explain the moderate and high concentrations of arsenic in the study unit, however, which indicate other sources of arsenic.

Arsenic concentrations were generally higher in samples from non-marine sediments (Qpc) than from marine sediments (TK) or recent alluvium (Q) (table 10), but were not correlated to groundwater age (table 9). Of the 14 grid sites from which samples had high or moderate concentrations of arsenic, 7 were in non-marine sediments, and 3 were in recent alluvium where sediments could have originated from non-marine rocks (fig. 15A). It is possible that the non-marine sediments could be the one source of the high and moderate arsenic concentrations. Other sources of arsenic could be present that were not evaluated in this report, however.

Arsenic solubility increases with increasing water temperature, such that hydrothermal fluids often have high arsenic concentrations (Ballantyne and Moore, 1988; Webster and Nordstrom, 2003), as does older groundwater that has had extended exposure to arsenic-bearing minerals. Arsenic was negatively correlated with distance to geothermal sources (table 9), indicating arsenic concentrations were higher near geothermal sources. Arsenic was not correlated to water temperature (Spearman's $\rho = 0.189$, $p=0.066$), however, which indicates either geothermal sources were not an important source of arsenic in the study unit or geochemical factors such as redox conditions or pH kept arsenic in solution as water moved away from geothermal sources and cooled.

Unlike many other the GAMA-PBP study units, arsenic showed no significant relations with measures of well depth or groundwater age (table 9). The lack of correlation between arsenic concentration and well depth was expected, given the lack of significant correlations between redox conditions or values of DO and pH with measures of well depth (tables 5, 6).

Arsenic concentrations were positively correlated to nitrate (table 11), but not to the percentage of agricultural land use (tables 9, 10); in addition, there was no registered use of arsenical pesticides (California Department of Pesticide Regulation, 2014) in the study unit, indicating that agricultural practices did not significantly contribute to the moderate or high concentrations of arsenic.

Understanding Assessment for Boron

Boron was detected at high relative concentrations in 2.2 percent of the shallow aquifer (table 8A); the HBSL for boron is 6,000 $\mu\text{g/L}$. The high concentration was in a sample from the Highlands study area (fig. 11A) near Paso Robles (fig. 15B). In general, boron concentrations were higher in the Highlands study area than in the Pajaro Valley study area (table 10). Sources of boron in the study unit are likely to be natural.

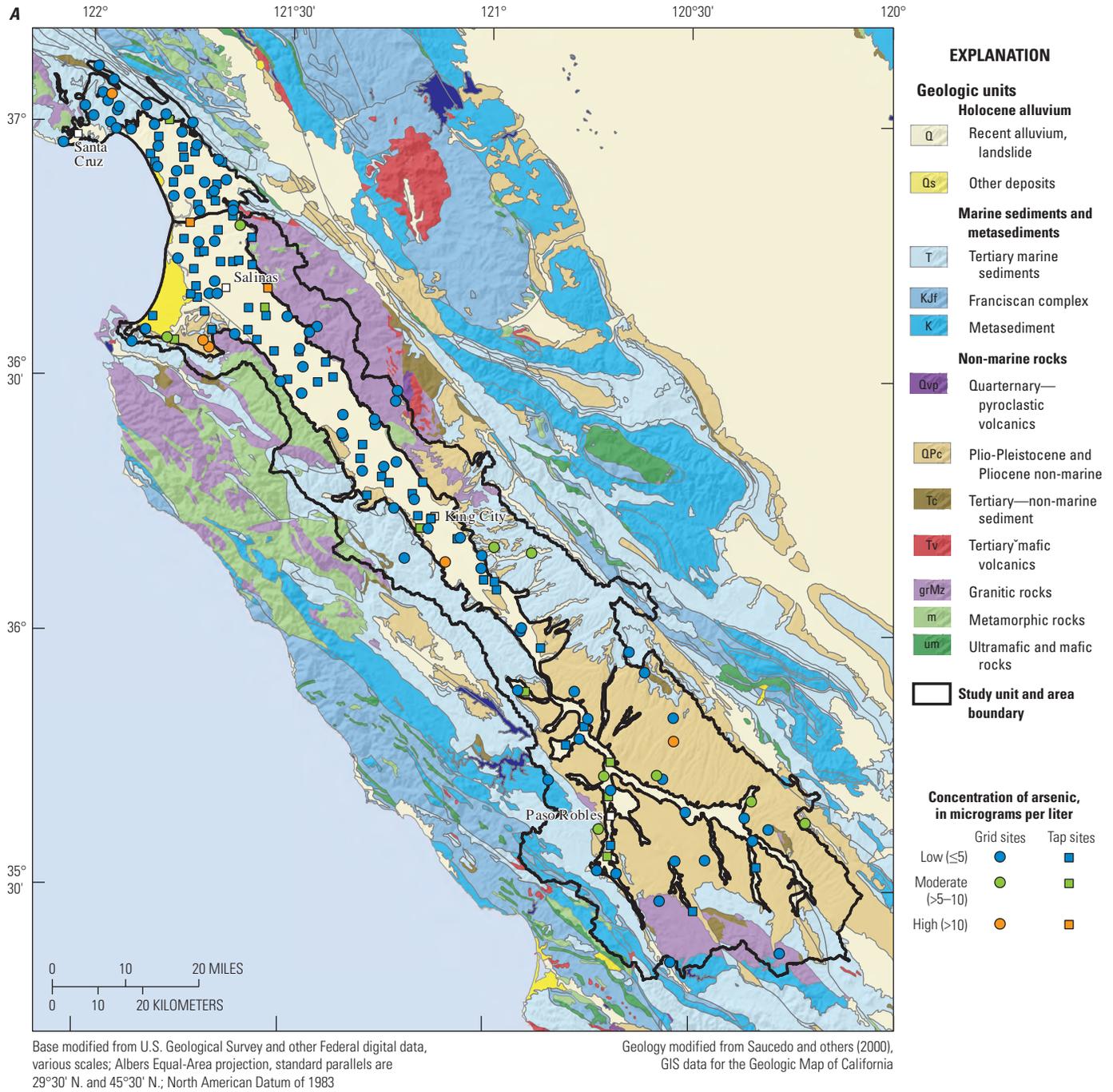


Figure 15. Concentrations of selected trace elements in water samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: A, arsenic; B, boron; C, iron; D, manganese; E, molybdenum; F, selenium; and G, strontium.

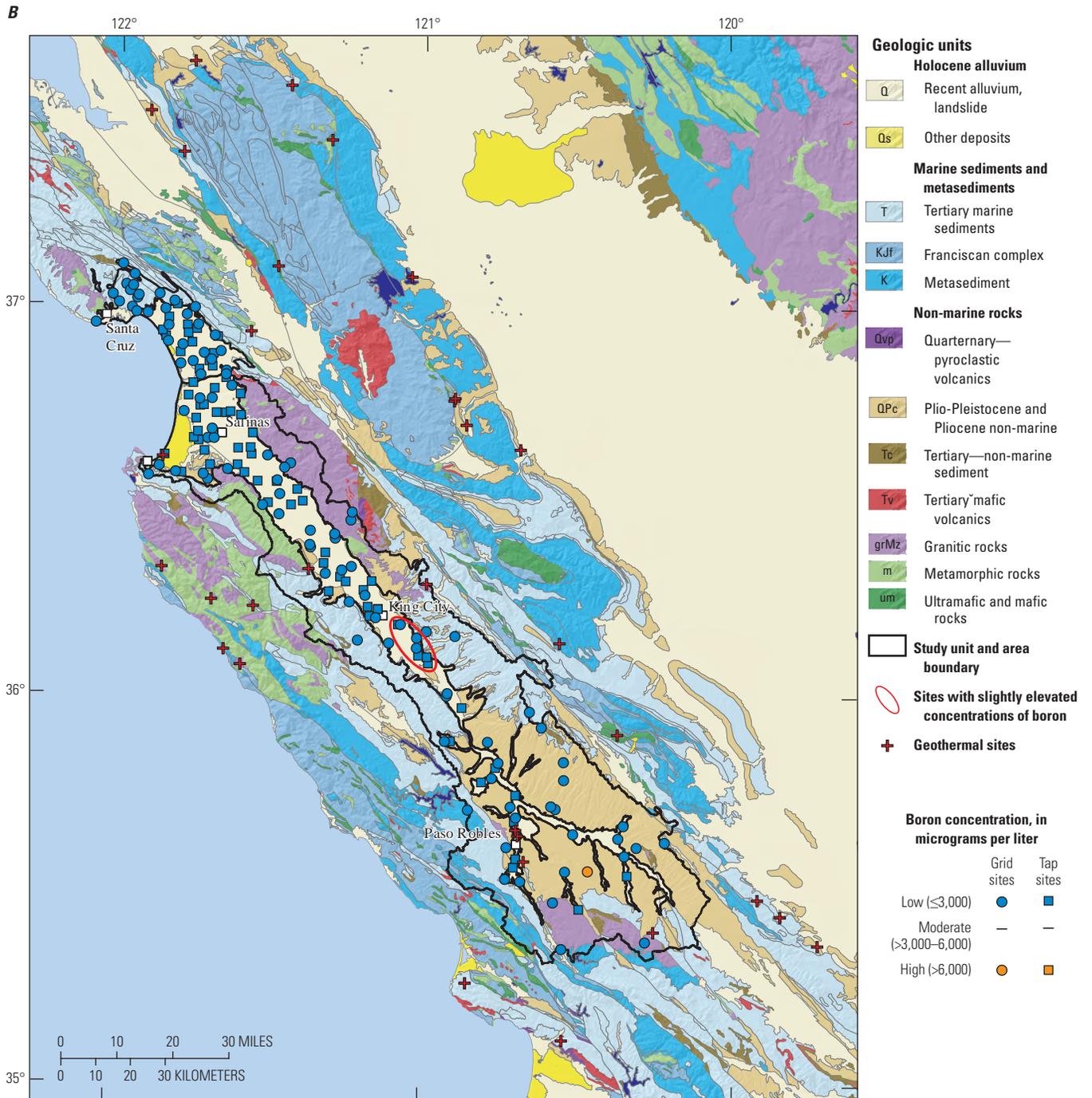


Figure 15. —Continued

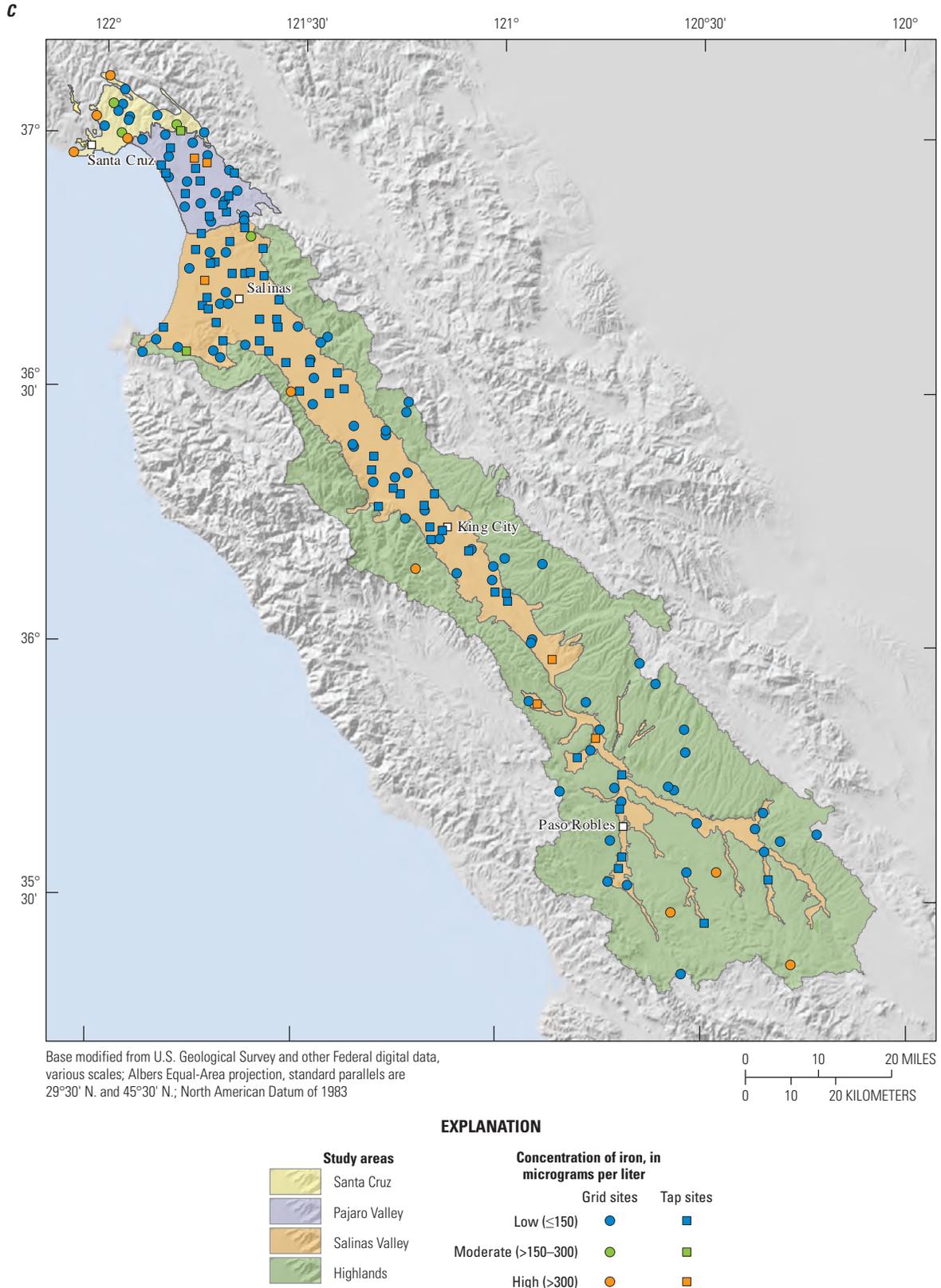
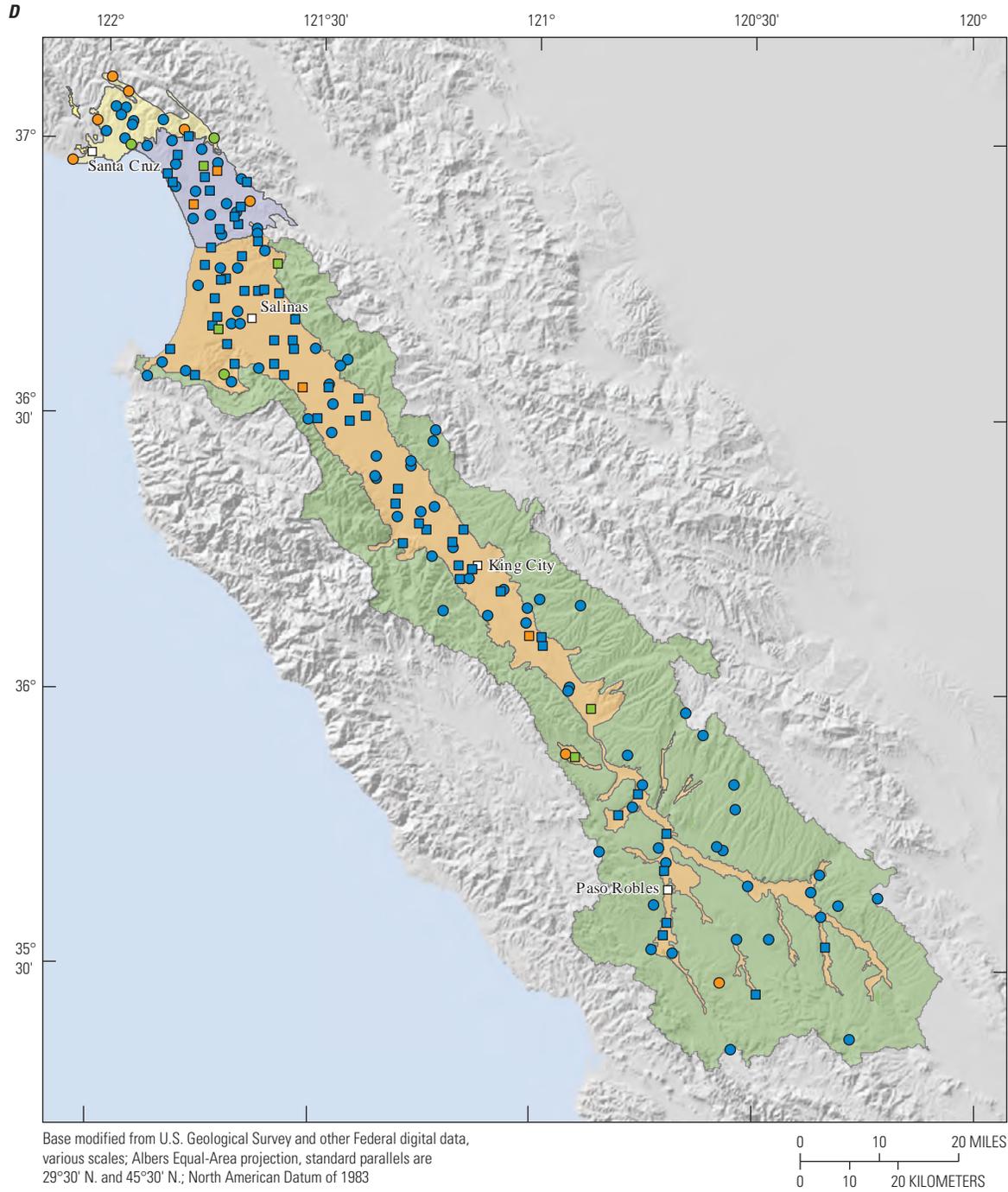


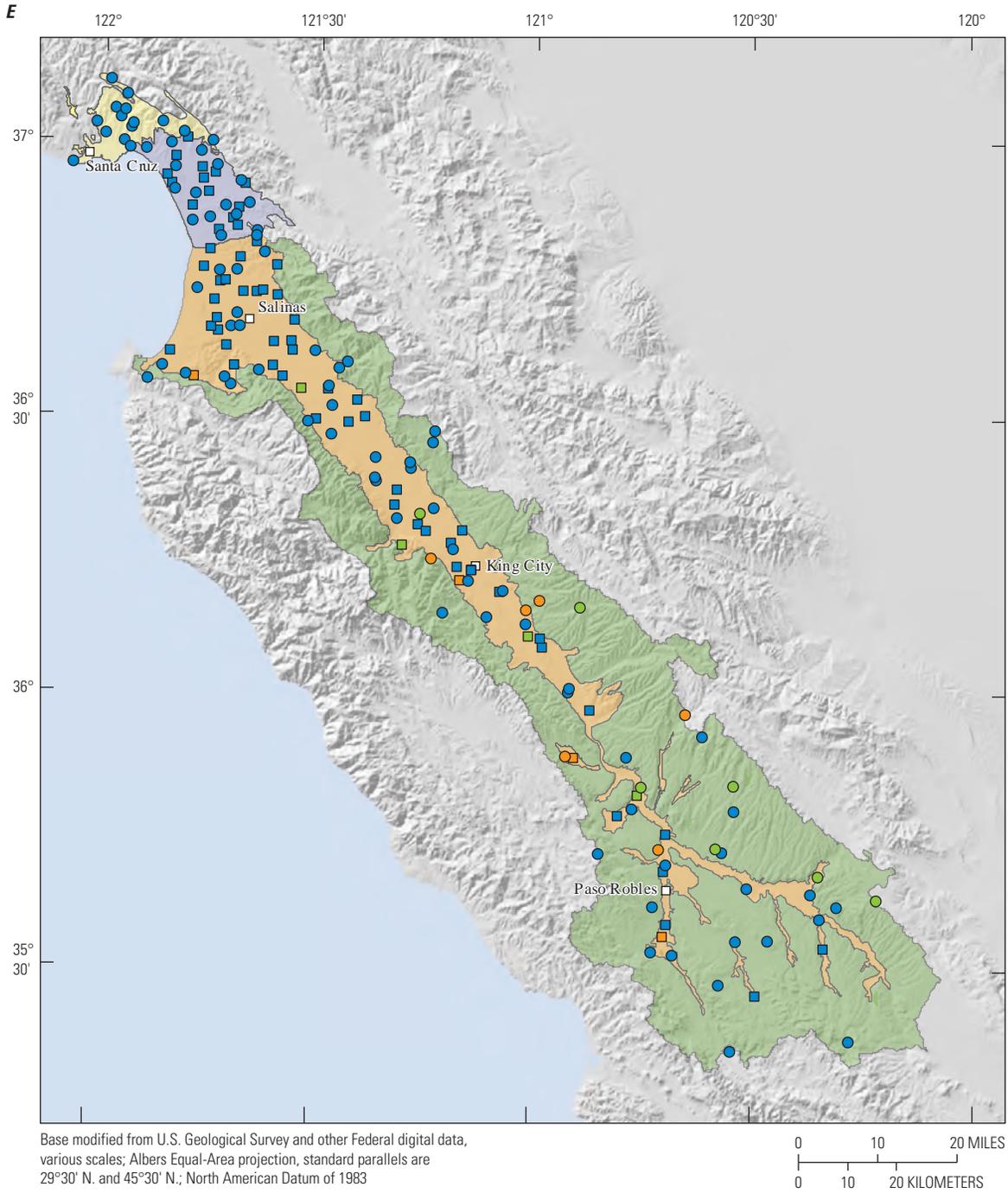
Figure 15. —Continued



EXPLANATION

Study areas		Concentration of manganese, in micrograms per liter	
	Santa Cruz	Grid sites	Tap sites
	Pajaro Valley	Low (≤ 150)	
	Salinas Valley	Moderate ($>150-300$)	
	Highlands	High (>300)	

Figure 15. —Continued

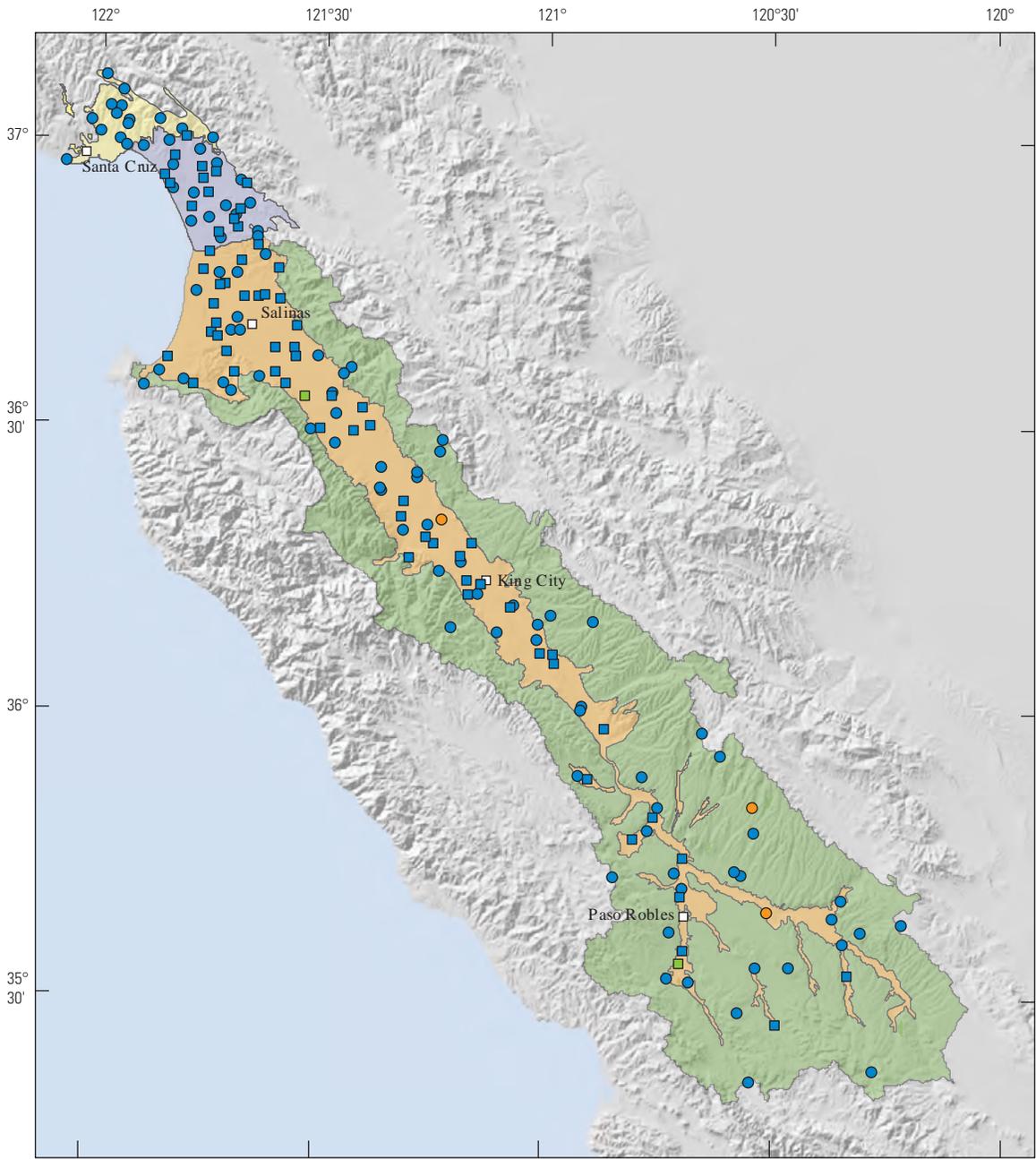


EXPLANATION

Study areas		Concentration of molybdenum, in micrograms per liter	
<ul style="list-style-type: none"> Santa Cruz Pajaro Valley Salinas Valley Highlands 	<ul style="list-style-type: none"> Low (≤ 20) Moderate ($>20-40$) High (>40) 	<p style="text-align: center;">Grid sites</p> <ul style="list-style-type: none"> Low (≤ 20) Moderate ($>20-40$) High (>40) 	<p style="text-align: center;">Tap sites</p> <ul style="list-style-type: none"> Low (≤ 20) Moderate ($>20-40$) High (>40)

Figure 15. —Continued

F



Base modified from U.S. Geological Survey and other Federal digital data, various scales; Albers Equal-Area projection, standard parallels are 29°30' N. and 45°30' N.; North American Datum of 1983



EXPLANATION

Study areas		Concentration of selenium, in micrograms per liter	
	Santa Cruz	Grid sites	Tap sites
	Pajaro Valley	Low (≤ 25)	 
	Salinas Valley	Moderate (25.1–50)	 
	Highlands	High (>50)	 —

Figure 15. —Continued

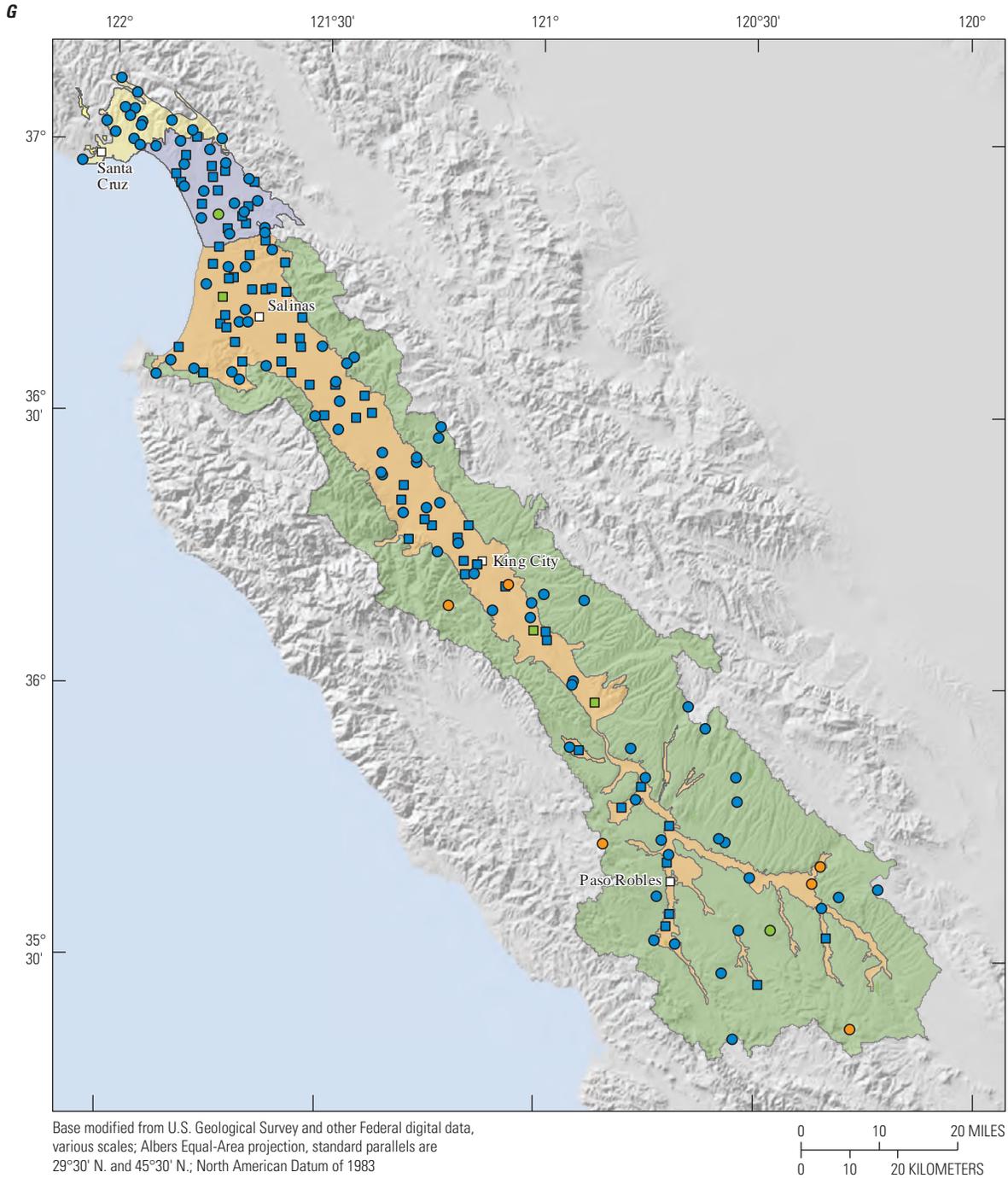


Figure 15. —Continued

Boron is an essential nutrient for plants, but is toxic to many plants at concentrations above the NL-CA of 1,000 µg/L (Grieve and others, 2011). At concentrations greater than the HAL-US of 5,000 µg/L, boron can adversely affect fetal development (U.S. Environmental Protection Agency, 2008). Boron is a semi-metallic element that is natural in the environment and highly soluble in water. Boron can be found in wastewater because borax is a component of many detergents. Other anthropogenic uses of boron compounds include borosilicate glass, boric acid insecticide, chemical reagents, semi-conductors, and fertilizers.

