

Prepared in cooperation with the California State Water Resources Control Board

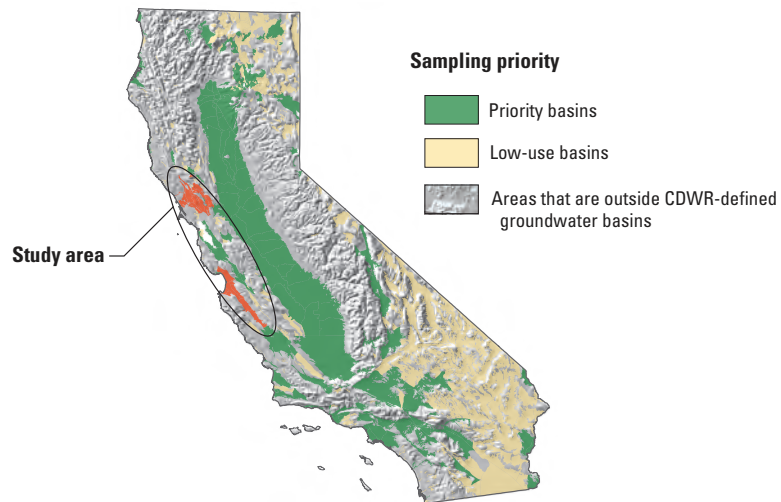
*A product of the California Groundwater Ambient Monitoring and Assessment (GAMA) Program*

## **Variations on a Method for Evaluating Decadal-Scale Changes in the Groundwater Quality of Two GAMA Coastal Study Units 2004–14, California GAMA Priority Basin Project**



Scientific Investigations Report 2018–5088

**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:** Vineyard in Napa Valley, California (Photograph taken by George L. Bennett, U.S. Geological Survey.)

**Back cover:** View from Point Lobos State Natural Reserve, California (Photograph taken by Robert Kent, U.S. Geological Survey.)

# **Variations on a Method for Evaluating Decadal-Scale Changes in the Groundwater Quality of Two GAMA Coastal Study Units 2004–14, California GAMA Priority Basin Project**

By Robert Kent

Prepared in cooperation with the California State Water Resources Control Board

Scientific Investigations Report 2018–5088

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

**U.S. Department of the Interior**

RYAN K. ZINKE, Secretary

**U.S. Geological Survey**

James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2018

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

For an overview of USGS information products, including maps, imagery, and publications, visit <https://store.usgs.gov>.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:

Kent, R., 2018, Variations on a method for evaluating decadal-scale changes in the groundwater quality of two GAMA coastal study units 2004–14, California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2018–5088, 75 p., <https://doi.org/10.3133/sir20185088>.

# Acknowledgments

We thank the following cooperators for their support: The California State Water Resources Control Board, the California Department of Public Health, and the California Department of Water Resources. We especially thank the cooperating well owners and water purveyors for their generosity in allowing the U.S. Geological Survey to collect groundwater samples from their wells.

## Contents

Abstract.....	1
Introduction.....	1
Purpose and Scope .....	2
Descriptions of the Evaluated Coastal Study Units.....	2
North San Francisco Bay Study Unit.....	2
Monterey Bay and Salinas Valley Basins Study Unit .....	2
Methods.....	6
Well Selection .....	6
Sample Collection and Analysis .....	6
Data Processing.....	7
Censored Results .....	8
Difference Thresholds .....	8
Difference Thresholds Set by the GAMA-PBP Replicate Acceptability Criteria .....	9
Difference Threshold Set by Confidence Intervals.....	9
Reporting Levels .....	10
Hypothesis Tests on the Differences.....	10
Additional Factors Considered .....	10
Quality Control .....	11
Field Blanks.....	11
Replicates.....	11
Laboratory Matrix Spikes .....	12
Results .....	12
Water-Quality Indicators .....	13
Nutrients.....	18
Major and Minor Ions and Silica.....	20
Trace Elements.....	31
Isotopic Constituents .....	43
Summary and Conclusions.....	47
Constituents Exhibiting Conclusive Evidence of Step Trends .....	47
Inconclusive Step-Trend Findings.....	49
Comparison of the Three Evaluation Methods .....	50
Implications for Water Managers.....	51
References Cited.....	51
Tables .....	54

## Figures

1. Map showing the study units sampled for the Groundwater Ambient Monitoring and Assessment Priority Basin Project, 2004–14, highlighting the two coastal study units that are the subject of this report.....	3
2. Map showing the North San Francisco Bay study unit of the Groundwater Ambient Monitoring and Assessment Priority Basin Project, the wells sampled in 2004, and the wells resampled in 2014 .....	4
3. Map showing the Monterey Bay and Salinas Valley study unit of the Groundwater Ambient Monitoring and Assessment Priority Basin Project, the wells sampled in 2005, and the wells resampled in 2014 .....	5
4. Graph showing paired results of water temperatures measured in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	13
5. Graph showing paired results of dissolved oxygen measured in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	14
6. Graph showing paired results of field-measured specific conductance of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	14
7. Graphs showing paired results of laboratory-measured specific conductance of groundwater during the collection of paired initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	15
8. Graph showing paired results of field-measured pH of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....	16
9. Graphs showing paired results of laboratory-measured pH of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....	17
10. Graphs showing paired results of carbonate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	18
11. Graphs showing paired results of total nitrogen concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....	19
12. Graphs showing paired results of nitrate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....	20

## Figures—Continued

13. Graphs showing paired results of orthophosphate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....21
14. Graphs showing paired results of calcium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....22
15. Graphs showing paired results of magnesium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....24
16. Graphs showing paired results of potassium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units.....25
17. Graphs showing paired results of sodium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....26
18. Graphs showing paired results of chloride concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....27
19. Graphs showing paired results of iodide concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....28
20. Graphs showing paired results of sulfate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....29
21. Graphs showing paired results of fluoride concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....30
22. Graphs showing paired results of silica concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....32
23. Graphs showing paired results of aluminum concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....33
24. Graphs showing paired results of arsenic concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....34

## Figures—Continued

25. Graphs showing paired results of barium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....35
26. Graphs showing paired results of iron concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....36
27. Graphs showing paired results of lead concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....37
28. Graphs showing paired results of lithium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....38
29. Graphs showing paired results of manganese concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....39
30. Graphs showing paired results of nickel concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....40
31. Graphs showing paired results of selenium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....41
32. Graphs showing paired results of strontium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....42
33. Graphs showing paired results of vanadium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....43
34. Graphs showing paired results of the isotopic ratio of oxygen-18 in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....44
35. Graphs showing paired results of the isotopic ratio of carbon-13 in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....45
36. Graphs showing paired results of tritium activities in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project study units .....46



## Tables

1.	Sample dates, elevations, and construction information for the 50 trend wells that were sampled two times, approximately 9–10 years apart, in the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units.....	54
2A.	Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.....	56
2B.	Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.....	62
2C.	Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.....	68
2D.	Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria: Summary of statistical evaluation results for constituents exhibiting step trends in this report .....	74
3.	Constituents for which one of three circumstances indicate step-trend results are inconclusive.....	75

## Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

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

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

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).  
National Geodetic Vertical Datum of 1929 (NGVD 29).

## 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 in either milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).

Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope ( $^i\text{E}$ ) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Delta notation,  $\delta^i\text{E}$ , the ratio of a heavier isotope of an element ( $^i\text{E}$ ) to the more common lighter isotope of that element, relative to a standard reference material, expressed as per mil.

## Abbreviations and Acronyms

CDWR	California Department of Water Resources
CI	confidence interval
EPA	U.S. Environmental Protection Agency
GAMA	Groundwater Ambient Monitoring and Assessment Program
GAMA PBP	Groundwater Ambient Monitoring and Assessment Program Priority Basin Project
GRAC	replicate acceptability criteria
HAL-US	lifetime health advisory level (USEPA)
MCL-US	maximum contaminant level (USEPA)
MCL-CA	California maximum contaminant level
NFM	National Field Manual (USGS)
NAWQA	National Water-Quality Assessment
NSF	North San Francisco Bay
NWQL	National Water Quality Laboratory (USGS)
PBP	Priority Basin Project
QA	quality assurance
QC	quality control

## Abbreviations and Acronyms—Continued

QSB	Quality Systems Branch (USGS)
SALMON	Monterey and Salinas Valley Basins
SMCL-CA	California secondary maximum contaminant level
SRL	study reporting level
TDS	total dissolved solids
USGS	U.S. Geological Survey
VOCs	volatile organic compounds



# Variations on a Method for Evaluating Decadal-Scale Changes in the Groundwater Quality of Two GAMA Coastal Study Units 2004–14, California GAMA Priority Basin Project

By Robert Kent

## Abstract

Decadal changes in groundwater quality in two study units on the north-central California coast were evaluated by the Priority Basin Project (PBP) of the Groundwater Ambient Monitoring and Assessment (GAMA) Program. Groundwater samples collected from wells during 2004–05 were compared on a pair-wise basis to samples collected from the same wells during 2014. The data set consisted of paired-samples from 50 public supply wells in 2 GAMA-PBP study units (25 wells each in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins), with analytical results for 160 water-quality constituents. Statistical analysis was done on grouped results for the 59 constituents that were detected in at least 10 percent of the samples during either sampling period to evaluate decadal-scale change by a step-trend analysis.

The data for both of the sampling periods were processed three different ways, resulting in three variations of the paired results to be submitted for statistical analyses. The first evaluation method variation processed data only to facilitate comparison of data when one or both of the results was a non-detection. The second and third variations applied the additional requirement that differences between initial and decadal-sample results exceed a defined threshold to prevent small differences from supporting the conclusion of a step trend. One method for setting the difference threshold between initial-sampling and resampling results is based on criteria used by the GAMA-PBP to determine whether or not replicate results are acceptable. The other difference-threshold-setting method uses a calculated confidence interval around each result based on demonstrated analytical variability for the constituents during each sampling period. Finally, constituents for which decadal-scale changes were statistically significant were identified using the Wilcoxon-Pratt signed-rank test on each of the three evaluation method variations.

Step trends were identified by at least 1 of the 3 method variations for 33 constituents. After considering other factors, however, such as water-quality context and the results of quality-control samples, it was concluded that decadal changes were meaningful for 14 constituents in at least 1 of the 2 study units. Constituents for which step trends indicated meaningful increases were dissolved oxygen, total nitrogen, nitrate, orthophosphate, calcium, chloride, sulfate, iron, and lithium. Constituents for which step trends indicated meaningful decreases were temperature, arsenic, lead, the isotopic ratio of carbon-13, and tritium.

## Introduction

The California State Water Resources Control Board implemented the Groundwater Ambient Monitoring and Assessment (GAMA) program to assess California groundwater quality (California State Water Resources Control Board, 2003). Part of the GAMA program is the Priority Basin Project (GAMA-PBP), undertaken in cooperation with the U.S. Geological Survey (USGS; <http://ca.water.usgs.gov/gama/>; Belitz and others, 2003; Kulongoski and Belitz, 2004). The GAMA-PBP is assessing water quality in three ways: (1) status of groundwater quality, (2) understanding of factors that affect groundwater quality, and (3) trends in groundwater quality. The statewide assessments for status and understanding of groundwater quality were done by sequentially sampling more than 2,300 wells in 35 defined “study units” ranging in area from less than 80 square kilometers (km<sup>2</sup>) for the Santa Barbara study unit to more than 40,000 km<sup>2</sup> for the Sierra Nevada study unit. Sampling for the statewide assessment of temporal trends in California groundwater quality is ongoing (Kent and Landon, 2013; Kent and others, 2014; Kent, 2015; Kent and Landon, 2016; Mathany, 2017).

## Purpose and Scope

The purpose of this report is to present variations on a method to identify step trends for water-quality constituents measured in groundwater samples collected during two distinct periods about 10 years apart. Differences were evaluated using a step-trend analysis comparing results of paired samples collected from 50 wells in two coastal GAMA-PBP study units during 2004–05 with those collected in 2014. The method to identify step trends presented here consists of data processing and statistical testing to determine the significance of the measured changes, and it is illustrated using paired sample data from the two sampling periods. The present study builds on methods used to evaluate step trends in “Major Aquifer Studies” by the National Water-Quality Assessment (NAWQA) Project (Rosen and Lapham, 2008; Rupert, 2008; Lindsey and Rupert, 2012). The report is not intended to explore the causative factors leading to the observed changes, and the evaluations are not intended to predict whether the observed changes might continue in the future.

## Descriptions of the Evaluated Coastal Study Units

Groundwater-quality trend assessments are facilitated by grouping study units into regions with relatively similar geologic, climatic, and hydrologic characteristics. The two coastal study units—the North San Francisco Bay study unit and the Monterey Bay and Salinas Valley Basins study unit—are separated by about 160 miles of the north-central California coast (fig. 1), are nearly the same size, and share similar climates, although the geologic and hydrologic characteristics differ. Water-bearing deposits in both study units include Quaternary alluvium. Pliocene volcanic deposits are important in the North San Francisco Bay study unit, however, whereas sandstones are important in the Monterey Bay and Salinas Valley Basins study unit. Note that these differences in geology and hydrology between the two study units limit the usefulness of the grouped study unit evaluations.

### North San Francisco Bay Study Unit

The GAMA-PBP assessed area of the North San Francisco Bay study unit (figs. 1, 2) is nearly 2,600 square

kilometers (km<sup>2</sup>), mostly in Napa, Sonoma, and Marin Counties, and is in the Northern Coast Ranges hydrogeologic province (Belitz and others, 2003). The climate is characterized by warm, dry summers and cool, moist winters, with an average precipitation of 76 centimeters falling primarily during the winter and early spring (Kulongoski and others, 2006). The study unit consists of seven California Department of Water Resources (CDWR)-defined groundwater basins (California Department of Water Resources, 2003). The hydrogeologic settings of the North San Francisco Bay study unit, its groundwater basins, its individual study areas, and groundwater-quality results for the GAMA-PBP wells in the study unit are described by Kulongoski and others (2006). The status of groundwater quality in the primary aquifers in the North San Francisco Bay study unit and an understanding assessment of the natural and human factors affecting groundwater quality in the study unit are provided by Kulongoski and others (2010). Results of 3-year trend sampling in the North San Francisco Bay study unit are provided by Kent and others (2014).

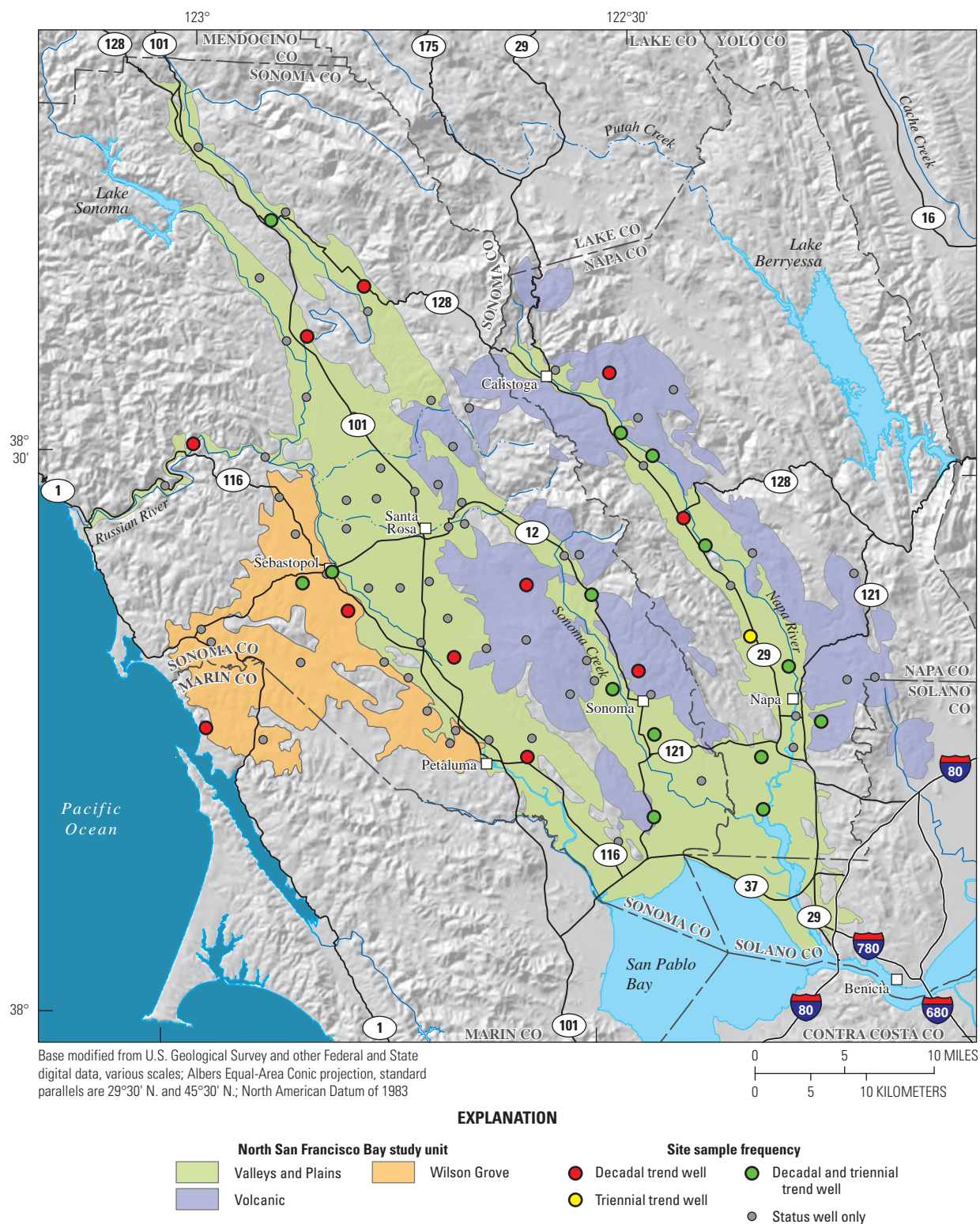
### Monterey Bay and Salinas Valley Basins Study Unit

The GAMA-PBP assessed area of the Monterey Bay and Salinas Valley Basins study unit (figs. 1, 3) is nearly 2,600 km<sup>2</sup> in Monterey, Santa Cruz, and San Luis Obispo Counties and is in the Southern Coast Ranges hydrogeologic province (Belitz and others, 2003). The climate is characterized by warm, dry summers and cool, moist winters, with an average precipitation of 50 centimeters falling primarily during the winter and early spring (Kulongoski and Belitz, 2007). The study unit consists of eight CDWR-defined groundwater basins (California Department of Water Resources, 2003). The hydrogeologic settings of the Monterey Bay and Salinas Valley Basins study unit, its groundwater basins and subbasins, and its individual study areas are described by Kulongoski and Belitz (2007). The status of groundwater quality in the primary aquifers in the Monterey Bay and Salinas Valley Basins study unit and an understanding assessment of the natural and human factors affecting groundwater quality in the study unit are provided by Kulongoski and Belitz (2011). Results of 3-year trend sampling in the Monterey Bay and Salinas Valley Basins study unit are provided by Kent and others (2014).



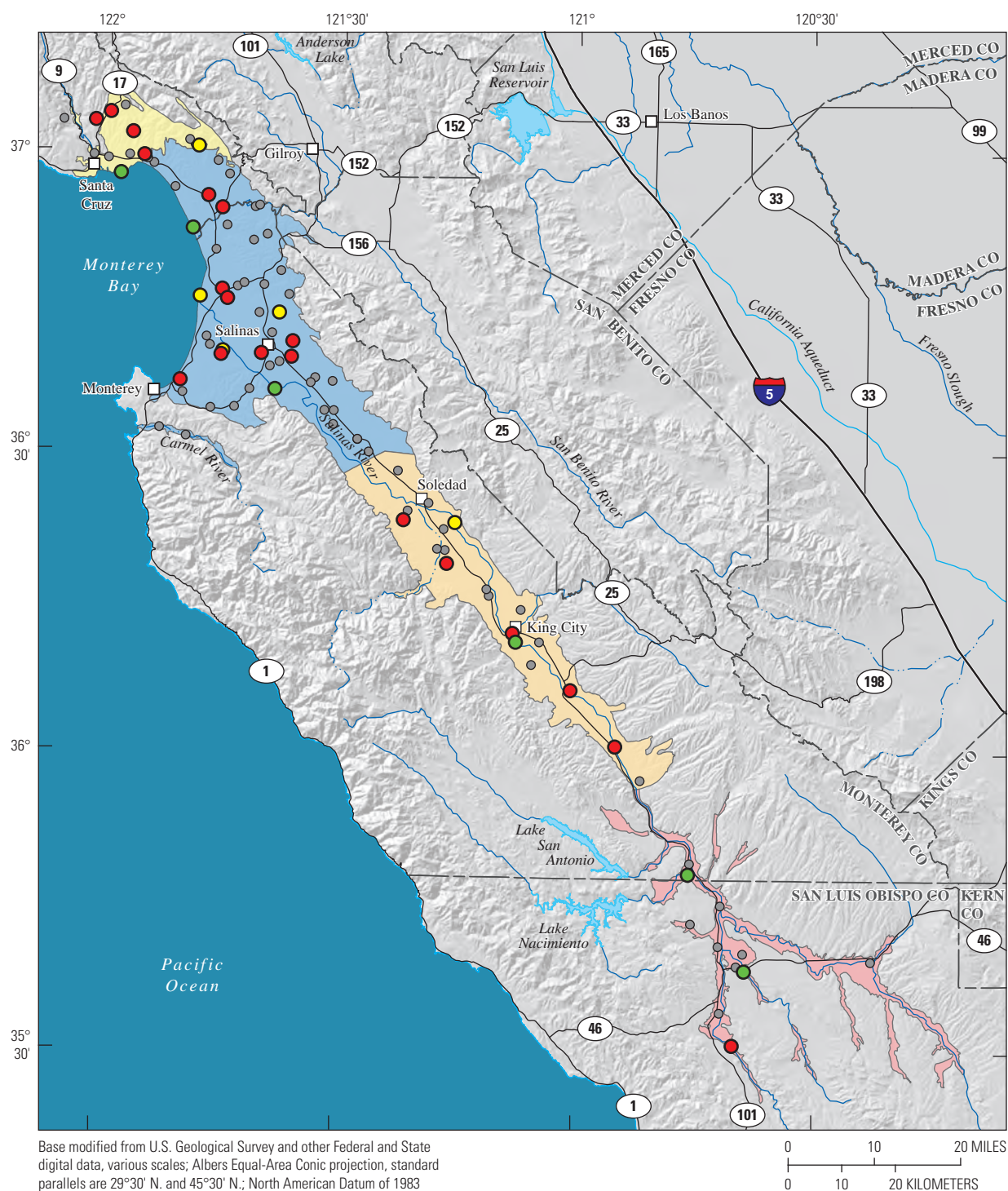
**Figure 1.** Study units sampled for the Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project, 2004–14, highlighting the two coastal study units that are the subject of this report.





**Figure 2.** North San Francisco Bay study unit of the Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project, the wells sampled in 2004, and the wells resampled in 2014.





**Figure 3.** Monterey Bay and Salinas Valley study unit of the Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project, the wells sampled in 2005, and the wells resampled in 2014.

## Methods

This study evaluated changes in the groundwater quality of two coastal GAMA study units using five broad steps: (1) select wells for initial sampling and select a subset of these same wells approximately 10 years later for resampling; (2) collect, process, and have samples analyzed (including quality-control, or QC, samples) for the water-quality constituents of interest; (3) compile the groundwater and QC sample results and perform data verification on the two data sets to characterize any potential bias that could affect the groundwater sample results from one or both of the sampling periods; (4) for all constituents detected in more than 10 percent of the samples for either sampling period, process the quality-assured, paired results iteratively to handle censored data (non-detections) and to ensure that differences between the initial and resampling results meet a sufficient threshold to support a conclusion of a change in groundwater quality; and (5) submit the processed grouped data pairs to a nonparametric hypothesis test on differences between the initial and resampling results. The method builds on methods used by the USGS NAWQA program to identify step trends in groundwater quality (Rosen and Lapham, 2008; Rupert, 2008; Lindsey and Rupert, 2012; Lindsey and others, 2016). Differences between the NAWQA method and the method used in the present study are described in the relevant subsections of this “Methods” section.

### Well Selection

The well networks were designed to provide a spatially unbiased assessment of the quality of untreated groundwater used for public water supplies. The relatively deep production wells were selected by using a spatially distributed, randomized grid-based method (Belitz and others, 2010) to provide statistical representation of the water quality in the primary aquifers in the areas assessed. Wells selected for sampling in this way are referred to as “grid wells.” They are also referred to as “status wells,” because the results from their sampling were used to characterize the status of groundwater quality in the study units (Kulongoski and others, 2010; Kulongoski and Belitz, 2011). Additional wells were sampled to improve understanding of specific groundwater-quality issues. Such wells are referred to as “understanding wells.” For the 2 coastal study units included in this report, 175 status wells were initially sampled: 84 wells in the North San Francisco Bay study unit (Kulongoski and others, 2006) and 91 in the Monterey Bay and Salinas Valley Basins study unit (Kulongoski and Belitz, 2007).

Approximately 10 years after the initial sampling, 50 previously sampled wells (approximately 25 percent of the

number of status wells) were selected for resampling to assess step trends (“trend wells”). Twenty-five wells were selected from each of the two study units. As with the initial selection of status wells, priority for the selection of trend wells was randomly assigned to the status wells; however, other factors were considered during the process of selecting trend wells. An effort was made to maintain spatial distribution and avoid areal clustering of trend wells. Also, preference was given to wells that had already been resampled once to assess trends approximately 3 years after the initial sampling (Kent and others, 2014; Kent and Landon, 2016). In addition, preference was given to wells for which the initial samples were analyzed for the most complete suites of constituents, including organic constituents, inorganic constituents, and selected isotopes. Many initial samples collected from the GAMA-PBP status wells in 2004–05 were not analyzed for inorganic constituents, such as major ions, trace elements, nutrients, or the selected isotopes (Kulongoski and others, 2006; Kulongoski and Belitz, 2007). Status wells that were sampled for these constituents were given preference when selecting trend wells so that a greater number of constituents could be evaluated for step trends. Well identifiers, sample dates, elevations, and depth information for the 50 trend wells are provided in [table 1](#). [Table 1](#) also provides links to the analytical results for the trend wells.

### Sample Collection and Analysis

Samples were collected following modified USGS National Field Manual (NFM; U.S. Geological Survey, variously dated) and modified USGS NAWQA Project (Koterba and others, 1995) sampling protocols. These sampling protocols were followed so that samples would represent groundwater in the aquifer and the potential for contamination would be minimal. Following these protocols also allows for comparison to data collected by the GAMA-PBP throughout California and to other USGS projects in California and the Nation. For detailed descriptions of specific sampling procedures and analytical methods used during initial sampling in the two study units, see Kulongoski and others (2006) and Kulongoski and Belitz (2007). For detailed descriptions of the trend-sample collection (resampling) and analyses, see Kent and others (2014).

Table 1 of the data release (Kent, 2018 <https://doi.org/10.5066/F7GH9GF5>) lists the 160 water-quality indicators and chemical constituents, by class, that were analyzed for most initial and decadal samples. Included were 4 field-measured parameters, 6 laboratory-measured water-quality indicators, 5 nutrient species of nitrogen or phosphorus, perchlorate, 9 major ions, silica, 22 trace elements, 44 volatile organic compounds, 63 pesticide compounds, and 5 isotopic constituents.



Five laboratories were used for chemical analyses of samples collected during the initial-sampling period (Kulongoski and others, 2006; Kulongoski and Belitz, 2007) and the decadal-sampling period (Kent and others, 2014). Most of the analyses were done at the USGS National Water Quality Laboratory (NWQL). The NWQL maintains a quality-assurance (QA) program (Pirkey and Glodt, 1998; Maloney, 2005). The USGS Quality Systems Branch (QSB) maintains independent oversight of QA at the NWQL. The QSB documents bias and variability for the NWQL through the use of blind QA samples and provides periodic data-quality assessment summaries based on the sample results. Step-trend evaluations potentially affected by bias or variability documented in these summaries are discussed in the “Results” and the “Summary and Conclusions” sections.

Initial and decadal-sample data for 50 wells were used for the present study. During decadal sampling, all 160 constituents were measured for samples from all 50 wells, with only a few exceptions. In contrast, initial samples lacked analyses for some constituents, particularly for field-measured parameters and inorganic constituents. For this reason, the number of paired-sample measurements for field-measured parameters, water-quality indicators, nutrients, perchlorate, major ions, trace elements, and carbon isotopes varied from 21 to 50 (Kent, 2018, table 1, <https://doi.org/10.5066/F7GH9GF5>).

Some of the trend wells lacking initial-sample data were resampled approximately 3 years later (Kent and Landon, 2016). Data from 12 wells, resampled in 2007–08, were substituted as initial samples to supplement some of the lacking data for nutrients (11 trend wells), perchlorate (4), major ions and trace elements (6), and carbon isotopes (9). The initial-sample counts provided for these constituents in table 1 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>) include these supplemental data.

During the initial-sampling period, samples were analyzed for 88 volatile organic compounds (VOCs; Kulongoski and others, 2006; Kulongoski and Belitz, 2007). During the trend-sampling period, samples were analyzed for 87 VOCs (Kent and others, 2014). Forty-four VOCs were common to the analyses used during each period and could be evaluated for step trends (Kent, 2018, table 1, <https://doi.org/10.5066/F7GH9GF5>). Samples from all 50 wells in each study period were analyzed for most (42) of these constituents. For 2 constituents—methyl acetate and *tert*-butyl alcohol—only 36 initial samples were analyzed.

During the initial-sampling period, samples were analyzed for 63 pesticide compounds (Kulongoski and others, 2006; Kulongoski and Belitz, 2007). During the decadal-sampling period, samples were analyzed for 80 pesticide compounds (Kent and others, 2014). All of the samples were analyzed for pesticide compounds during both sampling periods, with one exception. The sample bottle for the initial

sample from one well (NSFVOL-06) was broken during transit to the NWQL. The 63 compounds common to the analyses used during each period could be evaluated for step trends (Kent, 2018, table 1, <https://doi.org/10.5066/F7GH9GF5>).

Five isotopes were evaluated for step trends. Nearly all of the samples were analyzed for the stable isotopes of hydrogen and oxygen in water, as wells as for tritium, during both sampling periods. Only 21 of the initial samples from the 50 trend wells were analyzed for the 2 carbon-isotope parameters, however. Carbon-isotope samples collected from an additional 9 trend wells in 2007–08 to evaluate 3-yr trends were used as the initial samples, to make a total of 30 carbon-isotope sample pairs (Kent, 2018, table 1, <https://doi.org/10.5066/F7GH9GF5>).

## Data Processing

The results from initial and decadal sampling for all constituents detected in at least 10 percent of the samples from either sampling period were processed before performing statistical hypothesis tests on the differences between the grouped result pairs in an effort to prevent false detections of step trends. Constituents detected in fewer than 10 percent of the samples were unlikely to have sufficient data to detect step trends, so these constituents were not evaluated for step trends. The NAWQA program imposes a similar restriction on the number of statistical evaluations and considers constituents for which there are fewer than 10 untied, paired results “insufficient data”; constituents with insufficient data are not submitted to the statistical test (Lindsey and others, 2016). Data processing for the present study was done to achieve two objectives. The first objective was to manage censored results so that the magnitude of differences between sample pairs that included a censored result (reported only as less than the reporting level) was not overestimated. The second objective was to establish minimum thresholds for the differences between the paired results so that small differences due to analytical variability would not support the conclusion of a step trend. An example of the procedure used for processing the data for each constituent is provided in table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>), an Excel workbook using the constituent lead as an example. The Excel workbook processes the input variables for each trend well. The input variables consist of the initial and 10-year sampling results for the constituent, the result-specific reporting levels, the effective study reporting levels (when applicable), and the standard deviations and relative standard deviations determined by replicate samples collected during each sampling period. In the table, the formulas used to process the input variables are given in row 2 for the first trend well (MSSC-06). The data for this well are processed in row 3.

## Censored Results

Many sample results in this study, especially those for VOCs and pesticide compounds, were expressed as non-detections and were censored. That is, they were expressed as less than their reporting level. Conservative approaches were used to process censored data to avoid overestimating observed changes. In cases where the initial and decadal results were both censored, the results were considered analytically identical (tied), regardless of whether or not the two results were censored at the same reporting level. In cases where only the result for one of the two samples from a well was censored, the reporting level in effect at the time of analysis was substituted for the censored result so that the measured difference between the censored and uncensored results was minimized. For example, if the result for one of the two samples was 5 milligrams per liter (mg/L) and the result for the other was less than 1 mg/L, the difference between these sample results would be calculated as 4 mg/L, even though the difference could be as great as 5 mg/L if the constituent was absent in the sample with the censored result. In cases where an uncensored (detected) result was less than the reporting level of the censored result, however, they were considered tied, just as if both results were censored, because it would be impossible to discern a difference between them. The steps for processing censored data in this way are illustrated in columns K through M of table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>). The data in columns K and L are submitted to the hypothesis tests to determine step trends based on differences with no threshold requirement.

An alternative approach used by Bexfield (2008), Barlow and others (2012), Lindsey and Rupert (2012), Lindsey and others (2016), and other researchers substitutes a uniform concentration value less than the lowest detected concentration for all results not detected by the laboratory. This is the approach used by the NAWQA program (Lindsey and others, 2016). Although this approach overcomes difficulties associated with variable laboratory reporting limits, it can overestimate the true difference between paired results. The true concentration of a constituent result censored by a relatively high reporting limit could actually be closer to that relatively high reporting limit than to the lower, substituted value.

The potential difference overestimation could lead to perceived differences in paired results even though, for practical purposes, they are not different. When a censored result is paired with a detected result, the censored result is perceived to be the lesser of the two results because of the substitution. This is true even if the detected result is a concentration less than the reporting limit of the censored result. For example, if a constituent concentration of 0.003 micrograms per liter ( $\mu\text{g/L}$ ) is paired with a censored result of less than 0.007  $\mu\text{g/L}$ , the censored result is perceived

to be less than the detected result, even though the two results are consistent, because it would be substituted with a value lower than any detected result.

## Difference Thresholds

Difference thresholds were set so that small differences between results of the initial and decadal samples as a result of analytical variability would not support a conclusion that a step trend had occurred. Two methods were used to set difference thresholds. Both methods were based on results from replicate quality-control samples and distinguished results with low concentrations from results with high concentrations relative to the reporting limits for each constituent. For purposes of these evaluations, a low concentration was less than five times the reporting limit, and a high concentration was greater than or equal to five times the reporting limit. This result concentration boundary between low and high concentrations of five times the reporting level has been used by GAMA-PBP since 2009 for evaluating replicate results (Densmore and others, 2009). It is based on the observation described by Mueller and Titus (2005) that “Variability over a large range of concentrations can be approximated by dividing this range into segments over which either the standard deviation or the relative standard deviation are reasonably constant” (Anderson, 1987). The steps for processing the sample-pair data to categorize the concentrations as low or high are illustrated in columns N through P of table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>).

Other researchers apply no difference threshold. The justification for that approach could be that the random error associated with the results is expected to be expressed equally as slight positive or slight negative bias, and step-trend signals overcome such “noise” because the nonparametric statistical test assigns higher ranks to greater differences. Such an approach fails to take into consideration factors causing small analytical biases, such as changes in analytical methods over time and short-term laboratory issues. Short-term bias can affect the outcome of the statistical evaluation because a predominant number of the small (analytically identical) differences would be in just one direction.

Results for constituents for which step trends were indicated, but short-term analytical bias was documented by the QSB, were subjected to additional evaluation before concluding that step trends had occurred. Data collected during the period(s) affected by short-term analytical bias were adjusted by the magnitude of bias estimated by the QSB. The hypothesis tests on the differences between the grouped results were repeated with the adjusted data to see if the bias could have affected the outcome of the tests. If a step trend was no longer indicated after performing the test on the adjusted data, the step-trend finding was considered inconclusive.

## Difference Thresholds Set by the GAMA-PBP Replicate Acceptability Criteria

The first method for setting the difference threshold was based on methods used by the GAMA-PBP to determine whether the replicate results are acceptable (Kent and others, 2014, p. 148). This is not to say that the GAMA-PBP deems any results “unacceptable.” In cases where replicate results indicated high variability for a constituent during a study, mention of that high variability is included in reports prepared for that study. The GAMA-PBP replicate acceptability criteria (GRAC) was used to define high variability. The GRAC threshold-setting method asserts that if two results are similar enough to constitute a replicate that represents variability that is acceptable for project objectives, the small difference between them should not support the conclusion that there is a trend. The GAMA-PBP replicate results were considered acceptable (sufficiently similar) for low constituent concentrations if the standard deviation for the replicate pair was less than one half of the greater of the two reporting limits at the time of the analyses. For high concentrations (greater than five times the reporting limit), replicate results were acceptable if the relative standard deviation (also known as the coefficient of variation) for the replicate pair was less than 10 percent. When the difference between paired sampling results did not exceed the applicable threshold for the water-quality constituent in question, the two sample results were considered analytically identical, and each result was substituted with the sample-pair median so that a zero difference was indicated for that sample for the purpose of group tests on differences. The steps for processing constituent sample pairs for difference thresholds based on the GAMA-PBP replicate acceptability criteria (GRAC) are illustrated in columns Q through T of table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>). Results in columns R and S are submitted to the hypothesis tests to determine step trends.

Difference thresholds, set by GRAC, were calculated as described for all of the evaluated water-quality constituents, except for pH, carbon-14 (in percent modern carbon), and the isotopic ratios of hydrogen and oxygen in water. The concepts of detection level and reporting limit are not relevant for the measurements of pH, carbon-14, or the isotopic ratios of hydrogen and oxygen in natural water. Because of this, some modifications were made to calculate difference thresholds for these constituents. The manufacturer of the field meters used by the GAMA-PBP for the measurement of pH, specifies precision is within 0.2 standard pH units (<http://www.ysi.com/productsdetail.php?556MPS-21>). Because this level of precision implies that it would be possible for one of the two paired results to be as much as 0.2 units greater than the true value and the other to be as much as 0.2 units less than the true value, the difference threshold applied for field and laboratory-measured pH was 0.4 standard pH units. The three laboratories that analyzed samples for carbon isotopes provided estimates

of counting error in their measurements of carbon-14. The difference threshold for carbon-14 pairs was the greatest estimated error for the two results of percent modern carbon. No estimated error nor uncertainty was provided by the Reston Stable Isotope Laboratory for the results for isotopic ratios of hydrogen and oxygen in water. Therefore, the difference threshold between initial-sampling and resampling results for these isotopic ratios was set at a relative standard deviation greater than or equal to 10 percent.

## Difference Threshold Set by Confidence Intervals

The second method for setting the difference threshold between initial-sampling and resampling results, the confidence interval (CI) method, uses the variability between replicate samples collected during initial and decadal-sampling periods for each constituent to estimate the (period specific) uncertainty for each sample. A 95-percent confidence interval was used for each result, based on comparisons of actual replicates collected by the GAMA-PBP. The CI difference threshold was exceeded if confidence intervals around the initial and decadal-sample results did not overlap. Similar to the GRAC difference-threshold-setting method, this CI method used a two-tiered approach to establish difference thresholds for each result. The appropriate confidence interval was selected on the basis of result concentration relative to the reporting level. Again, for purposes of this evaluation, a low concentration was less than five times the reporting limit. For low concentrations, the CI was calculated using the following formula (Mueller and Titus, 2005):

$$CI = Result \pm Z_{(1-\alpha)} \bullet SD_{replicates} \quad (1)$$

where

<i>Result</i>	is the reported analytical result for the constituent evaluated,
$Z_{(1-\alpha)}$	is the two-tailed z-score (1.96 for the 95 percent CI), and
$SD_{replicates}$	is the mean standard deviation of replicate result pairs.

For high constituent concentrations, the CI was calculated using the following formula (Mueller and Titus, 2005):

$$CI = Result \pm Z_{(1-\alpha)} \bullet Result \bullet RSD_{replicates} / 100 \quad (2)$$

where

<i>Result</i>	is the reported analytical result for the constituent being evaluated,
$Z_{(1-\alpha)}$	is the two-tailed z-score (1.96 for the 95 percent CI), and
$RSD_{replicates}$	is the mean relative standard deviation of replicate result pairs.



The steps for processing constituent sample pairs for difference thresholds based on confidence intervals are illustrated in columns U through AJ in table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>). First, two separate confidence intervals were calculated for each result: one for the case that the concentration was categorized (column P) as low (columns U through X), another for the case that the concentration was categorized as high (columns Y through AB). In cases when confidence intervals for initial results overlapped confidence intervals for 10-year trend results, both results were replaced with their median value so that the results were considered tied (columns AC through AF). The difference threshold is not met for this method if the confidence intervals overlap. Finally, the applicable results, determined by whether the concentrations were categorized as low or high (column P), are applied (columns AG and AH) for submission to the hypothesis tests to determine step trends.

Similar to what was done with the GRAC difference-threshold-setting method, modifications were made to calculate confidence intervals for pH, carbon-14, and the isotopic ratios of hydrogen and oxygen in water. Because the concepts of detection level and reporting limit are not relevant for these constituents, the confidence intervals were calculated using only the high-concentration formula based on relative standard deviations.

## Reporting Levels

Reporting levels were used for both difference-threshold-setting methods described earlier. In the 10 years between sampling periods in this study, reporting levels at the laboratories changed for many of the constituents. If the reporting levels changed, the greater of the two reporting levels was used for the purpose of determining the threshold.

The GAMA-PBP has periodically evaluated the detections of constituents in project blank samples to define threshold concentrations above which one can be reasonably certain that detections in groundwater samples were not the result of contamination (Olsen and others, 2010; Fram and others, 2012; Davis and others, 2014). Based on such threshold concentrations, the program established study reporting levels (SRLs), which are used to censor results at concentrations sometimes greater than the laboratory reporting levels. Results at concentrations less than an established SRL are published in GAMA-PBP reports as less than or equal to the concentration reported by the laboratory. In this way, results censored by SRLs were treated differently than results censored by laboratory reporting levels, because the result was considered a range from zero to the detected concentration, rather than from zero to the reporting level. The application

of SRLs is illustrated in columns E and I in table 2 of the data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>).

## Hypothesis Tests on the Differences

After processing the data in this way, a Wilcoxon signed-rank test with a modification proposed by Pratt (1959) was used to compare the final paired results for each evaluated constituent to determine whether or not there was a step trend. The Wilcoxon signed-rank test is a nonparametric alternative to a paired t-test that is not dependent upon data distribution (Helsel and Hirsch, 2002). It is used to test whether the median difference between paired observations equals zero (null hypothesis). The absolute values of the differences are ranked, so that the relative magnitudes and the relative number of changes in each direction (increases or decreases) are both taken into account. When there is no difference between paired results, the traditional Wilcoxon signed-rank test discards that pair before the evaluation. Data used for the present study included many pairs with zero differences because of the prevalence of censored results (non-detections) and the imposed requirement that differences exceed the previously defined thresholds. The Wilcoxon signed-rank test with the modification proposed by Pratt (1959) was preferred for this study because it ranks all of the differences, including the zero differences, although it only uses the non-zero differences to calculate a  $p$  value. A trend was considered detected at a significance level greater than or equal to 95 percent (attained significance level,  $p=0.05$ ). The NAWQA program evaluates step trends with this statistical test for the 24 parameters assessed in common with this study, but applies a less conservative significance level of  $p=0.1$  (Lindsey and others, 2016).

## Additional Factors Considered

In recognition of the need to be conservative in determining trends when the evidence is limited to groups of paired data, additional factors were considered. Step-trend findings for a constituent were deemed inconclusive under any one of the following three circumstances: (1) analytical bias was documented by the USGS Quality Systems Branch (QSB) during one or both sampling periods, and, when the data were adjusted for the bias, the step trend was no longer statistically significant; (2) the step-trend finding was not consistent with the evaluated results of a different, generally correlated, water-quality constituent; and (3) the concentrations of the constituent for which the step trend was indicated were negligible relative to their potential effect on groundwater quality.

## Quality Control

The results from quality-control samples collected during each sampling period were evaluated for constituents detected in at least 10 percent of the samples during either sampling period to determine the extent to which analytical bias or variability could have affected step-trend findings. Three types of quality-control samples—field blanks, replicates, and spikes—were collected around the times of initial and decadal sampling. Replicate results were further used to calculate confidence intervals around the results for one of the two methods described previously to establish difference thresholds. The GAMA-PBP quality-control results are presented in tables 10, 11, 12, and 13 of the accompanying data release (Kent, 2018, <https://doi.org/10.5066/F7GH9GF5>) and discussed in the “Results” section of each of the potentially affected constituents. The periodic data-quality assessment summaries provided by the QSB provided an additional quality control used for this study. Step-trend evaluations of constituents potentially affected by bias or variability documented in these summaries were repeated after adjusting data by the bias estimated by the QSB. Results for these repeated evaluations are included in the “Results” section, and their implications are discussed in the “Summary and Conclusions” section. Quality-control results for constituents detected in less than 10 percent of the samples during both sampling periods are not presented in this report.

## Field Blanks

Field blanks were collected to assess inadvertent contamination (positive bias) of samples during collection, processing, transport, and analysis. Certified clean blank water was pumped through the sampling equipment (fittings and tubing) used to collect groundwater samples; then, it was processed and transported using the same protocols used for the groundwater samples. Field blanks were collected during both sampling periods for all constituents evaluated for step trends, except for the field-measured parameters (water temperature, dissolved oxygen, specific conductance, and pH) and the isotopes. Only the field blanks associated with sampling of the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units were used to evaluate positive bias during the initial-sampling period. For the initial-sampling period, the number of field-blank samples collected for each of the evaluated constituents ranged from 4 (alkalinity) to 22 (organic constituents). During the decadal-sampling period, field-blank samples collected for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units, as well as for an additional nine study units, were evaluated to provide a similar number of field-blank samples to that of the initial-sampling period. This was necessary because only about 25 percent of the wells sampled during the initial-sampling period were resampled for trends,

with a correspondingly lower number of quality-control samples collected for each study unit. Decadal-sampling was done in the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units from August to November 2014. The first and last field-blank samples evaluated for the decadal-sampling period were collected in January 2014 and May 2016, respectively. Sample results and summary statistics for the field-blank samples evaluated are provided in the data release (Kent, 2018, tables 10 and 13, <https://doi.org/10.5066/F7GH9GF5>). The summary statistics for field-blank samples include, by constituent and sampling period, the number of field blanks collected, the number of field blanks with a detection of the constituent, the maximum concentration detected in a field blank, and the minimum concentration detected in a groundwater sample used to evaluate step trends. In cases where there were no field-blank detections for a constituent, or where the maximum concentration of the constituent detected in a field blank was small relative to the minimum concentration detected in a groundwater sample, it was assumed that inadvertent contamination was not a source of positive bias, which could have contributed to the false finding of a step trend for that constituent.

## Replicates

Sequential replicate samples were collected to assess variability that can result from the processing and analyses of the constituents. For the present study, replicate results were also used to calculate the standard deviations and relative standard deviations for each constituent so that confidence intervals for the CI difference thresholds could be established. Replicates were collected during both sampling periods for all constituents evaluated for step trends, except for the field-measured parameters (water temperature, dissolved oxygen, specific conductance, and pH). Replicates of specific conductance and pH measured at the NWQL were evaluated. Replicates evaluated for the initial-sampling period included those collected during sampling of the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units, along with those collected during the sampling of an additional study unit (the Upper Los Angeles Basin study unit), which was sampled between sampling the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units.

Replicates evaluated for the decadal-sampling period included replicates collected for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units, as well as for an additional nine study units (Kent, 2018, table 11, <https://doi.org/10.5066/F7GH9GF5>). Three of the additional decadal-trend study units contributing replicates for evaluation during this study were sampled before sampling for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units. The three additional study units were the Northern San Joaquin Basin, the Southern Sacramento Valley, and the San Diego Drainages study units.

Six of the additional decadal-trend study units contributing replicates for evaluation during this study were sampled after sampling for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units. The six additional decadal-trend study units were the Cascade Range and Modoc Plateau, the Klamath Mountains, the Southeast San Joaquin Valley, the Kern County Subbasin, the Central Eastside San Joaquin Basin, and the Santa Barbara study units. Replicates were evaluated from the additional study units for each study period to improve the standard deviation and relative standard deviation estimates used for the confidence-interval difference thresholds. The first and last replicate samples evaluated for the decadal-sampling period were collected in January 2014 and April 2016, respectively. Only those replicate pairs for which the constituent was detected in both samples were used to calculate standard deviations and relative standard deviations, because these could be underestimated if replicate pairs for which the constituent was undetected in one or both samples was used. Individual standard deviations and relative standard deviations were calculated for each of the two sampling periods. The summary statistics for replicate samples include, by constituent and sampling period, the total numbers of replicates and the numbers of replicates with the constituent detected in both samples for each sampling period along with the standard deviations and relative standard deviations calculated from these replicates (Kent, 2018, table 13, <https://doi.org/10.5066/F7GH9GF5>).

## Laboratory Matrix Spikes

Laboratory matrix spikes are replicate samples to which the laboratory adds known concentrations of a constituents of analytical interest to assess bias (positive or negative) caused by characteristics of the groundwater matrix. Results from laboratory matrix spikes are evaluated against corresponding environmental sample results to calculate a percentage recovery. During this study, laboratory matrix spikes were only used for volatile, organic, and pesticide compounds. Evaluations and statistical summaries are only presented for the five volatile organic compounds and three pesticide compounds detected in at least 10 percent of the initial or decadal samples (Kent, 2018, tables 12 and 13, <https://doi.org/10.5066/F7GH9GF5>).

Only the laboratory matrix spikes associated with sampling of the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units were used to evaluate positive and negative bias during the initial-sampling period. Laboratory matrix spikes evaluated for the decadal-sampling period included those collected for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units, as well as for an additional nine study units (Kent, 2018, table 12, <https://doi.org/10.5066/F7GH9GF5>). Two

of the additional decadal-trend study units contributing laboratory matrix spikes for evaluation during this study were sampled before sampling for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units. These were the Southern Sacramento Valley and the San Diego Drainages study units. The other seven additional decadal-trend study units contributing laboratory matrix spikes for evaluation during this study were sampled after sampling for the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units. These were the San Fernando-San Gabriel, the Western San Joaquin Valley, the Southeast San Joaquin Valley, the Kern County Subbasin, the Central Eastside San Joaquin Basin, the Santa Barbara, and the Southern Sierra study units. The summary statistics for laboratory matrix-spike samples include, by constituent and sampling period, the numbers of laboratory matrix spikes evaluated to represent each sampling period along with the mean, median, minimum, and maximum percentage recoveries for the constituents of interest (Kent, 2018, table 13, <https://doi.org/10.5066/F7GH9GF5>).

## Results

Of the 160 water-quality constituents that were analyzed both in initial and in decadal samples, 59 were detected in at least 10 percent of the samples during either period (Kent, 2018, table 1, <https://doi.org/10.5066/F7GH9GF5>). Analytical results for initial and decadal samples, as well as for other samples collected at the trend wells, are linked to the USGS station identification numbers in [table 1](#). Some of the additional results for these trend wells are from samples that were collected to evaluate 3-year trends (Kent and others, 2014; Kent and Landon, 2016) and groundwater quality in shallow aquifers (Goldrath and others, 2016). Some of the data collected to evaluate triennial trends were used to supplement the initial-sample data ([table 1](#)).

The 59 constituents detected in at least 10 percent of initial or decadal samples were evaluated for step trends by processing the data and applying the statistical tests as described in the “[Methods](#)” section. [Table 2A](#) gives the results of 3 step-trend test methods applied to the results of the 2 study units combined for each of the 59 constituents: (1) no difference threshold applied, (2) the difference threshold established by the GAMA replicate acceptability criteria (GRAC) applied, and (3) the difference threshold established by confidence intervals (CI) applied. [Tables 2B](#) and [C](#) give the same types of results from the step-trend tests for the individual study units, North San Francisco Bay (NSF) and the Monterey and Salinas Valley Basins (SALMON). [Table 2D](#) summarizes the findings provided in [tables 2A](#), [B](#), and [C](#).



Step trends were identified by at least 1 of the evaluations in at least 1 of the 2 study units or in the combined study units for 33 of the 59 constituents (table 2). Step trends were indicated for more constituents when no difference threshold was applied (27 constituents) than when the GRAC (15 constituents) or the CI (23 constituents) difference threshold was applied. The CI difference threshold could not be applied to 11 of the constituents, however, because it was not possible to calculate confidence intervals for them (table 2). Replicate samples for the five field-measured parameters of air and water temperature, dissolved oxygen, specific conductance, and pH were not collected. Six of the evaluated constituents—thallium, carbon disulfide, methyl-*tert*-butyl ether (MTBE), tetrachloroethene (PCE), trichloroethene (TCE), and simazine—were not detected in both samples of the replicated pairs during the decadal-sampling period. Statistical analyses of the results for all 59 constituents detected in at least 10 percent of initial or decadal samples are presented in tables 2A, B, and C. Only the 33 constituents for which step trends were indicated by at least 1 of the evaluations are discussed.

One-to-one plots showing initial and trend results are presented for each of the 33 constituents in the “Results” sections that follow. Data point symbols that lie close to the one-to-one line indicate no step trend. Data points below the one-to-one line indicate a decrease in the decadal sample compared to the initial sample, and those above the line indicate an increase. Relevant findings from quality-control results, including from the USGS Quality Systems Branch (QSB) data-quality assessment summaries, are presented and discussed in the “Results” section for each potentially affected constituent.

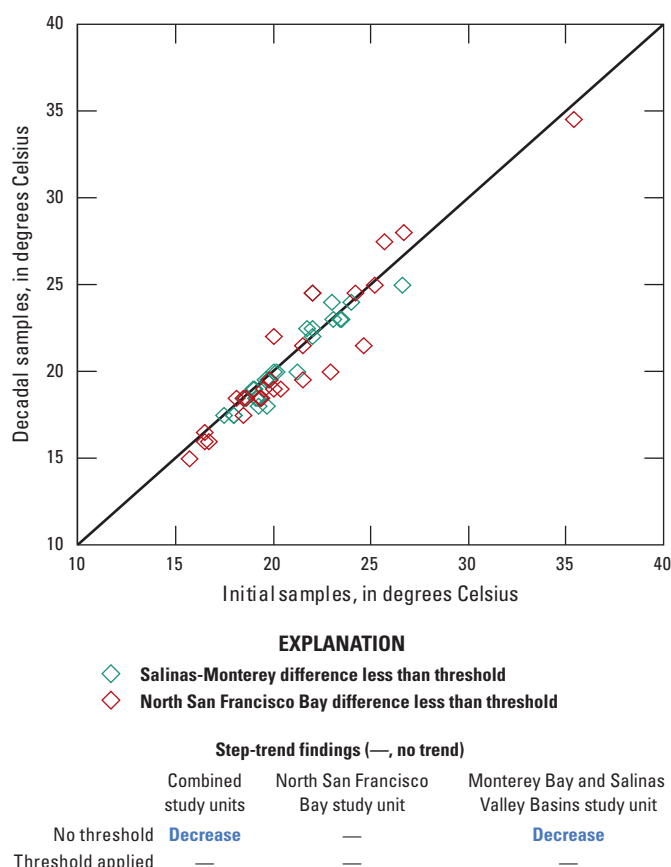
Results for constituents that did not exhibit step trends by any of the evaluations are not discussed. The lack of step trends for the five volatile organic compounds (VOCs) and three pesticide compounds with sufficient detection frequency to be evaluated is notable (table 2). A national evaluation of decadal trends has evaluated all of these compounds, except carbon disulfide, for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Step trends were found in fewer than 10 networks for each of the VOCs, chloroform, PCE, TCE, and MTBE. More step trends were found for the pesticide compounds, however. Atrazine increased in six networks and decreased in seven of the networks. Simazine increased in seven networks and decreased in two of the networks. The herbicide degradate, 2-Chloro-4-isopropylamino-6-amino-s-triazine (deethylatrazine) increased in 17 networks and decreased in 6 of the networks.