Higher concentrations of boron were detected in samples with older groundwater, as indicated by the negative correlation to the percentage of modern carbon-14, which, together with negative correlations to the density of septic tanks and the percentage of urban land use (table 9), indicate boron concentrations were not likely to be elevated as a result of anthropogenic sources. The negative correlation to the percentage of modern carbon-14 indicates that longer exposure to boron-bearing marine sediments could contribute to elevated boron concentrations.

Natural sources of boron to groundwater include dissolution of evaporate minerals, such as borax, ulexite, and colemanite, and boron-bearing silicate minerals, such as tourmaline, that are primarily found in igneous rocks

(Hem, 1985; Klein and Hurlbut, 1993). Seawater contains approximately 4,500 µg/L of boron; thus, interactions with marine sediments, connate fluids, or seawater also can be natural sources of boron to groundwater. Boron concentrations were positively correlated to salinity factors (chloride, sulfate, and TDS, table 11). This indicates that interaction with marine sediments could be a source of boron. Although boron concentrations were not significantly higher in marine sediments than in non-marine sediments and rocks in the study unit (table 10), the generally low concentrations of boron were higher in samples from sites in the Salinas Valley study area just south of King City (fig. 15B), where the alluvium could be influenced by marine deposits in the adjacent Highland areas.

Boron generally is associated with thermal springs and volcanic activity (Hem, 1985). In the MS-SA study-unit, boron concentrations were not correlated to distance from geothermal sites (table 9); however, boron concentrations were positively correlated to water temperature (fig. 16; Spearman's rho = 0.368, $p < 0.001$). In fact, the sample with a high boron concentration (H14) had a water temperature over 30 degrees Celsius (°C), indicating the influence of a thermal spring, even though a thermal spring at the site was not in the compilation referenced by National Oceanic and Atmospheric Administration (Berry and others, 1980) or the USGS Mineral Resources Data System (<http://tin.er.usgs.gov/mrds/>).

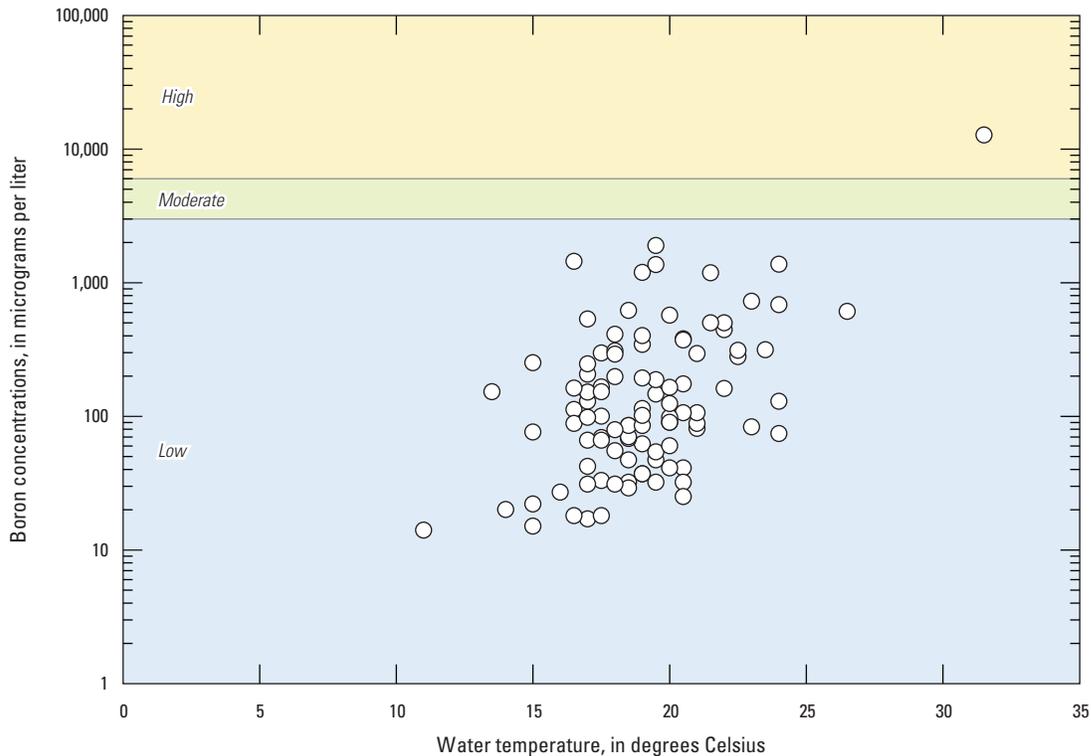


Figure 16. Boron concentrations in relation to the water temperature in samples for grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Boron, unlike arsenic, was negatively correlated to DO concentrations (table 9). Boron also was negatively correlated with the aridity index (table 9). Boron concentrations were higher in areas categorized as semiarid (aridity index 0.2–0.5) than in areas categorized as subhumid (aridity index 0.5–0.65) or humid (aridity index greater than 0.65). This correlation is more likely a result of covariance of the aridity index with dissolved oxygen or some other geologic explanatory factor not discussed in this report than of a causative relationship.

Understanding Assessment for Manganese and Iron

Manganese was detected at high relative concentrations in 6.4 percent of the MS-SA study unit and at moderate relative concentrations in 1.7 percent (table 8A). Iron was detected at high relative concentrations in 13 percent of the MS-SA study unit and at moderate relative concentrations in 1.2 percent. The HBSL for manganese is 300 µg/L, and the SMCL-CA for iron is 300 µg/L. Although iron has an aesthetic benchmark, it is included in this discussion because of its geochemical affiliation with manganese. High relative concentrations of these constituents were detected more frequently and at higher concentrations in the Santa Cruz study area (figs. 11A, B, 15C, D; tables 8B, 10). Sources of manganese and iron in the study unit are likely to be natural.

Natural sources of manganese and iron to groundwater include the dissolution of igneous and metamorphic rocks and the dissolution of various secondary minerals like oxyhydroxides (Hem, 1985). Rocks that contain large amounts of manganese and iron are composed primarily of the mafic minerals olivine, pyroxene, and amphibole. Potential anthropogenic sources of manganese and iron to groundwater include effluents associated with the mining industry (Reimann and de Caritat, 1998); however, there has been relatively little mining in the MS-SA study unit compared to other areas of the State (<http://tin.er.usgs.gov/mrds/>).

Redox conditions strongly influence the concentrations of manganese and iron in groundwater. In sediments, amorphous phases and oxyhydroxide minerals of manganese and iron are common as coatings on particle surfaces (Sparks, 1995). These amorphous phases and oxyhydroxide minerals are stable in oxygenated systems. Under anoxic conditions, the process of reductive dissolution destabilizes these minerals, which can lead to the contribution of dissolved manganese and iron to aquifer systems (Sparks, 1995).

In the MS-SA study unit, manganese and iron both showed significant negative correlation to DO content (table 9; fig. 17), and concentrations were higher in anoxic redox conditions (table 10). These results indicate that the reductive dissolution of amorphous phases and oxyhydroxide minerals are important mechanisms contributing dissolved manganese and iron to groundwater. The high manganese and iron concentrations in the Santa Cruz study area were likely related to the low DO content of the groundwater sampled in this area. Manganese concentrations were higher in pre-modern groundwater than in modern groundwater, and manganese

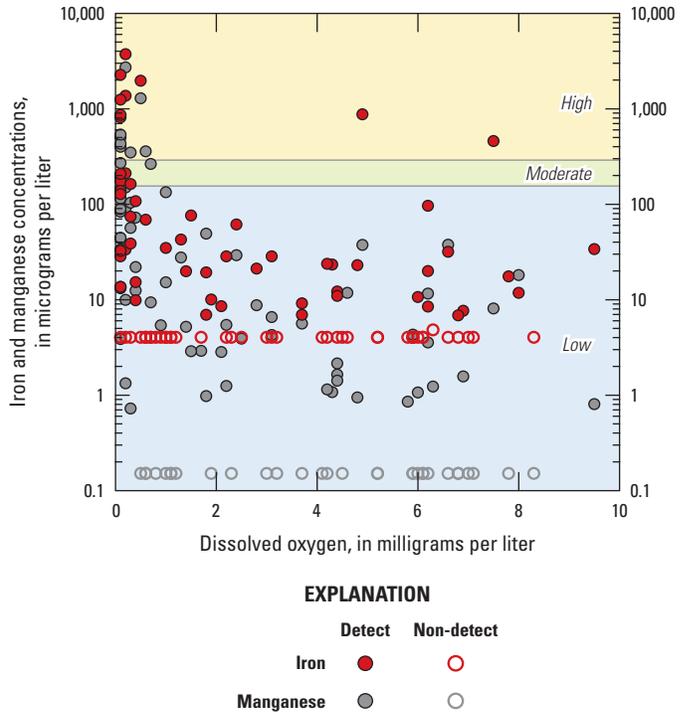


Figure 17. Relations of manganese and iron to dissolved oxygen in samples collected from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

and iron concentrations were higher in samples with low percentages of modern carbon-14 (tables 9, 10), which indicates reductive dissolution over a long time contributed to the elevated manganese concentrations in older groundwater.

Manganese and iron concentrations were higher in areas of marine rocks rather than areas of alluvium or non-marine rocks (table 10) and were lower in areas of agricultural land use (table 9). Both these factors were correlated to redox conditions and DO concentrations (tables 5, 6), so the correlations to manganese and iron might not be causative, but reflect covariance among the factors instead. Manganese and iron were not correlated with well depth, most likely because well depth was not correlated to redox conditions or DO.

Understanding Assessment for Molybdenum

Molybdenum was detected at high relative concentrations in 14 percent and at moderate relative concentrations in 11 percent of the MS-SA study unit (table 8A). The HBSL for molybdenum is 40 µg/L, and it is included on the EPA's "Contaminant Candidate List 3" (U.S. Environmental Protection Agency, 2009a). The high and moderate relative concentrations primarily were in samples from the Highlands study area (table 8B; figs. 11A, 15E). High and moderate relative concentrations also were detected in samples from the Salinas Valley study area. The sources of elevated molybdenum in the study unit are likely to be natural.

High levels of molybdenum in animals (including humans) can interfere with uptake of copper. Molybdenum is a metallic trace element found in ore deposits associated with porphyry granite or quartz monzonite plutons; the primary ore mineral is the sulfide mineral molybdenite (MoS_2 ; for example, Misra, 2000). Molybdenum can readily accumulate in vegetation and is an essential trace nutrient for nitrogen-fixing plants and can even be a limiting nutrient in molybdenum-poor environments (Goldman, 1960; Evans and Barabash, 2010).

Molybdenum is more soluble in oxic conditions than in anoxic conditions (Drever, 1997; Reimann and de Caritat, 1998). The major soluble species of molybdenum at pH values greater than 5 is the molybdenum (VI) oxyanion MoO_4^{-2} (Evans and Barabash, 2010). In the MS-SA study-unit samples, unlike other GAMA study units (Fram and Belitz, 2012; Fram and Shelton, 2015; Fram, 2016), molybdenum concentrations were not significantly greater in oxic samples than in anoxic or mixed samples (table 10). Molybdenum was not correlated to DO concentrations (table 9) because of the parabolic relationship of molybdenum and DO concentrations in samples from the MS-SA study unit (fig. 18A). Like other metal oxyanions, MoO_4^{-2} can sorb to iron oxyhydroxides and clays, and the sorption is increasingly inhibited as pH values increase (Evans and Barabash, 2010). In the study unit overall, molybdenum was not correlated to pH (table 9); however, this correlation was observed under oxic redox conditions. Among the 33 samples with anoxic or mixed redox conditions, molybdenum was not correlated with pH (Spearman's rho = -0.251, $p=0.158$), whereas among the 67 samples with oxic conditions, molybdenum showed a positive correlation with pH (fig. 18B; Spearman's rho = 0.407, $p<0.001$).

Molybdenum concentrations did not differ significantly between groundwater-age classes; however, molybdenum concentrations were negatively correlated to the percentage of modern carbon-14, indicating higher concentrations in older groundwater (table 9). Molybdenum concentrations, like arsenic and boron, were negatively correlated with the aridity index, indicating that concentrations were generally higher in samples from semiarid climates (aridity index 0.2–0.5) than from subhumid (aridity index 0.5–0.65) or humid (aridity index greater than 0.65) climates. This correlation was most likely a result of correlation of the aridity index with geology, or some other explanatory factor not discussed in this report rather than a causative relationship.

Potential anthropogenic sources to groundwater include the manufacture and use of molybdenum-steel alloys, dry lubricants, and other industrial products and the surface application of biosolids (Evans and Barabash, 2010). The higher concentrations of molybdenum in older groundwater, as indicated by its negative correlation to the percentage of modern carbon-14 and percentage of urban land use, indicate that anthropogenic sources of molybdenum associated with urban land use were not an important source of molybdenum.

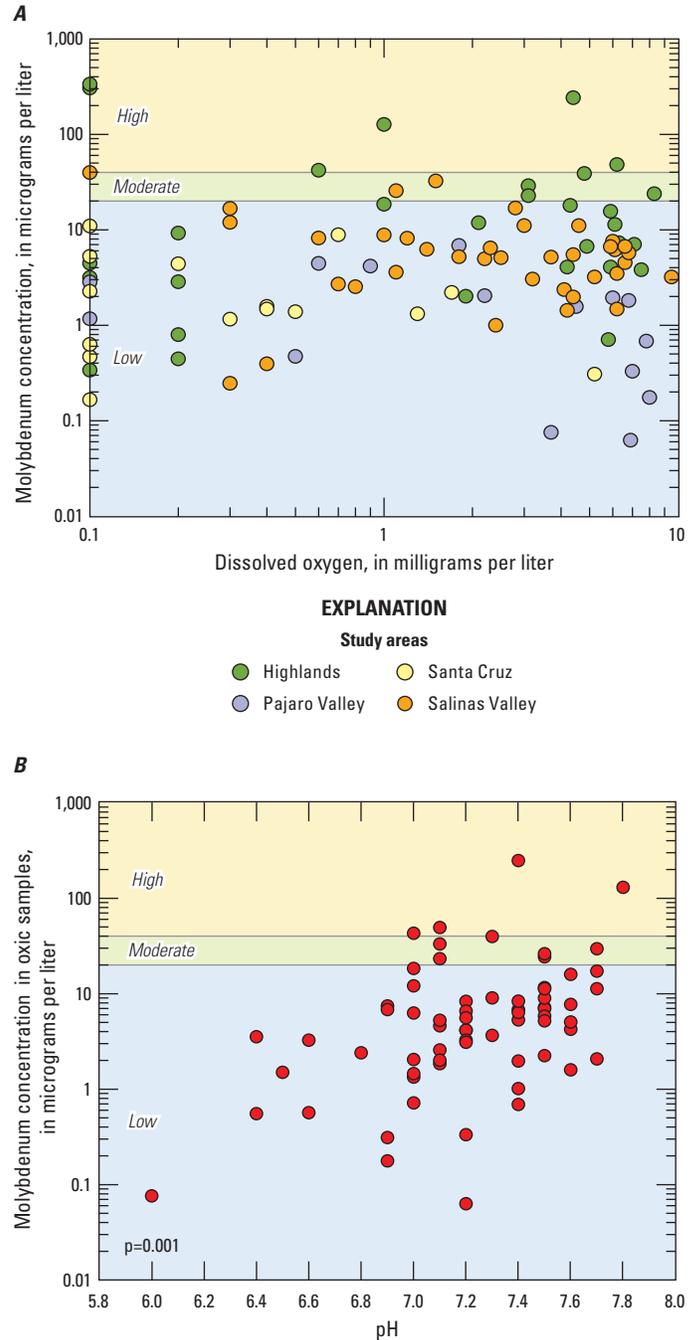


Figure 18. Relation of molybdenum concentrations in samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013, to *A*, dissolved oxygen, and *B*, pH under oxic redox conditions for grid sites.

Understanding Assessment for Selenium

Selenium was detected at high relative concentrations in 3.2 percent of the MS-SA study unit (table 8A); the MCL-US for selenium is 50 µg/L. High relative concentrations were detected in samples from the Salinas Valley and Highlands study areas (table 8B; figs. 11A, 15F). Moderate relative concentrations were detected only in tap sites in the Salinas Valley study area (fig. 15F). Natural and anthropogenic sources are both likely to have contributed to elevated selenium concentrations in the study unit.

Selenium is an essential nutrient at low concentrations, but long-term exposure to concentrations above the MCL-US can cause damage to nervous and circulatory systems, hair and fingernail loss, and damage to kidney and liver tissue (U.S. Environmental Protection Agency, 1995). Selenium is found primarily in sedimentary rocks, particularly in shale, and to a much lesser extent in igneous rocks (Burau, 1985; Hem, 1985). In the western San Joaquin Valley, the source of selenium in these soils and sediments is likely Cretaceous marine shale that is found throughout the California Coast Ranges (Presser and others, 1990; Presser, 1994; Fram, 2016).

Selenium was not correlated to marine geology in the MS-SA; however, the surficial non-marine sediments (Qpc) in the Paso Robles area (fig. 4) were underlain by the marine Monterey Formation (Durham, 1974), which could be a source of selenium. Two of the three detections of high concentrations of selenium were in samples from the Paso Robles area (fig. 15F).

Selenium is used in agriculture as a component in pesticide formulations and as a nutritional feed additive for poultry and livestock. Selenium was significantly correlated to agricultural land use (table 9), and concentrations were higher in samples from areas of agricultural land than in urban or natural land (table 10; fig. 19). These correlations indicate that agricultural practices could be a source of selenium or could mobilize naturally present selenium, as was determined in the western San Joaquin Valley. High selenium concentrations observed in shallow groundwater in the western San Joaquin Valley have been attributed to the leaching by irrigation-return water of selenium naturally present in soils and sediments under oxic conditions (Presser and others, 1990; Dubrovsky and others, 1993; Fram, 2016). Selenium is most mobile in its most oxidized state (McNeal and Balistrieri, 1989). Selenium was positively correlated to DO concentrations (table 9; fig. 19), and concentrations were higher in oxic than anoxic groundwater (table 10). Selenium was positively correlated to nitrate (oxic conditions) and negatively correlated to manganese (reduced conditions; table 11); therefore, it is a reasonable assumption that the same process contributing selenium to shallow groundwater in the western San Joaquin Valley could also be contributing selenium to groundwater in the MS-SA study unit. Also, agricultural land use and oxic groundwater conditions were positively correlated (tables 5, 6).

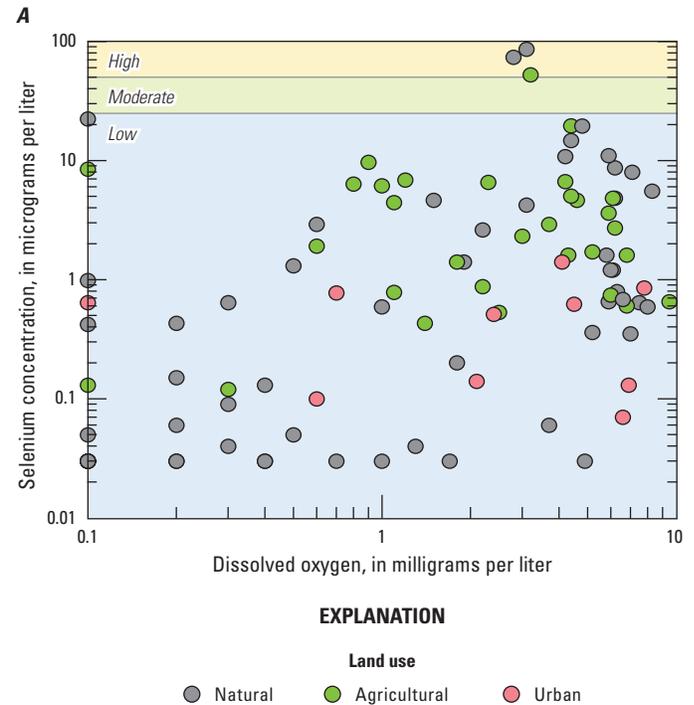


Figure 19. Relation of selenium to dissolved oxygen and land use for water samples from grid and tap sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Understanding Assessment for Strontium

Strontium was detected at high relative concentrations in 9.5 percent of the MS-SA study unit and at moderate relative concentrations in 3.1 percent (table 8A); the HAL-US for strontium is 4,000 µg/L. Relative concentrations of strontium were highest in samples from the Highlands study area and lowest in those from the Santa Cruz and Pajaro Valley study areas (tables 8B, 10). The high relative concentrations of strontium were detected mostly in samples collected in the southern parts of the Highlands and Salinas Valley study areas (fig. 15G). High relative concentrations of strontium in the Salinas Valley study area were mostly detected in samples collected near the border with the Highlands study area, rarely in the valley trough. Except for one sample collected at a site in the Pajaro Valley study area, moderate concentrations of strontium were only detected in samples collected in the Highlands and Salinas Valley study areas. Sources of strontium in the study unit are likely to be natural.

The consumption of drinking water with concentrations of strontium greater than the HAL-US over a lifetime could affect bone and tooth growth (Alfredo and others, 2014). The chemistry of strontium is similar to that of calcium (Hem, 1985). The most common natural sources of strontium to groundwater are weathering of silicate minerals, particularly feldspars; dissolution of carbonate and sulfate minerals; mixing with seawater (contains 7,750 µg/L strontium); and mixing with brines (McNutt, 2000; Faure and Mensing, 2004).

Strontium was correlated to sulfate, chloride, and bicarbonate (table 11); however, strontium concentrations were higher in groundwater where sulfate was the dominant anionic water type rather than chloride or bicarbonate (fig. 20). Also, like most of the trace elements discussed in this report, strontium concentrations were not significantly different among groundwater age classes, but were negatively correlated to the percentage of modern carbon-14 (table 9), indicating concentrations were higher in older groundwater.

In the United States during 2001, the primary use of strontium was for the manufacturing of ceramic and glass products (U.S. Department of Health and Human Services, 2004). Strontium was negatively correlated to the anthropogenic explanatory factors of the percentage of urban land use and density of septic tanks. Strontium relative concentrations also were higher in drier climates and older groundwater, based on the negative correlations to the aridity index and the percentage of modern carbon-14. These correlations indicated that elevated strontium concentrations were not likely to have anthropogenic sources.

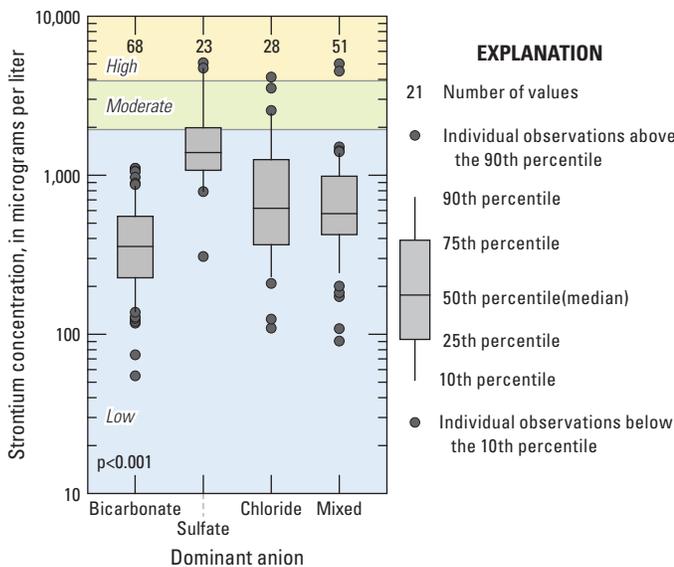


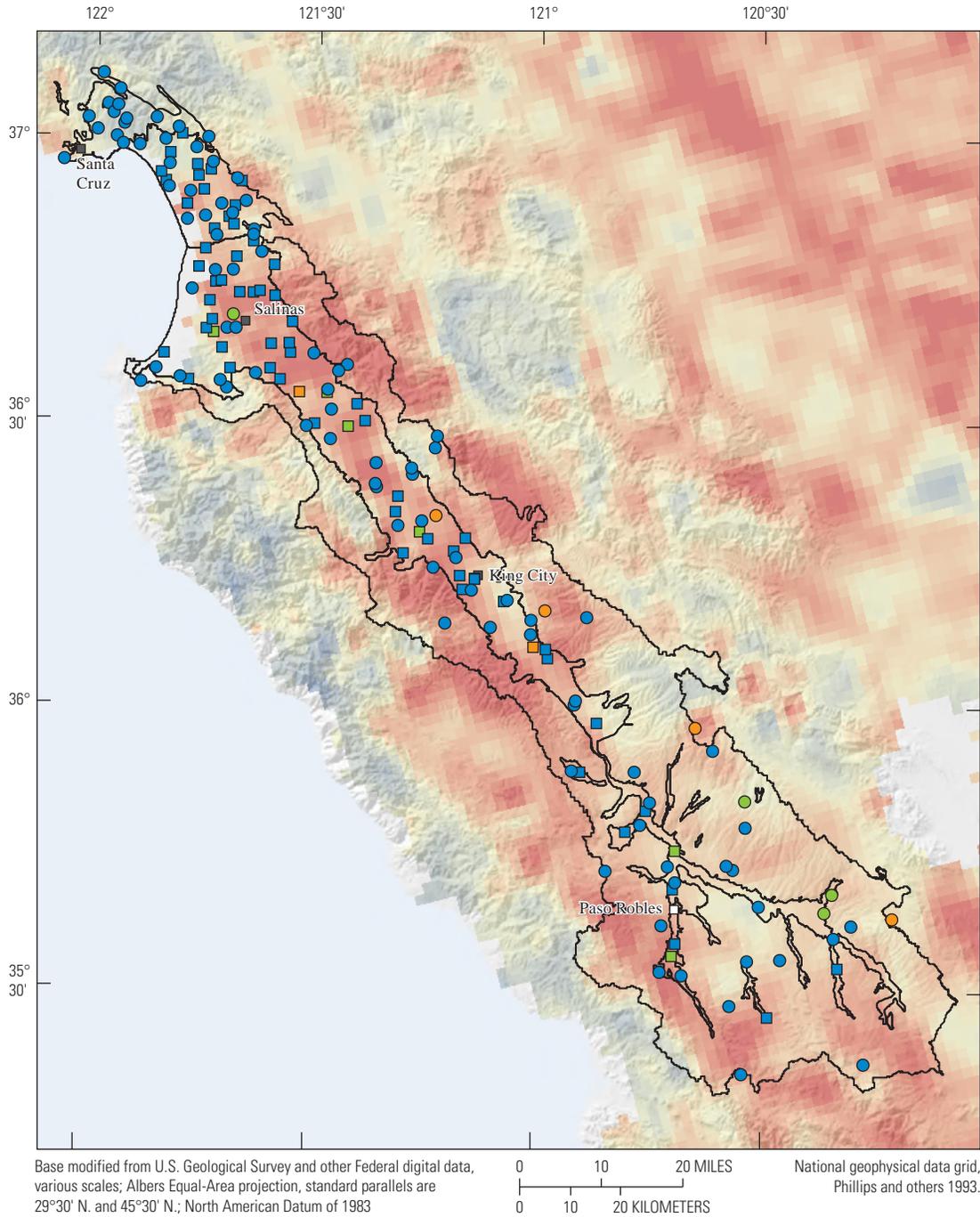
Figure 20. Strontium concentrations by the dominate anion water type in samples from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Uranium and Radioactive Constituents

Most of the radioactivity in groundwater comes from decay of uranium and thorium that is natural in the rocks or sediments that compose the aquifers. Radioactive decay of uranium and thorium isotopes produces long series of radioactive daughter products, including isotopes of radium, uranium, and radon. These elements have different chemical properties, and their solubility in groundwater varies with geochemical conditions, water chemistry, and aquifer mineralogy (for example, Hem, 1985). This study included data for uranium, radon-222, and gross alpha- and gross beta-particle activities, which are measures of the activities of all radioactive elements in the water sample that decay by alpha- or beta-particle emission, respectively. Gross alpha- and gross beta-particle activities were counted at 72 hours and at 30 days after sample collection. Gross alpha- and gross beta-particle activity in a groundwater sample can change with time after sample collection as a result of radioactive decay and ingrowth (activity can increase or decrease depending on sample composition and holding time; Arndt, 2010). Data from the 72-hour counts are used in this report. The method of analysis used in this study for gross alpha-particle activities includes uranium as part of the measurement. In this report, uranium activities were subtracted from the gross alpha activities, which results in adjusted gross alpha-particle activities. Adjusted gross alpha-particle activities are reported because that is the constituent used for the MCL-US.

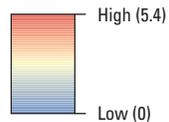
Radioactive constituents were present at high relative concentrations in 19 percent of the MS-SA study unit and at moderate relative concentrations in 20 percent (table 7A). Radioactive constituents were detected at high relative concentrations most frequently in the Highlands and Santa Cruz study areas (table 7B). Adjusted gross alpha activity (72-hour), gross beta activity (72-hour), and uranium activity were all detected at high relative concentrations (table 8A). Radon-222 was detected at moderate relative concentrations.

Gross alpha-particle activity was detected at high relative concentrations in samples from the Highlands and Santa Cruz study areas (table 8B; fig. 11A); the MCL-US is 15 picocuries per liter (pCi/L). Gross alpha-particle activity is used as a screening tool to determine whether other radioactive constituents must be analyzed. Gross beta-particle activity was detected at high concentrations only in samples from the Highlands study area; the MCL-CA is 50 pCi/L. Uranium was found at high relative concentrations in samples from the Highlands and Salinas Valley study areas (figs. 11A, 21); the MCL-US is 30 µg/L. Chronic exposure to uranium in drinking water at concentrations greater than the MCL-US can result in toxic effects to the kidneys or increased cancer risks (U.S. Environmental Protection Agency, 2000, 2009b).



EXPLANATION

Uranium, in milligrams of uranium per kilogram of sediment



Study area boundary

Concentration of uranium, in micrograms per liter

	Grid sites	Tap sites
Low or not detected (≤ 15)	●	■
Moderate ($>15-30$)	●	■
High (>30)	●	■

Figure 21. Concentrations of uranium in water samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Sources of uranium to groundwater include dissolution of uranium-bearing minerals, such as uraninite (UO₂), zircon, and titanite, and desorption of uranium from mineral surfaces in the presence of bicarbonate (Hem, 1985; Jurgens and others, 2010). Phillips and others (1993) showed that uranium concentrations are relatively high in the surficial geology of much of the Salinas Valley and Highlands study areas (fig. 21). Uranium concentrations were not correlated with pH, groundwater age, or well depth (tables 9, 10), but were correlated to other explanatory factors. The positive correlations of uranium to bicarbonate (table 11), DO, and the percentage of agricultural land use (table 9) indicate that uranium concentrations in the MS-SA study unit could be elevated as a result of enhanced desorption from sediments and mobilization of uranium by irrigation recharge having high bicarbonate concentrations (fig. 22). These results were similar to those from a local-scale investigation in the San Joaquin Valley near the city of Modesto (Jurgens and others, 2008), a regional investigation in the eastern San Joaquin

Valley (Jurgens and others, 2010), and other GAMA-PBP study units (Landon and others, 2010; Burton and others, 2012). The high concentrations of uranium in samples from the Highlands study area most likely result from the dissolution of uranium-bearing minerals.

Nitrate and Other Nutrients

Nutrients, as a class, were detected at high relative concentrations in 16 percent of the MS-SA study unit and at moderate relative concentrations in 19 percent (table 7A). Nutrients were detected at high relative concentrations in samples from the Salinas Valley, Pajaro Valley, and Highlands study areas (table 7B). Nitrate plus nitrite (referred to simply as nitrate, because nitrite concentrations were negligible compared to nitrate) and ammonia were the nutrients detected at high relative concentrations (table 8A; fig. 11A). The most common forms of dissolved nitrogen in groundwater are nitrate, nitrite, ammonium and ammonia, and dissolved nitrogen gas, and which form is dominant depends on redox conditions (for example, McMahon and Chapelle, 2007). In this study unit, nitrate concentrations were positively correlated to DO concentrations (table 9) and were higher in oxic groundwater than anoxic or mixed (table 10; fig. 23).

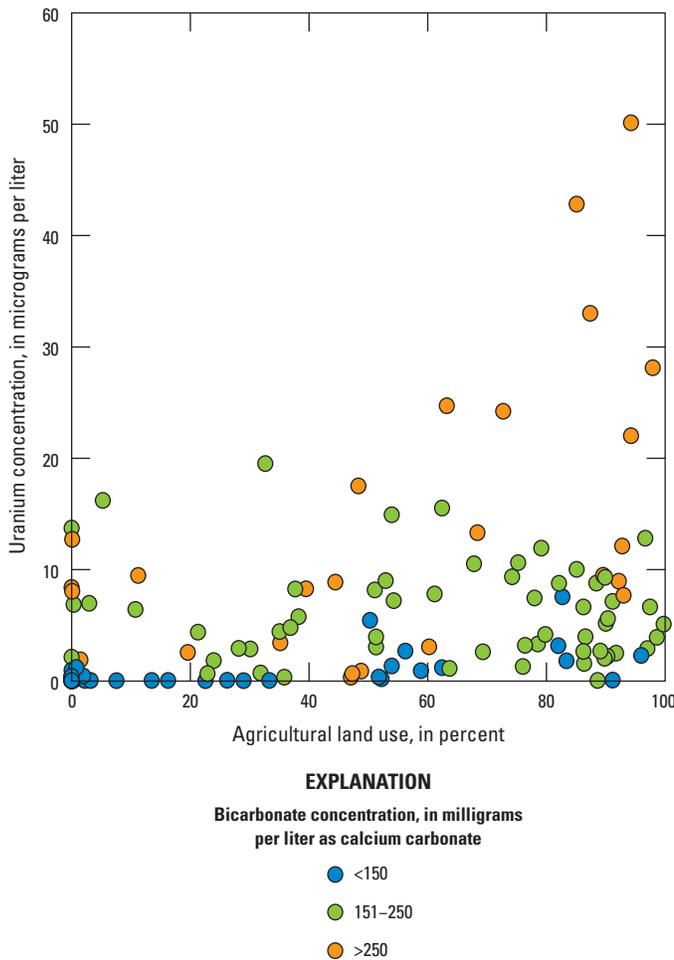


Figure 22. Uranium concentrations in relation to agricultural land use and bicarbonate concentrations for water samples from grid and tap sites in the Santa Cruz, Pajaro Valley, and Salinas Valley study areas of the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

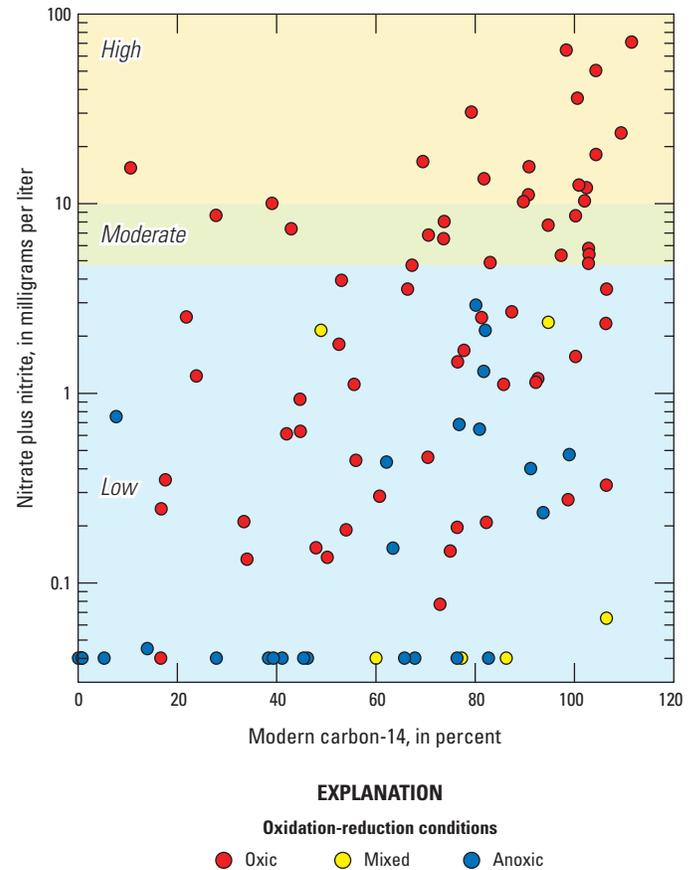


Figure 23. Nitrate concentrations in relation to the percentage of modern carbon-14 and oxidation-reduction conditions in water samples from grid sites, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Nitrate was detected at high relative concentrations in 14 percent of the MS-SA study unit (table 8A); the MCL for nitrate is 10 mg/L as nitrogen (N). Nitrate was detected at high relative concentrations in samples from the Salinas Valley, Pajaro Valley, and Highlands study areas (table 8B; fig. 24), but was not detected or only detected at low concentrations in samples from the Santa Cruz study area. The greatest proportion of high relative concentrations were in the Salinas Valley study area (table 8B; fig. 24). Anthropogenic sources contributed to elevated concentrations of nitrate in the study unit.

Nitrate and other nutrients in groundwater have natural and anthropogenic sources (Dubrovsky and others, 2010). Certain bacteria and algae naturally convert nitrogen gas from the atmosphere into nitrate, which is an important nutrient for plants. Other natural sources are atmospheric deposition, animal waste, and dissolution of organic material in soils. Anthropogenic sources of nitrate include application as a fertilizer in agriculture and landscaping and livestock, which, in concentrated numbers, produce nitrogenous waste that can leach into groundwater. Other anthropogenic sources include septic system discharge, leakage from municipal sewage lines, and atmospheric deposition of nitrogen oxides from the combustion of fossil fuels (Hem, 1985). High concentrations of nitrate can cause “blue baby” syndrome (U.S. Environmental Protection Agency, 2009b).

Nitrate concentrations were positively correlated to the percentage of modern carbon-14 (table 9; fig. 23) and were significantly higher in modern groundwater than in pre-modern or mixed (table 10). Nitrate concentrations were positively correlated to agricultural land use, indicating that irrigation-return water could be leaching nitrogen fertilizer applied to crops or animal wastes into groundwater in the MS-SA study unit. This hypothesis is supported by the results of a study by Harter and others (2012), which concluded that agricultural fertilizers were a major source of nitrate to groundwater in the Salinas Valley. Nitrate is highly soluble, and agriculture has been in the study unit for decades; nitrate from agricultural practices could have had time to percolate throughout the shallow aquifer. Nitrate was not correlated to well depth (table 9), however, unlike in other studies (Landon and others, 2010; Burton and others, 2012; Shelton and others, 2013), partly because well depth was not correlated to redox conditions or DO concentrations in this study unit.

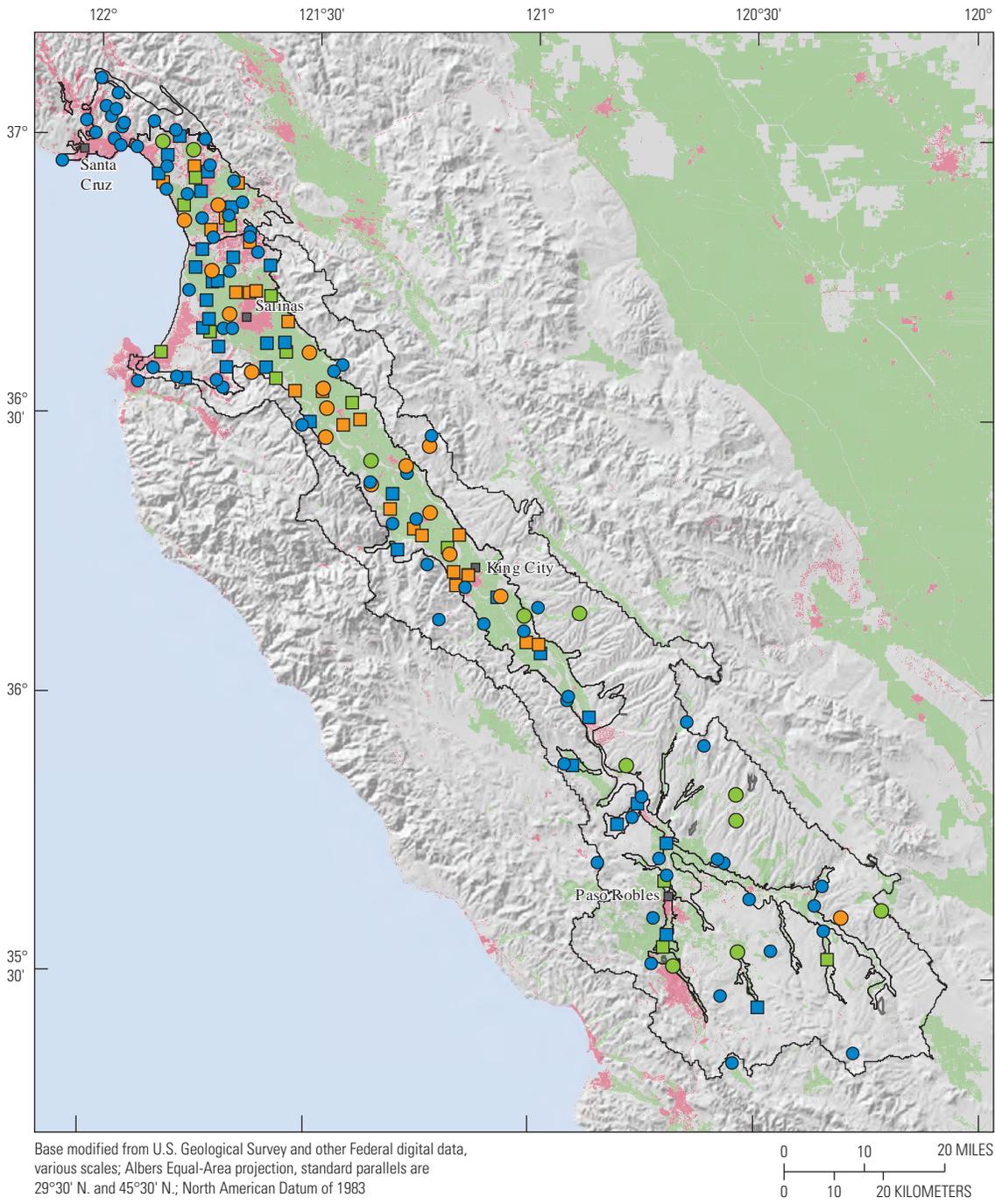
Septic systems also can introduce nitrogenous waste into groundwater. Nitrate concentrations were negatively correlated to the density of septic systems (table 9), indicating that septic systems were not a significant source of elevated nitrate concentrations. This lack of correlation could reflect a lower density of septic systems in agricultural areas (table 6) or indicate nitrogen fertilizer was the primary source of nitrate in samples from the MS-SA study unit.

Organic and Special-Interest Constituents

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

In the MS-SA study unit, 21 of the 148 organic constituents analyzed were detected, 19 of which had health-based benchmarks (table 4). Organic constituents, as a class, were not detected at high relative concentrations in the MS-SA study unit, but were detected at moderate relative concentrations in 0.7 percent of the shallow aquifer (table 7A). Organic constituents were only detected at moderate relative concentrations in the Salinas Valley study area, with aquifer proportions of 2.5 percent (table 7B). The fumigant 1,2-dichloropropane (1,2-DCP) was detected at moderate relative concentrations (fig. 25; table 8A). The trihalomethane chloroform and the herbicide simazine were detected at low relative concentrations in more than 10 percent of the MS-SA study-unit grid sites sampled (figs. 25, 26).

The number of VOCs detected at a site ranged from no detections to five compounds. Most of the sites with more than one VOC detected in samples were in the Pajaro Valley and northern part of the Salinas Valley study areas (fig. 27A). The number of VOC detections per site was correlated to the density of septic tanks (table 9). This could reflect a causative relationship or the correlation of septic tanks with urban land use (tables 5, 6). The number of VOC detections was not correlated to any other explanatory factors, including land use (tables 9, 10).



EXPLANATION

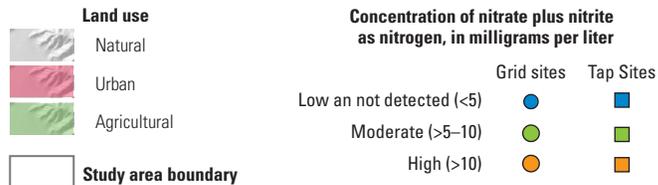


Figure 24. Concentrations of nitrate plus nitrite as nitrogen in samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

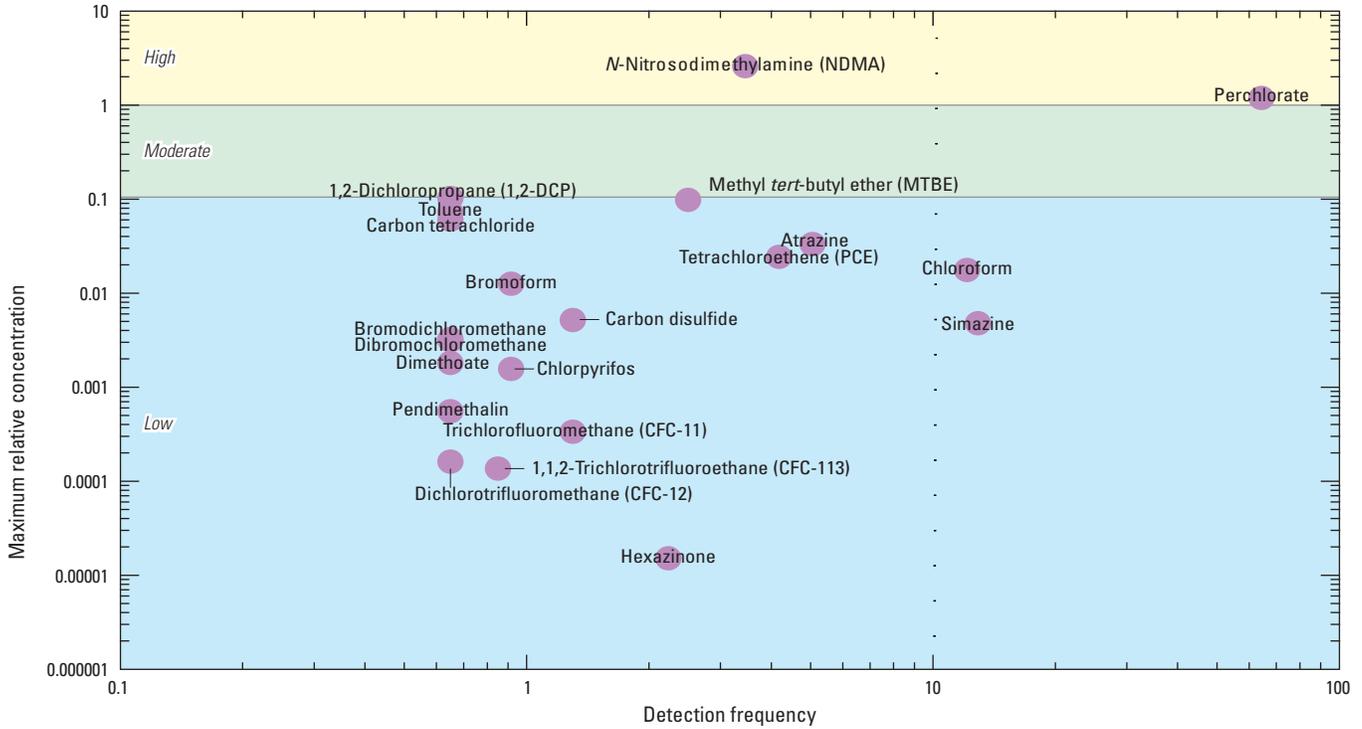


Figure 25. Detection frequency and maximum relative concentration of organic and special-interest constituents detected in water samples from U.S. Geological Survey grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

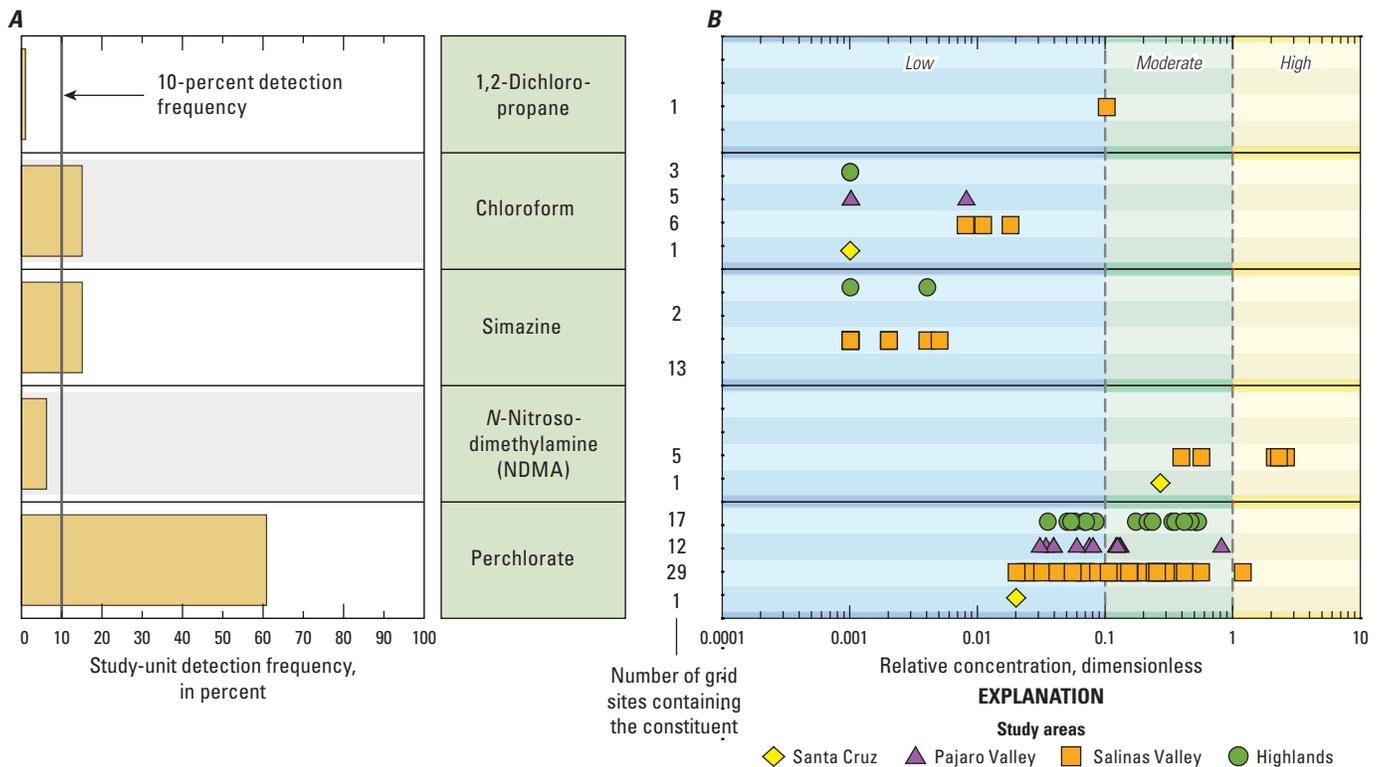


Figure 26. Results for selected organic and special-interest constituents in water samples from U.S. Geological Survey grid sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: *A*, overall detection frequency, and *B*, relative concentrations by study area.