## Water-Quality Indicators

The water-quality indicators that were evaluated for step trends were water temperature, dissolved oxygen, specific conductance, total dissolved solids, pH, alkalinity, bicarbonate,

and carbonate. Step trends were evaluated for specific conductance and pH measurements collected both in the field and at the NWQL. Step trends were found for at least one of the study units or the combined study units by at least one of the evaluation methods for water temperature, dissolved oxygen, specific conductance, pH, and carbonate (table 2).

A step trend was indicated for decreased temperature in groundwater from the combined study units and the SALMON study unit when no difference threshold was applied, but not when the GRAC difference threshold was applied (tables 2A, C, D; fig. 4). Differences in water temperature did not exceed the GRAC difference threshold for any of the trend wells. The few wells where groundwater temperatures increased in the SALMON study unit were located in the central part of the Monterey Bay study area. No spatial pattern was observed for the few NSF wells where groundwater temperatures increased.

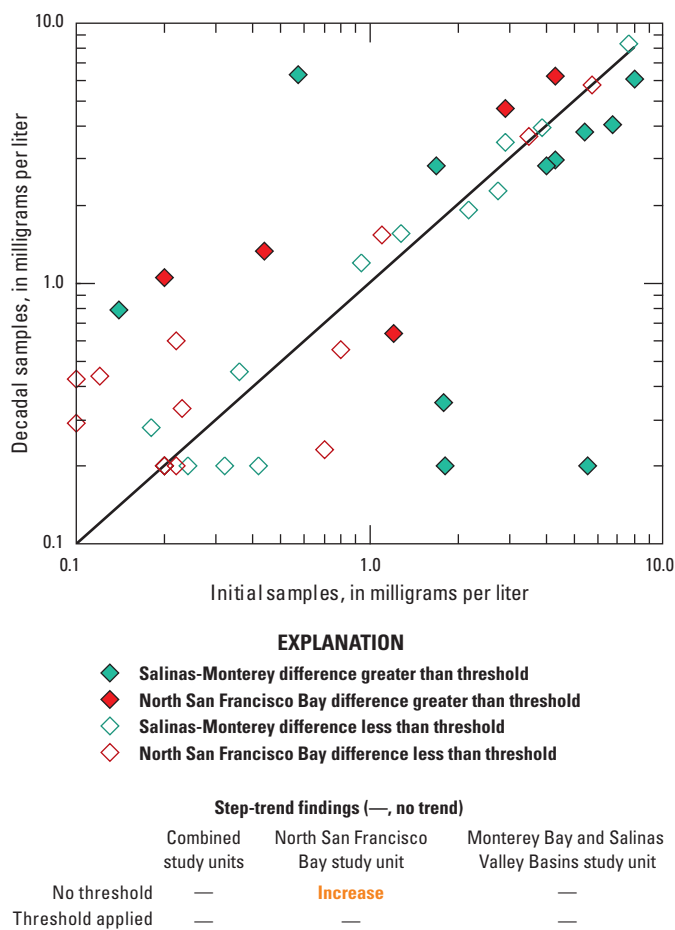


**Figure 4.** Paired results of water temperatures measured in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units.

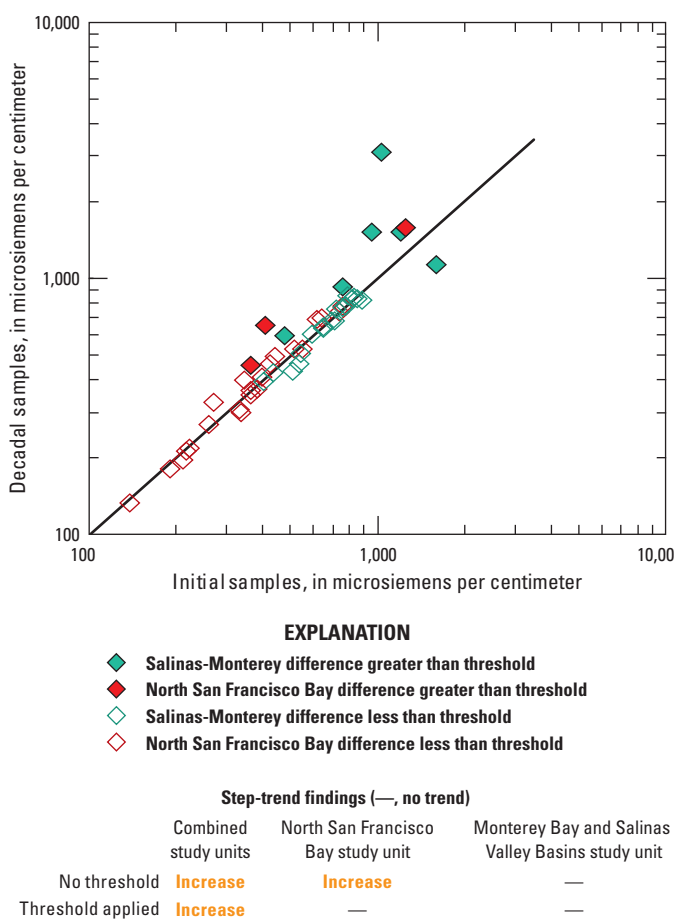
A step trend was only found for increased concentrations of dissolved oxygen for wells in the NSF study unit when no difference threshold applied (table 2B, D; fig. 5). With the GRAC difference threshold applied, no step trends were found for dissolved oxygen. Replicate measurements of water temperature and dissolved oxygen were not done, so no CI difference threshold could be applied to these parameters.

Field and laboratory specific conductance values for samples from the combined study units and for the NSF study unit indicated step trends of increased values, except for field-measured specific conductance in NSF samples with the GRAC difference threshold applied (tables 2A, B, D; figs. 6, 7A, B). Replicate measurements of field-measured specific conductance were not done, so no CI difference threshold could be applied to this parameter. The QSB

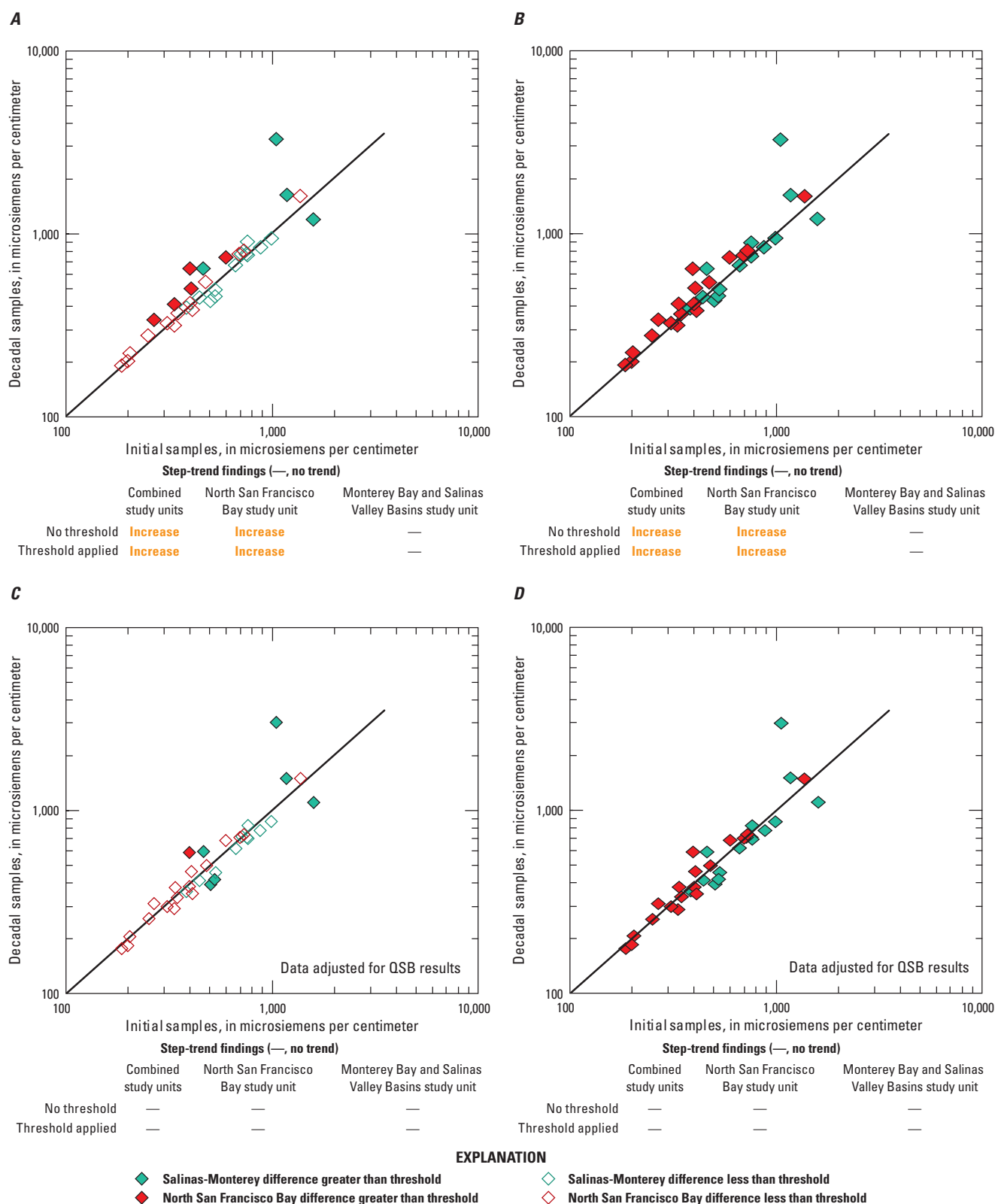
data-quality assessment summaries for the time of the decadal-sampling period indicated a positive bias of 5 to 8 percent for laboratory-measured specific conductance. Thus, specific conductance measured by the NWQL might have been greater than the true concentrations by up to 8 percent during the decadal sampling. This potential positive bias during the decadal-sampling period could have contributed to the findings of increased values. To test the potential effect of this documented bias on the step trends, the evaluations were repeated on the paired-sample data after subtracting 8 percent from each decadal-trend period result. After adjusting the data in this way, none of the evaluations showed a step trend for laboratory-measured specific conductance (table 2D; figs. 7C, D).



**Figure 5.** Paired results of dissolved oxygen measured in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units.



**Figure 6.** Paired results of field-measured specific conductance of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units.



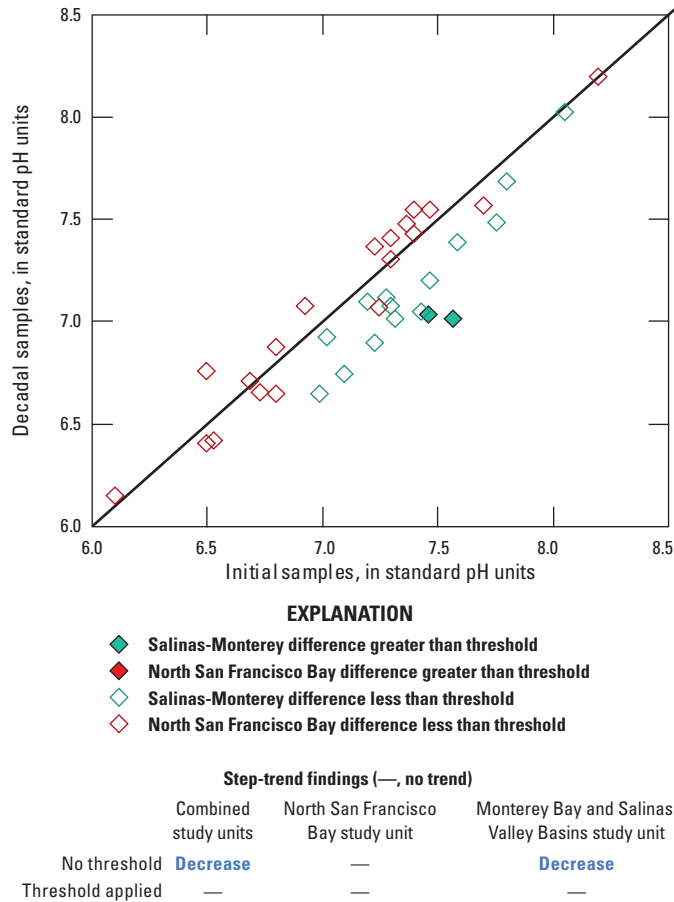
**Figure 7.** Paired results of laboratory-measured specific conductance of groundwater during the collection of paired initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 8 percent (maximum demonstrated bias approximation) from the decadal-sample concentrations; and *D*, with the CI difference threshold applied after subtracting 8 percent (maximum demonstrated bias approximation) from the decadal-sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the USGS Quality Systems Branch (QSB).

Interestingly, no step trends were found for total dissolved solids (TDS) by any of the evaluations in either of the study units nor the combined study units. There is typically a correlation between specific conductance and TDS in water samples, and specific conductance is often used as a surrogate for TDS. It would be expected, therefore, that step trends for specific conductance would also be indicated for TDS. Nevertheless, in the present study, TDS concentrations in groundwater from about as many wells increased as decreased. The TDS concentrations in samples from several trend wells in the SALMON study unit were equal to or greater than the California secondary maximum contaminant level (SMCL-CA) of 500 mg/L. In contrast, TDS concentrations in groundwater from most NSF study-unit trend wells were less than the SMCL-CA, and a study in the area of the NSF study unit concluded that TDS concentrations are not changing in a meaningful way there (RMC Water and Environment, 2013). A national evaluation of decadal trends evaluated TDS (but not specific conductance) for decadal step trends in 67 groundwater networks nationwide (Lindsey and Rupert, 2012; Lindsey and others, 2016). Concentrations of TDS were found to have increased in 25 of these networks and to have decreased in 2 networks.

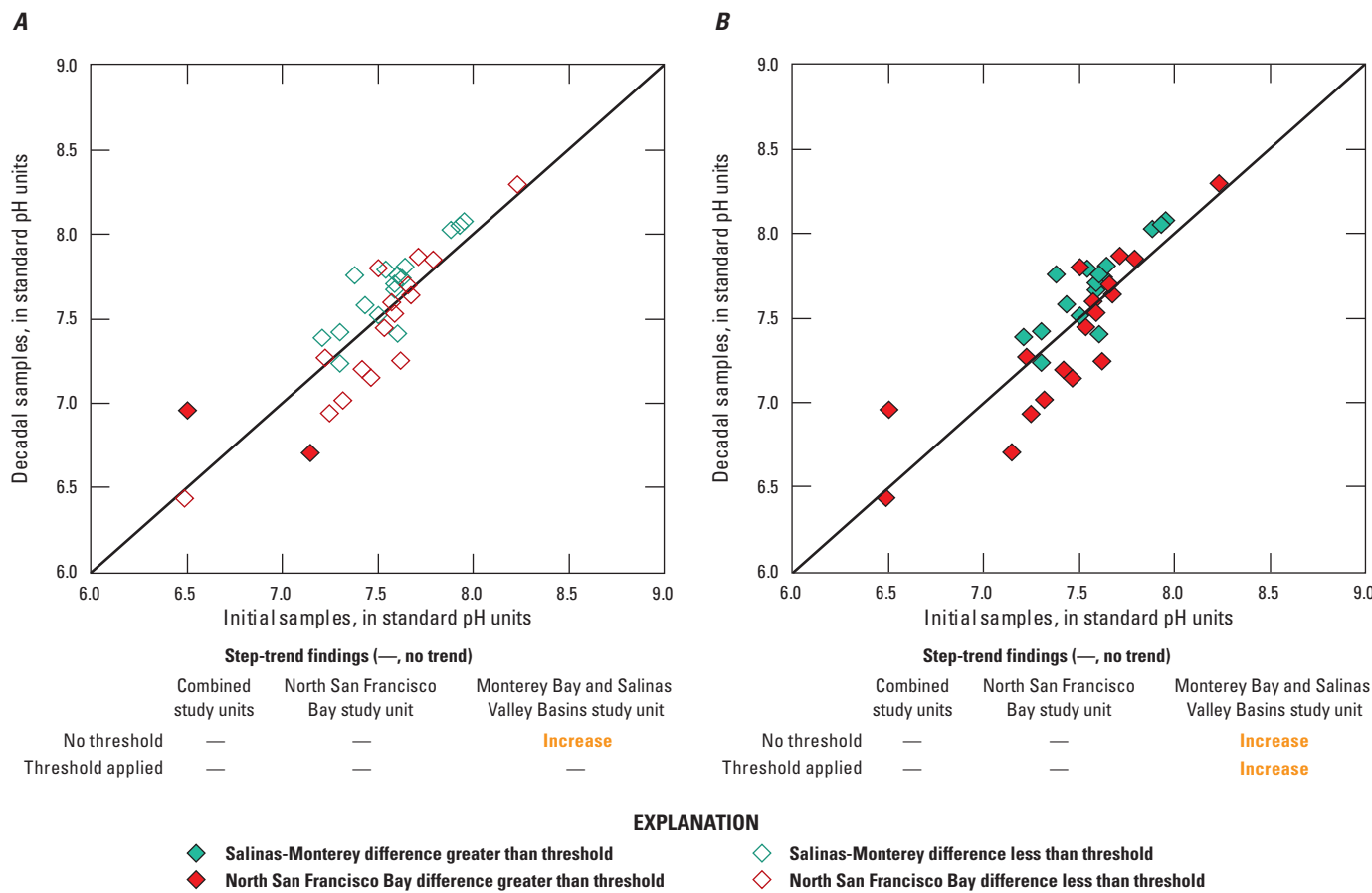
Field and laboratory measurements of pH in groundwater samples did not indicate a consistent change over time. Field measurements of pH are more reliable than are laboratory measurements because the pH of a water sample can change substantially within hours or even minutes after sample collection (U.S. Geological Survey, variously dated). No step trend by any evaluation method was found for field or laboratory-measured pH for samples from the NSF study unit (tables 2B, D; figs. 8, 9A, B). A step trend of decreasing field-measured pH was indicated for samples from the SALMON study unit and from the combined study units when no difference threshold was applied (tables 2C, D; fig. 8). An opposite step trend of increased pH was found for samples from the SALMON study unit for laboratory-measured pH when no difference threshold was applied and when the CI difference threshold was applied (tables 2C, D; figs. 9A, B). No step trend was found for pH measured in the field or at the laboratory for the SALMON study unit and for the combined study units when no difference threshold was applied (tables 2A, B, C, D; figs. 8, 9A). Replicate measurements of field-measured pH were not made, so no CI difference threshold could be calculated.

Carbonate concentrations decreased for the SALMON and combined study units when no difference threshold was

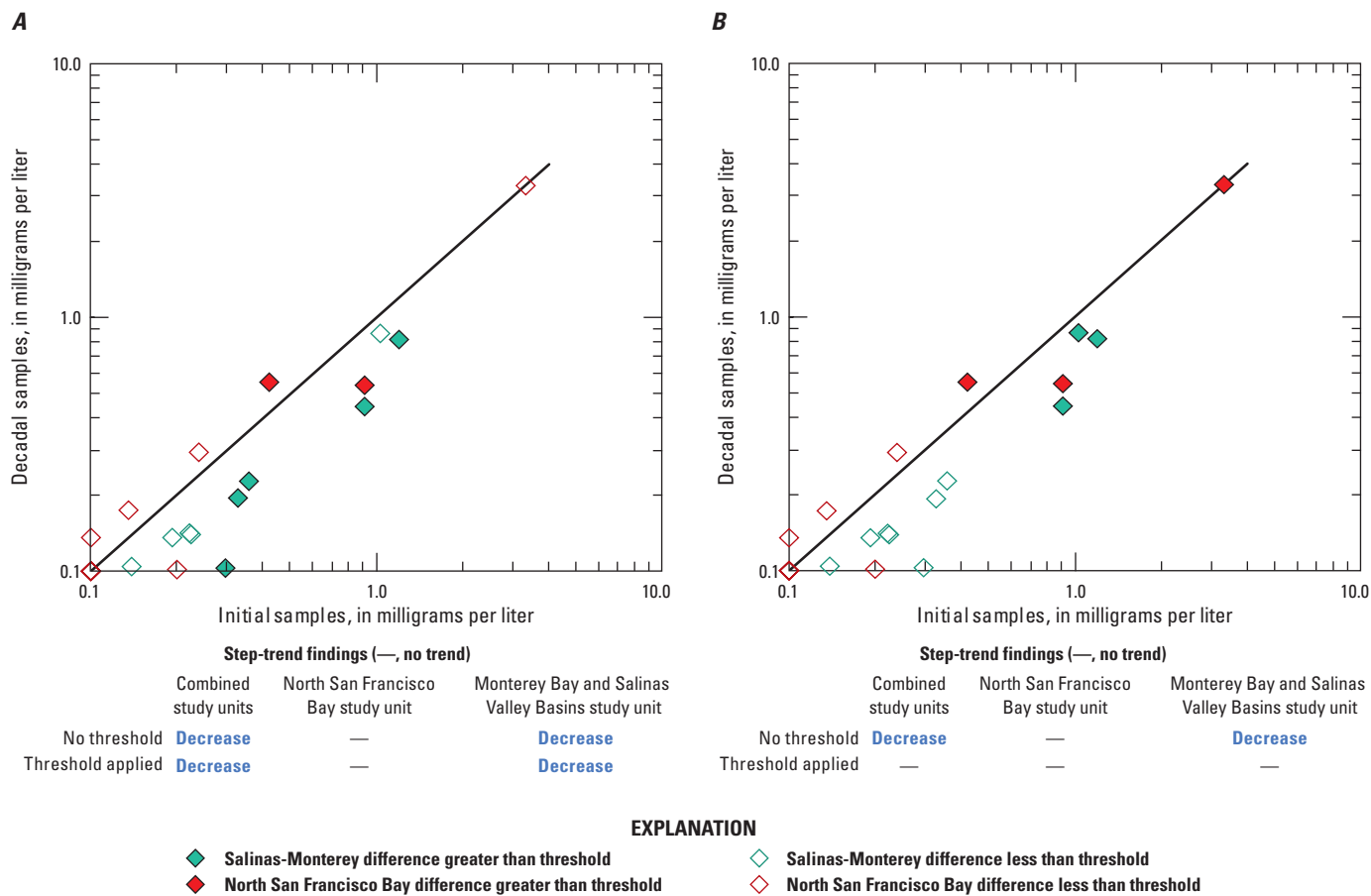
applied and when the GRAC difference threshold was applied (tables 2A, B, C, D; fig. 10A). No step trend for carbonate was indicated when the CI difference threshold was applied, and this appeared to be because differences in paired results from well samples where carbonate was less than 0.5 mg/L were all less than the CI difference threshold (tables 2A, B, C, D; fig. 10B).



**Figure 8.** Paired results of field-measured pH of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units.



**Figure 9.** Paired results of laboratory-measured pH of groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.



**Figure 10.** Paired results of carbonate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

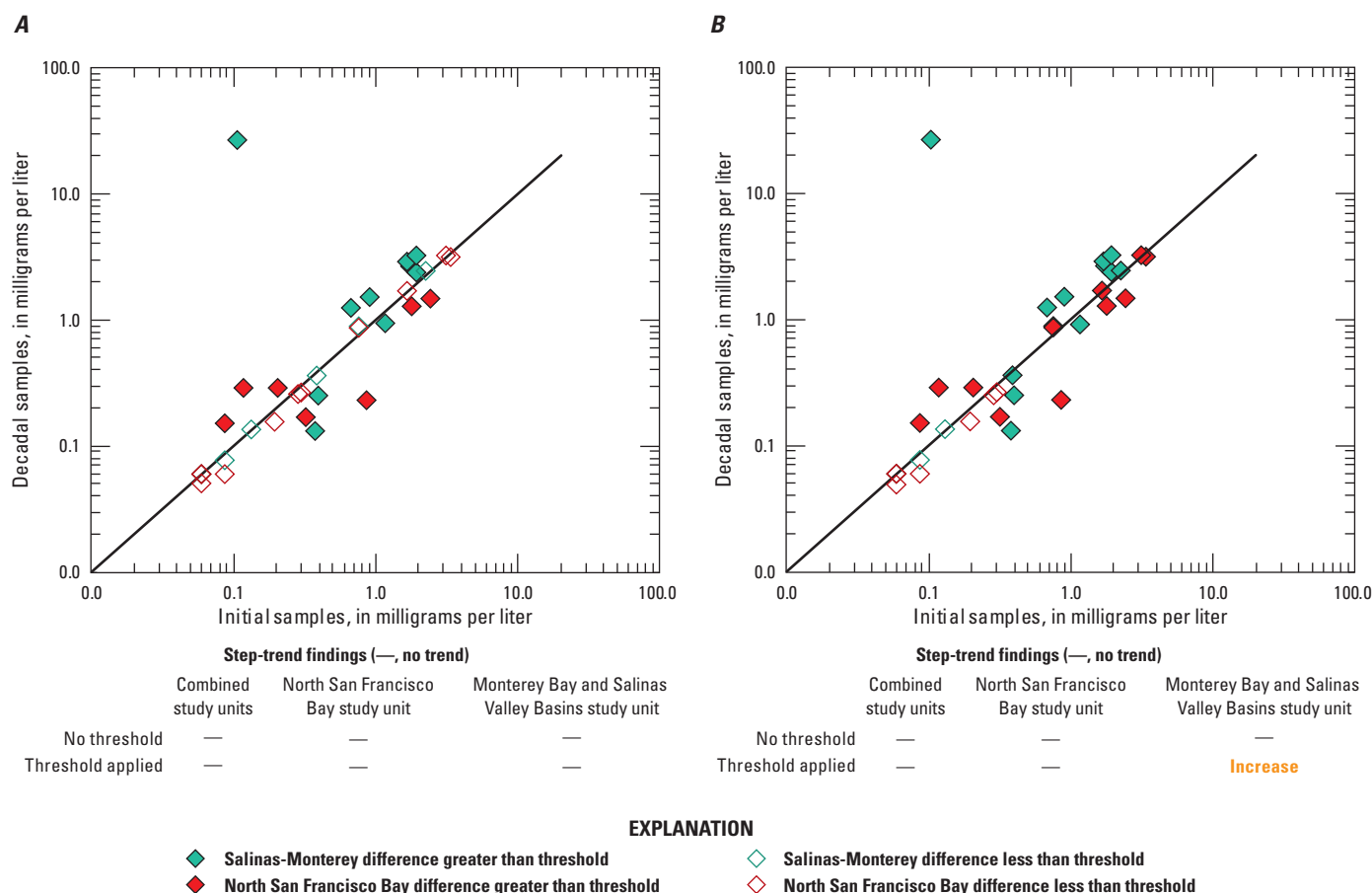
Nutrients

Five nutrient species of nitrogen and phosphorus were evaluated for step trends. Analytical results for the nutrient species of nitrogen and phosphorus are reported in mg/L as N and P, respectively. Step trends were found in the SALMON study unit or the combined study units by at least one of the evaluation methods for total nitrogen, nitrate, and orthophosphate (table 2).

An increase in total nitrogen concentrations was indicated only for the SALMON study unit when the CI difference threshold was applied (tables 2C, D; fig. 11B). It is apparent in figure 11 (A, B) that the decadal-sampling result for one well in the SALMON study unit (MSSV-03) was an outlier, perhaps not representative of the study unit as a whole. Because, the concentrations of several trace elements and major ions in groundwater from well MSSV-03, along with

nitrate, all increased significantly, it could be suspected that samples were mixed up at the laboratory. An additional sample that was collected from this well for a separate GAMA study in 2013, however, confirmed the changes in the quality of water from this well (Kent, 2018, tables 4 and 5, <https://doi.org/10.5066/F7GH9GF5>). The concentration of total nitrogen in the samples from this well increased from 0.1 to 26 mg/L. The Central Coast Regional Water Quality Control Board (State of California) attributes the rapid deterioration of water quality in this well to a land-use shift in its area of recharge from non-irrigated vineyard and scrub to intensively irrigated vegetable crops. Details of this land-use shift and remediation steps that are being taken by stakeholders in the area are available at a County of Monterey web link (<http://www.co.monterey.ca.us/government/departments-i-z/resource-management-agency-rma/-planning/current-major-projects/san-lucas-water-district>).