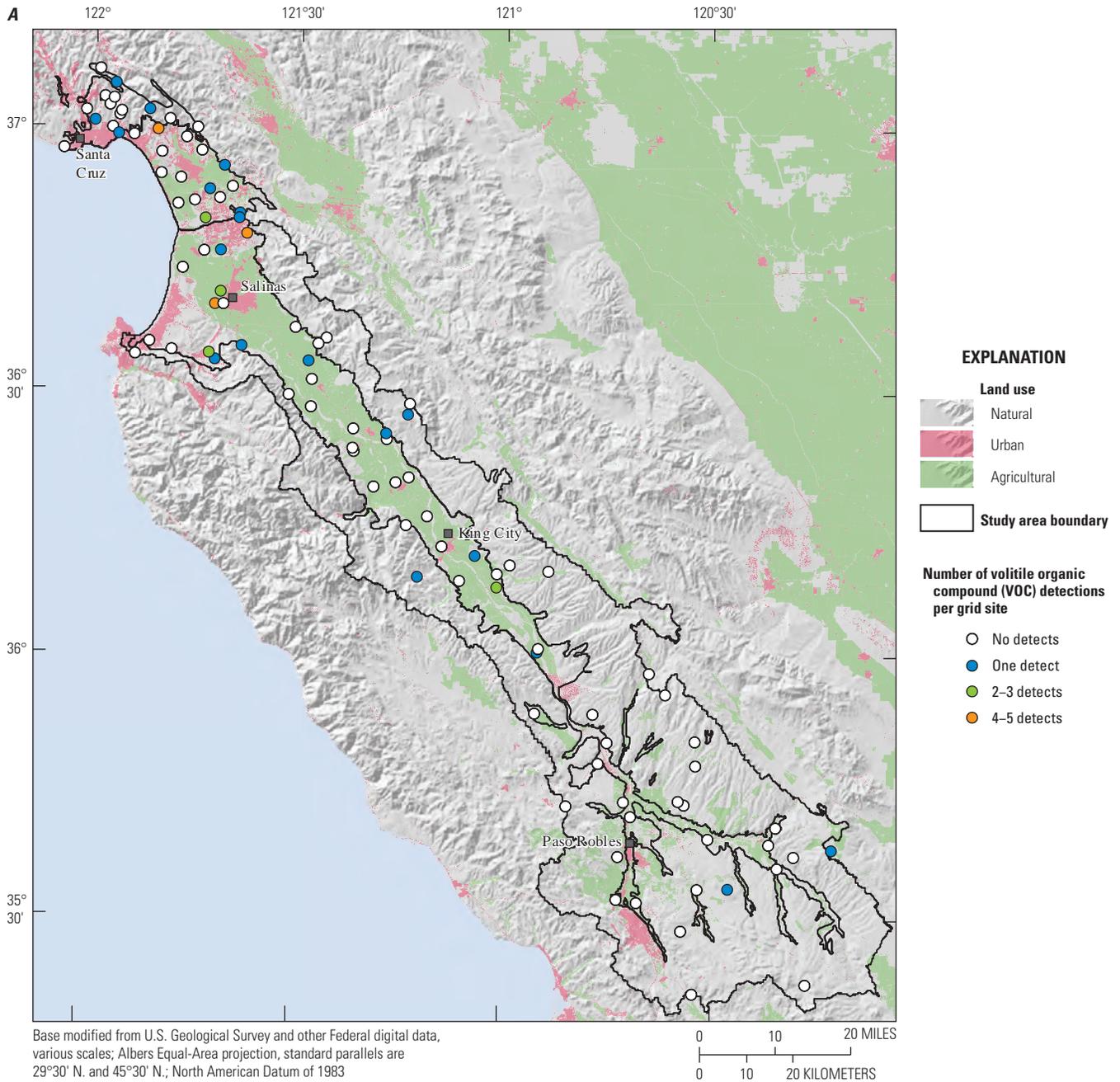


Figure 27. Distribution of sites with organic constituents detected in water samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013: *A*, volatile organic compounds (VOC) detected per site; *B*, pesticides detected per site; *C*, concentrations of the trihalomethane chloroform; *D*, concentrations of the herbicide simazine; *E*, concentrations of the special-interest constituent *N*-nitrosodimethylamine (NDMA); and *F*, concentrations of the special-interest constituent perchlorate.

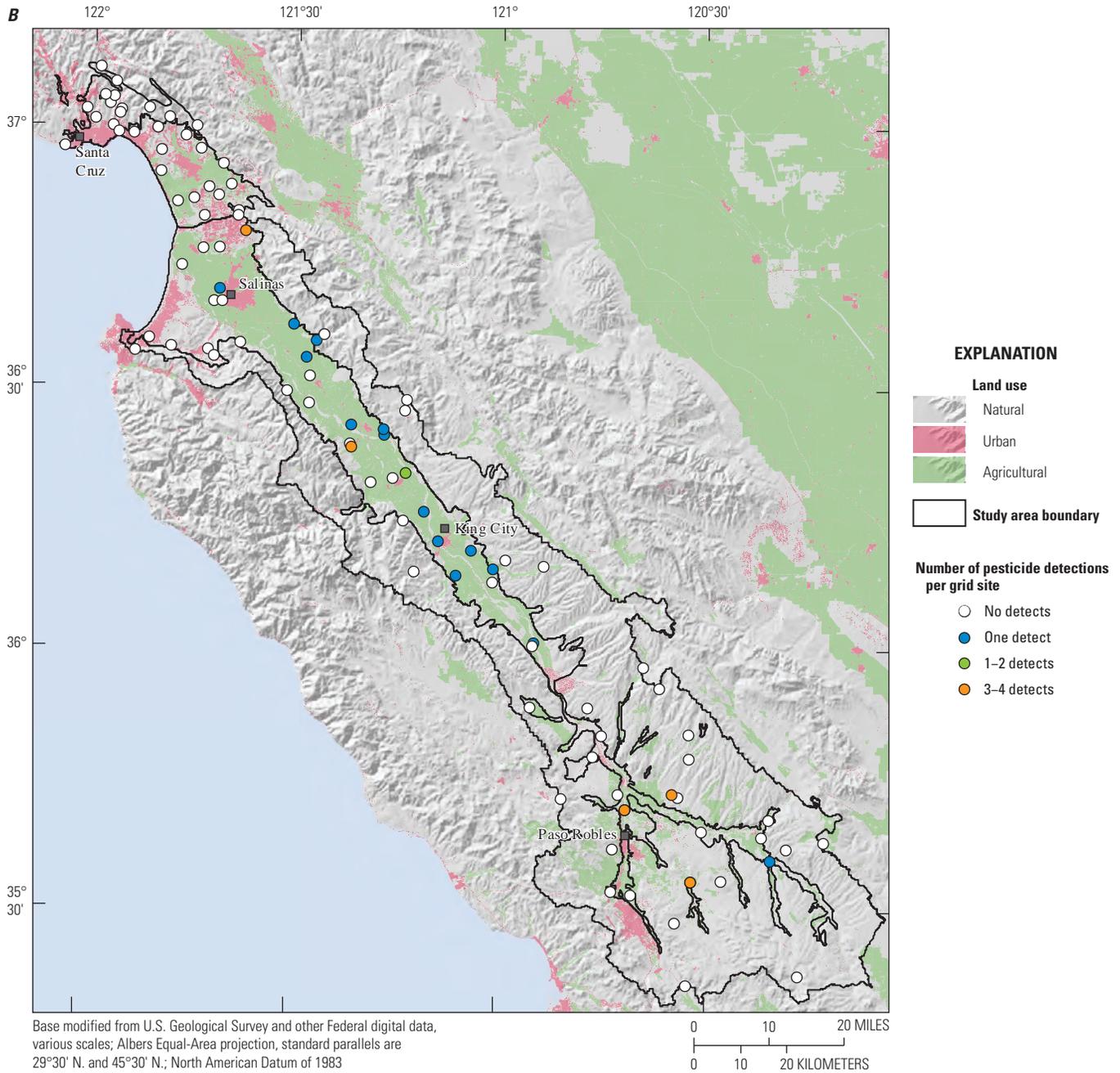


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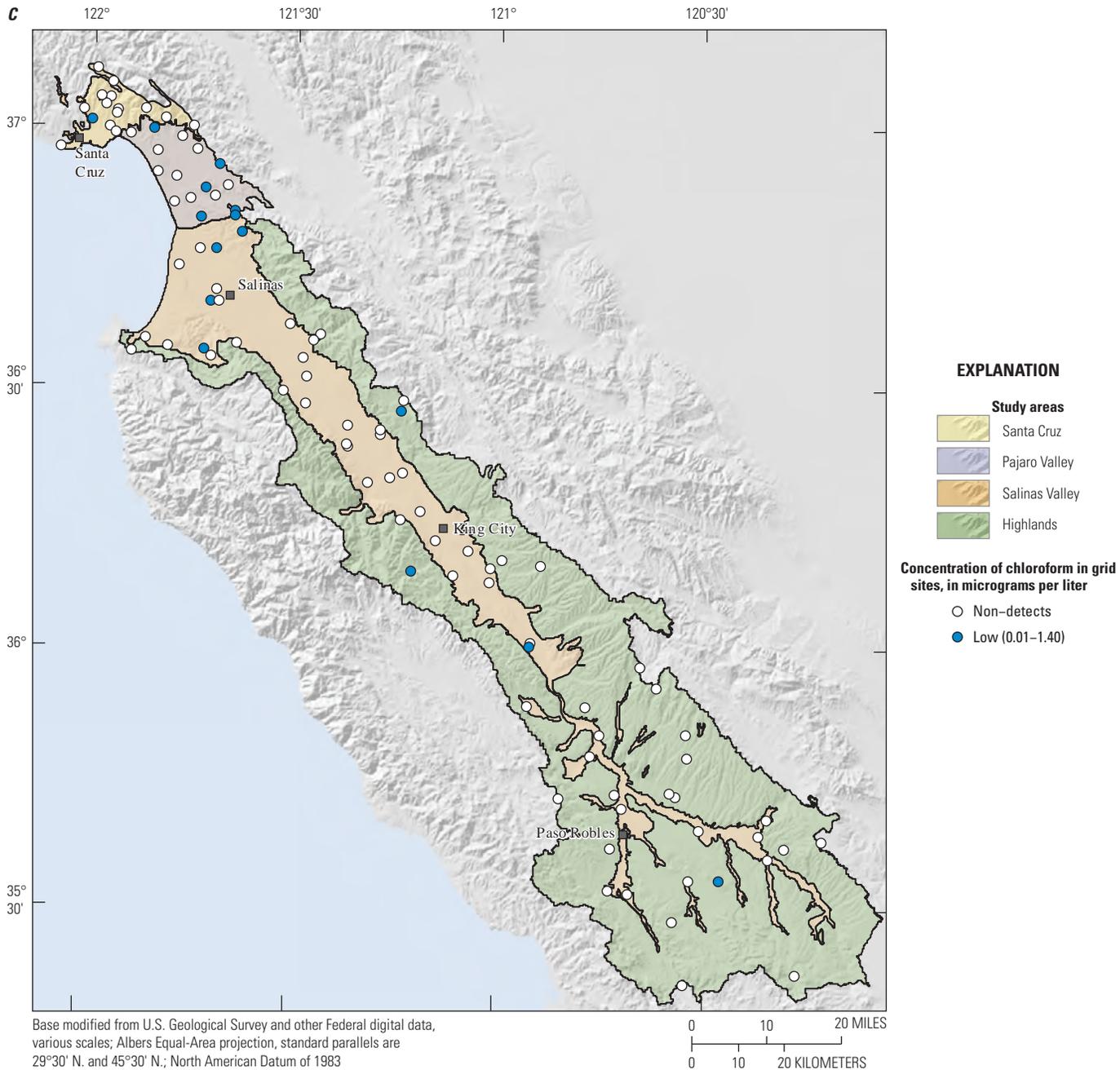


Figure 27. —Continued

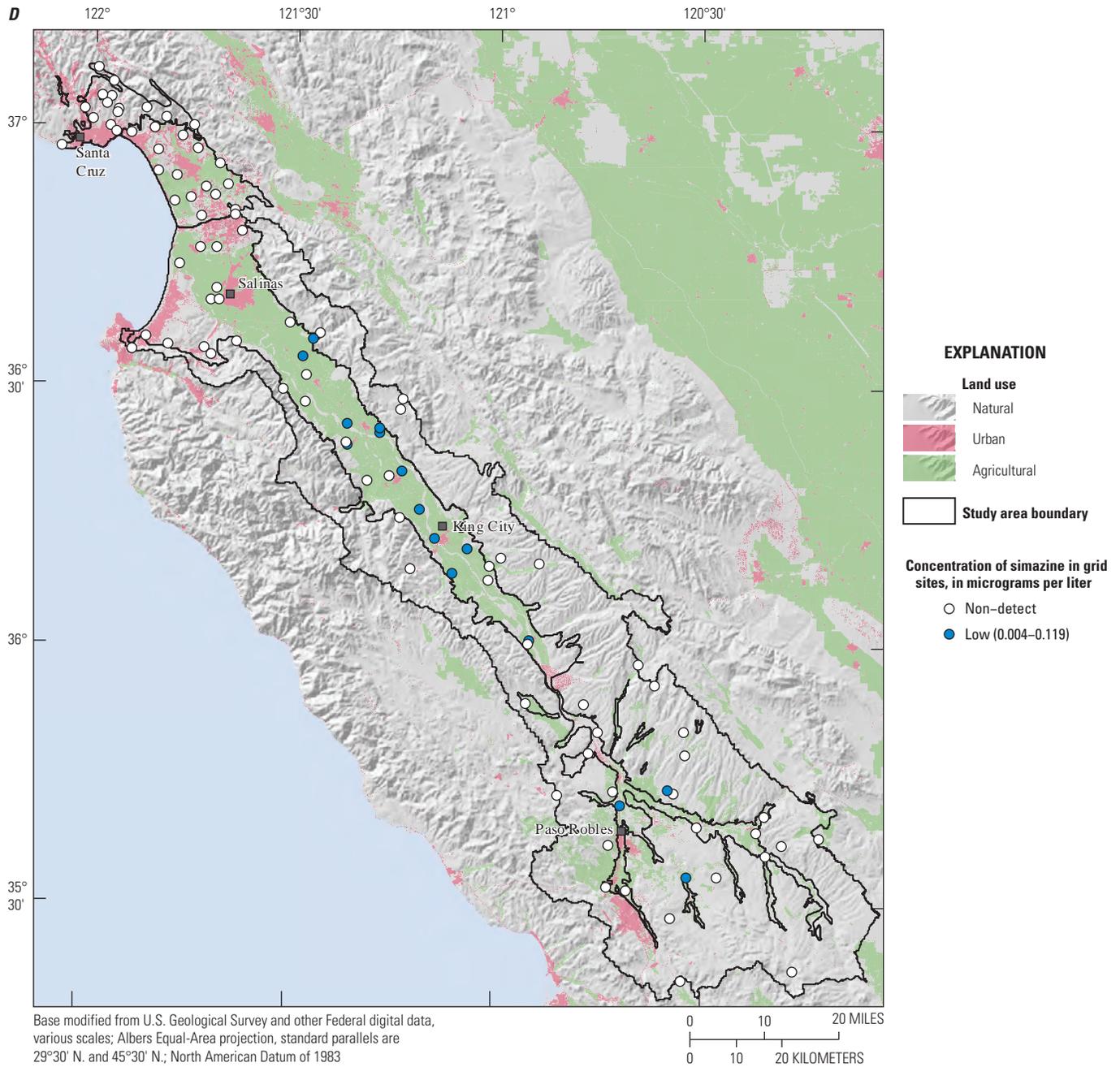


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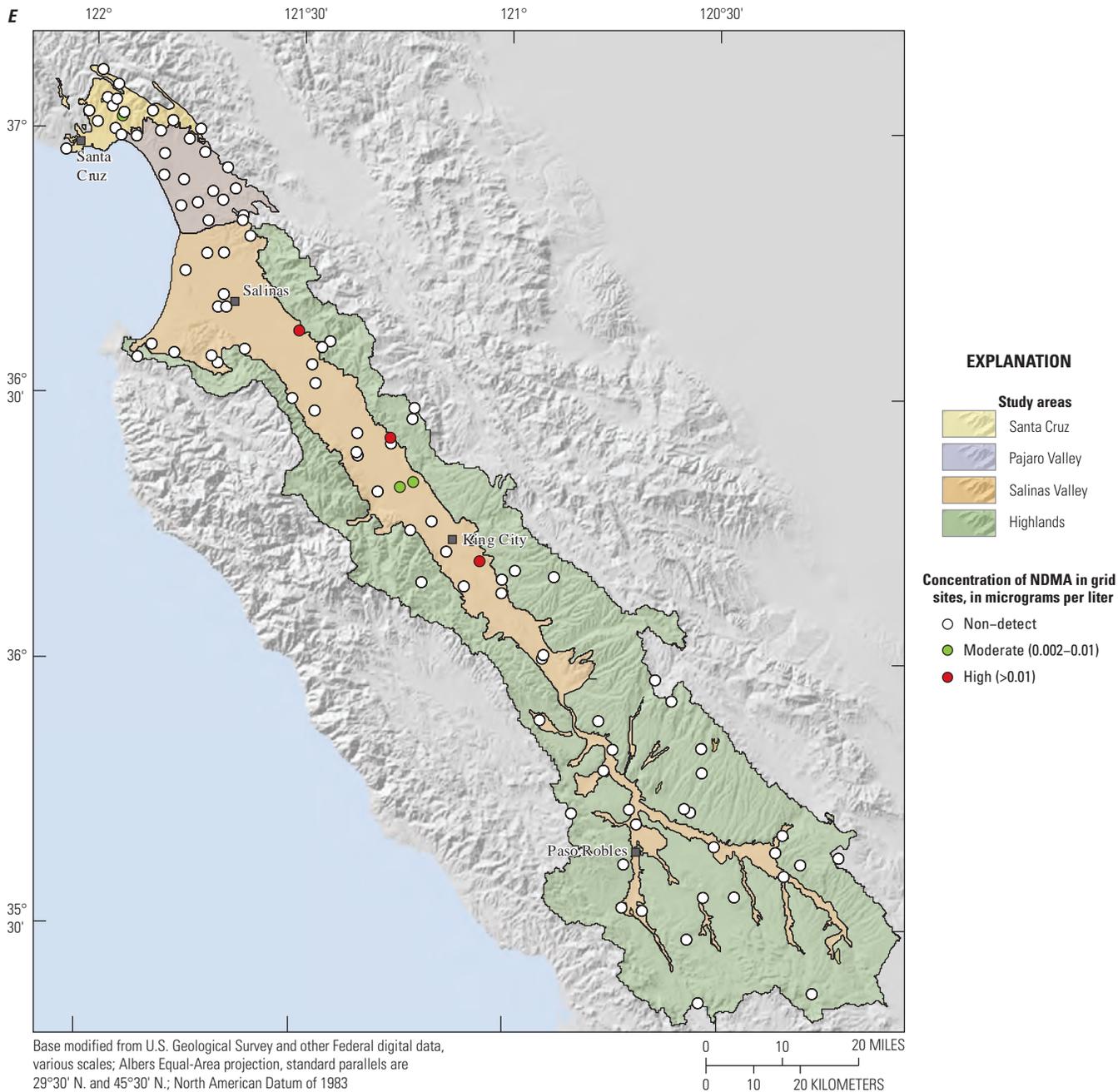


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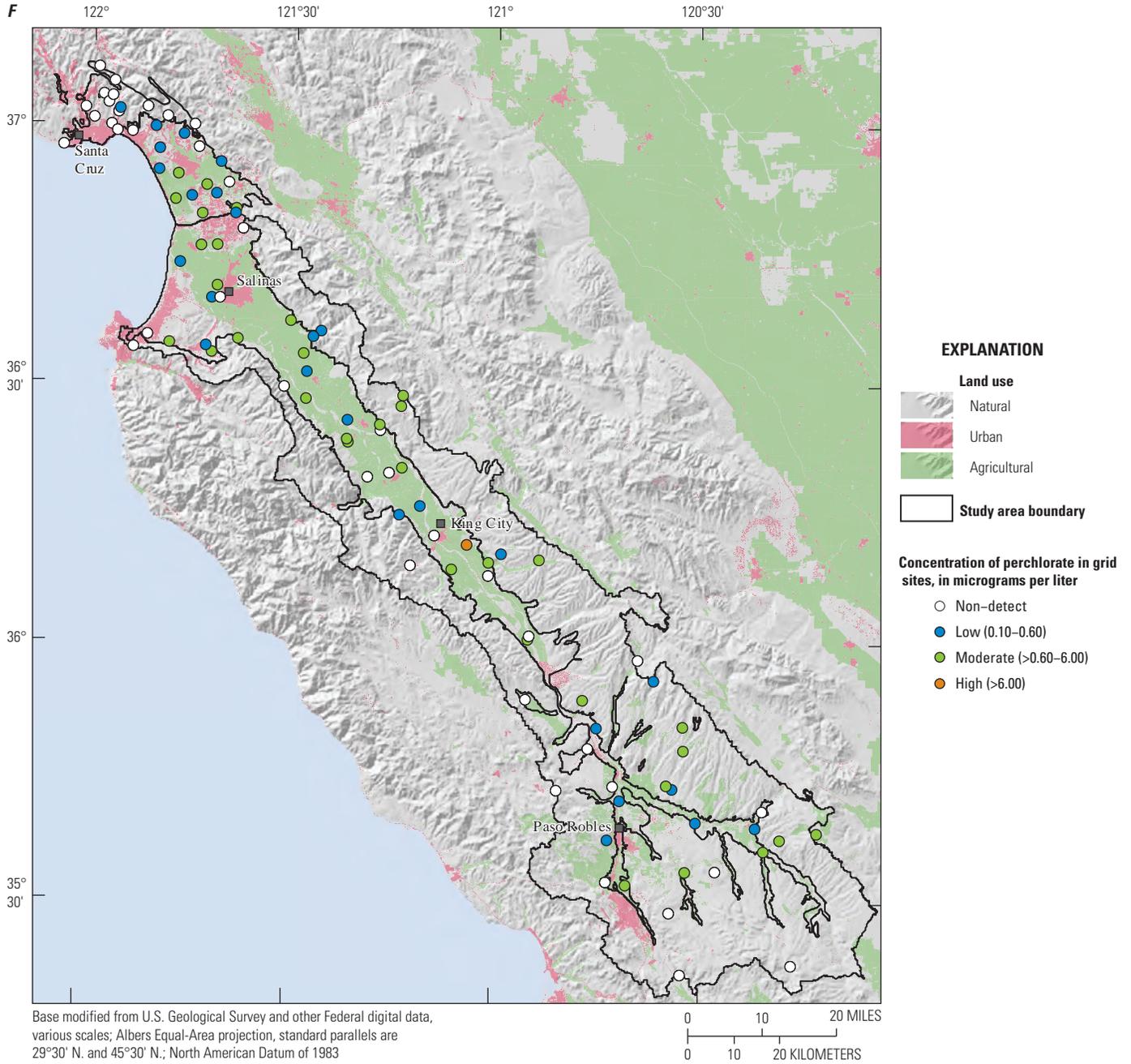


Figure 27. —Continued

Understanding Assessment for Trihalomethanes

Water used for drinking water and other household uses in domestic and public-supply systems can be disinfected with chlorine solutions (for example, bleach). In addition to disinfecting the water, the chlorine compounds react with organic matter to produce trihalomethanes (THMs) and other chlorinated or brominated disinfection byproducts (for example, Ivahnenko and Barbash, 2004). The THMs can then enter groundwater by infiltration of chlorinated water from septic systems or landscape irrigation. In addition, shock chlorination (often carried out by pouring bleach down a well) is a recommended procedure for treating bacterial contamination and odor problems in domestic drinking-water supply wells (U.S. Centers for Disease Control and Prevention and U.S. Department of Housing and Urban Development, 2006), which could cause a reservoir of chlorinated water to form in the well bore and surrounding aquifer material. The chlorine would decay rapidly, but any THMs formed by reaction between the chlorine and organic matter could remain in the aquifer to be pumped by the well. The MCL-US for total trihalomethanes, 80 µg/L, applies to the sum of the concentrations of the four THMs: chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Chloroform was the most frequently detected VOC in groundwater across the United States (Zogorski and others, 2006).

Only low relative concentrations of THMs were detected in 12 percent of the MS-SA study unit. The highest aquifer-scale proportion for THMs in the shallow aquifer, 30 percent, was in the Pajaro Valley study area, followed by the Salinas Valley study area at 15 percent. Chloroform, the primary THM detected, was detected in 15 percent of the grid sites sampled in the study unit (figs. 25, 26). Chloroform, like the number of VOC detections per site, was positively correlated to the density of septic tanks, but was not significantly correlated to any land-use type or any other potential explanatory factors evaluated in this report (tables 9, 10).

Understanding Assessment for Pesticides

Pesticides include insecticides, fungicides, fumigants, and herbicides. Pesticides, as a class, were detected at moderate relative concentrations in 0.7 percent (table 7A) and at low relative concentrations in 18 percent of the MS-SA study unit. The highest aquifer-scale proportion for pesticides (the fumigant 1,2-dichloropropane) at moderate relative concentrations in the shallow aquifer was 2.5 percent in the Salinas Valley study area (table 7B).

The number of pesticides detected in a sample from a site ranged from no detections to four (fig. 27B). Sites with

detections generally were in the Salinas Valley study area (fig. 27B; table 10). Unlike VOCs, the number of pesticides detected per site was positively correlated to the percentage of agricultural land use and negatively correlated to natural land use (table 9). The number of pesticide detections also was positively correlated with the percentage of modern carbon-14 (table 9), and there were more detections in modern groundwater than in pre-modern groundwater (table 10), indicating the number of pesticides detected was higher in sites with younger groundwater. The number of pesticide detections per site was inversely correlated to the density of septic tanks (table 9). This relationship most likely reflects the low density of septic tanks in agricultural areas.

The herbicide simazine was the most frequently detected pesticide in grid samples (figs. 25, 26), but was detected only at low relative concentrations. Simazine was detected in 15 percent of the samples collected in the MS-SA study unit (fig. 26A) and was detected most frequently (32 percent), and at higher concentrations, in samples from sites in the Salinas Valley (figs. 26B, 27D; table 10). Simazine is among the most commonly detected herbicides in groundwater in major aquifers across the United States (Gilliom and others, 2006) and is the most frequently detected herbicide in groundwater in California (Troiano and others, 2001).

Simazine was positively correlated to agricultural land use (table 9), and concentrations were higher in modern groundwater than in pre-modern groundwater (table 10), indicating that herbicide application to crops was a potential source of this constituent to groundwater sampled in the MS-SA study unit. Simazine was negatively correlated to well depth (table 9), indicating concentrations were higher in samples from shallower wells.