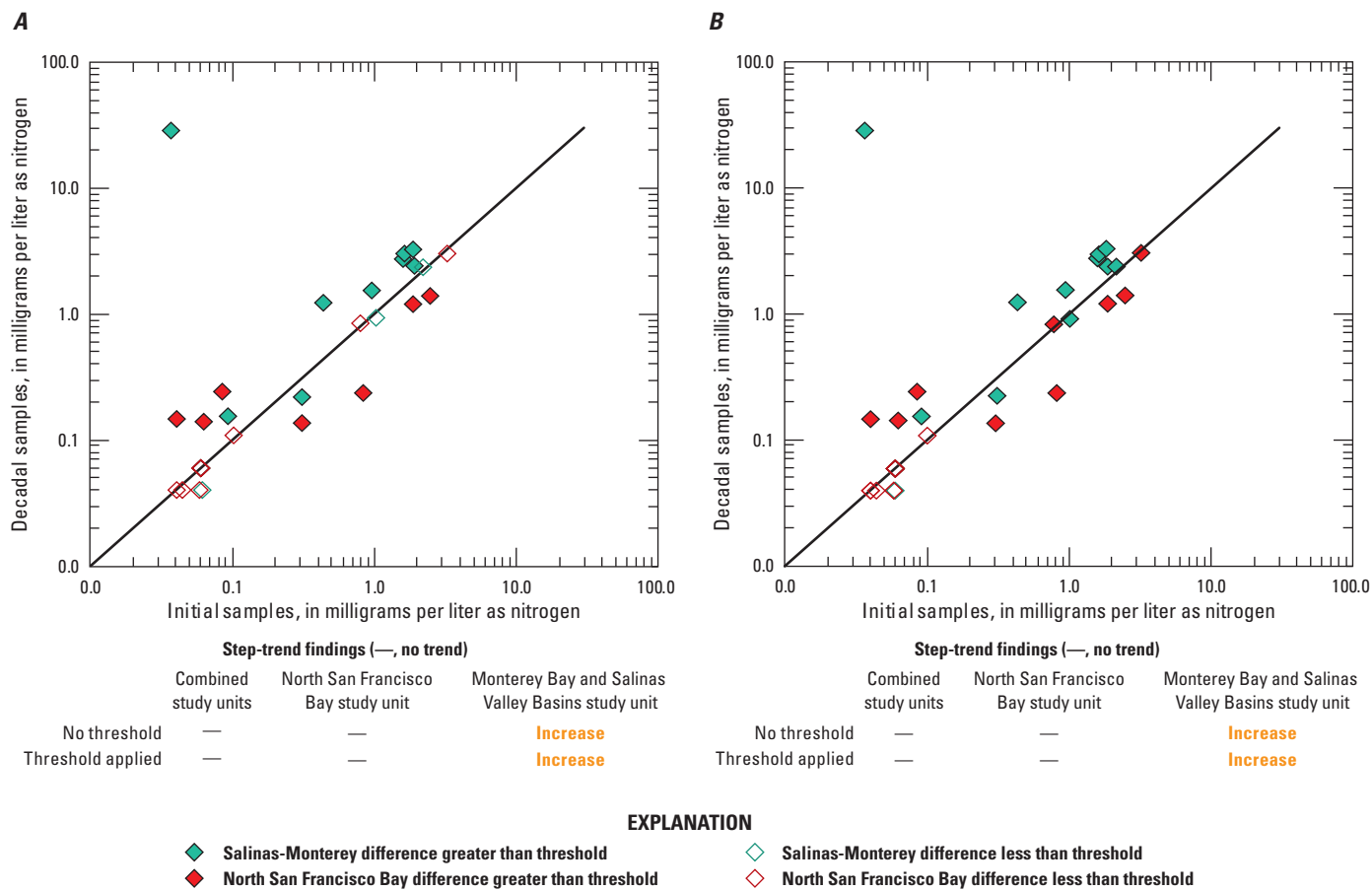


**Figure 11.** Paired results of total nitrogen concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

An increase in nitrate concentrations was also found only for the SALMON study unit. In contrast to the increased concentration for total nitrogen by only one evaluation method, however, the step trend of increased nitrate in the SALMON study unit was indicated by all three evaluation methods, and these findings did not change when the evaluations excluded data from MSSV-03 (tables 2C, D; figs. 12A, B). This finding was consistent with the findings of a recent study (Harter and Lund, 2012) that found significant nitrate increases in the area of the SALMON study unit. That study concluded that nitrate-source reduction actions might not reverse this trend for several decades because of the long groundwater travel times in this area. The QSB data-quality assessment summaries published around the decadal-sampling period indicated a negative bias of 6 to 8 percent for nitrate. Decadal-sampling period nitrate measured by the NWQL might have been less than the true concentration by up to

8 percent. The step trends of increasing nitrate concentrations were found despite this potential decadal-sampling period negative bias, which could have obscured the trend.

With the exception of the 2014 sample from MSSV-03, nitrate concentrations in groundwater from wells sampled were all less than the EPA maximum contaminant level (MCL-US) of 10 mg/L as nitrogen. Nitrate concentrations in groundwater from all NSF study-unit trend wells were less than the MCL-US. No step trend was found for nitrate in the NSF study unit, and there is a published study that concluded that nitrate concentrations in this area are not changing in a meaningful way (RMC Water and Environment, 2013). A national evaluation of decadal trends has evaluated nitrate for decadal step trends in 67 groundwater networks nationwide (Lindsey and Rupert, 2012; Lindsey and others, 2016). Nitrate was found to have increased in 14 of these networks and to have decreased in 6 networks.



**Figure 12.** Paired results of nitrate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

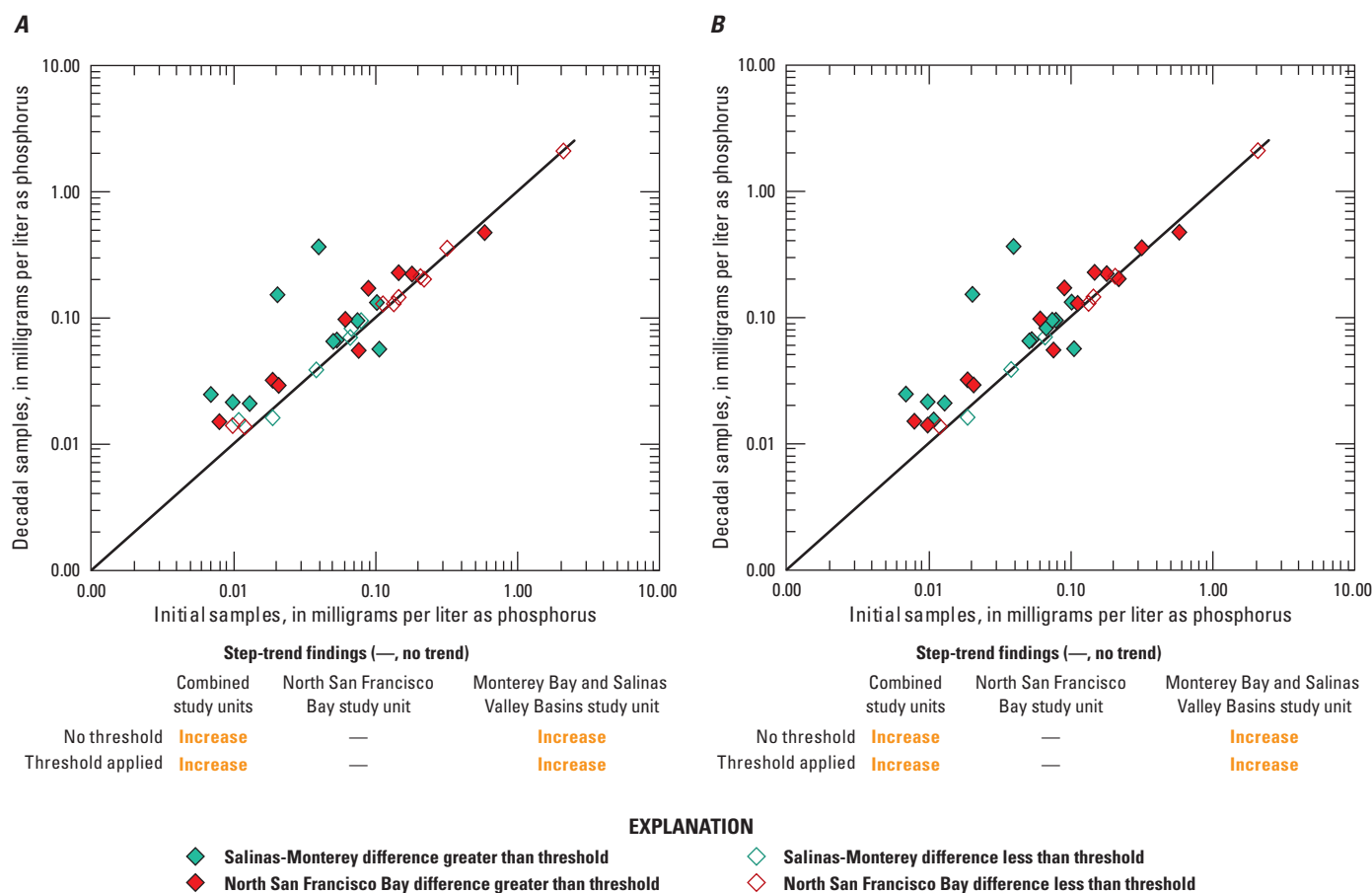
Orthophosphate concentrations in groundwater increased according to all three evaluations for the SALMON study unit and for the combined study units (tables 2A, C, D; figs. 13A, B). Orthophosphate concentrations were less than 0.6 mg/L as phosphorus during both sampling periods, with one exception. Orthophosphate concentrations in water from well NSFVP-48 were 2.09 mg/L as phosphorus in the initial sample and 2.11 mg/L as phosphorus in the decadal sample. This difference did not exceed either difference threshold (figs. 13A, B). A national evaluation of decadal trends has evaluated orthophosphate for decadal step trends

in 67 groundwater networks nationwide (Lindsey and others, 2016). Orthophosphate was found to have increased in 13 of these networks and to have decreased in 9 networks.

### Major and Minor Ions and Silica

Nine major and minor ions, and silica, were evaluated for step trends. Step trends were found in at least one of the study units or the combined study units by at least one of the evaluation methods for all of these constituents except bromide (tables 2A, B, C, D).



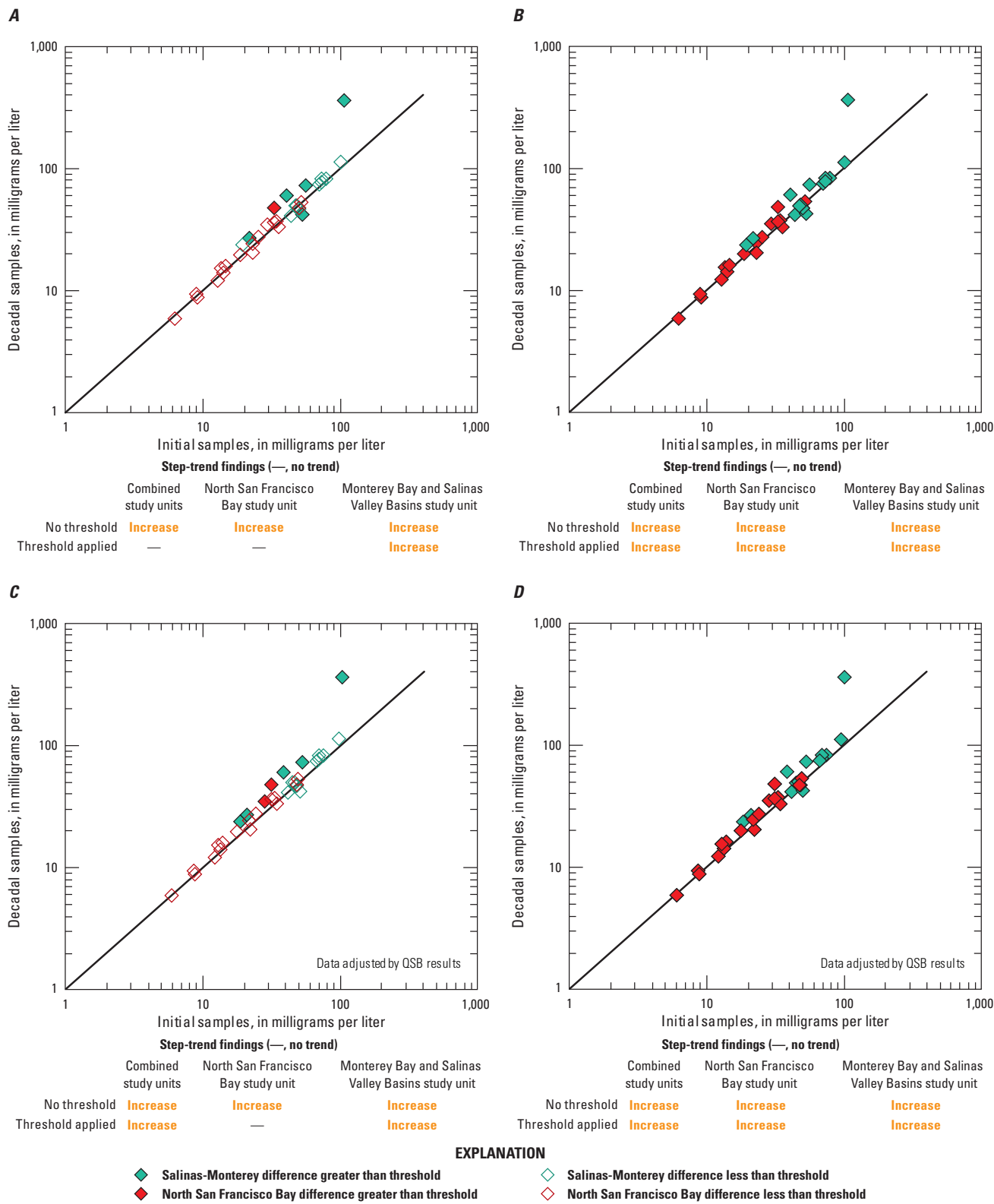


**Figure 13.** Paired results of orthophosphate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

Calcium concentrations increased in groundwater samples from the NSF study unit and the combined study units with no difference threshold applied and with the CI difference threshold applied (tables 2A, B, D; figs. 14A, B). For the SALMON study unit, increased concentrations were indicated by all three step-trend evaluation approaches (tables 2C, D). The QSB data-quality assessment summaries published around the initial-sampling period indicated a positive bias of about 5 percent for calcium. Calcium measured by the NWQL during the initial period might have been greater than the true concentration. Summaries published around the time of the decadal-sampling period did not indicate any bias in calcium analyses at the NWQL. This potential positive bias during the initial period could have decreased the magnitude of the measured increases in calcium concentrations. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after subtracting 5 percent from each initial-period result. After adjusting the data in this way, calcium showed

a step trend of increased concentrations for the combined study units by all three evaluations (table 2D; figs. 14C, D). After the data adjustment, the NSF study unit still showed no step trend for calcium when the GRAC difference threshold was applied (fig. 14C). While no spatial pattern was noted for calcium increases in the SALMON study unit, calcium increases in the NSF study unit groundwater primarily occurred in the eastern side of the study unit.

Magnesium concentrations increased in groundwater from the SALMON study unit when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, C, D; figs. 15A, B). For the NSF study unit and the combined study units, the step trend of increased magnesium concentrations was indicated by all three evaluation methods (tables 2A, B, D). All paired differences in magnesium exceeded the CI difference threshold, so this threshold had no effect on the statistical test. The QSB reported biases for analyses performed by the NWQL that could have influenced the finding of increased magnesium concentrations. The



**Figure 14.** Paired results of calcium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 5 percent (demonstrated bias approximation) from the initial sample concentrations; and *D*, with the CI difference threshold applied after subtracting 5 percent (demonstrated bias approximation) from the initial sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.

QSB data-quality assessment summaries published around the initial-sampling period indicated a negative bias of about 5.5 percent for magnesium, whereas the summaries published around the time of the decadal-sampling period indicated a positive bias of about 9 percent. Magnesium measured by the NWQL during the initial period might have been less than the true concentration, and decadal-sampling period magnesium measurements might have been greater than the true concentrations. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after adding 5.5 percent to each initial-period result and subtracting 9 percent from each decadal-sampling period result. After adjusting the data in this way, none of the evaluations indicated a step trend for magnesium (table 2D; figs. 15C, D).

Potassium concentrations increased only for the combined study units, and only when the GRAC difference threshold was applied (tables 2A, D; figs. 16A, B). Paired differences in potassium concentrations only exceeded the GRAC difference threshold in four wells (three of them in the SALMON study unit), but all four were increases. The QSB reported a positive bias for analyses done by the NWQL during both sampling periods. All potassium measured by the NWQL for this study might have been greater than the true concentration. The QSB data-quality assessment summaries published around the initial-sampling period indicated a positive bias of about 6 percent, whereas the summaries published around the time of the decadal-sampling period indicated a positive bias of about 8 percent. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after subtracting 6 percent from each initial-period result and subtracting 8 percent from each decadal-sampling period result. After adjusting the data in this way, potassium concentrations decreased (opposite direction from the combined study unit result when the GRAC difference threshold was applied before adjustment) in samples from the NSF study unit when no difference threshold was applied and when the CI difference threshold was applied (tables 2B, D; fig. 16D).

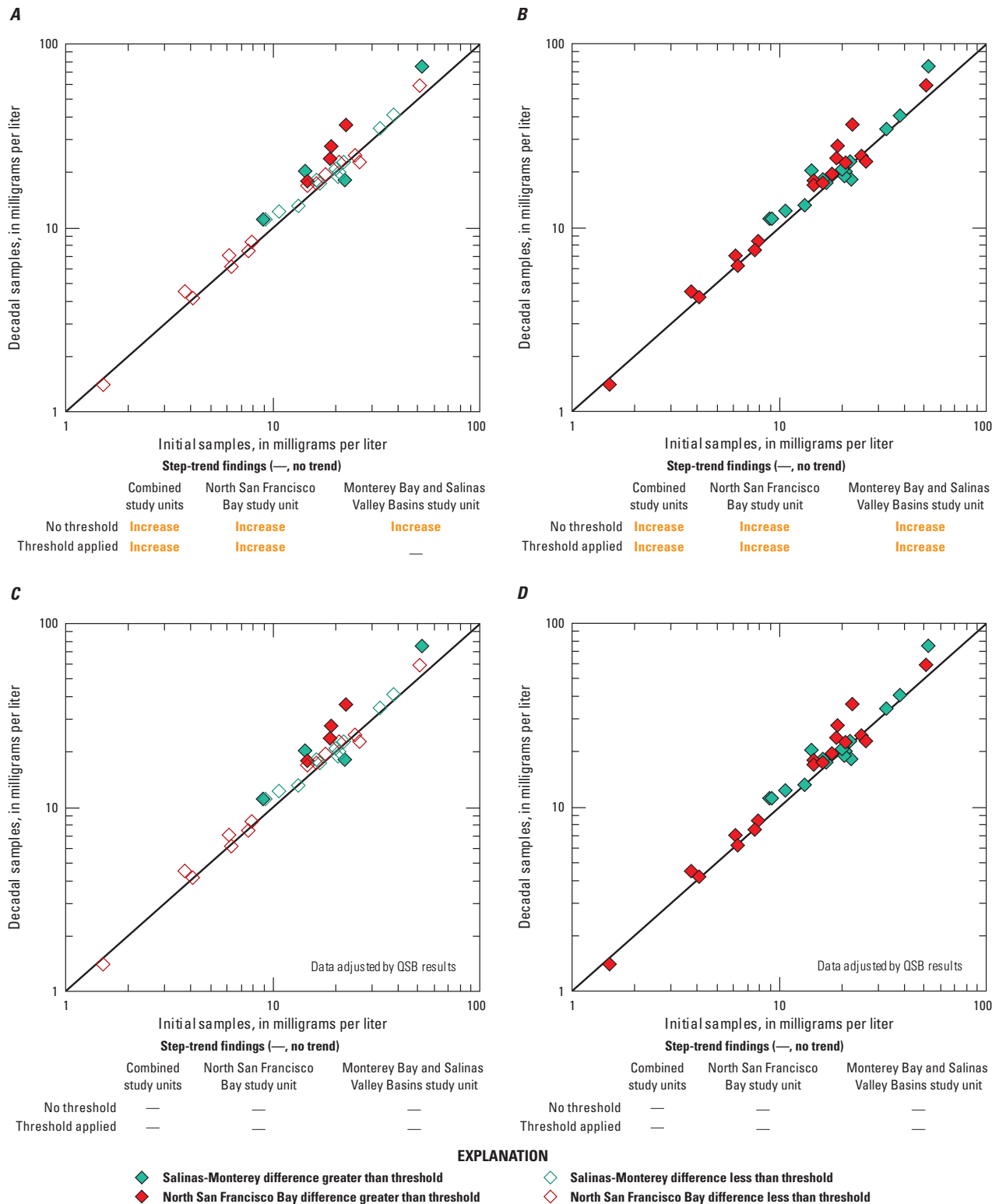
Sodium concentrations increased only in groundwater from the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, D; figs. 17A, B). No step trend was found for sodium with the GRAC difference threshold applied. The QSB data-quality assessment summaries published around the decadal-sampling period indicate a positive bias of about 8 percent for sodium. Decadal-sampling period sodium measured by the NWQL could have been greater than the true concentration. Summaries published around the time of the initial-sampling period did not indicate any bias in sodium analyses at the NWQL. This potential positive bias during the decadal-sampling period might have contributed to the increased concentrations indicated by two of the evaluations

for the combined study units. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after subtracting 8 percent from each decadal-sampling period result. After adjusting the data in this way, the step trend of increased sodium concentrations for the combined study units was no longer indicated, and a step trend of decreased sodium concentrations (opposite direction from the combined study unit result before adjustment) was indicated for the NSF study unit when no difference threshold was applied and when the CI difference threshold was applied (table 2D; figs. 17C, D).

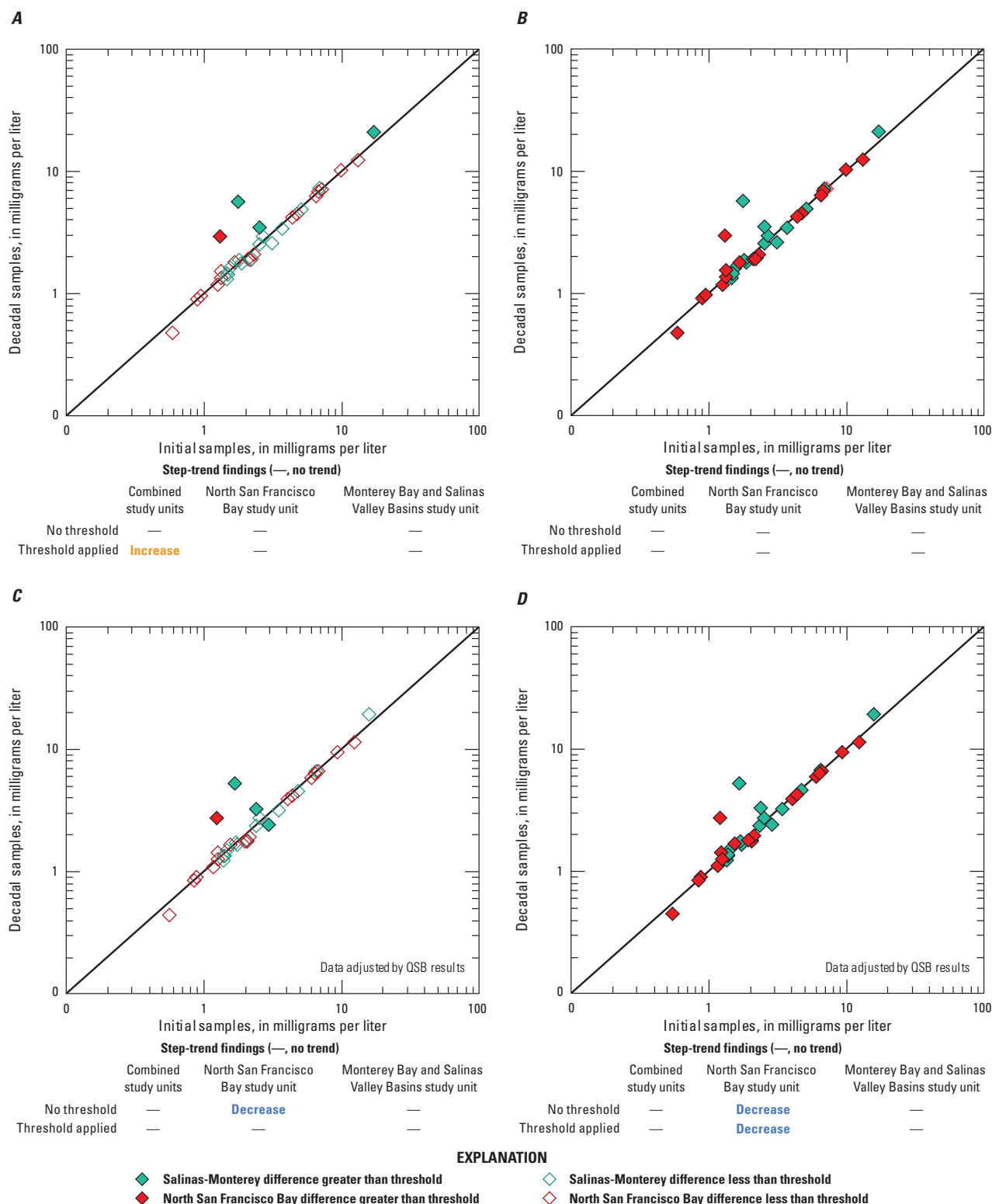
Chloride concentrations increased in groundwater from the NSF study unit when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, D; figs. 18A, B). All paired differences in chloride exceeded the CI difference threshold, so this threshold had no effect on the statistical test. No step trends were found when the GRAC difference threshold was applied. One well from each study unit had chloride concentrations greater than the secondary maximum contaminant level of 250 mg/L established by the California Department of Public Health (SMCL-CA). Chloride concentrations increased in both of these wells (figs. 18A, B). A national evaluation of decadal trends has evaluated chloride for decadal step trends in 67 groundwater networks nationwide (Lindsey and Rupert, 2012; Lindsey and others, 2016). Chloride was found to have increased in 31 of these networks and to have decreased in 2 networks.

Iodide concentrations decreased in groundwater from the NSF study unit only when the CI difference threshold was applied (tables 2B, D; fig. 19B). The CI difference threshold was an effective threshold for iodide, but only when sample concentrations were less than 0.01 mg/L in the paired samples (fig. 19B). The threshold was exceeded for all sample pairs from wells where iodide concentrations were greater than 0.01 mg/L. Neither field nor laboratory quality-control results revealed bias nor unusual variability in iodide results during the relevant sampling periods.