Constituents of Special Interest

Constituents of special interest analyzed for in the MS-SA study unit were perchlorate and *N*-nitrosodimethylamine (NDMA). These constituents were of special interest at the inception of the GAMA Priority Basin Project in 2003 because they had been detected in, or were considered to have the potential to reach, drinking-water supplies (Belitz and others, 2003; California State Water Resources Control Board, 2008a, b). As a class, special-interest constituents were detected at high relative concentrations in 2.0 percent of the MS-SA study unit, moderate relative concentrations in 36 percent, and low relative concentrations in 62 percent (table 7A). Perchlorate and NDMA were both detected at high relative concentrations (table 8A). All the high relative concentrations were in the Salinas Valley study area (tables 7B, 8B).

Understanding *N*-Nitroso-Dimethylamine (NDMA)

The compound NDMA was detected at high relative concentrations in 2.0 percent of the MS-SA study unit and at moderate relative concentrations in 1.5 percent (table 8A); the NL-CA for NDMA is 0.01 µg/L. All but one detection was in a sample from the Salinas Valley study area (figs. 26B, 27E). NDMA was detected in 9 of the 28 GAMA-PBP study units where NDMA was a measured analyte, including the MS-SA and MS-PA study units. NDMA was detected at high concentrations in two other GAMA-PBP study units other than the MS-SA—the Mojave study units (Mathany and Belitz, 2009) and the Northern Sacramento Valley study unit (Bennett and others, 2009).

NDMA is a semivolatile organic compound that belongs to the *N*-nitrosamine family of carcinogens (U.S. Environmental Protection Agency, 2014). NDMA is used in industries such as pesticide manufacturing, fish processing facilities, and rubber and tire manufacturing (Agency for Toxic Substances and Disease Registry, 1989). NDMA also is a disinfection byproduct that may form during chlorination of water supplies and wastewater (U.S. Environmental Protection Agency, 2014a). NDMA was negatively correlated to the aridity index (table 9), but this is not believed to be a causative relationship. NDMA was not correlated to any other explanatory factor (tables 9, 10). The source of the high NDMA concentrations is unknown.

Understanding Perchlorate

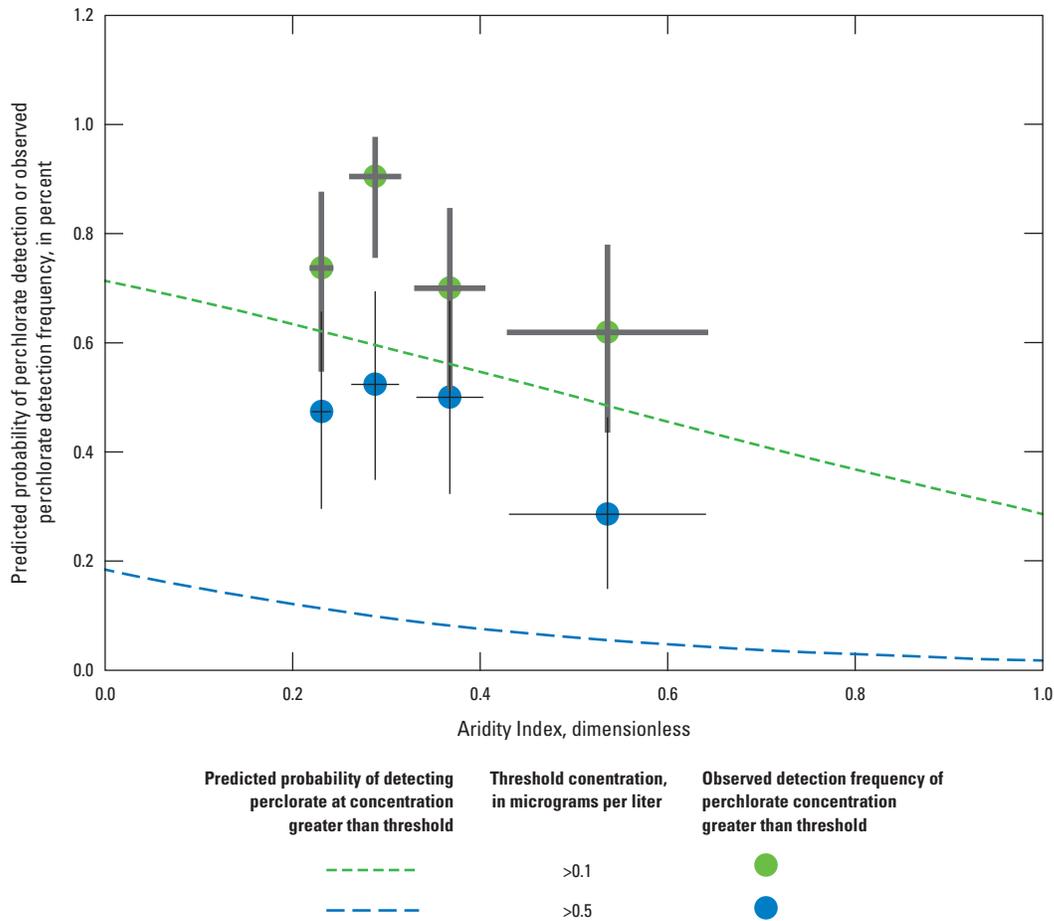
The MCL-CA of 6 µg/L for perchlorate was established in 2007, and although perchlorate is a highly soluble, inorganic constituent, it is classified as a special-interest constituent in this report for consistency with other GAMA Priority Basin Project reports. Perchlorate was detected at high relative concentrations in 0.7 percent of the MS-SA study unit and at moderate relative concentrations 35 percent (table 8A). Perchlorate was detected in 61 percent of samples (fig. 26A), and almost all of the detections were in the Pajaro Valley, Salinas Valley, and Highlands study areas (figs. 26B, 27F). Perchlorate is a health concern because it can disrupt the thyroid uptake of iodine needed to produce hormones for normal growth and development (California State Water Resources Control Board, 2008a).

Perchlorate has natural and anthropogenic sources to groundwater. Perchlorate can be present at low concentrations in groundwater under natural, especially arid, conditions (Fram and Belitz, 2011). Perchlorate forms naturally in the atmosphere and is present at low concentrations in precipitation (Rajagopalan and others, 2006, 2009). Perchlorate detection frequencies in the MS-SA study unit generally were greater than anticipated from the distribution of perchlorate in California groundwater under natural conditions (Fram and Belitz, 2011). In the Fram and Belitz (2011) study, the detection frequencies of perchlorate at

concentrations greater than threshold concentrations of 0.1 and 0.5 µg/L were compared to the predicted probability of detecting perchlorate under natural conditions as a function of aridity index. For the MS-SA study unit, the 81 grid sites with perchlorate data were divided into 4 groups of 19 to 21 sites by the aridity index, and, for each group, the average aridity index and the detection frequencies of perchlorate at concentrations greater than 0.1 µg/L and greater than 0.5 µg/L were calculated. The detection frequencies were greater than the predicted probabilities for detections greater than 0.5 µg/L. The detection frequencies for detections greater than 0.1 µg/L also tended to be greater than the predicted probabilities; however, the lower part of the 90-percent confidence interval of the detection frequencies for three of the groups was below the line for the predicted probability of detecting perchlorate (fig. 28). The results for the 0.5 µg/L threshold indicated that anthropogenic sources of perchlorate or anthropogenic processes most likely contributed to perchlorate concentrations in much of the MS-SA study unit.

Potential anthropogenic sources of perchlorate include industrial; manufacturing; or commercial uses such as rocket fuel, explosives, road flares, automobile air-bag systems, and other products. Mobilization of perchlorate naturally present in the unsaturated zone to the groundwater aquifer by irrigation recharge, an anthropogenic process, is another potential source (Fram and Belitz, 2011). Historical use of Chilean nitrate as a fertilizer also is a known source of perchlorate (Urbansky and others, 2001; Trumpolt and others, 2005). Import of Chilean nitrate into the United States for use as fertilizer began in the early part of the 20th century, but has declined in recent years (Dasgupta and others, 2006).

Perchlorate concentrations were positively correlated with agricultural land use, percentage of modern carbon-14 (table 9), and nitrate concentrations (table 11). Given these correlations, and that nitrate concentrations were also positively correlated to agricultural land use (table 9), mobilization of naturally present perchlorate or possibly perchlorate from the application of Chilean nitrate fertilizer could be sources of the perchlorate detected in groundwater sampled in the MS-SA study unit. Perchlorate concentrations also were higher in oxic than anoxic groundwater. The perchlorate in oxic groundwater in the study unit could reflect the relation of oxic groundwater and agricultural land use (tables 5, 6). Also, perchlorate biodegrades under anoxic conditions in some aquifers (Sturchio and others, 2007). Perchlorate and nitrate are reduced at similar oxidation-reduction potentials (Nozawa-Inoue and others, 2005). Perchlorate was not detected in 17 of the 19 samples (the 2 detections were just above reporting levels) with manganese-reducing or manganese- and iron-reducing redox conditions, which likely reflects degradation of perchlorate. Most of these samples were from the Santa Cruz study area (fig. 27F), where groundwater conditions were primarily anoxic (fig. 8B).



The 81 grid sites with perchlorate data were divided into 4 groups of 19 and 21 sites. Horizontal error bars equal plus or minus one standard deviation of the average aridity index. Vertical error bars are the 90-percent Jeffrey’s confidence interval for the observed detection frequency

Figure 28. Predicted probability of detecting perchlorate in groundwater as a function of aridity index and observed detection frequency and average aridity index for sites grouped by aridity index, Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring Assessment Priority Basin Project, October 2012 to May 2013.

Comparison of Water Quality of the Shallow and Public Drinking-Water Aquifer Systems

Study-unit characteristics (for example, well depth and land use) and water-quality results from the assessment of the groundwater resources used for public drinking water in the Monterey Bay and Salinas Valley (MS-PA; Kulongoski and Belitz, 2011) were compared to results from the MS-SA system assessment presented in this report. This was done to assess differences between water quality in the shallower groundwater primarily used for domestic supply and in the deeper groundwater primarily used for public drinking-water supply.

Comparison of Study-Unit Characteristics

A comparison of well-construction information verified that grid sites sampled for the MS-SA3 system were tapping a relatively shallow aquifer system compared to sites sampled for the MS-PA system (fig. 29A). Well depths in the MS-PA system were significantly deeper than well depths in the

MS-SA3 system (Mann-Whitney rank sum test, $p=0.002$). Depth to the top of perforations in the MS-PA system also tended to be deeper than in the MS-SA-3 system (Mann-Whitney rank sum test, $p=0.056$). Median well depths and depths to the top of perforations for grid sites in the MS-SA3 system were 88 and 49 m bls, respectively, and, for grid sites in the MS-PA system, 143 and 70 m bls, respectively. The MS-SA3 system had a higher percentage of natural land use in the 500-m buffer (1,640 ft) around sites, whereas the MS-PA system had a higher percentage of urban land use around sites (fig. 29B). Distribution of groundwater-age classes was varied between the aquifer systems; the MS-SA3 system had slightly more sites with modern and mixed groundwater ages, and the deeper MS-PA system had more sites with pre-modern groundwater age (fig. 29C). The MS-SA3 system had a higher percentage of sites that were oxic (70 percent) than the MS-PA system (55 percent). The MS-PA system had a higher percentage of sites that were anoxic or mixed redox (45 percent) than the 30 percent for the MS-SA3 system (fig. 29D). Both aquifer systems had pH values near or slightly above neutral pH (fig. 29E); however, the pH values in the MS-PA system tended to be slightly higher than those in the MS-SA3 system.

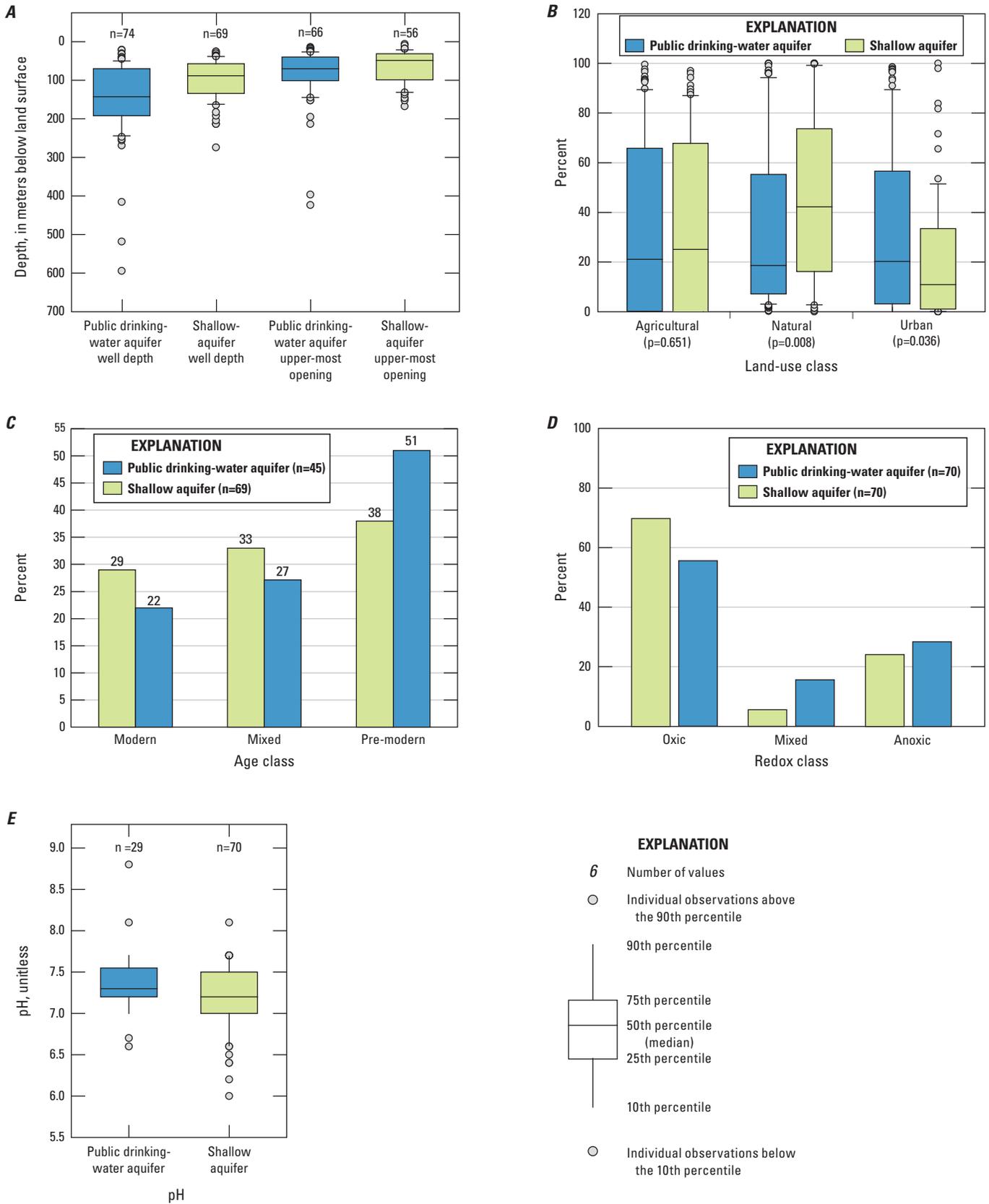


Figure 29. Comparison of the study-unit characteristics for the shallow and public drinking-water aquifer systems for the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project: *A*, well depths and depths to top of the upper-most opening; *B*, land use within 500-meter buffer; *C*, groundwater-age class; *D*, redox class; and *E*, pH.

Comparison of Inorganic Constituents

Inorganic constituents with health-based benchmarks, as a group, were detected at high relative concentrations in a larger aquifer-scale proportion of the MS-SA3 system than in the MS-PA system (fig. 30A). The aquifer-scale proportion of high and moderate relative concentrations for trace elements was greater in the MS-PA than in the MS-SA3. Radioactive constituents were mostly detected at low relative concentrations in both studies. The proportion of high relative concentrations for nutrients in the MS-SA3 system was more than three times higher than the proportions in the MS-PA.

The four trace elements detected at high relative concentrations in more than 2 percent of one or both aquifer systems were arsenic, manganese, molybdenum, and selenium. The source for all four of these trace elements is primarily natural for both aquifer systems. Arsenic and selenium were at high concentrations in higher proportions

of the MS-SA3 system than of the MS-PA system (fig. 30B). However, the aquifer-scale proportion with moderate arsenic concentrations was higher in the MS-PA system. The greater proportion of aquifer area with high relative concentrations of arsenic and selenium in the MS-SA3 could be because these constituents are more mobile in oxic groundwater, which was more common in the MS-SA3 aquifer system (fig. 29D). Concentrations of arsenic in the MS-PA are not likely to change as a result of percolation of water having high or moderate concentrations of arsenic from the MS-SA3 because the locations of high and moderate relative concentrations of arsenic frequently coincided in the two aquifers (fig. 15A; fig. 14B in Kulongoski and Belitz, 2011). Concentrations of selenium in the deeper system are not likely to increase above low relative concentrations by percolation from the shallower aquifer in most of the MS-PA aquifer system because the concentrations were low throughout most of both aquifer systems (fig. 31A).

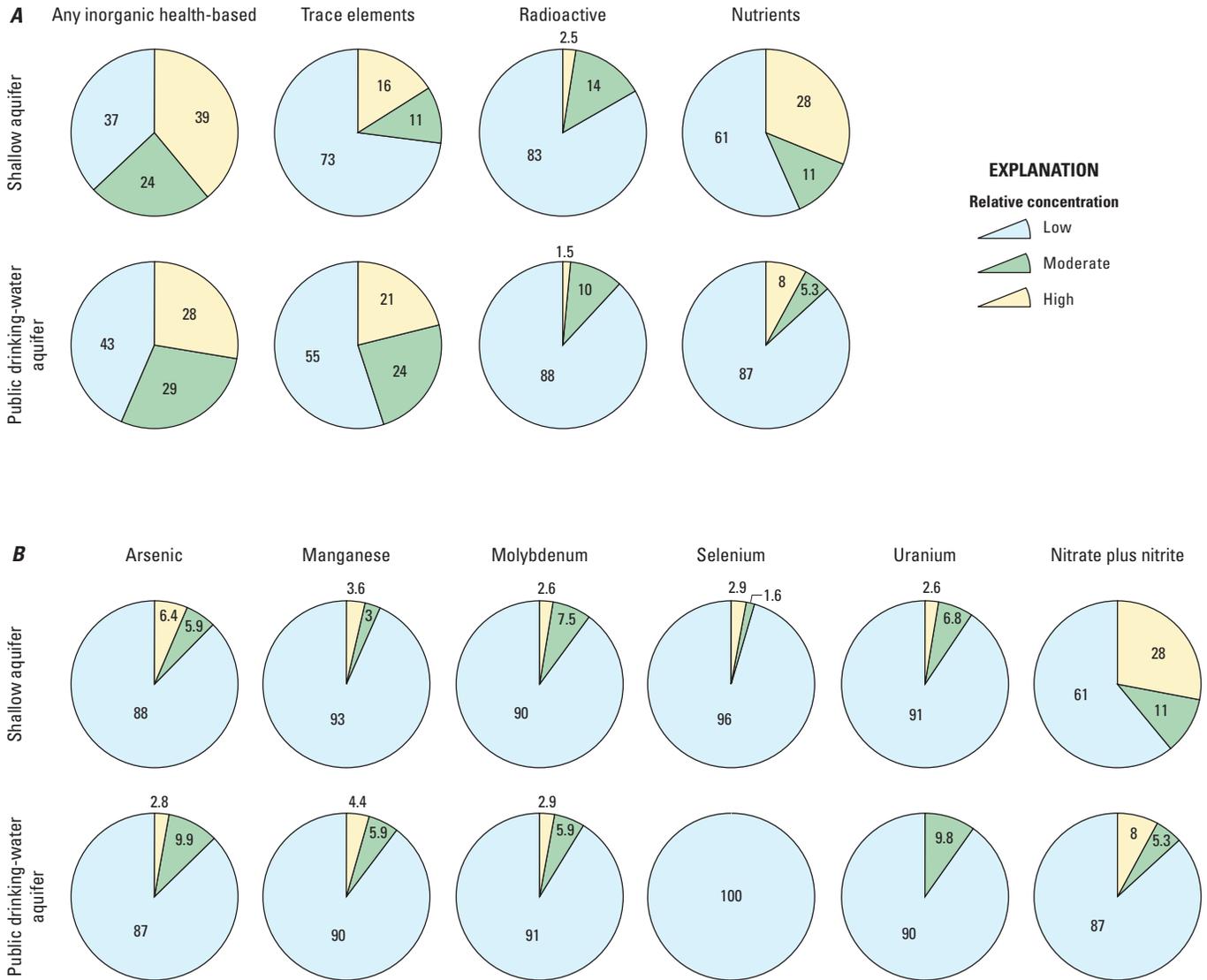


Figure 30. Comparison of aquifer-scale proportions having high, moderate, and low relative concentrations of inorganic constituents with health-based benchmarks in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer-system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project: A, by constituent class, and B, for constituents detected at high relative concentrations in more than 2 percent of an aquifer system.

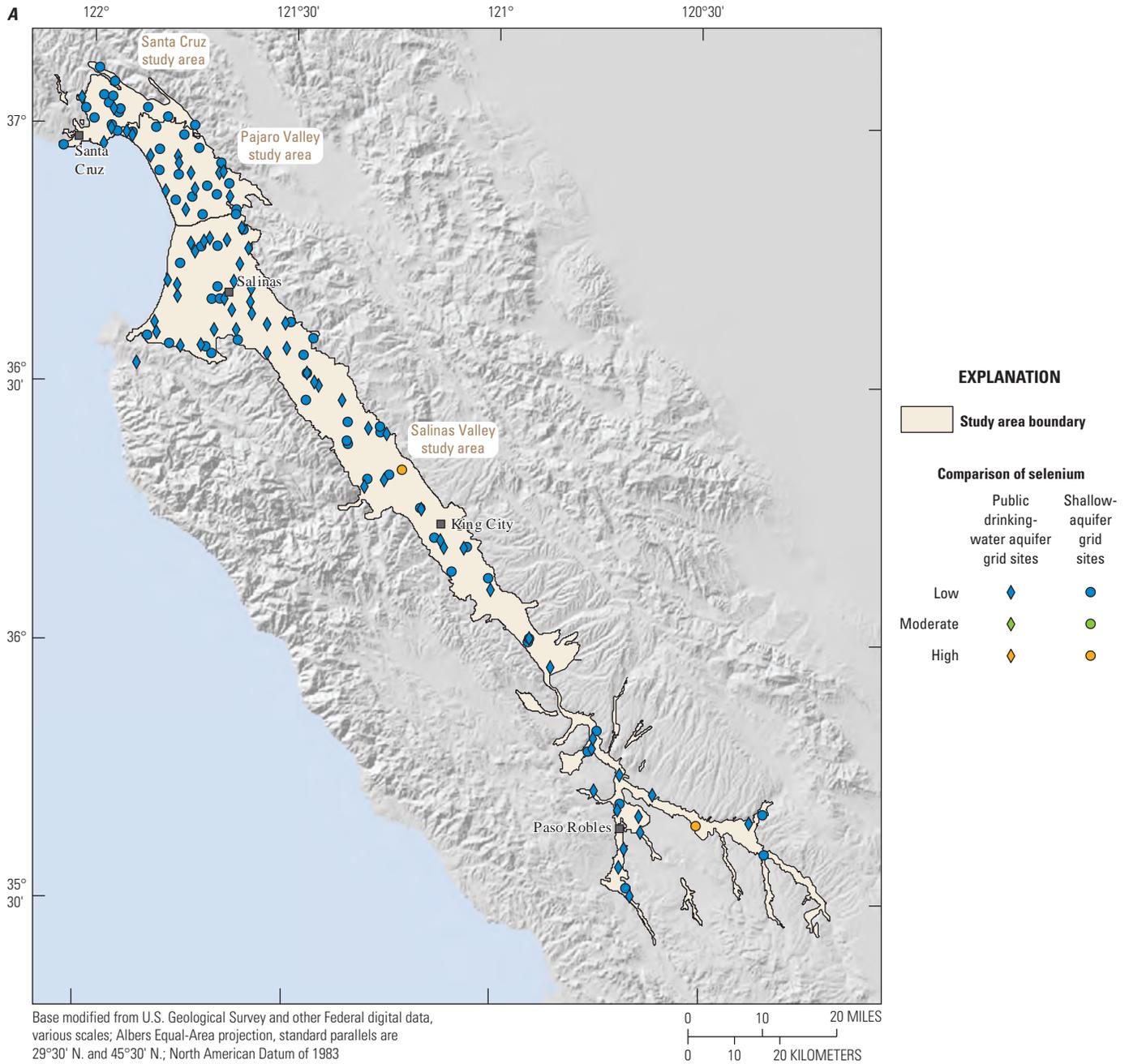


Figure 31. Concentrations of selected inorganic constituents with health-based benchmarks for samples collected from grid sites in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project: *A*, selenium; *B*, uranium; and *C*, nitrate.

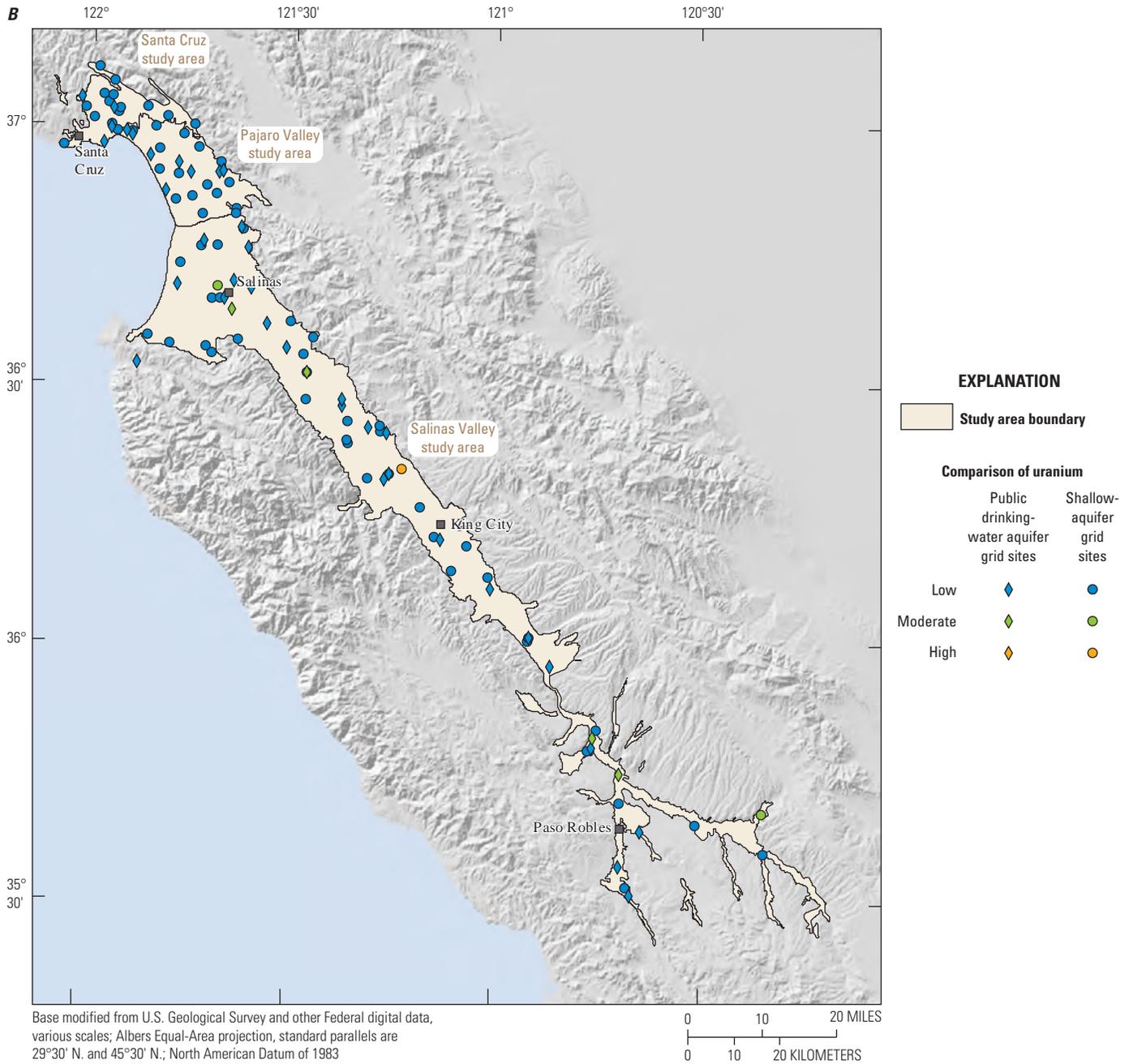


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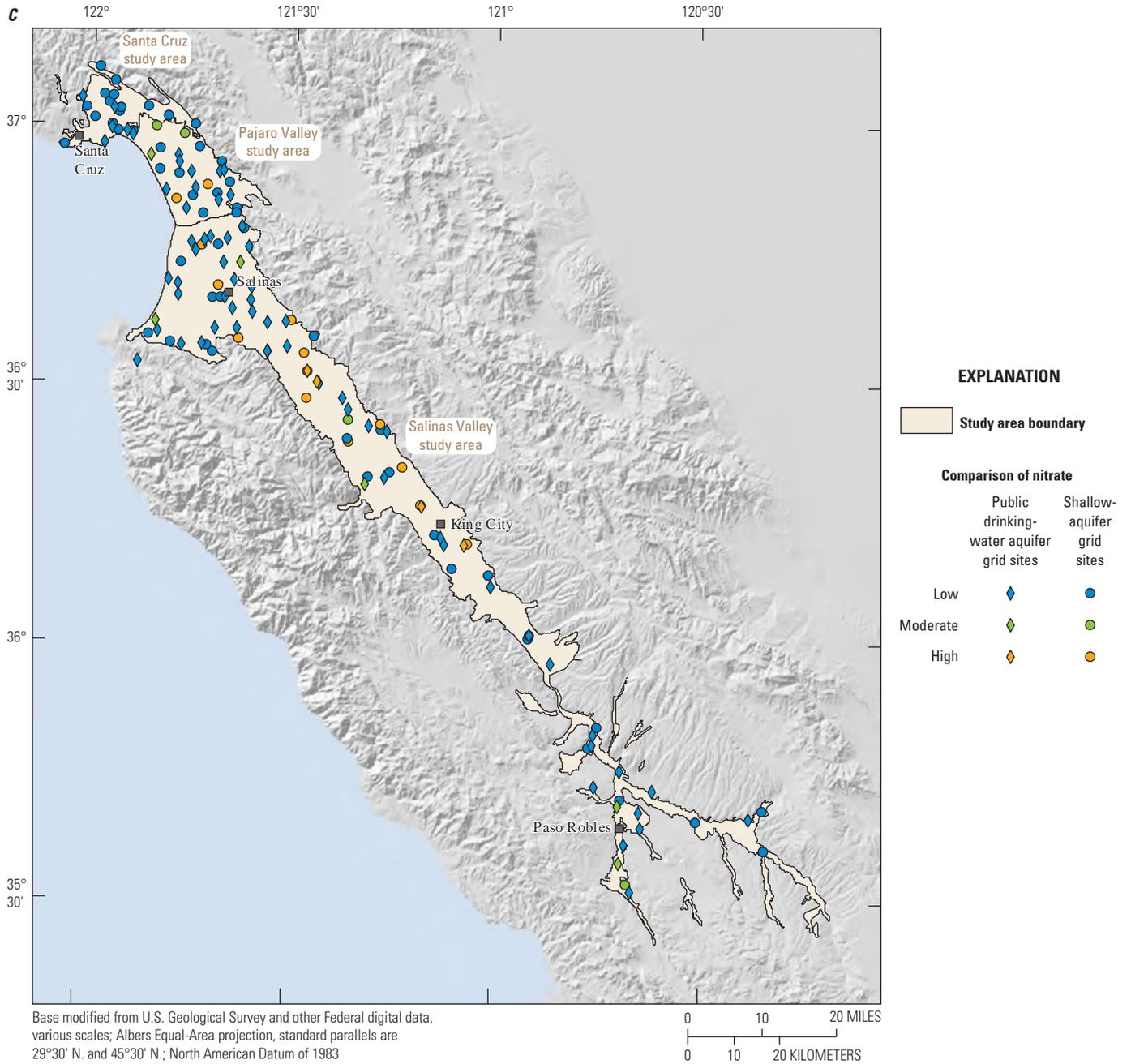


Figure 31. —Continued

Proportions of high and moderate relative concentrations of manganese were slightly higher in the MS-PA system than in the MS-SA3 system (fig. 30B). Concentrations were most likely higher in the MS-PA because anoxic conditions were more common in the MS-PA system (fig. 29D). Aquifer-scale proportions with high relative concentrations of molybdenum were similar in the MS-SA3 and MS-PA systems, but proportions with moderate relative concentrations were higher in the MS-SA3 system. Correlations with explanatory factors evaluated in this report and in Kulongoski and Belitz (2011) did not provide an adequate explanation for this distribution. It is unlikely that concentrations of manganese or molybdenum would change in the deeper aquifer system of the MS-PA because of the downward movement of these constituents, unless there is a change in the geochemical conditions (for example, redox or pH) of the primary aquifer.

Uranium was the primary radioactive constituent detected at high relative concentrations in more than 2 percent of one or both aquifer systems. Uranium was at high concentrations in higher proportions of the MS-SA3 system than of the MS-PA system (fig. 30B); however, the proportion with moderate concentrations was higher in the MS-PA system. Location of high and moderate relative concentrations of uranium did not always coincide in the MS-SA3 and MS-PA aquifers (fig. 31B). Uranium was correlated with oxic conditions and mobilized by irrigation practices of agricultural land use in the MS-SA3 aquifer system. It is possible that concentrations of uranium could increase in the MS-PA aquifer in agricultural areas as a result of changes in pH caused by irrigation water interacting with bicarbonate aquifer materials as the irrigation water percolates down to the primary aquifer, as discussed in the “[Uranium and Radioactive Constituents](#)” section.

Nitrate was the primary nutrient detected at high relative concentrations in more than 2 percent of both aquifer systems. High relative concentrations of nitrate were detected more than three times more frequently in samples collected in the MS-SA3 than in the MS-PA (fig. 30B). Agricultural land use around the sites sampled had a similar frequency distribution in the MS-SA3 and MS-PA (fig. 29B), indicating that the shallower (fig. 29A), oxic system (fig. 29D) sampled in the MS-SA3 study was more susceptible to the effects of agricultural land-use practices because it was in closer proximity to the agricultural sources of nitrate. Nitrate concentrations are likely to increase in some areas of the MS-PA aquifer system as a result of the downward movement of nitrate. Increases in nitrate concentrations in the MS-PA system would be most likely near King City, and farther north in the Salinas Valley and Pajaro Valley study areas, where the concentrations in the MS-SA3 system were frequently higher than in the MS-PA system (fig. 31C), and redox conditions were oxic. Because mixed and anoxic redox conditions were prevalent in the MS-PA aquifer system south of King City, however, denitrification processes could remove nitrate from percolating groundwater in some areas of the deeper primary aquifer system. In addition, the prevalence of pre-modern samples in the MS-PA (fig. 29E) indicates potentially fewer effects on groundwater quality from agricultural land-use practices.

Inorganic constituents with aesthetic-based benchmarks, as a group, were detected at high relative concentrations in a larger proportion of the MS-SA3 system than in the MS-PA system (fig. 32A). The aquifer-scale proportion with high relative concentrations of salinity indicators was more than three times higher in the MS-SA3 than in the MS-PA; the proportion of aquifer systems with moderate relative concentrations was the same for the MS-PA as for the MS-SA3 (fig. 32A).

Four inorganic constituents with SMCLs as benchmarks were detected at high relative concentrations in more than 2 percent of one or both aquifer systems. These constituents are the salinity indicators chloride, sulfate, and total dissolved solids (TDS) and iron. All three salinity indicators were at high relative concentrations in higher proportions of the MS-SA3 system than of the MS-PA system (fig. 32B). Chloride was at higher proportions of moderate relative concentrations in the MS-SA3 system than the MS-PA system; however, proportions with moderate relative concentrations of sulfate and TDS were about the same in the two aquifer systems (fig. 32B). The higher proportion with elevated concentrations of chloride in the MS-SA3 system was most likely a result of seawater intrusion near the coast; evaporative concentration; and from marine rocks, as discussed in the “[Understanding Assessment for Chloride](#)” section. In the coastal portion of the Salinas Valley and Pajaro Valley study areas, groundwater pumping has led to greater seawater intrusion in the relatively shallow 180-Foot Aquifer than in the deeper 400-Foot Aquifer (Brown and Caldwell, 2014). High relative concentrations of chloride and TDS were both detected in samples collected in this area of the MS-SA3.

The other salinity indicators, sulfate and TDS, were detected at high relative concentrations in the interior parts of the MS-SA3 study unit (figs. 33A, B). These high concentrations most likely were a result from dissolution of natural marine sediments and from agricultural practices. Sulfate and TDS were both correlated to agricultural land use in the MS-SA3. Sulfuric acid is used to lower the pH of irrigation water and to assist with nutrient uptake. Ammonium sulfate is used on a wide variety of crops in the Monterey and San Luis Obispo Counties (California Department of Pesticide Regulation, 2014). Sulfate has been identified as a primary constituent contributing to increased groundwater salinity in irrigated fields in an arid environment (Oren and others, 2004). High TDS concentrations in these samples could be due to the leaching of built-up salts in soil by irrigation-return water. The distribution of sulfate and TDS concentrations in the aquifer systems indicated that most moderate and high relative concentrations in the MS-SA3 system were near areas where there were high and moderate relative concentrations in the MS-PA system (figs. 33A, B). The predominance of samples with high relative concentrations of salinity indicators in the MS-SA indicated that the shallow aquifer system was more susceptible than the deeper system to the effects of anthropogenic activities at the land surface, such as irrigated agriculture or the disposal of wastewater. It is possible that elevated concentrations of sulfate and TDS could move downward and increase concentrations in the MS-PA system, however.

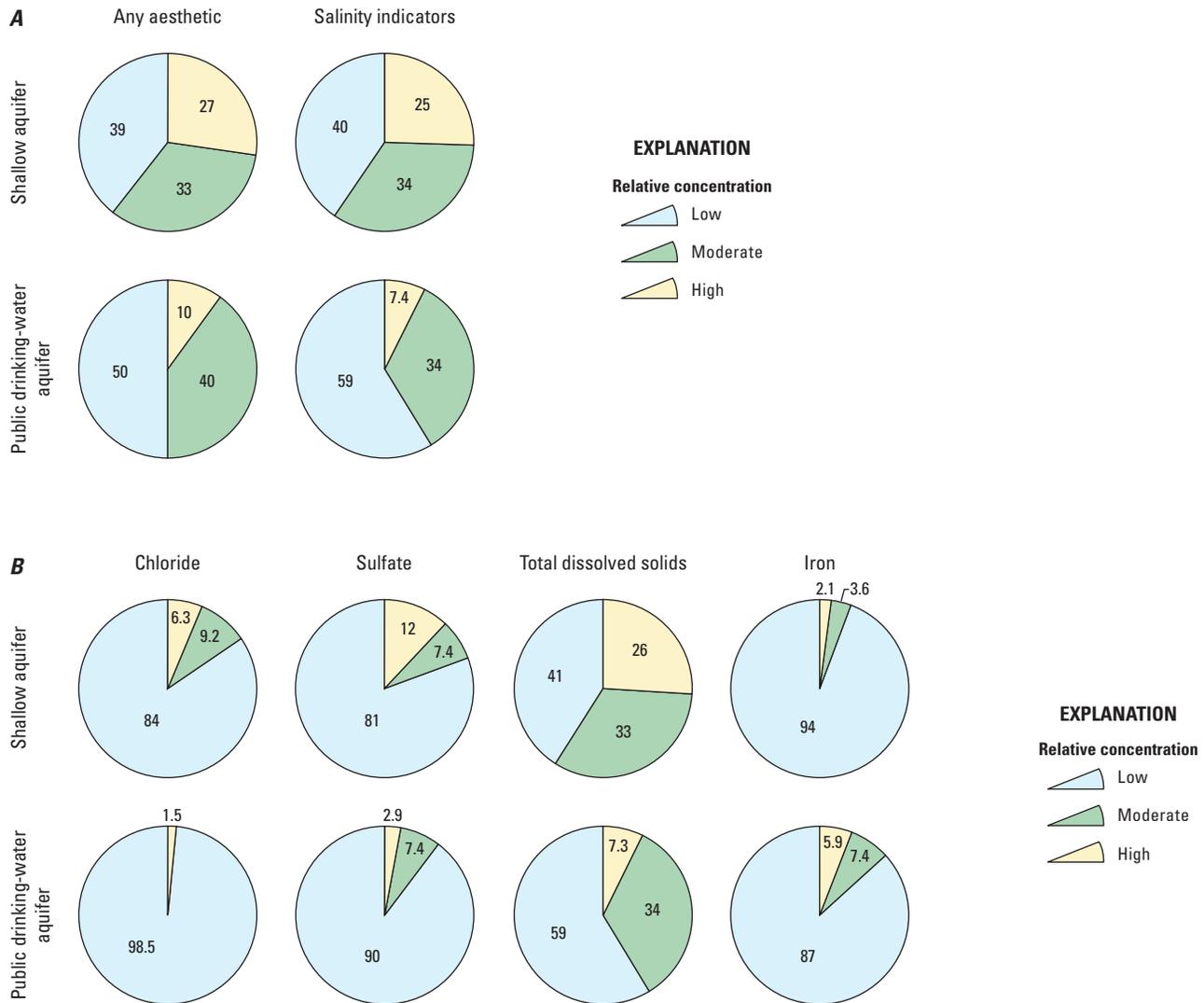


Figure 32. Comparison of aquifer-scale proportions having high, moderate, and low relative concentrations of inorganic constituents with secondary maximum concentration level benchmarks in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project: *A*, by constituent class, and *B*, for constituents detected at high relative concentrations in more than 2 percent of an aquifer system.

Iron was the only constituent with an SMCL detected at higher relative concentrations in the MS-PA than in the MS-SA3 system (fig. 32B). Similar to manganese, iron concentrations were most likely higher in the MS-PA because anoxic conditions were more common in the MS-PA system (fig. 29D). It is unlikely that concentrations of iron would change in the deeper aquifer system of the MS-PA from downward movement of dissolved iron.

Comparison of Organic Constituents

Eight organic constituents (VOCs and pesticides) were detected above the common censoring level in at least 10 percent of the grid samples collected in the MS-SA3

or MS-PA systems or were detected at moderate relative concentrations (fig. 34A). Most of the detections in both systems were at low relative concentrations and no organic constituents were detected at high relative concentrations. Organic constituents detected at moderate relative concentrations in the MS-PA system were the solvents tetrachloroethene (PCE), trichloroethene (TCE), and carbon tetrachloride; the gasoline additive methyl *tert*-butyl ether (MTBE); and the pesticide dieldrin. In the MS-SA3 system, the fumigant 1,2-DCP was the only organic constituent detected at moderate relative concentrations. Chloroform and PCE (MS-SA3 only) and simazine (both aquifer systems) were the only organic constituents detected at frequencies greater than 10 percent.

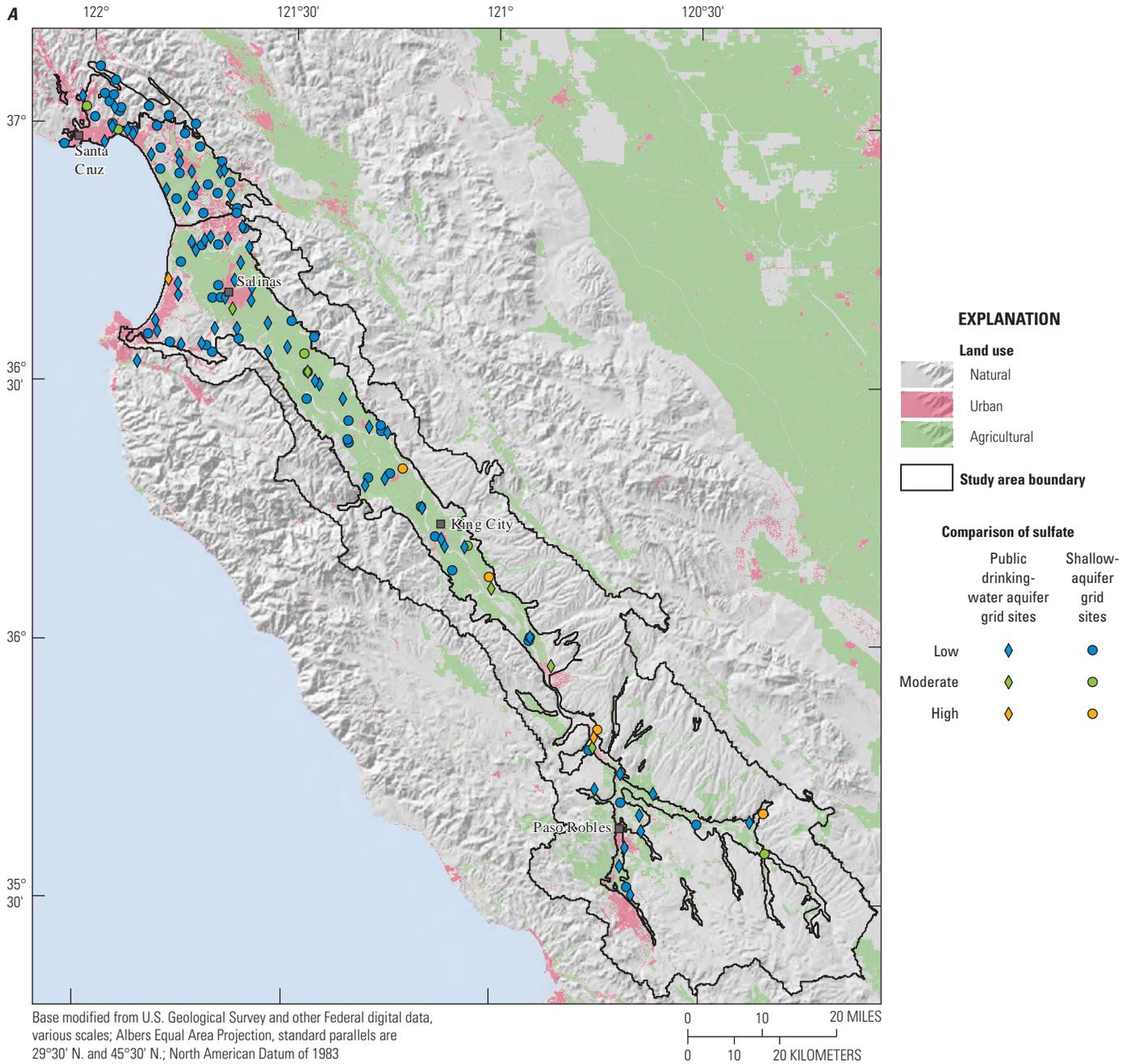


Figure 33. Concentrations of selected salinity indicators for samples collected from grid sites in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project: *A*, sulfate; *B*, total dissolved solids.

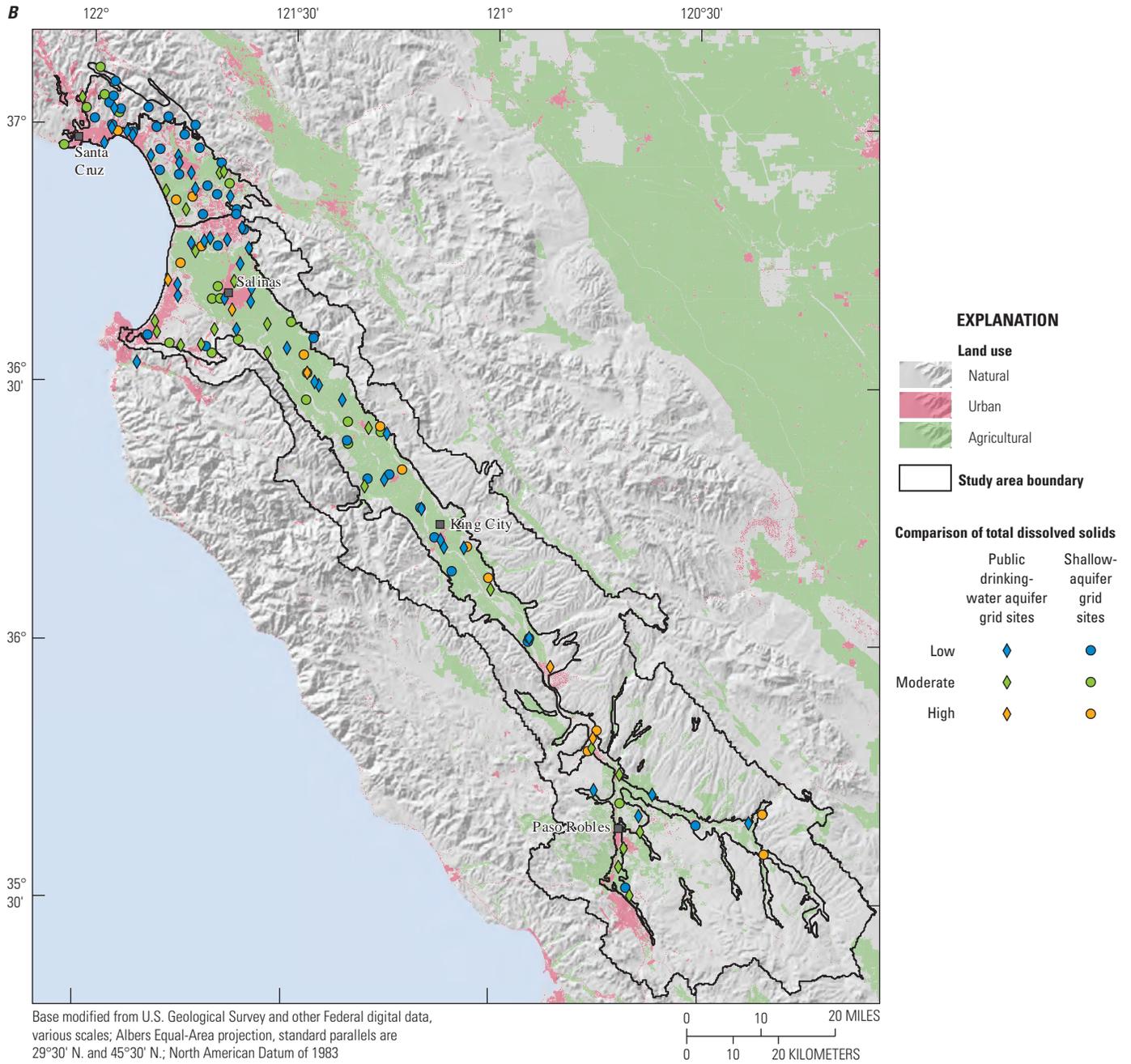


Figure 33. —Continued

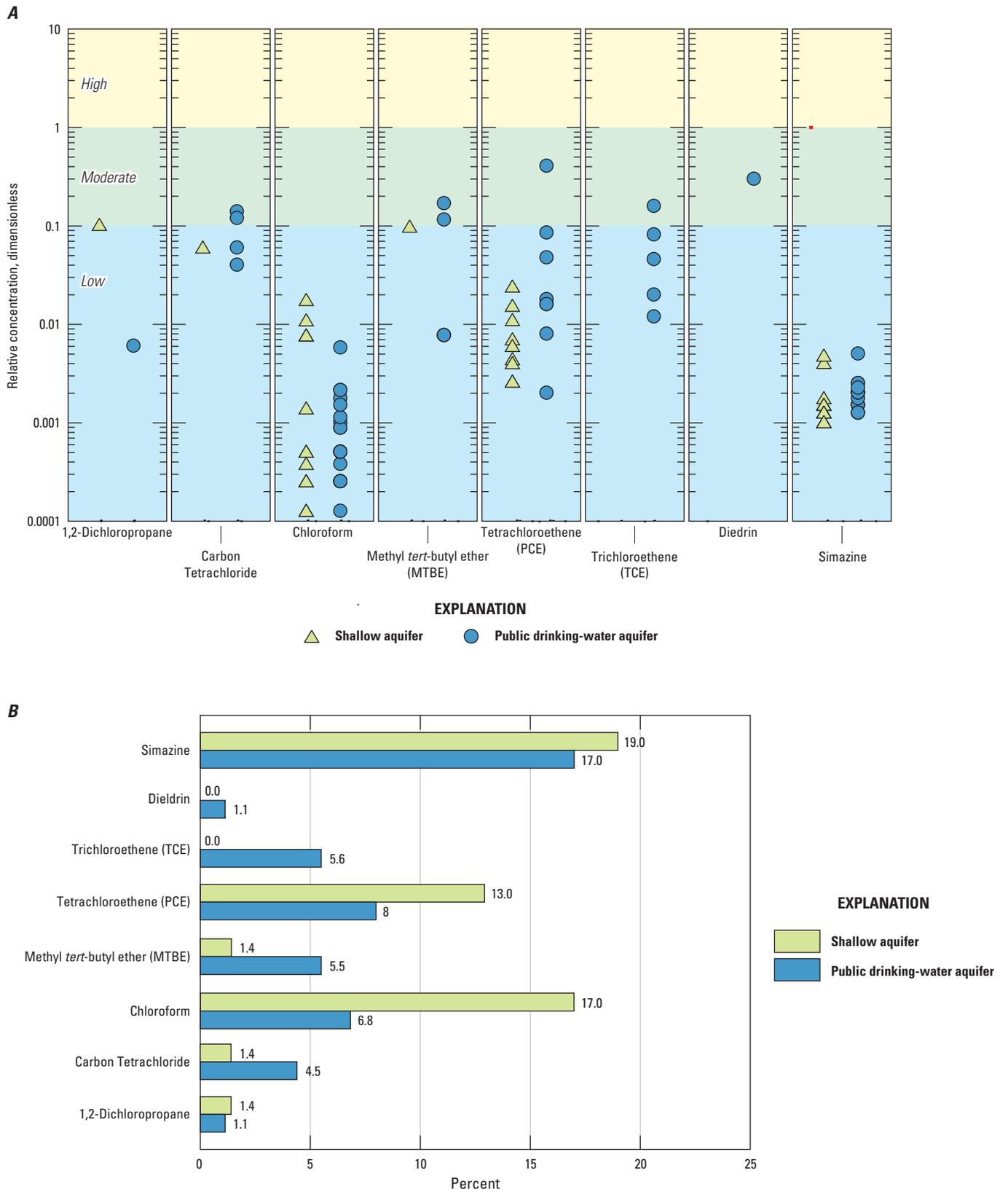


Figure 34. Organic constituents detected frequently in the Monterey-Salinas public drinking water (2005) and shallow (2012–13) aquifer system assessments, California Groundwater Ambient Monitoring Assessment Priority Basin Project, allowing comparison of *A*, relative concentrations (excluding censored results), and *B*, detection frequency.