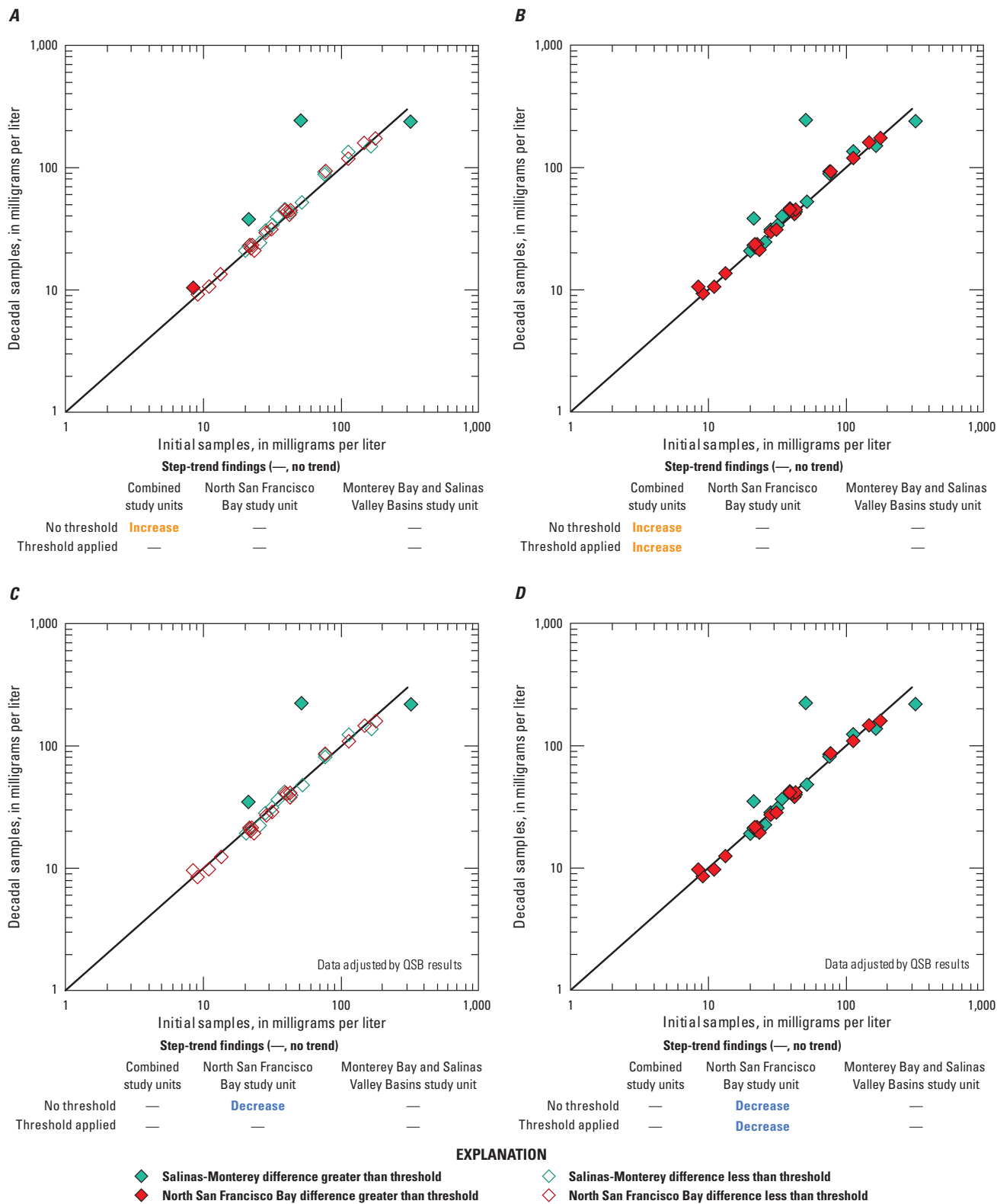
Sulfate concentrations increased by all three evaluations for the combined study units (tables 2A, D; figs. 20A, B) and with the GRAC difference threshold for the NSF study unit (tables 2B, D; fig. 20A). All paired differences in sulfate exceeded the CI difference threshold, so this threshold had no effect on the statistical test. While no spatial pattern was noted for sulfate increases in the SALMON study unit, sulfate increases in the NSF study unit groundwater primarily occurred in the eastern side of the study unit. A national evaluation of decadal trends has evaluated sulfate for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Sulfate was found to have increased in 16 of these networks and to have decreased in 6 networks. Neither field nor laboratory quality-control data indicated bias or significant variability in sulfate results during the sampling periods.



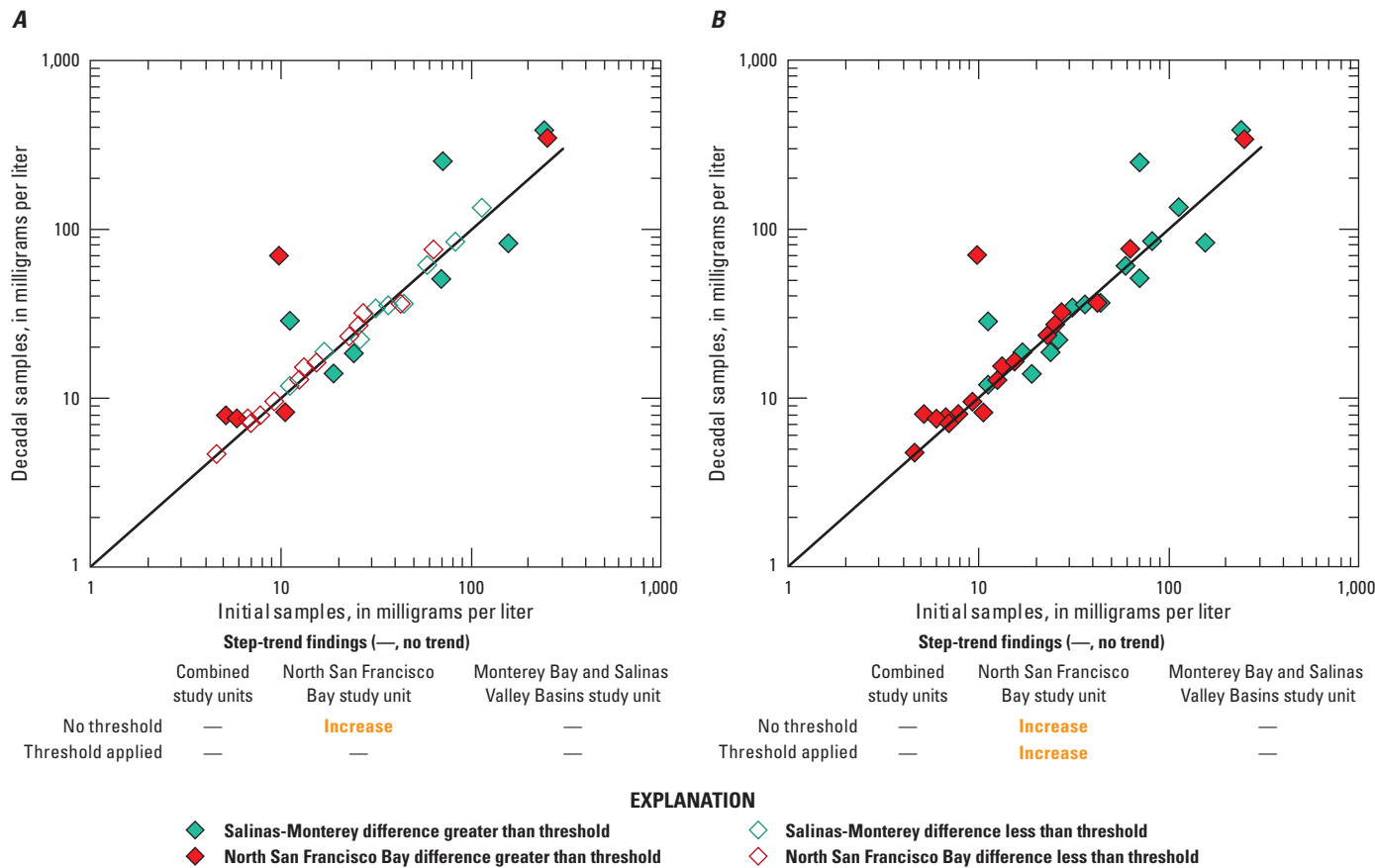
**Figure 15.** Paired results of magnesium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after adding 5 percent (demonstrated bias approximation) to initial sample concentrations and subtracting 9 percent (demonstrated bias approximation) from the decadal sample concentrations; and *D*, with the CI difference threshold applied after adding 5 percent (demonstrated bias approximation) to initial sample concentrations and subtracting 9 percent (demonstrated bias approximation) from the decadal sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.



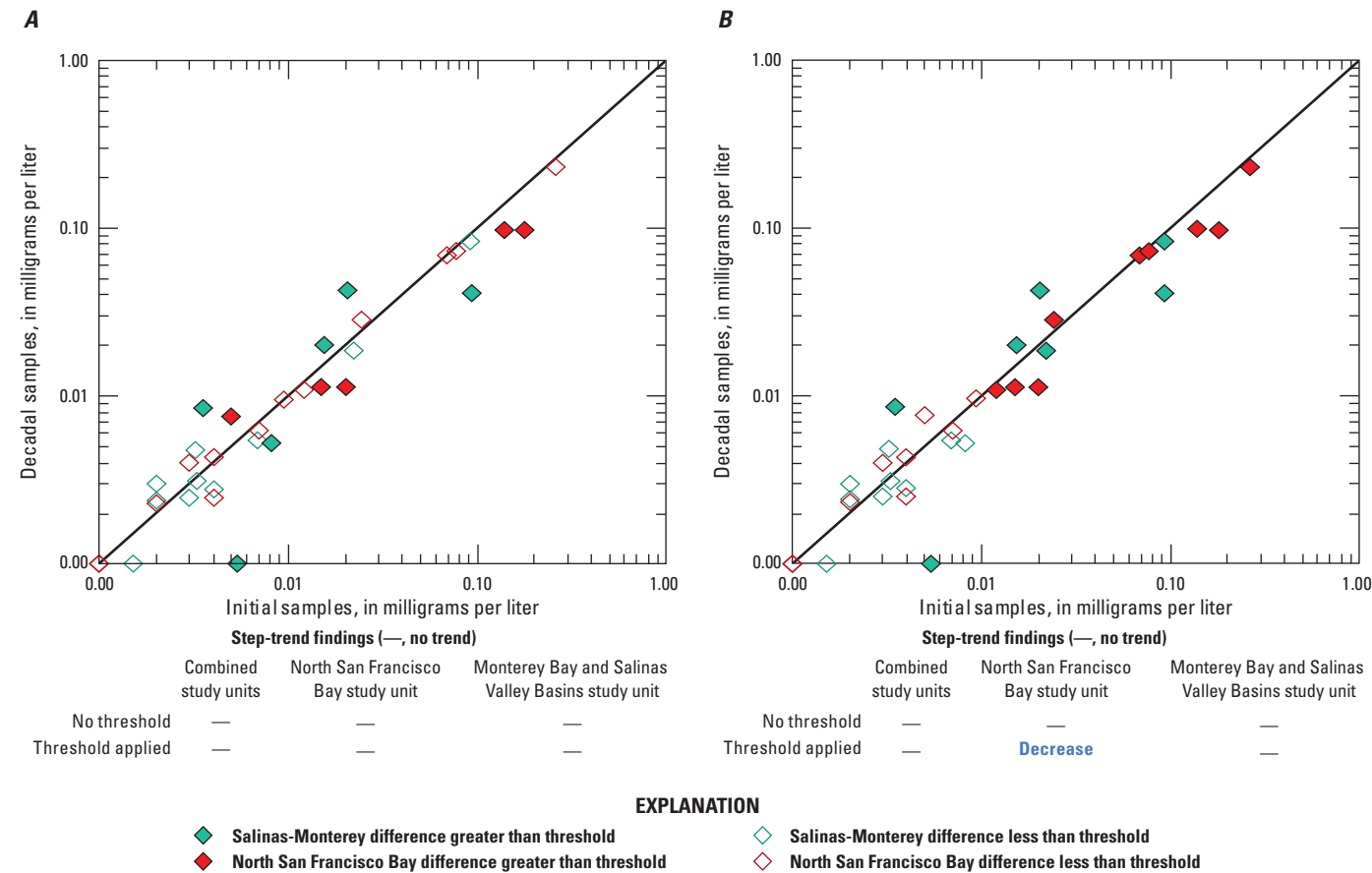
**Figure 16.** Paired results of potassium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 6 percent (demonstrated bias approximation) from initial sample concentrations and subtracting 8 percent from the decadal sample concentrations; and *D*, with the CI difference threshold applied after subtracting 6 percent (demonstrated bias approximation) from initial sample concentrations and subtracting 8 percent from the decadal sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.



**Figure 17.** Paired results of sodium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 8 percent (demonstrated bias approximation) from the decadal sample concentrations; and *D*, with the CI difference threshold applied after subtracting 8 percent (demonstrated bias approximation) from the decadal sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.

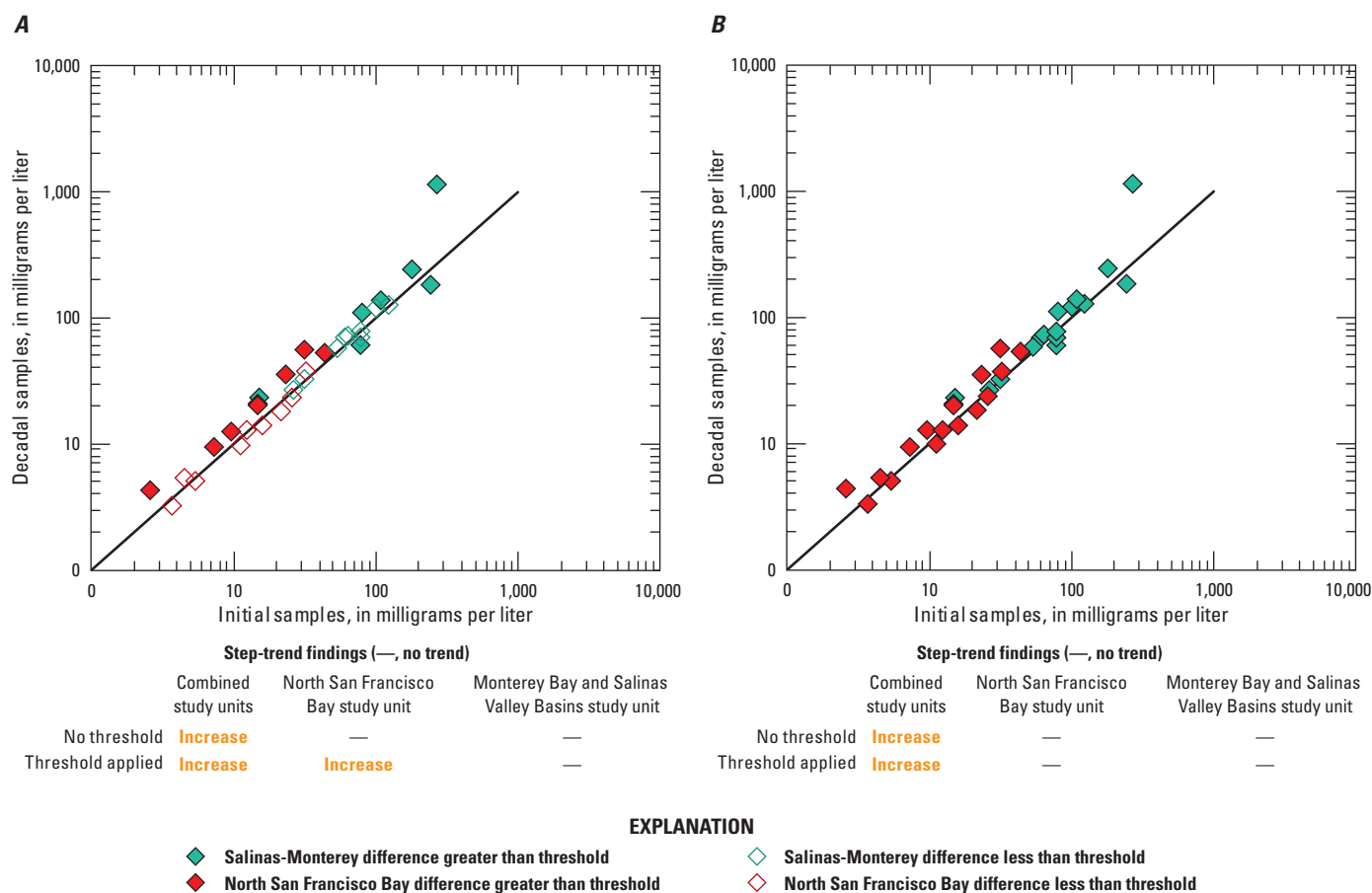


**Figure 18.** Paired results of chloride concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.



**Figure 19.** Paired results of iodide concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

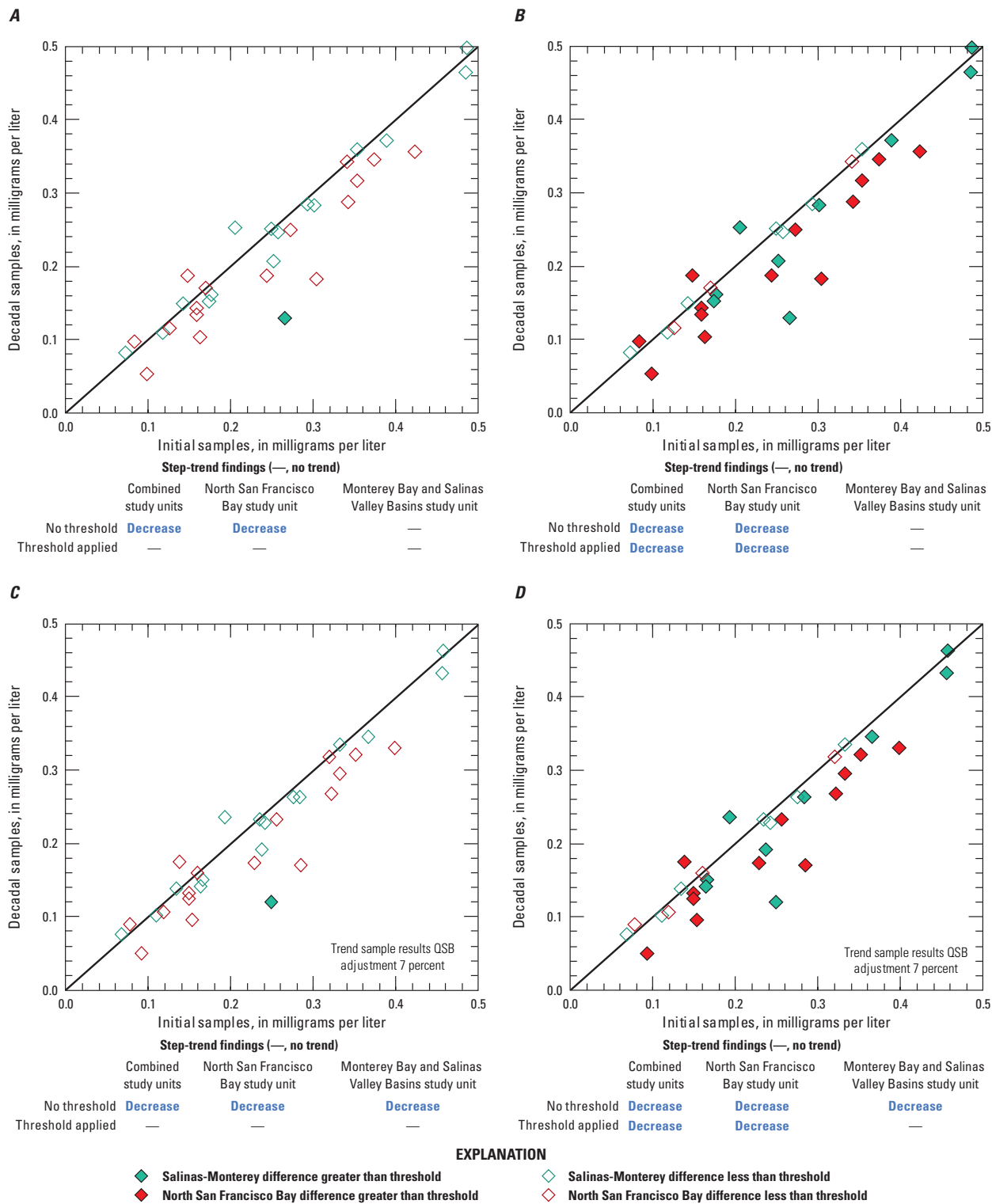




**Figure 20.** Paired results of sulfate concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

Fluoride concentrations decreased in groundwater from the NSF study unit and the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, D; fig. 21B). No step trend was found for fluoride when the GRAC difference threshold was applied. The QSB data-quality assessment summaries published around the decadal-sampling period indicated a positive bias in fluoride analyses at the NWQL of about 6 percent during the initial-sampling period and from 7 to 13 percent during the decadal-sampling period. Fluoride measured by the NWQL could have been greater than the true concentrations during both sampling periods, but the documented bias was larger during the decadal-sampling period. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after subtracting 6 percent from each initial-sampling period result and subtracting, first, 7 percent,

then 13 percent, from each trend period result. Results of the three evaluations changed little after adjusting the data in this way. In each case, decreased fluoride concentrations were indicated when no difference threshold was applied and when the CI difference threshold was applied for the NSF study unit and the combined study units. Additionally, decreased concentrations of fluoride were indicated for the SALMON study unit with both levels of data adjustment with no difference threshold applied and, at the 13 percent adjustment, with the CI difference threshold applied (table 2D; figs. 21D, F). Data adjustments did not change the finding of no step trend for fluoride when the GRAC difference threshold was applied (table 2D; figs. 21C, E). A national evaluation of decadal trends has evaluated fluoride for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Fluoride increased in 4 of these networks and decreased in 10 networks.



**Figure 21.** Paired results of fluoride concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 6 percent from initial sample concentrations and 7 percent (demonstrated bias approximation) from the decadal sample concentrations; *D*, with the CI difference threshold applied after subtracting 6 percent from initial sample concentrations and 7 percent (demonstrated bias approximation) from the decadal sample concentrations; *E*, with the GRAC difference threshold applied after subtracting 6 percent from initial sample concentrations and 13 percent (demonstrated bias approximation) from the decadal sample concentrations; and *F*, with the CI difference threshold applied after subtracting 6 percent from initial sample concentrations and 13 percent (demonstrated bias approximation) from the decadal sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.

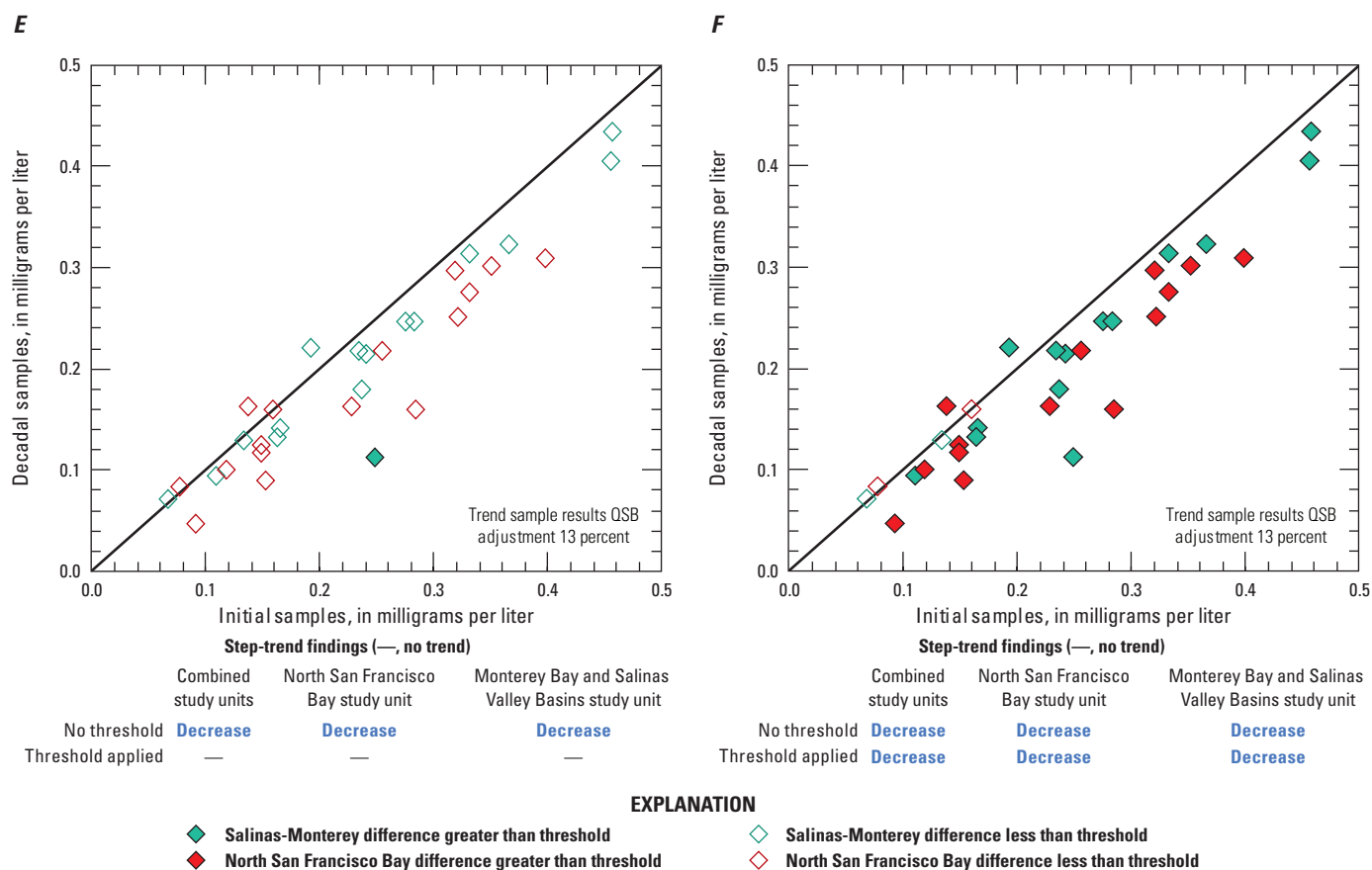


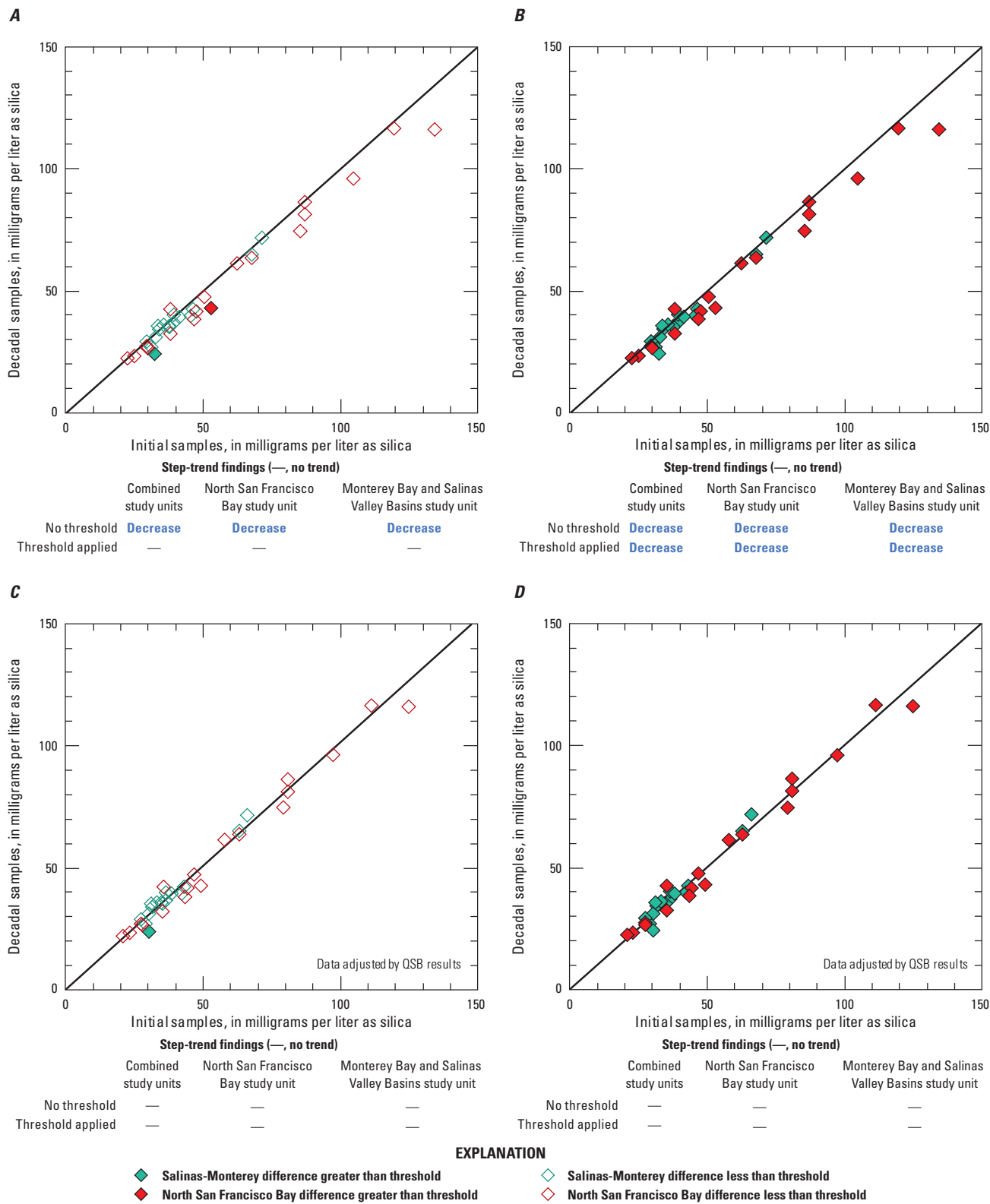
Figure 21. —Continued

Silica concentrations in groundwater decreased in each study unit and in the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, C, D; fig. 22B). No step trend was found for silica when the GRAC difference threshold was applied; only two of the paired sample differences exceeded the GRAC difference threshold. The QSB data-quality assessment summaries published around the initial-sampling period indicated a positive bias of about 7 percent for silica. Initial-sampling period silica measured by the NWQL could have been greater than the true concentrations. Summaries published around the time of the decadal-sampling period did not indicate any bias in silica analyses at the NWQL. The potential positive bias during the initial-sampling period could have contributed to the findings of decreased concentrations indicated by two of the evaluations. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after subtracting 7 percent from each initial-sampling period result. After adjusting the data in this way, none of the evaluations indicated a step trend for silica (table 2D; figs. 22C, D).