Five of eight organic constituents were detected in both systems. Trichloroethene and dieldrin were not detected in the MS-SA3 system (fig. 34A, B). The herbicide simazine was the most frequently detected organic constituent, but was only detected at low relative concentrations. Simazine, chloroform, and PCE were detected more frequently in the MS-SA3 system than in the MS-PA; carbon tetrachloride, MTBE, dieldrin, and TCE were detected more frequently in the MS-PA. The fumigant 1,2-DCP was detected at similar frequencies in both systems.

The greater detection frequency or higher concentration of VOCs for samples collected in the MS-PA could be because those samples were, on average, closer to sources. The VOC detections generally were in samples from urban areas, and the MS-PA had three times as many sites in urbanized areas than did the MS-SA (fig. 29B). It also is possible that changes at the land surface to prevent further contamination by carbon tetrachloride, MTBE, and TCE could have resulted in lower detection frequencies for the shallow aquifer. On a national scale, VOCs are more frequently detected in samples from urbanized areas (Zogorski and others, 2006). The herbicide simazine is used in agriculture, as well as for roadside weed control in urban and rural locations. Simazine was correlated to agricultural land use in the MS-SA3 aquifer system (table 9), which is more susceptible to the effects of agricultural land-use practices than the deeper aquifer system. Simazine was not correlated to land use in the MS-PA aquifer system (Kulongoski and Belitz, 2011).

Summary

Groundwater quality in the Monterey-Salinas Shallow Aquifer (MS-SA) study unit was investigated by the USGS in cooperation with and as part of the California State Water Resource Control Board's Groundwater Ambient Monitoring and Assessment Program Priority Basin Project (GAMA-PBP). The MS-SA study provides a spatially unbiased characterization of untreated-groundwater quality in the shallow aquifer system. The shallow aquifer was defined using wells with open or screened intervals shallower, on average, than those of the public-supply wells listed in the California State Water Resources Control Board Division of Drinking-Water database. The MS-SA study unit covers an area of approximately 7,820 square kilometers in Santa Cruz, Monterey, and San Luis Obispo Counties in the central coast region of California.

This study reported here describes the hydrogeologic setting of the MS-SA study unit, assesses the status of groundwater quality in the shallow aquifer system in the Monterey-Salinas study unit, relates groundwater quality to natural and anthropogenic factors that could be affecting its status, and compares the quality of groundwater in the shallow aquifer system (MS-SA study unit) with the quality of groundwater resources used for public drinking water (MS-PA study unit).

The MS-SA study unit was divided into four study areas. Three study areas—Santa Cruz, Pajaro Valley, and

Salinas Valley—were based on the California Department of Water Resources (CDWR) basin delineations, geology, and geography. The fourth study area, Highlands, consists of areas that primarily were served by domestic wells bordering the Salinas Valley study area, but were mostly outside of the CDWR defined basins.

Two types of assessments were made for the MS-SA study unit: (1) a *status assessment* provides a spatially unbiased characterization of groundwater quality in the shallow aquifers and (2) an *understanding assessment* provides an evaluation of natural and anthropogenic factors that could be affecting the groundwater quality. The assessments were based on water-quality data collected by the U.S. Geological Survey (USGS) from 100 grid sites and 70 tap sites from 2012 to 2013. Samples collected from these sites were analyzed for organic constituents (volatile organic compounds and pesticides), inorganic constituents (major ions, trace elements, radioactivity, and nutrients), special-interest constituents (perchlorate, NDMA), and geochemical and age-dating tracers.

Relative concentrations (sample concentration divided by the health- or aesthetic-based benchmark concentration) were used to evaluate groundwater quality for those constituents that had Federal or California regulatory or non-regulatory benchmarks for drinking-water quality. Relative concentrations greater than 1.0 were defined as high for all constituents. Aquifer-scale proportion was used as the primary metric for evaluating regional-scale groundwater quality. Aquifer-scale proportion is defined as the percentage of the shallow aquifer system where concentrations are greater than or less than specified relative concentrations derived from water-quality benchmarks; proportion is based on area rather than volume.

Inorganic constituents generally were detected at high and moderate relative concentrations more commonly than organic constituents. In the MS-SA study unit, at least one trace element, radioactive constituent, or nutrient with health-based benchmarks was detected at high relative concentrations in 51 percent of the study unit. High relative concentrations of trace elements and radioactive constituents were detected in the greatest proportion in samples from the Highlands and Santa Cruz study areas, whereas high relative concentrations of nutrients were most often detected in the Salinas Valley and Pajaro Valley study areas. The trace elements molybdenum, strontium, and boron, were detected at high relative concentrations in 14, 9.5, and 2.2 percent, respectively, of the MS-SA study unit, primarily in the Highlands study area. Arsenic was detected at high relative concentrations in 3.9 percent of the study unit, primarily in the Santa Cruz study area. Selenium was detected at high relative concentrations in 3.2 percent of the study unit, primarily in the Salinas Valley study area. Manganese was detected in 6.4 percent of the study unit, primarily in the Santa Cruz study area. The radioactive constituents adjusted gross alpha radioactivity and uranium were detected at high relative concentrations in 13 and 7.6 percent, respectively, of the study unit, primarily in the Highlands study area. The nutrient nitrate was detected in 14 percent of the study unit, primarily in the Salinas Valley and Pajaro Valley study areas.

Inorganic constituents with secondary maximum contaminant levels (SMCLs) were detected at high relative concentrations in 40 percent of the MS-SA study unit. Salinity indicators (total dissolved solids, sulfate, and chloride) were detected most frequently in the Highlands and Salinas Valley study areas. Total dissolved solids (TDS), sulfate, and chloride were detected at high relative concentrations in 38, 26, and 6.6 percent, respectively, of the study unit. Iron, the remaining constituent with an SMCL, was detected at high relative concentrations in 13 percent of the study unit, primarily in the Santa Cruz study area.

Organic constituents (volatile organic compounds, or VOCs, and pesticides) were not detected at high relative concentrations in any of the study areas. The fumigant 1,2-dichloropropane (1,2-DCP) was detected at moderate relative concentrations, but in less than 1 percent of the MS-SA study unit. The VOC chloroform and the herbicide simazine were detected in 15 percent of samples collected, but only at low relative concentrations.

As a class, the constituents of special-interest were detected at high relative concentrations in 2 percent of the MS-SA study unit. In the study unit, NDMA and perchlorate were detected at high relative concentrations in 2 and 0.7 percent, respectively; all high detections were in the Salinas Valley study area. Perchlorate was detected at moderate relative concentrations in 35 percent of the study unit.

The *understanding assessment* used statistical correlations between concentrations of constituents and values of selected potential explanatory factors to identify the factors potentially affecting the concentration and areal distribution of constituents found at high relative concentrations or, for organic constituents, with study-unit detection frequency greater than 10 percent. The potential explanatory factors evaluated were land-use characteristics (land use, septic systems), measures of location (study area, aridity index, well depths, and depth to top of perforations), geologic factors (aquifer lithology, distance to geothermal sites), groundwater age, and geochemical conditions (oxidation-reduction characterization, dissolved oxygen, and pH).

The salinity indicators TDS, chloride, and sulfate all have natural sources in the MS-SA study unit, primarily marine sediments. Concentrations of the constituents also were elevated by anthropogenic processes in the study unit. All three constituents could be elevated as a result of the evaporative concentration of irrigation water or precipitation. Evidence for this is indicated by stable isotope data from the groundwater samples collected for this study, which indicate many samples from the Highlands and Salinas Valley study areas had been affected by evaporative processes. In addition, chloride concentrations near the coast were affected by old seawater intrusion. Sulfate concentrations could be elevated by soil additives or fertilizer used for agriculture and leached to the groundwater by irrigation-return water.

Trace elements and radioactive constituents evaluated in this study came from natural sources and were not elevated by anthropogenic sources or processes evaluated in this report, except for selenium and the radioactive constituent uranium.

Arsenic was positively correlated to DO and pH, with higher concentrations found in oxic conditions. This indicated that desorption from iron and manganese oxyhydroxides in aquifer sediments as a result of the pH and oxic conditions could be the primary mechanism controlling arsenic in groundwater. Boron was positively correlated to salinity constituents and older groundwater, indicating that long exposure to boron-bearing marine sediments could be a source of boron. Geothermal springs could be a source of high concentrations of boron, based on the correlation of boron with water temperature and that the site with high concentrations of boron had a water temperature over 30 degrees Celsius. Manganese and iron were negatively correlated to DO concentrations, such that concentrations were higher in anoxic redox conditions. These results indicate that the reductive dissolution of amorphous phases of oxyhydroxide minerals is an important mechanism contributing dissolved manganese and iron to groundwater. Manganese concentrations were higher in pre-modern groundwater than in modern groundwater, indicating a long period of reductive dissolution. Molybdenum is more soluble under oxic conditions than anoxic conditions. Unlike other GAMA study units, molybdenum concentrations were not significantly greater in oxic samples than in anoxic or mixed samples. Molybdenum was not correlated to DO because of the parabolic relationship in samples from the MS-SA study unit. In the study unit overall, molybdenum was not positively correlated with pH; however, a positive correlation with pH was observed in samples from oxic redox conditions. The adsorption of molybdenum to iron oxyhydroxides and clays can be inhibited as pH values increase. Strontium concentrations were higher in groundwater where sulfate was the dominant anionic water type rather than chloride or bicarbonate. Strontium was negatively correlated with the percentage modern carbon-14, indicating concentrations are higher in older groundwater.

Selenium was the only trace element for which concentrations could have been elevated by anthropogenic sources or processes. Selenium was positively correlated to DO concentrations, and concentrations were higher in oxic than anoxic groundwater. Selenium concentrations were positively correlated to agricultural land use, such that concentrations were higher in samples from areas of agricultural land use than in urban or natural land use areas. The source of high selenium was most likely the Monterey Formation in the Paso Robles area, augmented by pesticides and feed additives used in agriculture. Selenium in soil and sediments was mobilized by irrigation water under the oxic conditions of the MS-SA study unit. The radioactive constituent uranium also could have been elevated by anthropogenic processes. Uranium comes from the dissolution of uranium-bearing minerals in the study unit. The positive correlations of uranium to bicarbonate and DO concentrations and the percentage of agricultural land use indicate that uranium concentrations in the MS-SA study unit could be elevated by enhanced desorption of uranium-bearing minerals from sediments mobilized by irrigation recharge having high bicarbonate concentrations.

Unlike most trace elements, nitrate is strongly affected by anthropogenic processes. Nitrate was positively correlated with agricultural land use, indicating that irrigation-return water could be leaching nitrogen fertilizer and elevating nitrate concentrations. Nitrate was positively correlated to the percentage of modern carbon-14 and was significantly higher in modern groundwater, indicating recent inputs of nitrate to the shallow aquifer system. Characteristically, nitrate was positively correlated with DO concentrations and was at higher concentrations in oxic groundwater than in anoxic or suboxic groundwater.

The number of VOCs detected per site ranged from none to five. The sites with most of the detections were in the Pajaro Valley and the northern part of the Salinas Valley. The number of VOCs detected per site was positively correlated to the density of septic tanks, but was not correlated to any other explanatory factor. The trihalomethane (THM) chloroform also was correlated to septic-tank density.

The number of pesticides detected per site ranged from none to four. Most of the detections were in the Salinas Valley study area. The number of pesticides detected was positively correlated to the percentage of agricultural land use and the percentage of modern C-14. Similarly, the herbicide simazine was positively correlated to the percentage of agricultural land use, and concentrations were higher in modern groundwater than pre-modern groundwater. The correlation of simazine concentrations to agricultural land use, and the lack of correlation to urban land use, indicates that the application of this herbicide to crops was the primary source of this constituent in groundwater.

Perchlorate, similar to nitrate, has natural and anthropogenic sources. Perchlorate was positively correlated to DO concentrations and was higher in oxic groundwater than anoxic groundwater. Perchlorate also was positively correlated to nitrate concentrations and agricultural land use. These correlations indicate that mobilization of naturally existing perchlorate, or possibly perchlorate from the application of Chilean nitrate fertilizer, could be a source of the perchlorate detected in groundwater sampled in the MS-SA aquifer system.

The quality of the water in the shallow aquifer system from this study was compared to the quality of water in the public drinking-water aquifer in a previous GAMA Monterey Bay and Salinas Valley (MS-PA) study of the same area. Only the Santa Cruz, Pajaro Valley, and Salinas Valley (MS-SA3) study areas of the MS-SA study unit were included in the comparison. The shallow system was more oxic, and the groundwater more modern than in the public drinking-water aquifer, which was more anoxic and had more pre-modern groundwater. Inorganic constituents were detected at high relative concentrations more frequently in the shallow system than the deeper one. Arsenic and selenium were found at high relative concentrations in a greater proportion of the shallow system than the deeper, public drinking water system. Manganese and iron were found at high relative concentrations

in a greater proportion of the public drinking-water aquifer. Uranium was found at higher relative concentrations in a greater proportion of the shallow system, but at moderate relative concentrations in a greater proportion of the public drinking-water aquifer. Concentrations of arsenic, iron, manganese, and molybdenum are not likely to change as groundwater percolates from the shallow system to the deeper system because there are no anthropogenic sources affecting these constituents. Uranium and selenium concentrations in the primary system could be affected by the higher concentrations in the shallow system, however, because of agricultural practices.

High relative concentrations of nitrate relative concentrations were more than three times greater in the shallow system than in the public drinking-water aquifer. The high concentrations in the shallow system are likely to affect the concentrations in the public drinking-water aquifer, especially in the northern half of the Salinas Valley, because of agricultural practices.

Salinity indicators were detected at high relative concentrations more than three times more frequently in the shallow system than in the public drinking-water aquifer. Elevated TDS and sulfate concentrations in the shallow system resulting from activities at the land surface such as irrigated agriculture could increase concentrations in parts of the public drinking-water aquifer as water from the shallow system percolates down to the public drinking-water.

Organic constituents were detected more frequently in the public drinking-water aquifer than in the shallow system. One reason for this result could be that more of the sites sampled in the public drinking-water aquifer were in urban areas than the sites sampled for the shallow system. Another reason could be that sources of contamination have decreased because of changes at the land surface.

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Appendix 1. Ancillary Datasets

Table 1–1. Data for explanatory factors used for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.

[grMz-m, Mesozoic granitic rocks and metamorphic rocks; km, kilometers; km², square kilometers; na, data not available; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments]

GAMA site identification number	Land use within 500 meters (1,640 feet) of the well (percent)			Land-use classification	Density of septic tanks (tanks/km ²)	Aridity index	Distance to nearest geothermal site (km)	Geology
	Agricultural	Natural	Urban					
Santa Cruz study-area grid sites								
S-MS-SC01	0	100	0	Natural	5.83	0.62	55	TK
S-MS-SC02	0	84	16	Natural	21.42	0.73	47	TK
S-MS-SC03	0	51	49	Natural	34.04	0.86	48	TK
S-MS-SC04	0	91	9	Natural	24.34	0.89	45	TK
S-MS-SC05	0	88	12	Natural	20.16	0.79	44	TK
S-MS-SC06	0	100	0	Natural	27.00	0.68	43	TK
S-MS-SC07	0	16	84	Urban	66.87	0.63	44	TK
S-MS-SC08	0	0	100	Urban	15.32	0.60	43	TK
S-MS-SC09	40	48	13	Mixed	18.90	0.64	42	TK
S-MS-SC10	23	48	29	Mixed	18.90	0.75	41	TK
S-MS-SC11	0	76	24	Natural	19.08	0.71	42	TK
S-MS-SC12	0	100	0	Natural	18.36	0.79	41	TK
S-MS-SC13	0	100	0	Natural	22.53	0.70	35	TK
S-MS-SC14	0	100	0	Natural	18.89	0.66	32	TK
S-MS-SC15	0	100	0	Natural	14.88	0.56	27	TK
Pajaro Valley study-area grid sites								
S-MS-P01	36	26	38	Mixed	37.00	0.50	38	Q
S-MS-P02	0	80	20	Natural	19.85	0.54	36	Q
S-MS-P03	0	70	30	Natural	34.37	0.57	40	Q
S-MS-P04	2	0	98	Urban	29.29	0.55	35	Q
S-MS-P05	0	69	31	Natural	20.16	0.50	30	Q
S-MS-P06	32	67	1	Natural	5.85	0.47	36	Q
S-MS-P07	59	1	40	Agricultural	6.69	0.44	40	Q
S-MS-P08	2	53	45	Natural	28.18	0.41	38	Q
S-MS-P09	24	27	49	Mixed	6.60	0.44	37	Q
S-MS-P10	16	36	48	Mixed	17.84	0.46	33	Q
S-MS-P11	0	60	39	Natural	10.14	0.48	29	Q
S-MS-P12	97	1	2	Agricultural	1.26	0.45	27	Q
S-MS-P13	49	48	4	Mixed	25.05	0.42	30	Q
S-MS-P14	20	50	30	Natural	13.96	0.43	33	Q
S-MS-P15	0	99	1	Natural	18.92	0.45	34	grMz-m

Table 1–1. Data for explanatory factors used for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[grMz-m, Mesozoic granitic rocks and metamorphic rocks; km, kilometers; km², square kilometers; na, data not available; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments]

GAMA site identification number	Land use within 500 meters (1,640 feet) of the well (percent)			Land-use classification	Density of septic tanks (tanks/km ²)	Aridity index	Distance to nearest geothermal site (km)	Geology
	Agricultural	Natural	Urban					
Salinas Valley study-area grid sites								
S-MS-SV01	51	3	46	Agricultural	2.59	0.34	102	Q
S-MS-SV02	11	74	15	Natural	1.00	0.25	91	Q
S-MS-SV03	0	47	53	Urban	13.61	0.43	28	QPc
S-MS-SV04	0	28	72	Urban	15.26	0.40	29	QPc
S-MS-SV05	0	87	13	Natural	3.47	0.39	28	Q
S-MS-SV06	0	18	82	Urban	1.37	0.36	29	TK
S-MS-SV07	69	21	9	Agricultural	0.99	0.33	45	Q
S-MS-SV08	91	0	8	Agricultural	2.44	0.31	39	Q
S-MS-SV09	50	42	7	Agricultural	9.44	0.43	33	Q
S-MS-SV10	61	17	22	Agricultural	0.61	0.23	6	Q
S-MS-SV11	96	3	1	Agricultural	0.65	0.27	5	Q
S-MS-SV12	79	21	0	Agricultural	0.36	0.27	32	Q
S-MS-SV13	0	99	1	Natural	0.16	0.23	80	Q
S-MS-SV14	0	100	0	Natural	0.16	0.23	78	Q
S-MS-SV15	87	8	6	Agricultural	0.57	0.23	54	Q
S-MS-SV16	76	21	2	Agricultural	0.36	0.24	24	Q
S-MS-SV17	82	17	1	Agricultural	0.61	0.25	7	Q
S-MS-SV18	88	8	3	Agricultural	0.92	0.25	18	Q
S-MS-SV19	54	3	43	Agricultural	1.81	0.31	40	Q
S-MS-SV20	94	4	1	Agricultural	2.37	0.32	42	Q
S-MS-SV21	52	47	1	Agricultural	11.62	0.33	44	Q
S-MS-SV22	68	18	15	Agricultural	0.87	0.24	23	Q
S-MS-SV23	85	15	0	Agricultural	0.61	0.22	11	Q
S-MS-SV24	51	7	42	Agricultural	7.87	0.23	10	Q
S-MS-SV25	80	17	3	Agricultural	1.14	0.23	18	Q
S-MS-SV26	47	37	15	Mixed	0.31	0.22	39	Q
S-MS-SV27	62	33	4	Agricultural	0.50	0.23	54	Q
S-MS-SV28	3	66	31	Natural	0.60	0.29	108	Q
S-MS-SV29	35	42	23	Mixed	0.36	0.21	31	Q
S-MS-SV30	87	12	1	Agricultural	2.25	0.22	12	Q

Table 1–1. Data for explanatory factors used for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[grMz-m, Mesozoic granitic rocks and metamorphic rocks; km, kilometers; km², square kilometers; na, data not available; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments]

GAMA site identification number	Land use within 500 meters (1,640 feet) of the well (percent)			Land-use classification	Density of septic tanks (tanks/km ²)	Aridity index	Distance to nearest geothermal site (km)	Geology
	Agricultural	Natural	Urban					
Salinas Valley study-area grid sites—Continued								
S-MS-SV31	86	13	1	Agricultural	0.61	0.22	12	Q
S-MS-SV32	90	9	2	Agricultural	0.77	0.25	27	Q
S-MS-SV33	26	74	0	Natural	11.62	0.34	43	Q
S-MS-SV34	0	34	66	Urban	52.52	0.45	35	grMz-m
S-MS-SV35	0	67	33	Natural	48.30	0.42	37	Q
S-MS-SV36	83	3	14	Agricultural	1.03	0.31	35	Q
S-MS-SV37	11	89	1	Natural	0.77	0.29	30	Q
S-MS-SV38	74	26	0	Agricultural	0.61	0.23	12	Q
S-MS-SV39	33	65	2	Natural	0.77	0.23	117	Q
S-MS-SV40	38	62	0	Natural	0.60	0.23	123	Q
Highlands study-area grid sites								
S-MS-H01	0	100	0	Natural	1.69	0.45	124	TK
S-MS-H02	0	100	0	Natural	2.59	0.47	114	grMz-m
S-MS-H03	47	11	42	Mixed	7.48	0.36	99	Q
S-MS-H04	60	40	0	Agricultural	11.43	0.35	93	QPc
S-MS-H05	0	100	0	Natural	0.97	0.36	78	TK
S-MS-H06	0	45	55	Urban	7.81	0.42	27	TK
S-MS-H07	14	86	0	Natural	0.92	0.37	23	grMz-m
S-MS-H08	2	98	0	Natural	0.99	0.32	15	TK
S-MS-H09	0	100	0	Natural	1.20	0.37	25	TK
S-MS-H10	60	40	0	Agricultural	0.57	0.29	63	Q
S-MS-H11	27	73	0	Natural	0.97	0.25	88	QPc
S-MS-H12	91	8	0	Agricultural	0.60	0.35	111	QPc
S-MS-H13	0	100	0	Natural	0.11	0.39	130	QPc
S-MS-H14	0	100	0	Natural	0.60	0.41	117	QPc
S-MS-H15	0	100	0	Natural	1.14	0.29	99	QPc
S-MS-H16	0	100	0	Natural	1.14	0.28	98	QPc
S-MS-H17	0	100	0	Natural	0.13	0.24	72	QPc
S-MS-H18	93	7	0	Agricultural	0.36	0.23	37	TK
S-MS-H19	10	90	0	Natural	0.77	0.31	31	grMz-m
S-MS-H20	0	100	0	Natural	0.61	0.31	19	grMz-m

Table 1–1. Data for explanatory factors used for grid and tap sites sampled in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[grMz-m, Mesozoic granitic rocks and metamorphic rocks; km, kilometers; km², square kilometers; na, data not available; Q, Holocene alluvial and sand dune deposits; Qpc, Plio-Pleistocene and Pliocene non-marine sediments; TK, Tertiary (Pliocene, Miocene, and Paleocene) marine sediment and Cretaceous metasediments]

GAMA site identification number	Land use within 500 meters (1,640 feet) of the well (percent)			Land-use classification	Density of septic tanks (tanks/km ²)	Aridity index	Distance to nearest geothermal site (km)	Geology
	Agricultural	Natural	Urban					
Highlands study-area grid sites—Continued								
S-MS-H21	0	100	0	Natural	0.36	0.26	38	TK
S-MS-H22	0	100	0	Natural	0.11	0.37	81	QPc
S-MS-H23	0	100	0	Natural	0.44	0.31	96	QPc
S-MS-H24	37	63	0	Natural	0.60	0.23	118	QPc
S-MS-H25	14	86	0	Natural	0.60	0.27	129	QPc
S-MS-H26	0	100	0	Natural	0.60	0.27	124	QPc
S-MS-H27	2	98	0	Natural	0.11	0.33	92	QPc
S-MS-H28	23	77	0	Natural	0.12	0.32	76	TK
S-MS-H29	48	52	0	Natural	0.17	0.32	46	Q
S-MS-H30	0	100	0	Natural	0.30	0.33	21	grMz-m

Table 1–2. Tritium, percentage of modern carbon, and age classification for samples collected from grid sites in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) and the Monterey Bay and Salinas Valley Groundwater Basins study unit (2005), California Groundwater Ambient Monitoring and Assessment Priority Basin Project.