## Trace Elements

Twenty trace elements were evaluated for step trends. Step trends were found in at least 1 of the study units or the combined study units by at least 1 of the evaluation methods for 11 of these trace elements (tables 2A, B, C, D).

Aluminum concentrations increased in groundwater from the NSF study unit and the combined study units by all three evaluation methods (tables 2A, B, C, D; figs. 23A, B). No step trends were indicated for aluminum in the SALMON study unit by any of the evaluation methods. The GAMA-PBB field-blank results indicated a potential positive bias for initial-sampling period aluminum concentrations (Kent, 2018, tables 10 and 13, <https://doi.org/10.5066/F7GH9GF5>), and a study reporting level (SRL) of 1.6 µg/L was applied to data collected during this period (Davis and others, 2014). The increased aluminum concentrations were found despite this potential initial-sampling period positive bias, which could have obscured the trend. During the decadal-sampling period, however, the GAMA-PBP replicate results



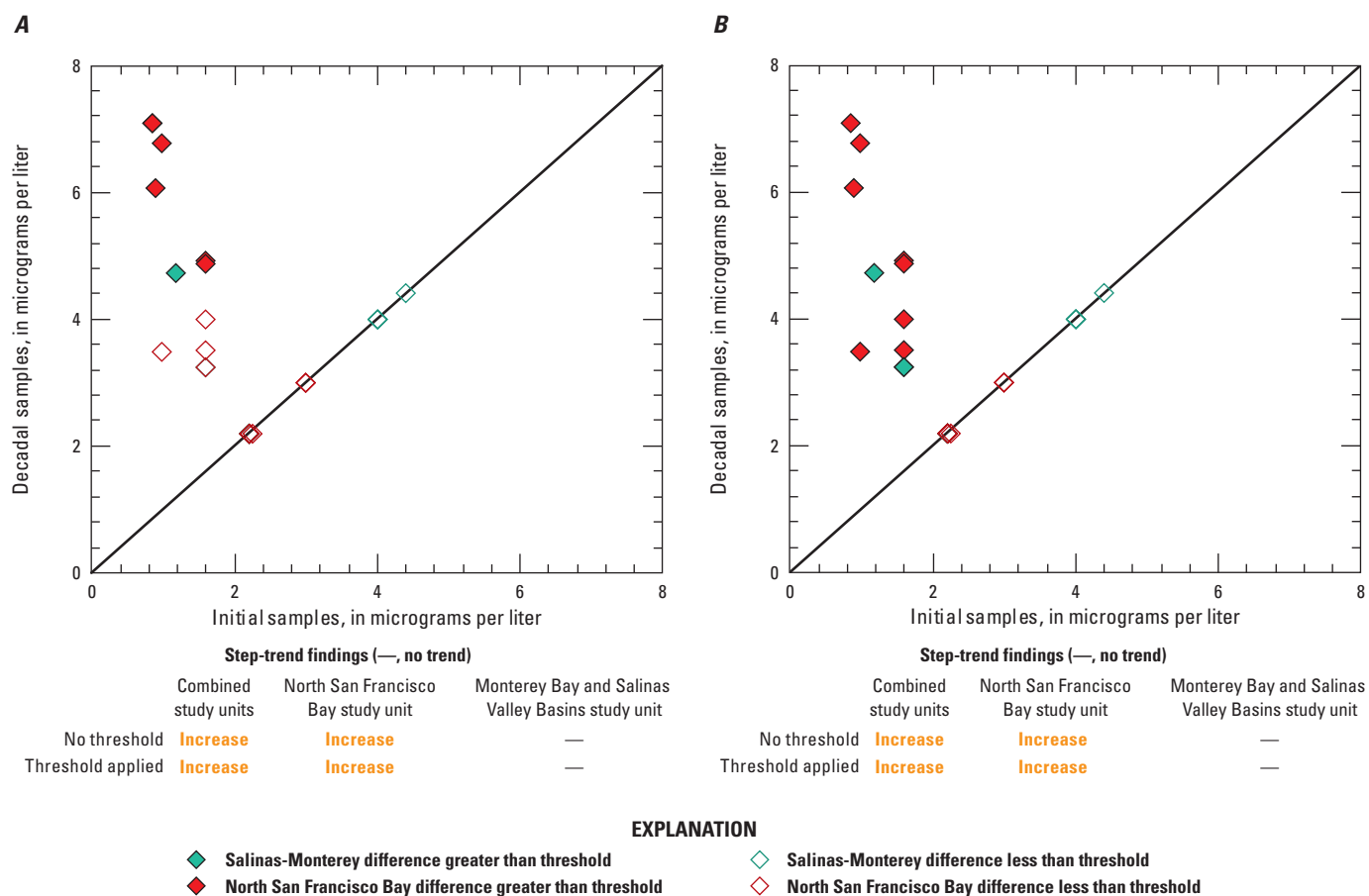
**Figure 22.** Paired results of silica concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with differences within the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with differences within the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 7 percent (demonstrated bias approximation) from the initial sample concentrations; and *D*, with the CI difference threshold applied after subtracting 7 percent (demonstrated bias approximation) from the initial sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.

(Kent, 2018, tables 11 and 13, <https://doi.org/10.5066/F7GH9GF5>) indicated that analytical results for aluminum were unusually variable. Project replicate results for aluminum had a mean relative standard deviation of 6.6 percent during decadal-sampling compared to 1.5 percent during the initial sampling period.

Arsenic concentrations decreased in groundwater from the NSF study unit and the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, D; fig. 24B). No step trend was found for arsenic when the GRAC difference threshold was applied. Arsenic has a California maximum contaminant level (MCL-CA) of 10  $\mu\text{g/L}$ ; concentrations in samples from most of the wells evaluated for this study were less than this benchmark. Arsenic concentrations in initial samples from wells NSFVP-38 and MSPR-03 were greater than the MCL-CA, however. Arsenic concentrations in NSFVP-38 were 17.2  $\mu\text{g/L}$  in 2004 and 15.9  $\mu\text{g/L}$  in 2014. The difference between these concentrations did not exceed

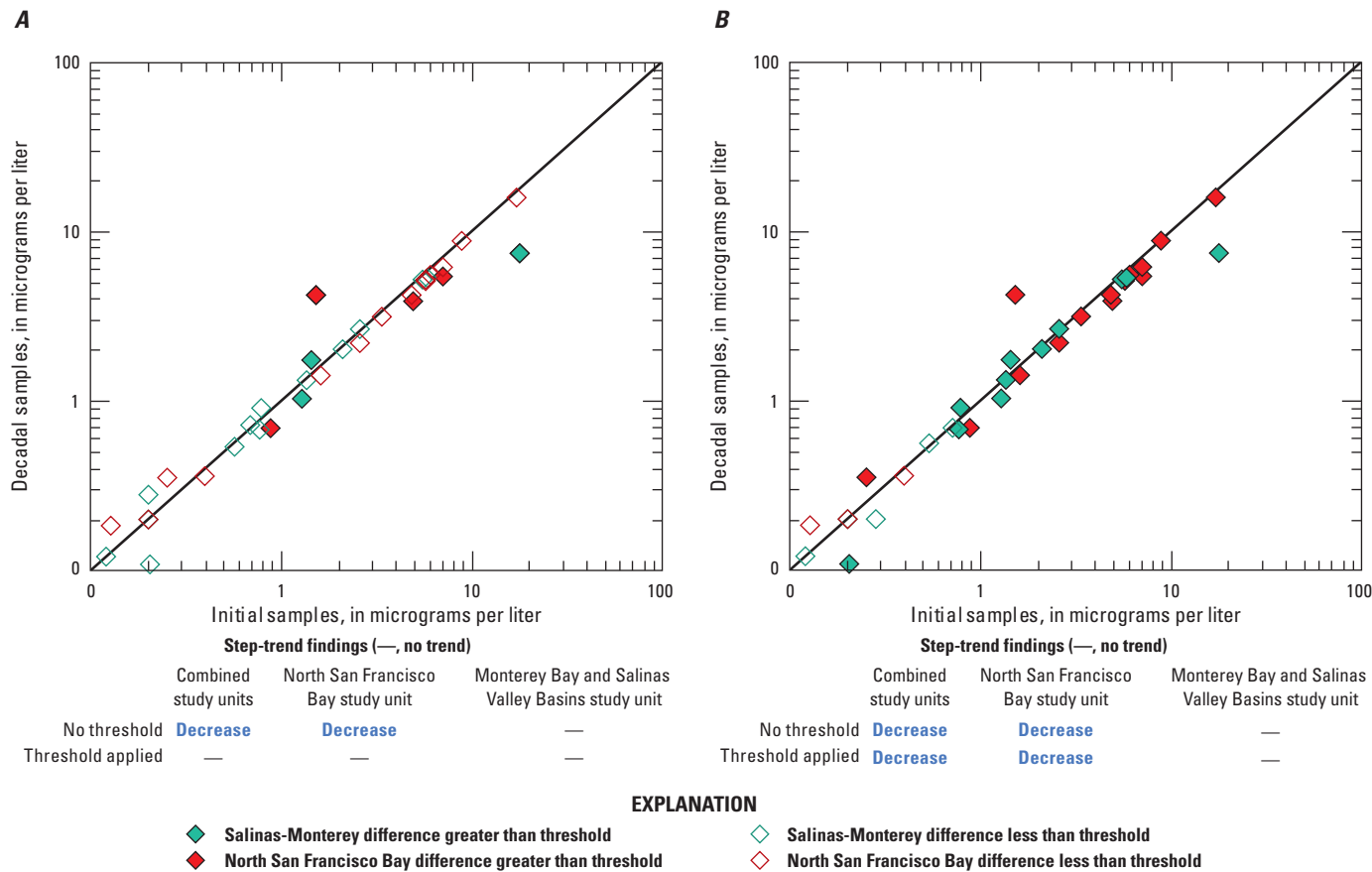
the GRAC difference threshold (fig. 24A). In contrast, the arsenic concentration measured in samples from MSPR-03 decreased from 17.7  $\mu\text{g/L}$  to 7.5  $\mu\text{g/L}$ . While no spatial pattern was noted for arsenic changes in the SALMON study unit, arsenic decreases in the NSF study unit groundwater primarily occurred in the southern-central and eastern areas of the study unit. A national evaluation of decadal trends has evaluated arsenic for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Arsenic was found to have increased in three of these networks and to have decreased in eight networks.

Barium concentrations increased in groundwater from the NSF study unit and the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B; fig. 25B). No step trend was indicated for barium when the GRAC difference threshold was applied. Barium has a MCL-CA of 1,000  $\mu\text{g/L}$ , and barium concentrations were all less than this benchmark.



**Figure 23.** Paired results of aluminum concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: A, with the GAMA replicate acceptability criteria difference threshold applied, and B, with the confidence interval difference threshold applied.



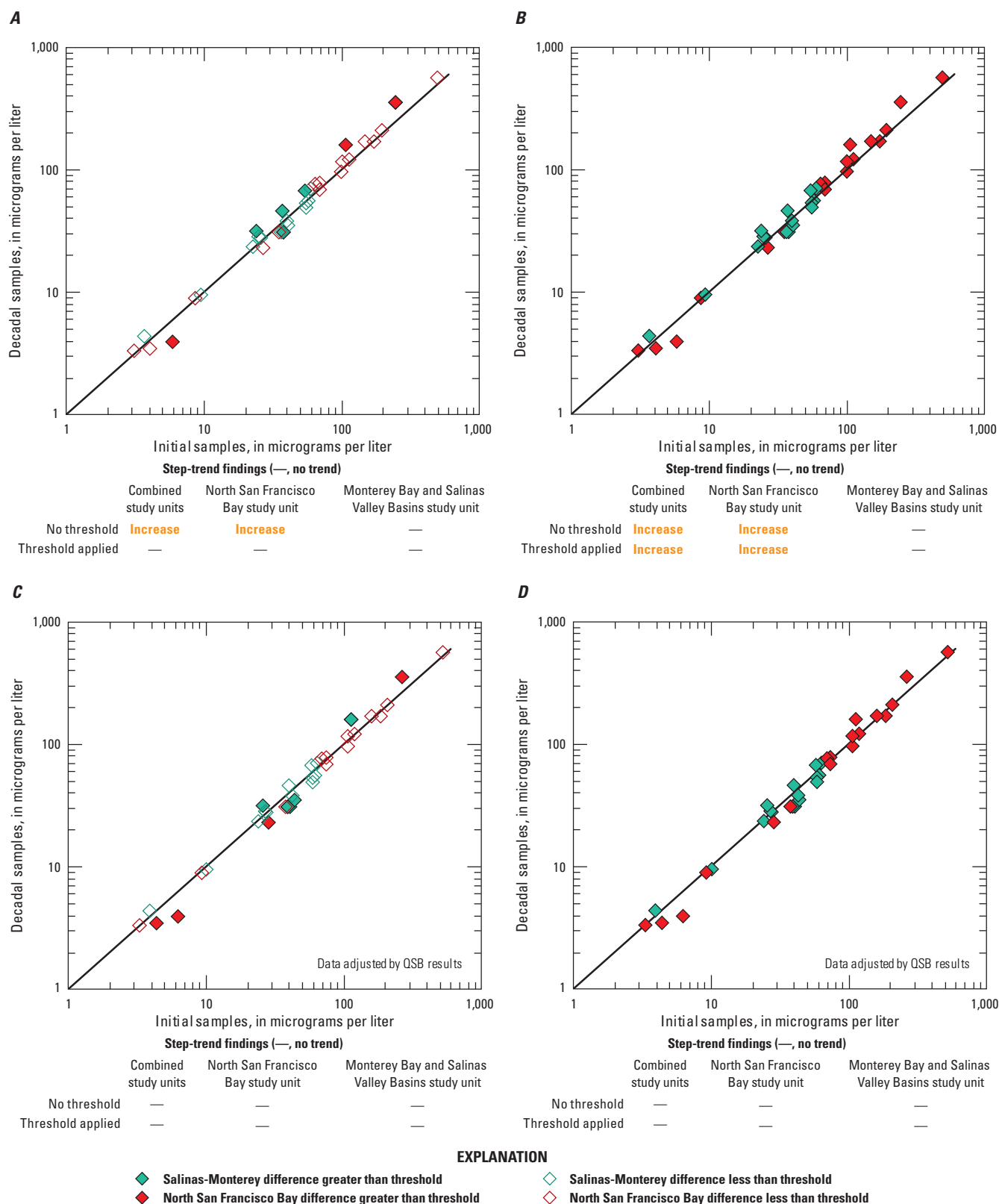


**Figure 24.** Paired results of arsenic concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

The QSB data-quality assessment summaries published around the initial-sampling period indicated a negative bias of about 7 percent for barium. Initial-sampling period barium measured by the NWQL could have been less than the true concentrations. Summaries published around the time of the decadal-sampling period did not indicate any bias for barium analyses by the NWQL. The potential negative bias during the initial-sampling period could have contributed to step trend of increased concentrations indicated by two of the evaluations. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired sample data after adding 7 percent to each initial-sampling period result. After adjusting the data in this way, none of the evaluation methods indicated a step trend for barium (table 2D; figs. 25C, D).

Iron concentrations in groundwater increased according to all three evaluations for the SALMON study unit and the combined study units (tables 2A, C, D; figs. 26A, B). The GAMA-PBP replicate variability for iron was greater than that of most other constituents. As a result of this, the standard

deviations calculated from replicate variability during each sampling period were greater than those for other constituents, and therefore, the CI difference threshold was comparable to the GRAC difference threshold for iron. Nevertheless, paired sample differences only failed to exceed the CI difference threshold when groundwater iron concentrations were less than about 20 µg/L (fig. 26B). All paired sample differences exceeded the CI difference threshold when groundwater iron concentrations were greater than 20 µg/L. The GAMA-PBB field-blank results indicated a potential positive bias in initial-sampling period iron concentrations (Kent, 2018, tables 10 and 13, <https://doi.org/10.5066/F7GH9GF5>). The step trend of increased iron concentrations was indicated despite the potential initial-sampling period positive bias, which might have obscured the trend. While no spatial pattern was noted for iron increases in the NSF study unit, the largest iron increases in the SALMON study unit were observed in wells in the northern part of the study unit. A national evaluation of decadal trends has evaluated iron for decadal step trends in 67 groundwater networks nationwide (Lindsey and others,



**Figure 25.** Paired results of barium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate criteria GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after adding 7 percent (demonstrated bias approximation) to the initial sample concentrations; and *D*, with the CI difference threshold applied after adding 7 percent (demonstrated bias approximation) to the initial sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.

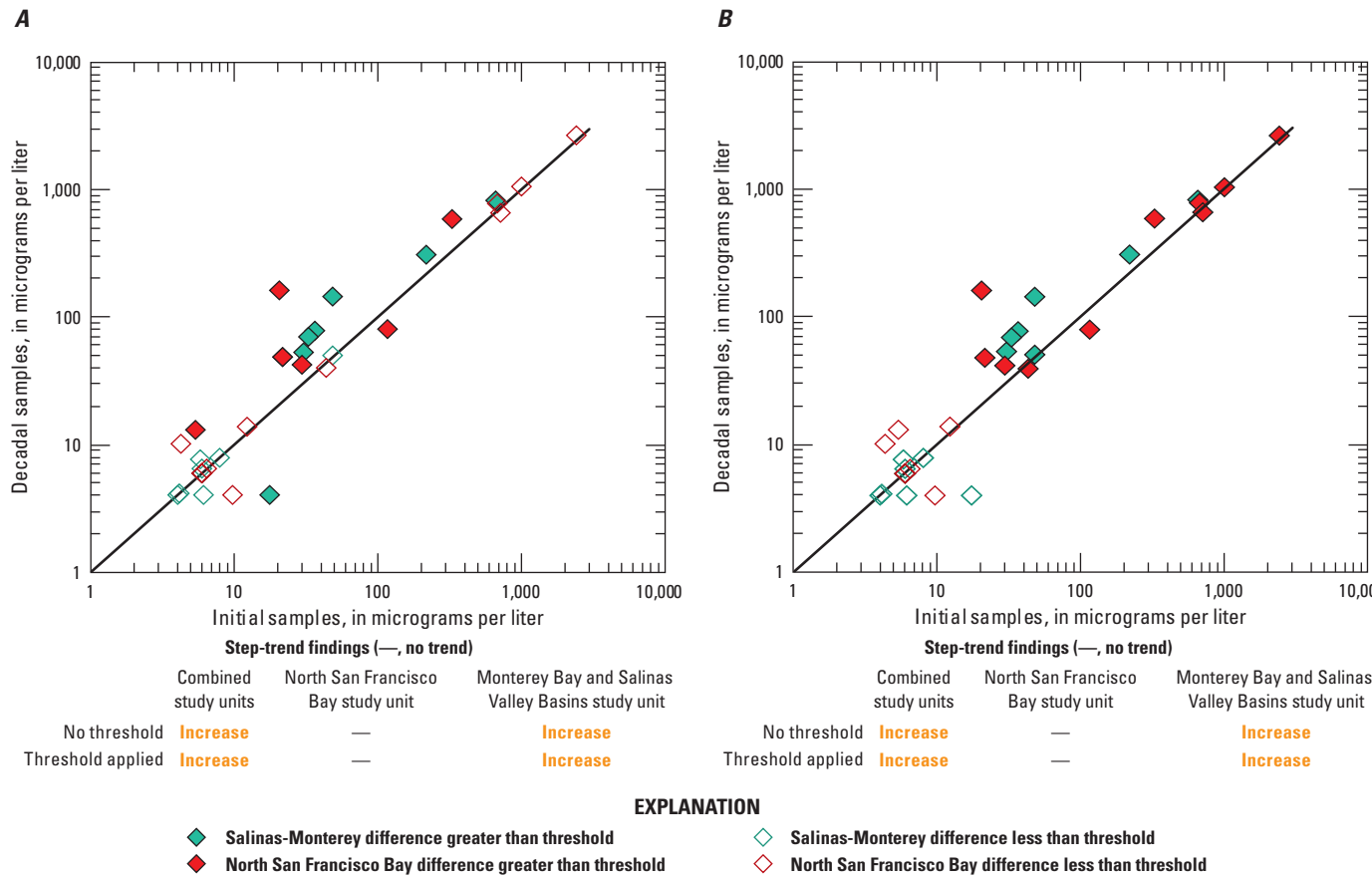
2016). Iron was found to have increased in 7 of these networks and to have decreased in 10 networks.

Lead concentrations in groundwater decreased only for the combined study units when the GRAC difference threshold was applied (tables 2A, D; fig. 27A). Based on GAMA-PBP field-blank results, study reporting levels (SRL) were applied to lead results from both sampling periods (Olsen and others, 2010; Davis and others, 2014). The SRL for the decadal-sampling period (0.82 µg/L) was slightly greater than the SRL for the initial-sampling period (0.65 µg/L). In addition, GAMA-PBB field-blank results indicated a potential positive bias in decadal-sampling period lead concentrations (Kent, 2018, tables 10 and 13, <https://doi.org/10.5066/F7GH9GF5>). The step trend of decreased lead concentrations for the combined study units was indicated despite the potential decadal-sampling period positive bias, which might have obscured the trend. Lead has a EPA action level of 15 µg/L, and lead concentrations in trend wells sampled for this study were all less than half this benchmark. While no spatial pattern was noted for lead changes in the SALMON study unit,

lead decreases in the NSF study unit groundwater primarily occurred in the southern part of the study unit.

Lithium concentrations in groundwater increased for the NSF study unit and the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, D; fig. 28B). All paired differences in lithium exceeded the CI difference threshold, so this threshold had no effect on the statistical test. No step trend was found for lithium when the GRAC difference threshold was applied. There was no evidence of analytical bias for lithium from project quality-control samples or the QSB data-quality assessment summaries.

Manganese concentrations in groundwater increased for the combined study units when no difference threshold was applied and when the CI difference threshold was applied; concentrations increased for the SALMON study unit according to all three evaluation methods (tables 2A, C, D; figs. 29A, B). Manganese concentrations were greater than the SMCL-CA of 50 µg/L in decadal samples from 14 wells. Of these 14 wells, 10 were in the NSF study unit. In



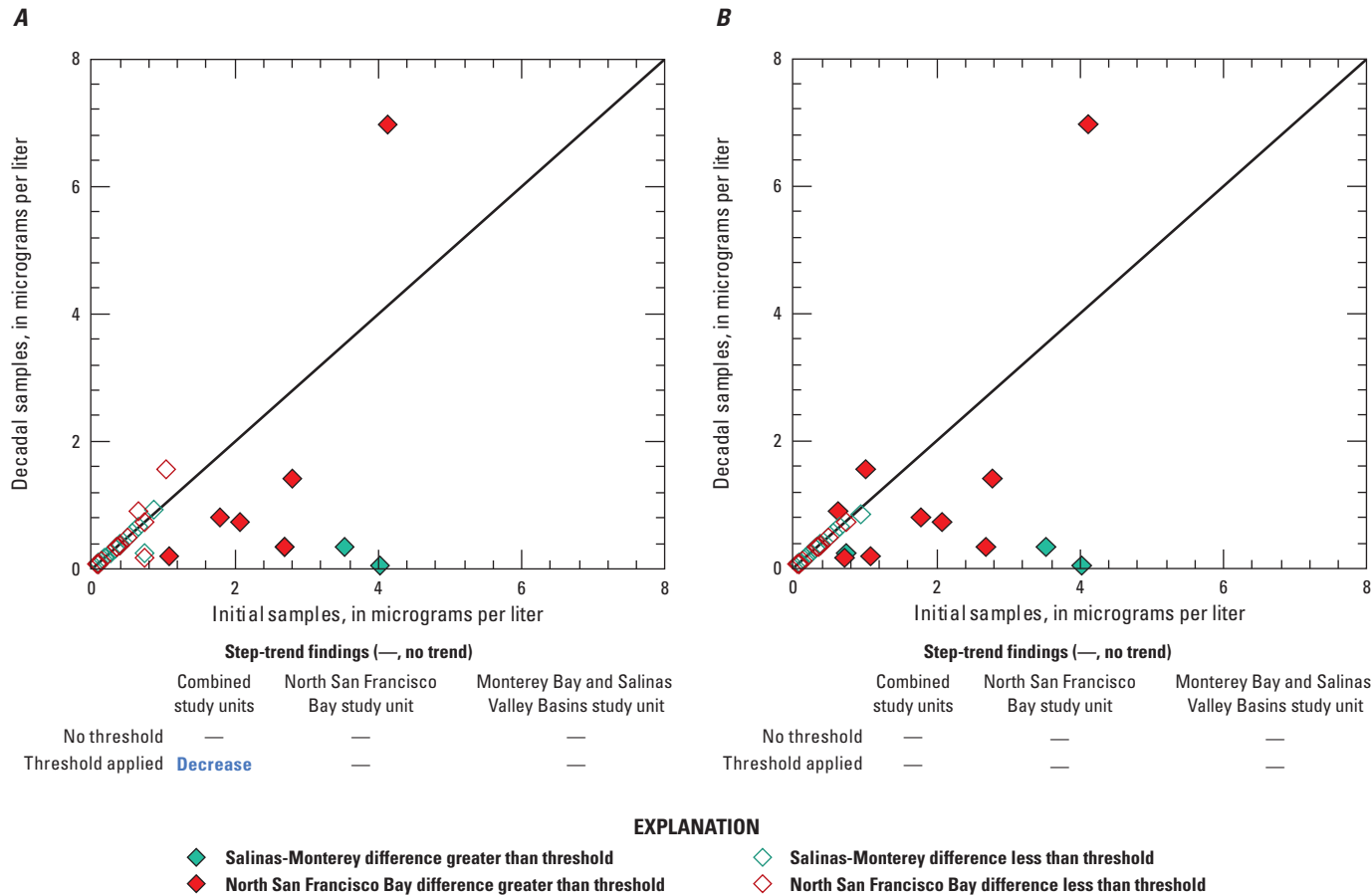
**Figure 26.** Paired results of iron concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: A, with the GAMA replicate acceptability criteria difference threshold applied, B, with the confidence interval difference threshold applied.

addition, manganese concentrations in initial samples from all but 1 of the 14 wells (MSPR-03) were also greater than the SMCL-CA. That is, manganese in groundwater from only one well changed from a concentration less than the SMCL-CA to a concentration greater than the benchmark between sampling periods.

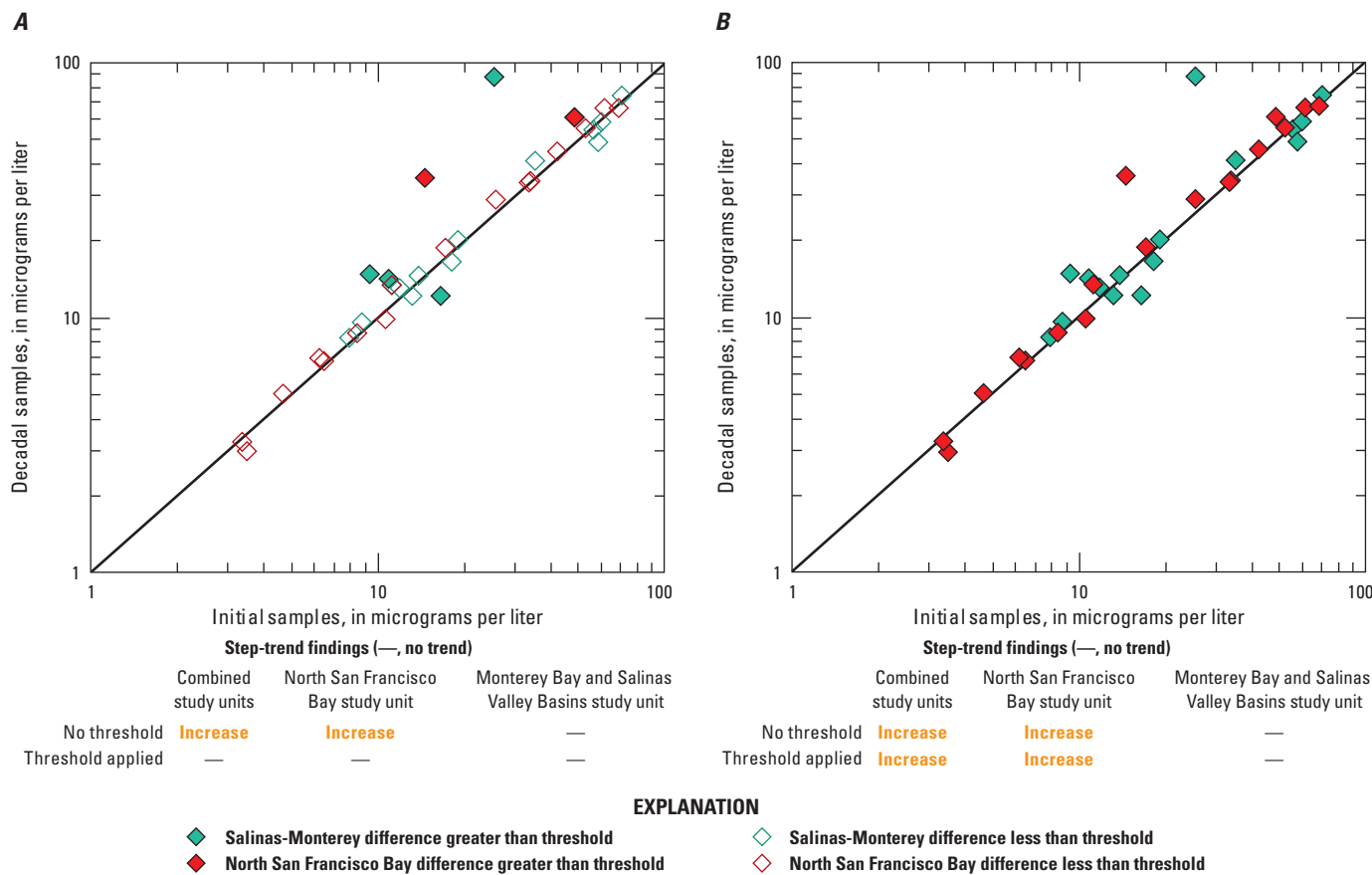
Based on GAMA-PBP field-blank results, study reporting levels (SRL) were applied to manganese results for both sampling periods (Olsen and others, 2010; Davis and others, 2014). The SRL for the decadal-sampling period (0.66 µg/L) was greater than the SRL for the initial-sampling period (0.2 µg/L). In contrast, the QSB data-quality assessment summaries published around the initial-sampling period indicated a negative bias of about 8 percent for manganese. Initial-sampling period manganese measured by the NWQL could have been less than the true concentrations. Summaries published around the time of the decadal-sampling period did not indicate any bias in manganese analyses by the NWQL. The negative bias during the initial-sampling period could have contributed to the findings of increased concentrations of manganese. To test the potential effect of this documented

bias on the findings of step trends, the three evaluations were repeated on the paired-sample data after adding 8 percent to each initial-sampling period result. After adjusting the data in this way, none of the evaluation methods indicated a step trend for manganese (table 2D; figs. 29C, D). A national evaluation of decadal trends has evaluated manganese for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Manganese was found to have increased in 6 of these networks and to have decreased in 21 networks.

Nickel concentrations increased in only the NSF study unit when no difference threshold was applied and when the CI difference threshold was applied (tables 2B, C, D; fig. 30B). Nickel has a MCL-CA of 100 µg/L, and nickel concentrations in trend wells sampled for this study were all substantially less than this benchmark. Groundwater in only one well—MSSV-03 in the SALMON study unit—had a nickel concentration greater than 10 µg/L. The nickel concentration in groundwater from that well increased from 3.5 µg/L in the initial sample to 32 µg/L in the decadal sample. The concentrations of several other trace elements and major ions, along with nitrate, all increased substantially in groundwater from MSSV-03. The



**Figure 27.** Paired results of lead concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, *B*, with the confidence interval difference threshold applied.



**Figure 28.** Paired results of lithium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

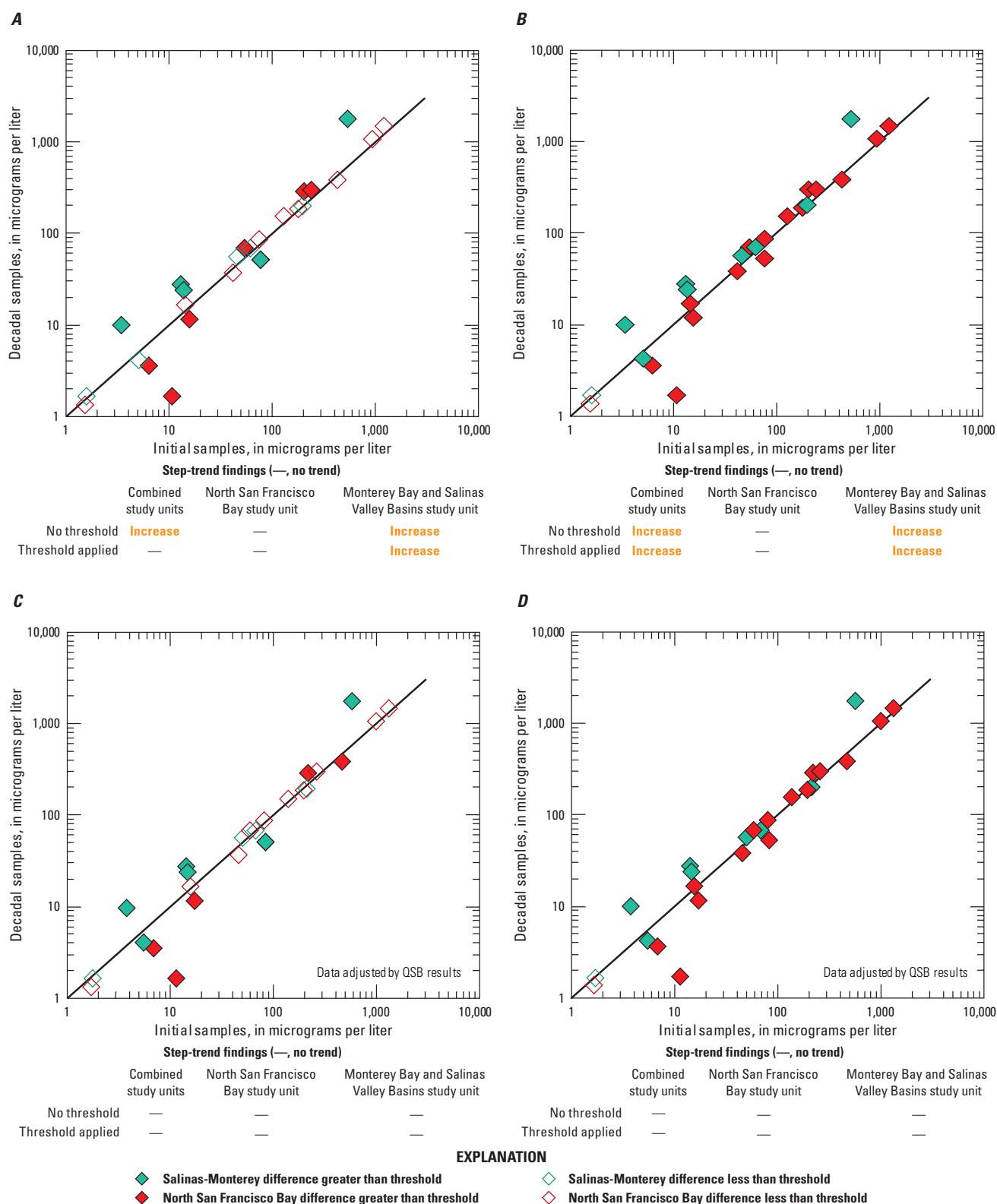
QSB data-quality assessment summaries published around the decadal-sampling period indicated a positive bias of about 17 percent for nickel. Decadal-sample period nickel measured by the NWQL could have been greater than the true concentrations. Summaries published around the time of the initial-sampling period did not indicate any bias in nickel analyses at the NWQL. The potential positive bias during the decadal trend period could have contributed to the increased concentrations found by two of the evaluations for the NSF study unit. To test the potential effect of this documented bias on the findings of step trends, the three evaluations were repeated on the paired-sample data after subtracting 17 percent from each decadal-sample period result. After adjusting the data in this way, none of the evaluation methods indicated a step trend for nickel (table 2*D*; figs. 30*C*, *D*).

Selenium concentrations decreased in groundwater from for the NSF study unit by all three evaluation methods (tables 2*B*, *D*; figs. 31*A*, *B*). No step trends were exhibited for selenium in the SALMON study unit nor in the combined study units by any of the evaluation methods. There was

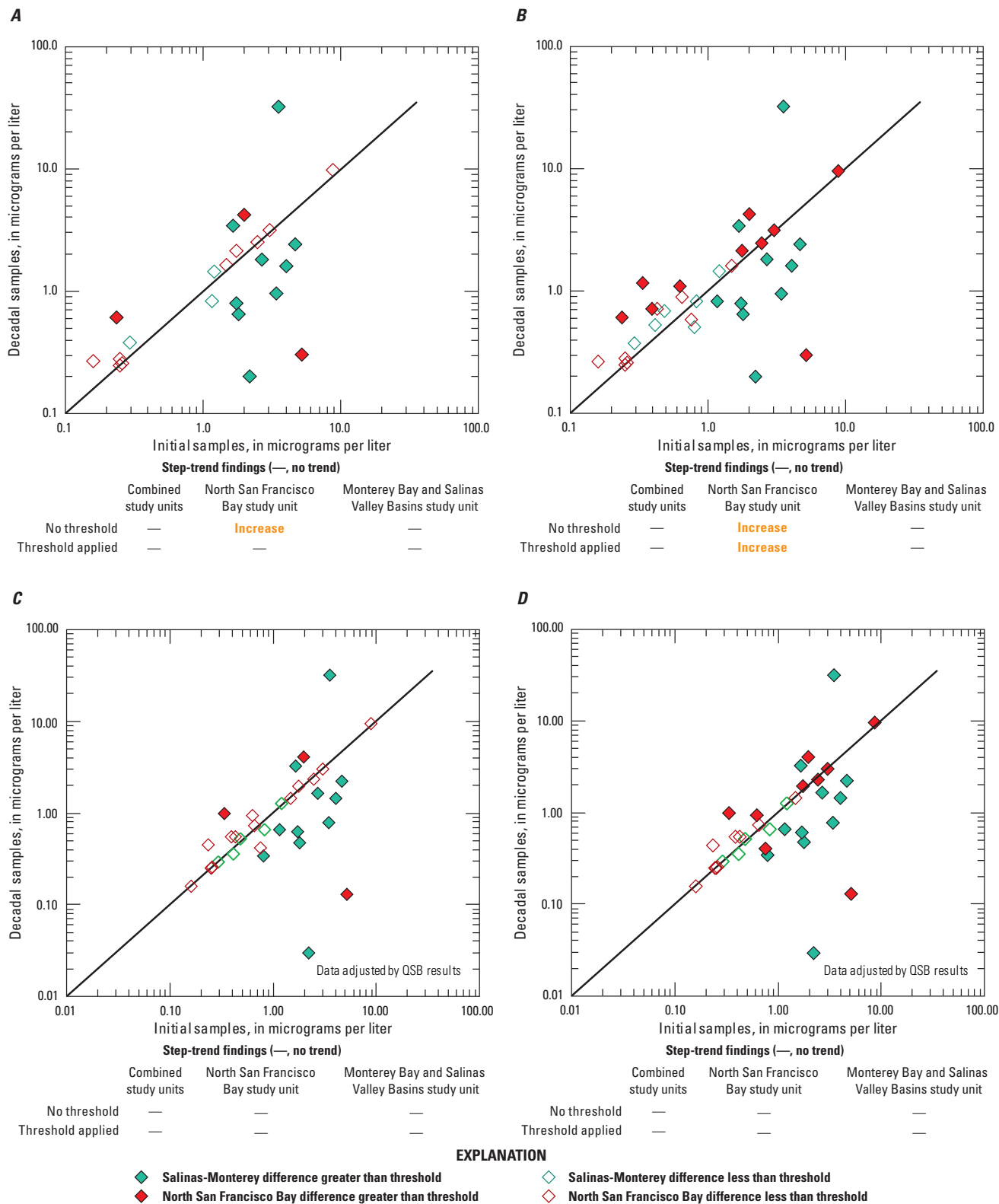
no evidence of analytical bias for selenium from project quality-control samples or the QSB data-quality assessment summaries.

Strontium concentrations increased for only the combined study units when the GRAC difference threshold was applied (tables 2*A*, *D*; figs. 32*A*). The QSB data-quality assessment summaries from the initial-sampling period indicated a positive bias of about 7 percent for strontium. Initial period strontium measured by the NWQL could have been greater than the true concentration. Summaries published around the time of the decadal-sampling period did not indicate any bias in strontium analyses at the NWQL. The step trend of increased strontium concentrations for the combined study units was indicated despite the potential initial-sampling period positive bias, which might have obscured the trend. A national evaluation of decadal trends has evaluated strontium for decadal step trends in 67 groundwater networks nationwide (Lindsey and others, 2016). Strontium was found to have increased in three of these networks and to have decreased in two networks.

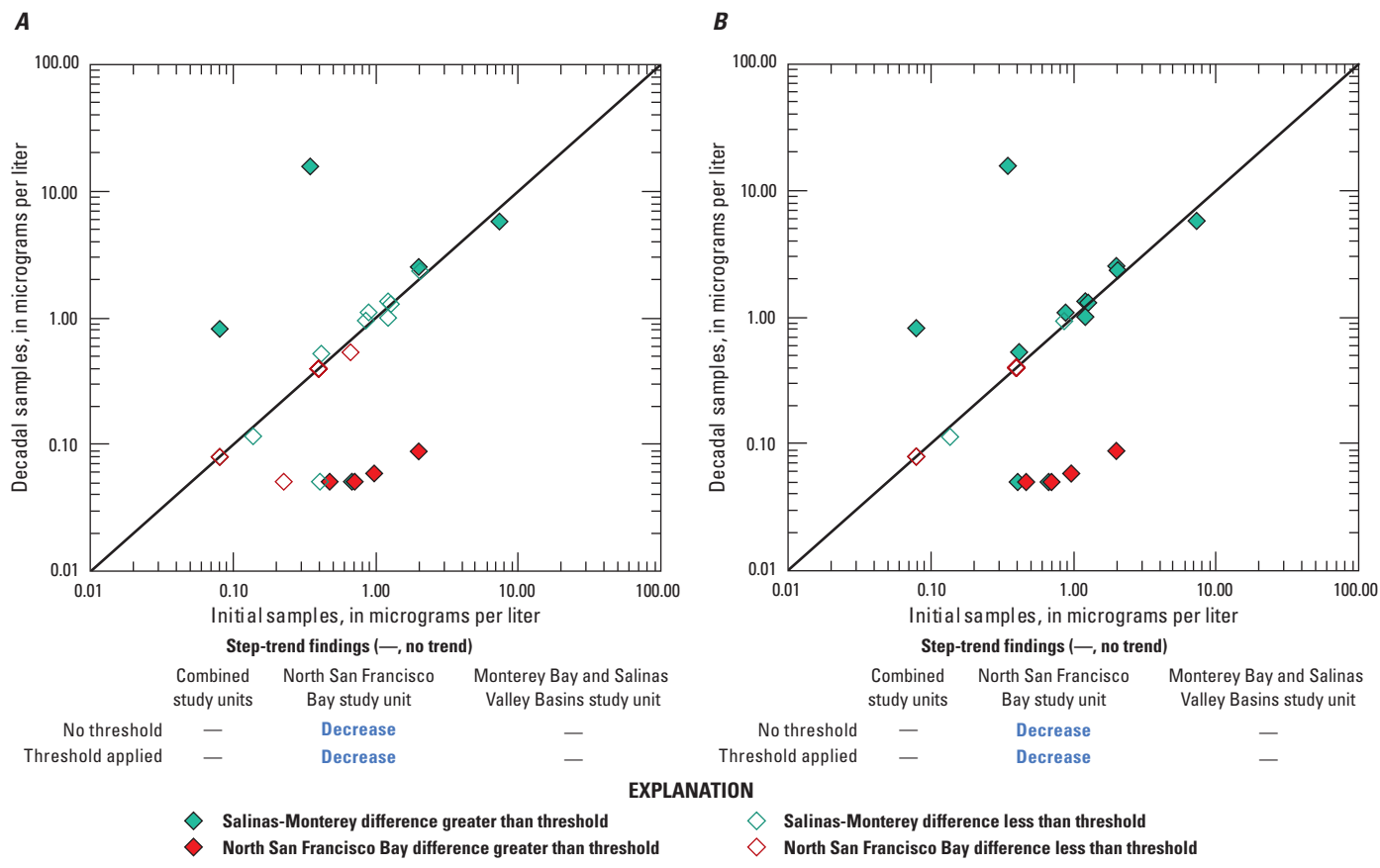




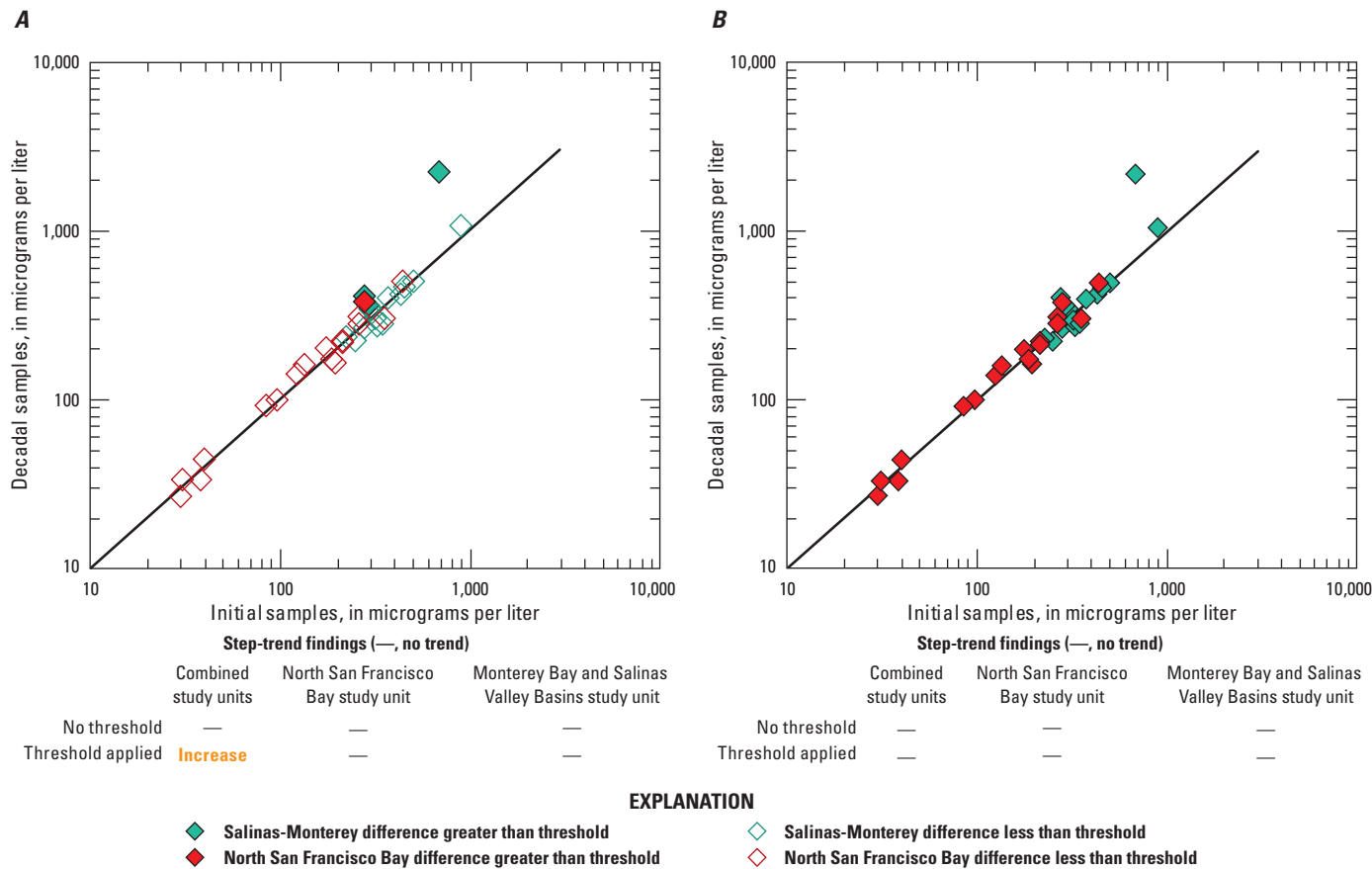
**Figure 29.** Paired results of manganese concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after adding 8 percent (demonstrated bias approximation) to the initial sample concentrations; and *D*, with the CI difference threshold applied after adding 8 percent (demonstrated bias approximation) to the initial sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.



**Figure 30.** Paired results of nickel concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria (GRAC) difference threshold applied; *B*, with the confidence interval (CI) difference threshold applied; *C*, with the GRAC difference threshold applied after subtracting 17 percent (demonstrated bias approximation) from the trend sample concentrations; and *D*, with the CI difference threshold applied after subtracting 17 percent (demonstrated bias approximation) from the trend sample concentrations. Bias approximations are based on periodic data-quality assessment summaries provided by the Inorganic Blind Sample Project of the U.S. Geological Survey Quality Systems Branch.



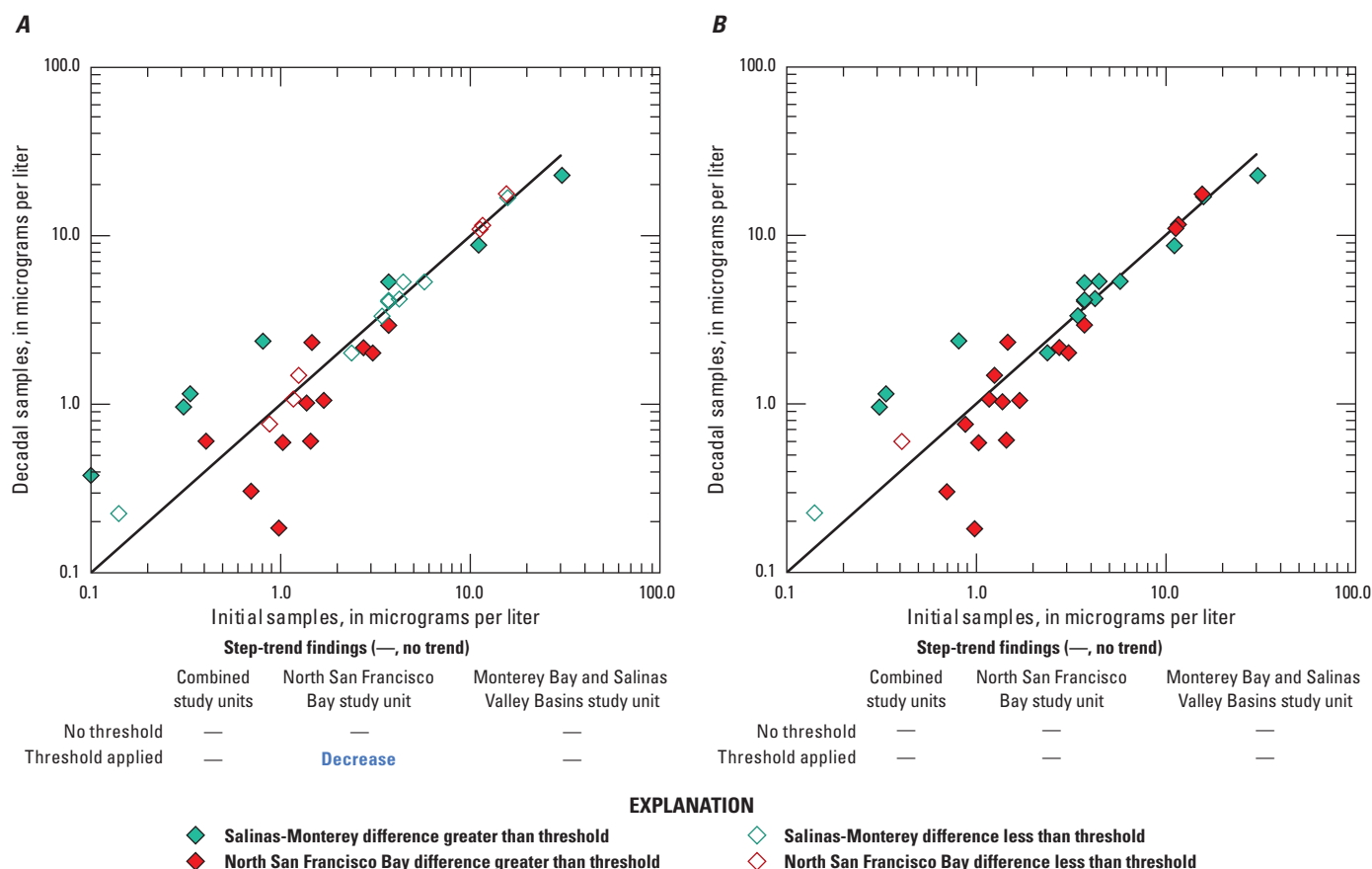
**Figure 31.** Paired results of selenium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, *B*, with the confidence interval difference threshold applied.



**Figure 32.** Paired results of strontium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

Vanadium concentrations decreased for only the NSF study unit when the GRAC difference threshold was applied (tables 2A, D; fig. 33A). The GAMA-PBP field-blank results indicated a potential positive bias in decadal-sampling period vanadium concentrations (Kent, 2018, tables 10 and 13, <https://doi.org/10.5066/F7GH9GF5>). The step trend of

decreasing vanadium concentrations was indicated despite this potential positive bias in decadal samples, which might have obscured the trend.