[Conversion factor: 1 tritium unit equals 3.19 picoCuries per liter. Abbreviations: modern, recharged after 1953; mixed, mixture of modern and pre-modern water; pre-modern, recharged prior to 1953; nc, not collected; <, less than; —, not applicable]

MS-SA sites				MS-PA sites			
GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification	GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification
S-MS-H01	<0.13	0.7	Pre-modern	MSMB-01	0.31	nc	—
S-MS-H02	0.47	38	Mixed	MSMB-02	1.4	57	Mixed
S-MS-H03	1.1	81	Mixed	MSMB-03	<0.13	5.4	Premodern
S-MS-H04	<0.13	24	Pre-modern	MSMB-04	0.69	6	Premodern
S-MS-H05	<0.13	5.3	Pre-modern	MSMB-05	1.2	nc	—
S-MS-H06	<0.13	17	Pre-modern	MSMB-06	0.50	nc	—
S-MS-H07	1.0	106	Modern	MSMB-07	0.19	nc	—
S-MS-H08	0.34	22	Mixed	MSMB-08	1.2	nc	—
S-MS-H09	<0.13	14	Pre-modern	MSMB-09	0.50	75	Mixed
S-MS-H10	0.53	83	Mixed	MSMB-10	0.19	nc	—
S-MS-H11	<0.13	0.5	Pre-modern	MSMB-11	0.31	34	Mixed
S-MS-H12	0.84	97	Modern	MSMB-12	<0.13	6	Premodern
S-MS-H13	<0.13	60	Pre-modern	MSMB-13	0.19	74	Premodern
S-MS-H14	<0.13	<0.1	Pre-modern	MSMB-14	0.19	nc	—
S-MS-H15	<0.13	8	Pre-modern	MSMB-15	0.69	nc	—
S-MS-H16	<0.13	53	Pre-modern	MSMB-16	0.31	60	Mixed
S-MS-H17	<0.13	39	Pre-modern	MSMB-17	<0.13	15	Premodern
S-MS-H18	<0.13	28	Pre-modern	MSMB-18	<0.13	57	Premodern
S-MS-H19	1.5	106	Modern	MSMB-19	<0.13	nc	—
S-MS-H20	1.5	109	Modern	MSMB-20	0.82	78	Mixed
S-MS-H21	<0.13	99	Mixed	MSMB-21	<0.13	nc	—
S-MS-H22	0.28	49	Pre-modern	MSMB-22	0.31	82	Mixed
S-MS-H23	0.31	74	Mixed	MSMB-23	<0.13	nc	—
S-MS-H24	<0.13	53	Pre-modern	MSMB-24	0.31	nc	—
S-MS-H25	0.50	95	Modern	MSMB-25	<0.13	nc	—
S-MS-H26	<0.13	11	Pre-modern	MSMB-26	0.41	62	Mixed
S-MS-H27	0.56	74	Mixed	MSMB-27	0.19	nc	—
S-MS-H28	1.5	17	Mixed	MSMB-28	0.50	99	Modern
S-MS-H29	<0.13	71	Pre-modern	MSMB-29	2.8	98	Modern
S-MS-H30	<0.13	50	Pre-modern	MSMB-30	<0.13	81	Premodern

Table 1–2. Tritium, percentage of modern carbon, and age classification for samples collected from grid sites in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) and the Monterey Bay and Salinas Valley Groundwater Basins study unit (2005), California Groundwater Ambient Monitoring and Assessment Priority Basin Project.—Continued

[Conversion factor: 1 tritium unit equals 3.19 picoCuries per liter. Abbreviations: modern, recharged after 1953; mixed, mixture of modern and pre-modern water; pre-modern, recharged prior to 1953; nc, not collected; <, less than; —, not applicable]

MS-SA sites				MS-PA sites			
GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification	GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification
S-MS-P01	0.15	78	Pre-modern	MSMB-31	2.1	65	Mixed
S-MS-P02	<0.13	70	Pre-modern	MSMB-32	0.41	nc	—
S-MS-P03	<0.13	68	Pre-modern	MSMB-33	0.50	55	Mixed
S-MS-P04	1.1	103	Modern	MSMB-34	0.31	nc	—
S-MS-P05	1.9	103	Modern	MSMB-35	2.5	99	Modern
S-MS-P06	0.21	80	Pre-modern	MSMB-36	0.50	nc	—
S-MS-P07	1.9	98	Modern	MSMB-37	<0.13	59	Premodern
S-MS-P08	<0.13	93	Mixed	MSMB-38	0.60	88	Mixed
S-MS-P09	<0.13	82	Pre-modern	MSMB-39	0.31	nc	—
S-MS-P10	1.4	91	Modern	MSMB-40	0.50	75	Mixed
S-MS-P11	<0.13	73	Pre-modern	MSMB-41	3.7	nc	—
S-MS-P12	<0.13	45	Pre-modern	MSMB-42	2.0	nc	—
S-MS-P13	1.3	86	Mixed	MSMB-43	3.2	nc	—
S-MS-P14	<0.13	76	Pre-modern	MSMB-44	2.3	nc	—
S-MS-P15	<0.13	56	Pre-modern	MSMB-45	2.2	94	Modern
S-MS-SC01	0.47	41	Mixed	MSMB-46	2.2	nc	—
S-MS-SC02	<0.13	34	Pre-modern	MSMB-47	<0.13	33	Premodern
S-MS-SC03	1.3	77	Mixed	MSMB-48	1.4	nc	—
S-MS-SC04	0.72	63	Mixed	MSPR-01	2.2	93	Modern
S-MS-SC05	0.50	28	Mixed	MSPR-02	1.4	nc	—
S-MS-SC06	0.21	48	Pre-modern	MSPR-03	<0.13	0.7	Premodern
S-MS-SC07	<0.13	46	Pre-modern	MSPR-04	0.50	nc	—
S-MS-SC08	1.2	66	Mixed	MSPR-05	0.19	nc	—
S-MS-SC09	<0.13	62	Pre-modern	MSPR-06	0.50	nc	—
S-MS-SC10	1.2	87	Mixed	MSPR-07	<0.13	nc	—
S-MS-SC11	1.4	106	Modern	MSPR-08	0.19	49	Premodern
S-MS-SC12	1.3	94	Modern	MSPR-09	<0.13	11	Premodern
S-MS-SC13	<0.13	77	Pre-modern	MSPR-10	<0.13	69	Premodern
S-MS-SC14	<0.13	76	Pre-modern	MSPR-11	<0.13	nc	—
S-MS-SC15	0.43	nc	—	MSSC-01	2.4	nc	—

Table 1–2. Tritium, percentage of modern carbon, and age classification for samples collected from grid sites in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) and the Monterey Bay and Salinas Valley Groundwater Basins study unit (2005), California Groundwater Ambient Monitoring and Assessment Priority Basin Project.—Continued

[Conversion factor: 1 tritium unit equals 3.19 picoCuries per liter. Abbreviations: modern, recharged after 1953; mixed, mixture of modern and pre-modern water; pre-modern, recharged prior to 1953; nc, not collected; <, less than; —, not applicable]

MS-SA sites				MS-PA sites			
GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification	GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification
S-MS-SV01	0.78	43	Mixed	MSSC-02	2.3	nc	—
S-MS-SV02	1.0	82	Mixed	MSSC-03	2.1	nc	—
S-MS-SV03	0.37	66	Mixed	MSSC-04	1.7	67	Mixed
S-MS-SV04	0.25	95	Mixed	MSSC-05	<0.13	39	Premodern
S-MS-SV05	1.4	76	Mixed	MSSC-06	1.4	72	Mixed
S-MS-SV06	1.2	54	Mixed	MSSC-07	0.41	32	Mixed
S-MS-SV07	<0.13	45	Pre-modern	MSSC-08	<0.13	59	Premodern
S-MS-SV08	0.90	56	Mixed	MSSC-09	1.4	nc	—
S-MS-SV09	1.5	104	Modern	MSSC-10	<0.13	24	Premodern
S-MS-SV10	0.72	101	Modern	MSSC-11	<0.13	1.6	Premodern
S-MS-SV11	0.18	82	Pre-modern	MSSC-12	<0.13	nc	—
S-MS-SV12	0.59	67	Mixed	MSSC-13	4.3	nc	—
S-MS-SV13	<0.13	0.8	Pre-modern	MSSV-01	<0.13	9.0	Premodern
S-MS-SV14	<0.13	42	Pre-modern	MSSV-02	2.1	103	Modern
S-MS-SV15	1.4	92	Modern	MSSV-03	2.1	100	Modern
S-MS-SV16	1.4	100	Modern	MSSV-04	0.69	nc	—
S-MS-SV17	0.37	81	Mixed	MSSV-05	2.0	nc	—
S-MS-SV18	1.4	102	Modern	MSSV-06	2.1	99	Modern
S-MS-SV19	0.18	75	Pre-modern	MSSV-07	1.9	103	Modern
S-MS-SV20	0.50	90	Mixed	MSSV-08	2.3	nc	—
S-MS-SV21	<0.13	82	Pre-modern	MSSV-09	2.0	nc	—
S-MS-SV22	1.9	101	Modern	MSSV-10	2.5	nc	—
S-MS-SV23	1.2	100	Modern	MSSV-11	2.7	93	Modern
S-MS-SV24	<0.13	33	Pre-modern	MSSV-12	2.5	nc	—
S-MS-SV25	1.3	102	Modern	MSSV-13	1.6	nc	—
S-MS-SV26	0.81	91	Modern	MSSV-14	1.8	nc	—
S-MS-SV27	1.3	99	Modern	MSSV-15	2.2	nc	—
S-MS-SV28	<0.13	18	Pre-modern	MSSV-16	<0.13	76	Premodern
S-MS-SV29	0.43	79	Mixed	MSSV-17	1.1	nc	—
S-MS-SV30	1.6	112	Modern	MSSV-18	<0.13	17	Premodern

Table 1–2. Tritium, percentage of modern carbon, and age classification for samples collected from grid sites in the Monterey-Salinas Shallow Aquifer study unit (October 2012 to May 2013) and the Monterey Bay and Salinas Valley Groundwater Basins study unit (2005), California Groundwater Ambient Monitoring and Assessment Priority Basin Project.—Continued

[Conversion factor: 1 tritium unit equals 3.19 picoCuries per liter. Abbreviations: modern, recharged after 1953; mixed, mixture of modern and pre-modern water; pre-modern, recharged prior to 1953; nc, not collected; <, less than; —, not applicable]

MS-SA sites				MS-PA sites			
GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification	GAMA site-identification number	Tritium (tritium units)	Modern carbon-14 (percent)	Age classification
S-MS-SV31	1.8	103	Modern	MSSV-19	<0.13	35	Premodern
S-MS-SV32	<0.13	91	Mixed				
S-MS-SV33	<0.13	86	Pre-modern				
S-MS-SV34	<0.13	61	Pre-modern				
S-MS-SV35	0.21	45	Pre-modern				
S-MS-SV36	1.2	104	Modern				
S-MS-SV37	1.7	106	Modern				
S-MS-SV38	1.2	69	Mixed				
S-MS-SV39	0.31	39	Mixed				
S-MS-SV40	0.62	83	Mixed				

Table 1–3. Oxidation-reduction constituents, redox classification, and pH values for samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.[Fe-SO₄, iron or sulfate reducing; mg/L, milligrams per liter; Mn, manganese reducing; Mn-Fe, manganese or iron reducing; na, not available; NO₃, nitrate reducing; NO₃-Mn, nitrate or manganese reducing; µg/L, micrograms per liter; <, less than; —, not applicable]

GAMA site-identification number	Dissolved oxygen (mg/L)	Nitrate as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox main classification (oxic, mixed, anoxic)	Anoxic subclassification	pH (standard units)
S-MS-H01	0.2	<0.039	1.32	33.3	152	Anoxic	Suboxic	7.9
S-MS-H02	0.2	<0.038	2700	3700	1130	Anoxic	Fe-SO ₄	6.9
S-MS-H03	<0.2	0.643	114	<4	185	Anoxic	Mn-Fe	7.2
S-MS-H04	4.3	1.23	1.07	23.2	122	Oxic	—	7.0
S-MS-H05	<0.2	<0.037	3.84	13.1	658	Anoxic	Suboxic	7.5
S-MS-H06	2.1	0.21	2.81	8.5	24	Oxic	—	7.0
S-MS-H07	7.5	0.065	8.02	455	156	Mixed	Fe-SO ₄	6.7
S-MS-H08	6.2	2.52	11.5	95.8	1210	Oxic	—	7.1
S-MS-H09	0.2	0.044	90.3	1360	1750	Anoxic	Fe-SO ₄	6.4
S-MS-H10	<0.2	<0.04	498	28.2	1040	Anoxic	Mn	6.9
S-MS-H11	1	<0.04	15.1	<4	165	Oxic	—	7.8
S-MS-H12	4.2	5.32	1.14	23.6	122	Oxic	—	7.2
S-MS-H13	4.9	<0.04	37.2	870	1080	Mixed	Fe-SO ₄	6.9
S-MS-H14	<0.2	<0.039	43.6	806	1	Anoxic	Fe-SO ₄	6.9
S-MS-H15	0.2	0.75	9.87	<4	40	Anoxic	NO ₃	8.2
S-MS-H16	3.1	3.93	6.54	<4	19	Oxic	—	7.7
S-MS-H17	6.1	9.99	<0.15	<4	14	Oxic	—	7.5
S-MS-H18	4.4	8.64	1.63	12.1	323	Oxic	—	7.4
S-MS-H19	6.3	2.33	1.22	<4.8	27	Oxic	—	6.9
S-MS-H20	5.8	23.5	0.85	<8	85	Oxic	—	7.0
S-MS-H21	<0.2	0.456	82.9	13.5	541	Anoxic	Mn	7.2
S-MS-H22	1	2.12	133	34.6	179	Mixed	Mn	7.0
S-MS-H23	7.1	8.02	<0.15	<4	34	Oxic	—	7.5
S-MS-H24	1.9	1.81	<0.3	10	737	Oxic	—	7.0
S-MS-H25	8.3	7.67	<0.15	<4	18	Oxic	—	7.5
S-MS-H26	5.9	15.4	<0.15	<4	120	Oxic	—	7.6
S-MS-H27	3.1	6.52	4.23	28.2	131	Oxic	—	7.1
S-MS-H28	0.6	<0.04	<0.45	<8	868	Oxic	—	7.0
S-MS-H29	4.8	6.81	0.94	22.9	1320	Oxic	—	7.3
S-MS-H30	5.9	0.13	4.27	<4	103	Oxic	—	7.2

Table 1-3. Oxidation-reduction constituents, redox classification, and pH values for samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.— Continued

[Fe-SO₄, iron or sulfate reducing; mg/L, milligrams per liter; Mn, manganese reducing; Mn-Fe, manganese or iron reducing; na, not available; NO₃, nitrate reducing; NO₃-Mn, nitrate or manganese reducing; µg/L, micrograms per liter; <, less than; —, not applicable]

GAMA site-identification number	Dissolved oxygen (mg/L)	Nitrate as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox main classification (oxic, mixed, anoxic)	Anoxic subclassification	pH (standard units)
S-MS-P01	4.5	1.68	<0.15	<4	34	Oxic	—	7.6
S-MS-P02	7	0.458	<0.15	<4	8	Oxic	—	7.2
S-MS-P03	<0.2	<0.038	33.4	32.3	30	Anoxic	Suboxic	8.1
S-MS-P04	6.9	5.79	1.56	7.6	23	Oxic	—	7.2
S-MS-P05	3.7	5.38	<0.54	6.9	23	Oxic	—	6.0
S-MS-P06	0.5	2.91	<0.15	<4	111	Mixed	NO ₃	7.3
S-MS-P07	6.8	64.3	<0.3	6.8	209	Oxic	—	7.1
S-MS-P08	8	1.19	18	11.7	6	Oxic	—	6.9
S-MS-P09	<0.2	2.14	88.5	13.5	234	Anoxic	NO ₃ -Mn	7.1
S-MS-P10	7.8	11.1	<0.48	17.4	16	Oxic	—	7.4
S-MS-P11	2.2	0.077	5.41	28.3	36	Oxic	—	7.7
S-MS-P12	0.9	0.928	5.35	<4.4	92	Oxic	—	7.6
S-MS-P13	0.6	<0.04	356	68.3	197	Mixed	Mn	7.4
S-MS-P14	1.8	0.196	48.9	6.9	52	Oxic	—	7.5
S-MS-P15	6	1.11	<0.56	<4	8	Oxic	—	7.4
S-MS-SC01	<0.2	<0.04	398	1240	113	Anoxic	Fe-SO ₄	7.2
S-MS-SC02	0.7	0.126	9.32	<4	78	Oxic	—	7.3
S-MS-SC03	0.5	<0.038	1280	1950	368	Mixed	Fe-SO ₄	6.7
S-MS-SC04	<0.2	0.141	427	857	248	Anoxic	Fe-SO ₄	7.0
S-MS-SC05	0.2	<0.038	149	209	138	Anoxic	Fe-SO ₄	7.1
S-MS-SC06	1.7	0.132	2.89	<4	37	Oxic	—	7.5
S-MS-SC07	<0.2	<0.04	44.1	172	32	Anoxic	Fe-SO ₄	7.7
S-MS-SC08	<0.2	<0.039	268	2250	399	Anoxic	Fe-SO ₄	7.4
S-MS-SC09	0.4	0.4	12.4	9.8	107	Anoxic	Suboxic	7.2
S-MS-SC10	5.2	2.68	<0.52	<5.5	24	Oxic	—	6.9
S-MS-SC11	1.3	0.327	27.5	42.3	16	Oxic	—	7.0
S-MS-SC12	0.3	0.233	346	38.5	32	Anoxic	Mn	6.9
S-MS-SC13	0.4	0.677	72.1	15.2	46	Anoxic	NO ₃ -Mn	7.3
S-MS-SC14	<0.2	<0.04	533	207	13	Anoxic	Fe-SO ₄	7.7
S-MS-SC15	<0.2	<0.04	190	137	32	Anoxic	SO ₄	7.4

Table 1–3. Oxidation-reduction constituents, redox classification, and pH values for samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued[Fe-SO₄, iron or sulfate reducing; mg/L, milligrams per liter; Mn, manganese reducing; Mn-Fe, manganese or iron reducing; na, not available; NO₃, nitrate reducing; NO₃-Mn, nitrate or manganese reducing; µg/L, micrograms per liter; <, less than; —, not applicable]

GAMA site-identification number	Dissolved oxygen (mg/L)	Nitrate as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox main classification (oxic, mixed, anoxic)	Anoxic subclassification	pH (standard units)
S-MS-SV01	5.2	7.35	<0.15	<4	32	Oxic	—	7.2
S-MS-SV02	0.3	1.3	0.72	<4	131	Anoxic	NO ₃	7.3
S-MS-SV03	4.1	3.53	<0.34	<4	22	Oxic	—	6.8
S-MS-SV04	0.7	2.36	263	<5.5	22	Mixed	Mn	6.2
S-MS-SV05	6.2	1.46	<0.24	8.4	31	Oxic	—	6.4
S-MS-SV06	6.6	0.164	37.4	31.5	62	Oxic	—	7.1
S-MS-SV07	2.2	0.628	1.24	<8	89	Oxic	—	7.6
S-MS-SV08	1.8	0.442	0.97	19.2	175	Oxic	—	7.4
S-MS-SV09	6.2	18.1	3.54	19.8	51	Oxic	—	6.5
S-MS-SV10	6.1	35.9	<0.16	<5.9	132	Oxic	—	7.0
S-MS-SV11	6	0.208	1.06	10.6	74	Oxic	—	7.6
S-MS-SV12	5.9	4.72	<0.15	<4	83	Oxic	—	7.4
S-MS-SV13	0.4	<0.04	21.8	107	118	Anoxic	Fe-SO ₄	7.7
S-MS-SV14	1.5	0.61	2.87	75.7	574	Oxic	—	7.1
S-MS-SV15	1	1.14	<0.15	<4.3	77	Oxic	—	7.5
S-MS-SV16	3	1.56	<0.27	<4	116	Oxic	—	7.7
S-MS-SV17	6.8	2.5	<0.15	<4	70	Oxic	—	7.5
S-MS-SV18	1.2	12.1	<0.6	<4	179	Oxic	—	7.2
S-MS-SV19	1.4	0.146	5.17	19.7	149	Oxic	—	7.4
S-MS-SV20	0.8	10.2	<0.36	<5.2	114	Oxic	—	7.1
S-MS-SV21	na	13.5	1.14	19	28	Oxic (estimated)	—	6.4
S-MS-SV22	2.3	12.5	<0.15	<4.5	239	Oxic	—	7.2
S-MS-SV23	1.1	8.6	<0.32	<4	185	Oxic	—	7.3
S-MS-SV24	1.1	0.207	<0.43	<4.9	126	Oxic	—	7.5
S-MS-SV25	0.6	10.3	<0.15	<4	126	Oxic	—	7.4
S-MS-SV26	0.3	<0.4	103	73.7	932	Anoxic	Mn	7.0
S-MS-SV27	2.5	0.272	3.89	<4	61	Oxic	—	7.5
S-MS-SV28	2.8	0.349	8.68	21	68	Oxic	—	7.7
S-MS-SV29	4.4	30.3	1.41	<8	350	Oxic	—	7.2
S-MS-SV30	3.2	70.9	<0.45	<12	1430	Oxic	—	7.2

Table 1–3. Oxidation-reduction constituents, redox classification, and pH values for samples from the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued

[Fe-SO₄, iron or sulfate reducing; mg/L, milligrams per liter; Mn, manganese reducing; Mn-Fe, manganese or iron reducing; na, not available; NO₃, nitrate reducing; NO₃-Mn, nitrate or manganese reducing; µg/L, micrograms per liter; <, less than; —, not applicable]

GAMA site-identification number	Dissolved oxygen (mg/L)	Nitrate as nitrogen (mg/L)	Manganese (µg/L)	Iron (µg/L)	Sulfate (mg/L)	Redox main classification (oxic, mixed, anoxic)	Anoxic subclassification	pH (standard units)
S-MS-SV31	4.6	4.83	11.7	<5.3	176	Oxic	—	7.5
S-MS-SV32	4.4	15.6	2.13	10.9	301	Oxic	—	7.1
S-MS-SV33	na	1.11	<0.22	18.8	7	Oxic (estimated)	—	6.6
S-MS-SV34	2.4	0.284	29.1	60.9	7	Oxic	—	7.4
S-MS-SV35	0.3	<0.04	56	162	9	Anoxic	Fe-SO ₄	7.3
S-MS-SV36	9.5	50.2	0.8	33.6	71	Oxic	—	6.6
S-MS-SV37	6.6	3.53	<0.15	<4	27	Oxic	—	6.9
S-MS-SV38	3.7	16.6	5.59	9.1	112	Oxic	—	7.1
S-MS-SV39	<0.2	<0.04	149	127	528	Anoxic	Fe-SO ₄	7.2
S-MS-SV40	4.2	4.88	<0.15	<4	256	Oxic	—	7.0

¹Mixed (oxic-anoxic).

Table 1–4. Information for other explanatory factors evaluated but not used for samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.[km², square kilometers; km, kilometers; LUFT, leaking and formerly leaking underground fuel tank]

GAMA site- identification number	Density of LUFTs (tanks/km²)	Distance to nearest perchlorate source (km)	Nearest oil or gas field (km)	Distance to nearest halite source (km)	Nearest faults (km)
S-MS-H01	0.006	58	15	240	0
S-MS-H02	0.014	72	29	243	2
S-MS-H03	0.009	80	40	254	4
S-MS-H04	0.074	89	35	246	1
S-MS-H05	0.008	102	23	231	2
S-MS-H06	0.124	12	48	109	1
S-MS-H07	0.005	31	33	127	1
S-MS-H08	0.006	66	1	162	3
S-MS-H09	0.013	77	6	173	1
S-MS-H10	0.003	112	5	211	2
S-MS-H11	0.016	100	25	236	7
S-MS-H12	0.003	80	37	240	4
S-MS-H13	0.001	64	24	216	1
S-MS-H14	0.003	81	36	233	7
S-MS-H15	0.007	98	32	244	12
S-MS-H16	0.007	99	31	242	12
S-MS-H17	0.002	117	5	217	9
S-MS-H18	0.001	81	9	181	7
S-MS-H19	0.003	26	28	119	12
S-MS-H20	0.014	43	20	142	2
S-MS-H21	0.001	81	12	181	10
S-MS-H22	0.003	121	17	222	3
S-MS-H23	0.002	107	29	238	12
S-MS-H24	0.001	91	33	226	7
S-MS-H25	0.001	93	20	213	1
S-MS-H26	0.001	90	28	220	2
S-MS-H27	0.002	112	27	234	9
S-MS-H28	0.003	115	14	216	3
S-MS-H29	0.001	85	14	186	10
S-MS-H30	0.014	41	22	140	2
S-MS-P01	0.056	29	22	73	6
S-MS-P02	0.102	25	22	69	3
S-MS-P03	0.500	28	21	64	5
S-MS-P04	0.030	23	22	64	1
S-MS-P05	0.188	20	17	68	1

Table 1-4. Information for other explanatory factors evaluated but not used for samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued[km², square kilometers; km, kilometers; LUFT, leaking and formerly leaking underground fuel tank]

GAMA site- identification number	Density of LUFTs (tanks/km²)	Distance to nearest perchlorate source (km)	Nearest oil or gas field (km)	Distance to nearest halite source (km)	Nearest faults (km)
S-MS-P06	0.084	27	18	75	4
S-MS-P07	0.052	23	20	80	5
S-MS-P08	0.055	21	16	85	7
S-MS-P09	0.052	24	16	81	6
S-MS-P10	0.120	24	12	80	2
S-MS-P11	0.837	20	13	71	1
S-MS-P12	0.020	22	8	76	2
S-MS-P13	0.054	19	8	81	2
S-MS-P14	0.255	21	11	82	1
S-MS-P15	0.026	17	11	87	0
S-MS-SC01	0.033	42	23	63	2
S-MS-SC02	0.094	34	16	59	8
S-MS-SC03	0.119	35	14	56	5
S-MS-SC04	0.041	30	5	49	1
S-MS-SC05	0.078	31	11	55	3
S-MS-SC06	0.024	30	13	57	4
S-MS-SC07	0.164	31	18	61	7
S-MS-SC08	0.263	31	20	63	7
S-MS-SC09	0.024	29	16	59	4
S-MS-SC10	0.024	28	15	58	3
S-MS-SC11	0.024	29	12	55	2
S-MS-SC12	0.056	28	9	52	0
S-MS-SC13	0.030	22	18	59	1
S-MS-SC14	0.030	19	22	63	3
S-MS-SC15	0.071	16	16	67	0
S-MS-SV01	0.015	79	38	253	1
S-MS-SV02	0.008	97	28	240	4
S-MS-SV03	0.019	14	41	114	2
S-MS-SV04	0.019	12	40	113	2
S-MS-SV05	0.047	8	43	110	0
S-MS-SV06	3.081	8	44	107	1
S-MS-SV07	0.043	9	27	94	6
S-MS-SV08	0.047	9	31	103	2
S-MS-SV09	0.018	16	35	113	1
S-MS-SV10	0.005	49	14	143	2

Table 1–4. Information for other explanatory factors evaluated but not used for samples collected from grid and tap sites in the Monterey-Salinas Shallow Aquifer study unit, California Groundwater Ambient Monitoring and Assessment Priority Basin Project, October 2012 to May 2013.—Continued[km², square kilometers; km, kilometers; LUFT, leaking and formerly leaking underground fuel tank]

GAMA site- identification number	Density of LUFTs (tanks/km²)	Distance to nearest perchlorate source (km)	Nearest oil or gas field (km)	Distance to nearest halite source (km)	Nearest faults (km)
S-MS-SV11	0.006	57	6	152	3
S-MS-SV12	0.001	80	1	178	4
S-MS-SV13	0.006	109	15	227	8
S-MS-SV14	0.006	113	12	224	12
S-MS-SV15	0.003	100	3	199	1
S-MS-SV16	0.009	72	7	170	7
S-MS-SV17	0.005	48	15	143	2
S-MS-SV18	0.014	36	28	131	2
S-MS-SV19	0.191	11	30	104	3
S-MS-SV20	1.146	11	28	101	5
S-MS-SV21	0.072	14	22	92	8
S-MS-SV22	0.028	33	32	126	5
S-MS-SV23	0.007	45	19	139	5
S-MS-SV24	0.006	57	5	153	8
S-MS-SV25	0.003	65	5	163	8
S-MS-SV26	0.001	84	9	183	5
S-MS-SV27	0.003	99	3	199	2
S-MS-SV28	0.011	91	41	239	10
S-MS-SV29	0.001	76	7	175	8
S-MS-SV30	0.006	56	7	154	10
S-MS-SV31	0.005	48	15	144	8
S-MS-SV32	0.028	31	33	122	6
S-MS-SV33	0.103	16	20	93	8
S-MS-SV34	0.060	17	12	88	0
S-MS-SV35	0.032	16	14	92	3
S-MS-SV36	0.010	25	27	114	9
S-MS-SV37	0.003	28	30	119	10
S-MS-SV38	0.005	47	16	143	8
S-MS-SV39	0.001	95	30	225	5
S-MS-SV40	0.001	87	33	223	6

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