**Figure 33.** Paired results of vanadium concentrations in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

## Isotopic Constituents

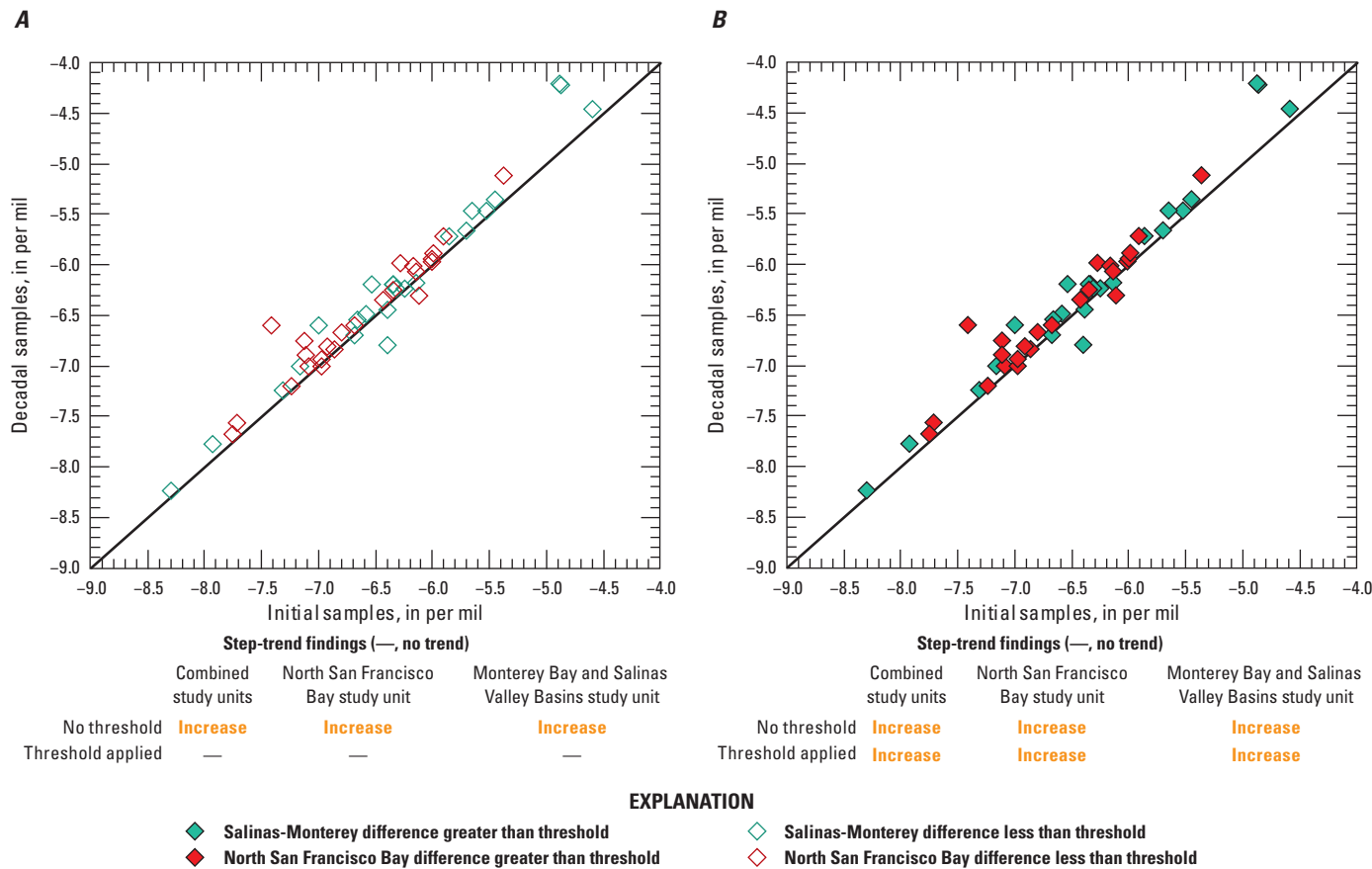
Five isotopic constituents were evaluated for step trends. Step trends were found for at least one of the study units or the combined study units by at least one of the evaluation methods for the ratio of oxygen-18 in water ( $\delta^{18}\text{O-H}_2\text{O}$ ), the ratio of the stable isotope carbon-13 ( $\delta^{13}\text{C}$ ), and tritium (tables 2A, B, C, D).

The isotopic ratio of oxygen-18 in water ( $\delta^{18}\text{O-H}_2\text{O}$ ) increased in groundwater from each study unit and for the combined study units when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, B, C, D; fig. 34B). An increase in an isotopic ratio is defined here to mean that the isotopic composition has become less negative or heavier (enriched in regard to the heavier isotope). All paired differences in  $\delta^{18}\text{O-H}_2\text{O}$  exceeded

the CI difference threshold, so this threshold had no effect on the statistical test. In contrast, no paired sample differences in  $\delta^{18}\text{O-H}_2\text{O}$  exceeded the GRAC difference threshold; thus, no step trend was indicated when this difference threshold was applied.

The ratio of the stable isotope carbon-13 ( $\delta^{13}\text{C}$ ) in groundwater decreased in the SALMON study unit when no difference threshold was applied and when the CI difference threshold was applied (tables 2A, C, D; fig. 35B). A decrease in an isotopic ratio is defined here to mean that the isotopic composition has become more negative or lighter (depleted in regard to the heavier isotope). As was the case with the stable isotope in water  $\delta^{18}\text{O-H}_2\text{O}$ , all paired differences for  $\delta^{13}\text{C}$  exceeded the CI difference threshold, but no paired differences for  $\delta^{13}\text{C}$  exceeded the GRAC difference threshold.

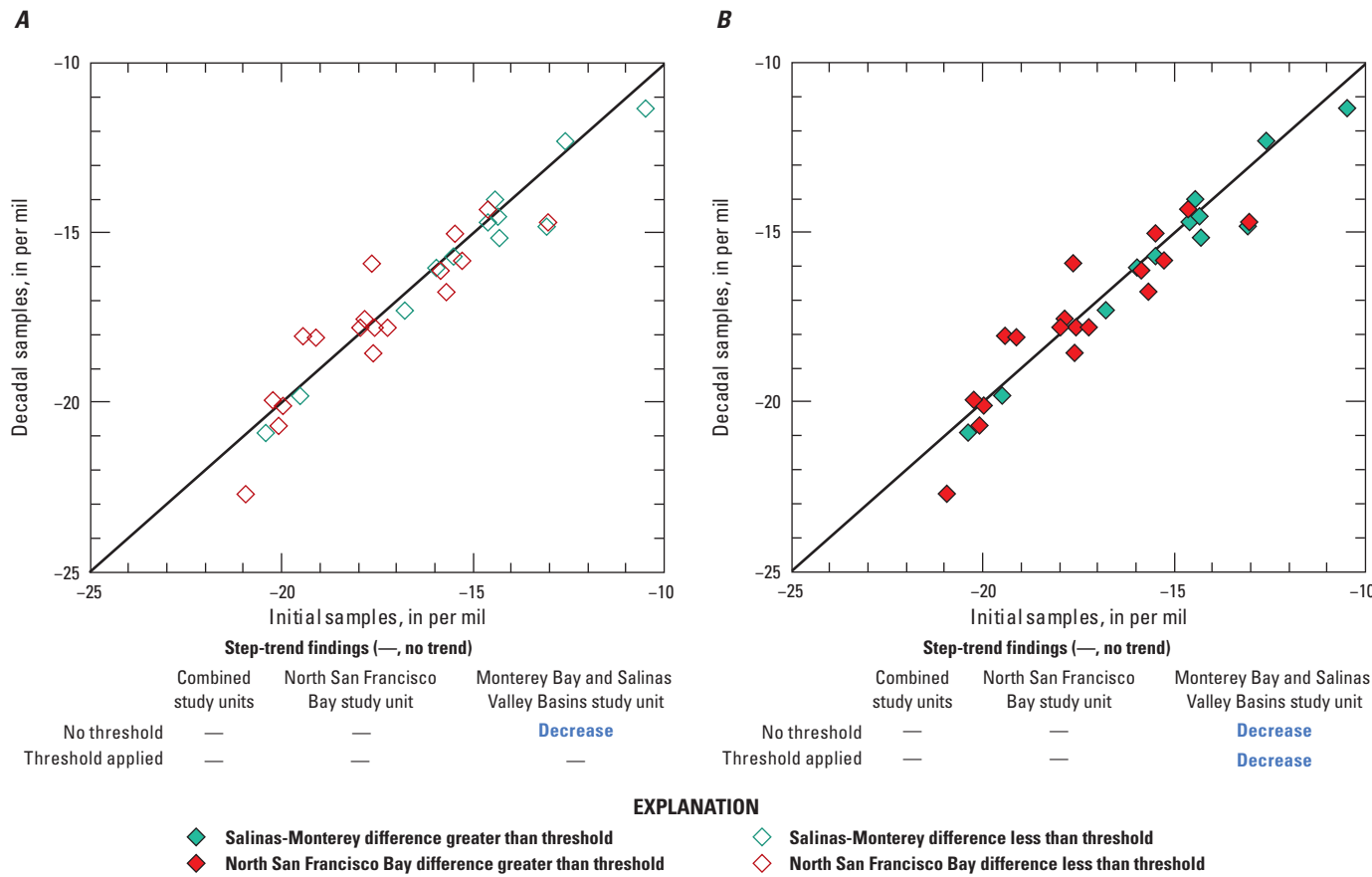




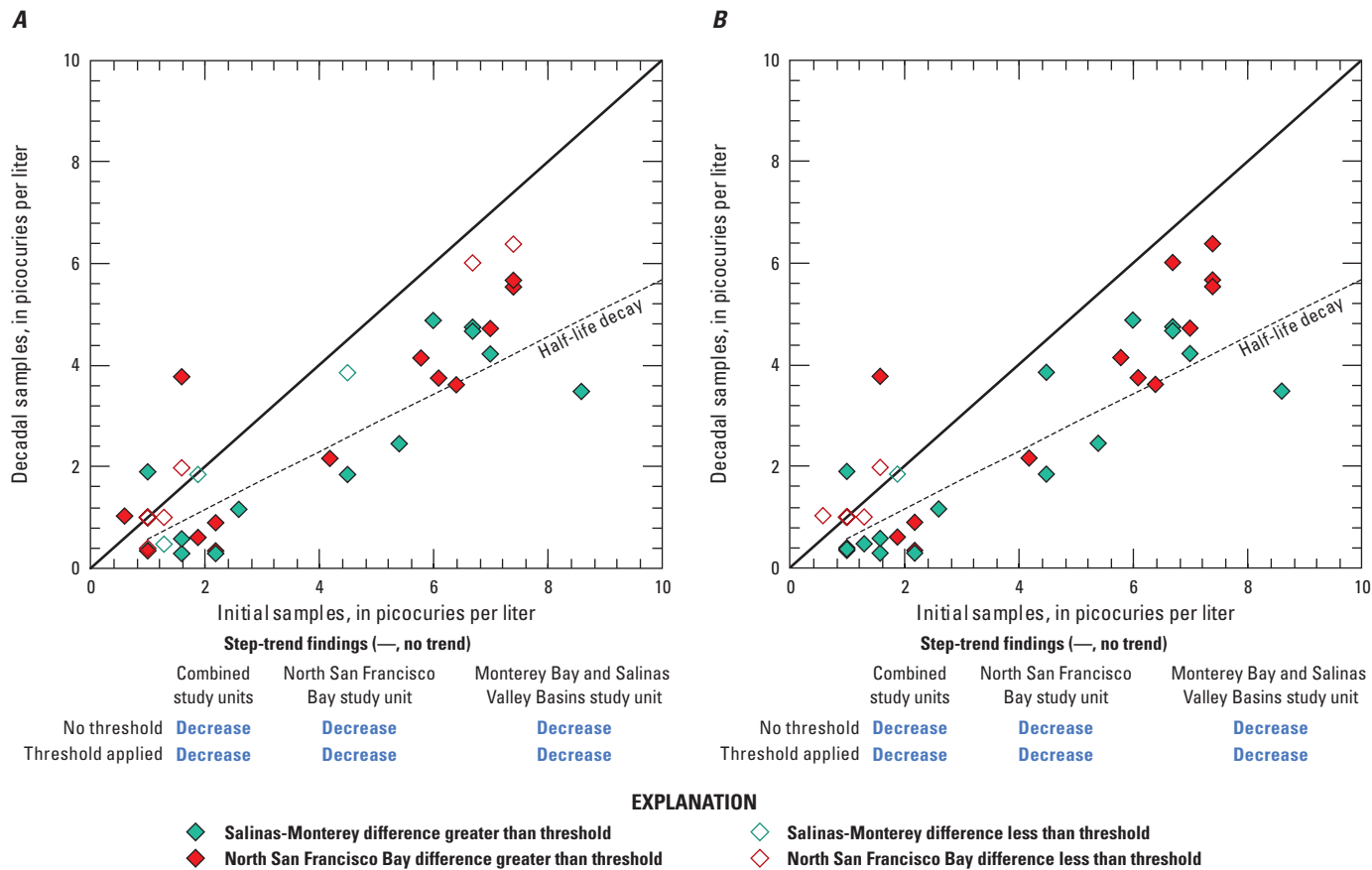
**Figure 34.** Paired results of the isotopic ratio of oxygen-18 ( $\delta^{18}\text{O}$ ) in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

Tritium in groundwater decreased in each study unit and the combined study units according to all three evaluations (tables 2A, B, C, D; figs. 36A, B). Tritium decreases were far more common than increases, which would be expected. Tritium is an unstable (radioactive) isotope of hydrogen with a half-life of approximately 12.3 years (Plummer and others, 1993). Figure 36 (A, B) includes a dotted line representing the

decrease in tritium activity predicted by radioactive decay. It is interesting that when initial activities in groundwater were less than about 6 picocuries per liter (pCi/L), tritium decreased more than expected by radioactive decay alone, but when initial activities were greater than about 6 pCi/L, tritium decreased less than expected.



**Figure 35.** Paired results of the isotopic ratio of carbon-13 ( $\delta^{13}\text{C}$ ) in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.



**Figure 36.** Paired results of tritium activities in groundwater during the collection of initial samples (2004–05) and decadal samples (2014) in the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins Groundwater Ambient Monitoring and Assessment Priority Basin Project (GAMA-PBP) study units: *A*, with the GAMA replicate acceptability criteria difference threshold applied, and *B*, with the confidence interval difference threshold applied.

## Summary and Conclusions

Three variations of a method to identify step trends in groundwater quality are presented for a case study on the north-central California coast as part of a statewide investigation of groundwater quality by the U.S. Geological Survey (USGS) for the Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project (PBP). The GAMA-PBP is being carried out in cooperation with the California State Water Resources Control Board to assess and monitor the quality of groundwater resources applied for drinking-water supply and to improve public knowledge of groundwater quality in California. Paired samples were collected from 50 public supply wells in 2 GAMA-PBP study units during 2 sampling periods separated by approximately 10 years. During both sampling periods, 160 water-quality constituents were measured. The initial-sampling period was from 2004 to 2005. For a few wells, data collected in 2007–08 supplemented the initial-sample data for inorganic constituents that were not analyzed in the samples collected in 2004–05. The decadal-sampling period to assess step trends was in 2014; decadal samples were generally analyzed for all of the common constituents.

To identify step trends, a nonparametric hypothesis test (Wilcoxon signed-rank test with the Pratt correction) on the differences in constituent results between the two sampling periods was used. Before doing the statistical evaluations (the hypothesis tests), the data were processed three different ways, resulting in three variations of the evaluation method. Data was processed to prevent small differences from supporting the conclusion of a step trend and to overcome challenges of comparing result pairs in which one or both of the results was a non-detection. The first evaluation method variation was limited to processing the data to overcome challenges comparing result pairs in which one or both of the results was a non-detection (a result expressed simply as less than the reporting level). The second and third variations added a requirement that the paired-result differences exceed a defined threshold. If the threshold was not exceeded, the results were considered analytically identical (tied) for the statistical evaluation. The objective of both difference-threshold-setting methods was to prevent small differences from supporting the conclusion of a step trend. The GAMA-PBP replicate acceptability criteria (GRAC) method for setting the difference threshold between initial-sampling and resampling results is based on criteria used by the GAMA-PBP to determine whether or not replicate results are acceptable (Kent and others, 2014, p. 148); that is, if two results are similar enough to constitute an acceptable replicate, the small difference between them should not support the conclusion that there is a trend. In contrast, the confidence interval (CI) difference-threshold-setting method uses the actual results of replicate

samples collected during each sampling period to calculate a 95-percent confidence interval around each result. This threshold is exceeded if the confidence intervals for the initial and decadal-sample results do not overlap.

Step trends were identified by at least 1 of the 3 evaluations for 33 of the 59 constituents detected in at least 10 percent of samples analyzed (a requirement imposed for evaluation; [tables 2A, B, C, D](#)). The statistical evaluations alone do not provide sufficient evidence to conclude that all 33 constituents with statistically significant results for a step trend are actually changing in groundwater on the north-central California coast, however. Therefore, results of the statistical evaluations were further examined critically and in context. After such examination, some step-trend findings were deemed inconclusive.

## Constituents Exhibiting Conclusive Evidence of Step Trends

There is evidence to support the findings of meaningful changes for 14 of the 33 constituents for which step trends were indicated by 1 or more of the evaluation methods. Constituent concentrations changed in one or both of the study units or in the combined study units. The constituents that increased were dissolved oxygen, total nitrogen, nitrate, orthophosphate, calcium, chloride, sulfate, iron, and lithium. The constituents that decreased were temperature, arsenic, lead, the isotopic ratio of carbon-13 ( $\delta^{13}\text{C}$ ), and tritium.

Dissolved oxygen concentrations increased in groundwater of the North San Francisco Bay (NSF) study unit; concentrations increased in paired samples from 13 wells and decreased in paired samples from 4 wells. Changes in dissolved oxygen concentrations are most meaningful when they indicate the groundwater converted from oxic to anoxic conditions or vice versa. McMahon and Chapelle (2008) defined anoxic groundwater as having a dissolved oxygen concentration less than 0.5 mg/L. Using this criterion, groundwater from four of the NSF wells changed from anoxic to oxic between sampling periods, and groundwater from one NSF well changed from oxic to anoxic.

Total nitrogen, mostly in the form of nitrate, increased in groundwater of the SALMON study unit. This is consistent with a recent study (Harter and Lund, 2012) that found nitrate increased significantly in the area of the SALMON study unit. That study concluded that nitrate source reduction actions might not reverse this trend for several decades because of the long groundwater travel times in this area. No step trend was indicated for nitrate in the NSF study unit. A national evaluation of decadal step trends found that nitrate had increased in 14 groundwater networks and had decreased in 6 networks after approximately 10-year intervals (Lindsey and Rupert, 2012; Lindsey and others, 2016).

Orthophosphate increased in groundwater from the SALMON study unit and from the combined study units. A study that evaluated 3-year step trends found that orthophosphate increased statewide in California (Kent and Landon, 2016). Interestingly, that study found no step trend for orthophosphate in the hydrogeologic area (coastal) that included wells from the NSF and the SALMON GAMA-PBP study units. That study included only two wells from the SALMON study unit, however, and orthophosphate in both of those wells increased by more than the GRAC difference threshold after 3 years. A national evaluation of decadal step trends found that orthophosphate increased in 13 groundwater networks and decreased in 9 networks after approximately 10-year intervals (Lindsey and others, 2016).

Calcium concentrations increased in groundwater from both study units and from the combined study units. Calcium and magnesium are the primary contributors to water hardness (Hem, 1985), and calcium was the greatest contributor to hardness in the groundwater of 30 out of the 34 wells evaluated during this study. Moreover, the groundwater in 26 out of these 34 wells would be classified as “hard” or “very hard” on the basis of the combined concentrations of calcium and magnesium (Durfor and Becker, 1964). Although there is no human health threshold for calcium concentrations in water, increases in calcium concentration pose a potentially important groundwater-quality concern in the study area. While no spatial pattern was noted for calcium increases in the SALMON study unit, calcium increases in the NSF study unit groundwater primarily occurred in the eastern side of the study unit.

Chloride concentrations increased in groundwater from the NSF study unit. At the time of this study, most chloride concentrations in the study areas were not at levels of concern. Chloride concentrations in groundwater from two trend wells were greater than the California secondary maximum contaminant level (SMCL-CA) of 250 mg/L. A national evaluation of decadal step trends found that chloride increased in 31 groundwater networks and decreased in 2 networks after approximately 10-year intervals (Lindsey and others, 2016).

Sulfate concentrations increased in groundwater from the NSF study unit and from the combined study units. At the time of this study, most sulfate concentrations in the study areas were not at levels of concern. In one trend well, the sulfate concentration was greater than the SMCL-CA of 250 mg/L. That well (MSSV-03) was in the SALMON study unit, for which a step trend for sulfate concentrations was not indicated. A national evaluation of decadal step trends found that sulfate concentrations increased in 16 groundwater networks and decreased in 6 networks after approximately 10-year intervals (Lindsey and others, 2016). While no spatial pattern was noted for sulfate increases in the SALMON study unit, sulfate increases in the NSF study unit groundwater primarily occurred in the eastern side of the study unit.

Iron concentrations increased in groundwater from the SALMON study unit and from the combined study units. Iron concentrations were greater than the SMCL-CA of 300 µg/L

in samples from seven wells, and iron in one of these wells (MSSC-08) increased from 218 to 308 µg/L to exceed this non-regulatory benchmark during the study period. Iron concentrations generally increased in groundwater from wells for which the initial concentration was greater than 20 µg/L. In wells from which the initial concentration was less than 20 µg/L, there were about as many increases as there were decreases in iron concentrations, and the changes did not generally exceed either difference threshold. A national evaluation of decadal step trends found that iron increased in 7 groundwater networks and decreased in 10 networks after approximately 10-year intervals (Lindsey and others, 2016). While no spatial pattern was noted for iron increases in the NSF study unit, the largest iron increases in the SALMON study unit were observed in wells in the northern part of the study unit.

Lithium concentrations increased in groundwater from the NSF study unit and from the combined study units. There is no human health threshold for lithium concentrations in water. Lithium can be toxic to plants, however, and citrus trees can be damaged by irrigation water containing 60–100 µg/L of lithium (Bradford, 1963). Lithium concentrations in groundwater from four trend wells were in this range during the initial sampling, and concentrations in groundwater from five trend wells were in this range during the decadal sampling.

The temperature of groundwater from most wells sampled for this study decreased by a mean of about 0.7 degrees Celsius (°C). The measured decreases in groundwater temperature cannot be explained by differences in sampling conditions between initial and decadal sampling. Groundwater was pumped to land surface before field parameters were measured, so air temperature could affect the water-temperature measurement. Air temperatures were greater at the time of the decadal sampling than at the time of the initial sampling for 9 of the 13 wells in which groundwater temperatures decreased. The few wells where groundwater temperatures increased in the SALMON study unit were located in the central part of the Monterey Bay study area. No spatial pattern was observed for the few NSF wells where groundwater temperatures increased.

Arsenic concentrations decreased in groundwater from the NSF study unit and from the combined study units. Arsenic in California groundwater is generally naturally present, but can also derive from agricultural activities, including pesticide application, and industrial activities (Balazs and others, 2012). In 2001, the EPA adopted a new maximum contaminant level for arsenic of 10 µg/L, which replaced the old standard of 50 µg/L (U.S. Environmental Protection Agency, 2001), and compliance with the new standard has been burdensome for some (particularly small) water agencies (Jones and Joy, 2006). A national evaluation of decadal step trends found that arsenic increased in three groundwater networks and decreased in eight networks after approximately 10-year intervals (Lindsey and others, 2016).



While no spatial pattern was noted for arsenic changes in the SALMON study unit, arsenic decreases in the NSF study unit groundwater primarily occurred in the southern-central and eastern areas of the study unit.

Lead concentrations decreased in groundwater from the combined study units. A study that evaluated 3-year step trends found that lead decreased statewide in California (Kent and Landon, 2016). As was the case for orthophosphate, that study found no step trend for lead in the hydrogeologic area (coastal) that included wells from the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins GAMA-PBP study units. Only three wells in the present study area were included in that 3-year evaluation, however, so the data were insufficient to find step trends. Lead concentrations in two of those three wells were less than the applied reporting level (an SRL) in both samples (non-detections in all cases). The lead concentration in the third well decreased from 2.68 to 0.45  $\mu\text{g/L}$  in 3 years. While no spatial pattern was noted for lead changes in the SALMON study unit, lead decreases in the NSF study unit groundwater primarily occurred in the southern part of the study unit.

The isotopic ratio of carbon-13 ( $\delta^{13}\text{C}$ ) decreased in groundwater from the SALMON study unit. Changes in  $\delta^{13}\text{C}$  do not indicate a change in groundwater quality, but could indicate that groundwater recharge or mineralization conditions changed in the aquifer (Awad, 2014). The decrease in  $\delta^{13}\text{C}$  in groundwater can also reflect atmospheric decreases in  $\delta^{13}\text{C}$  caused by the Suess Effect (Keeling, 1979). The Suess Effect is the decrease in atmospheric  $\delta^{13}\text{C}$  and  $\delta^{14}\text{C}$  values due to fossil fuel emissions, which are depleted in  $^{13}\text{C}$  and do not contain  $^{14}\text{C}$ .

Tritium decreased in groundwater from both study units and from the combined study units. Tritium is an unstable (radioactive) isotope of hydrogen and has a half-life of approximately 12.3 years (Plummer and others, 1993). As a result, tritium activity in an isolated parcel of water is expected to decrease. Because a finding of decreasing tritium is expected, the ability to systematically detect the decrease demonstrates that the trend-evaluation method is capable of detecting change.

## Inconclusive Step-Trend Findings

There is insufficient evidence to conclude that there were meaningful changes in groundwater quality for 19 of the 33 constituents exhibiting a step trend by at least 1 of the evaluation methods. Step-trend findings for a constituent were deemed inconclusive under any one of the following three circumstances: (1) analytical bias was documented by the USGS Quality Systems Branch (QSB) during one or both sampling periods, and, when the data were adjusted for the bias, the step trend was no longer statistically significant; (2) the step-trend finding was not consistent with the evaluated results of a different, generally correlated, water-quality

constituent; and (3) the concentrations of the constituent for which the step trend was indicated were negligible relative to their potential effect on groundwater quality. In consideration of these circumstances, findings were deemed inconclusive for 19 of the 33 constituents for which step-trend results were initially significant.

Analytical bias that could have affected step-trend findings was documented by the QSB for seven of the water-quality constituents for which step trends were indicated by at least one of the evaluation methods (table 3). These constituents included the major ions magnesium (figs. 15C, D), potassium (figs. 16C, D), sodium (figs. 17C, D), silica (figs. 22C, D), and the trace elements barium (figs. 25C, D), manganese (figs. 29C, D), and nickel (figs. 30C, D). In each of these cases, after adjusting the data for the bias, step trends were no longer indicated.

Step-trend findings for five constituents were deemed inconclusive because of a lack of support from the evaluations of other constituents that are generally correlated with these constituents (table 3). An increase indicated for field (fig. 6) and laboratory-measured (fig. 7) specific conductance was not supported by the evaluations of total dissolved solids, which failed to indicate a statistically significant increase. A decrease in field-measured pH for the SALMON study unit and the combined study units (fig. 8) was partially contradicted by the indication of increased laboratory-measured pH in groundwater from the SALMON study unit (fig. 9). Finally, the increased isotopic ratio of oxygen-18 in water ( $\delta^{18}\text{O-H}_2\text{O}$ ; fig. 34) was not accompanied by a corresponding increase in the isotopic ratio of deuterium in water ( $\delta^2\text{H-H}_2\text{O}$ ). Almost invariably,  $\delta^{18}\text{O-H}_2\text{O}$  co-varies with  $\delta^2\text{H-H}_2\text{O}$  (Ingraham, 1998). No step trend was found by any of the evaluation methods for  $\delta^2\text{H-H}_2\text{O}$ , however.

The concentrations of seven constituents for which step trends were indicated were small relative to their potential effect on groundwater quality (table 3). As a result, the step trends were not considered important. Neither carbonate (fig. 10) nor iodide (fig. 19) has a health-based or non-health-based drinking water threshold. Carbonate is most important in natural waters for its contribution, along with bicarbonate, to alkalinity (Hem, 1985). The contribution of carbonate to alkalinity in samples from trend wells during this study was negligible, however. Iodide concentrations measured during this study were about average for drinking water in the United States and were much less than concentrations shown to cause adverse health effects in humans (World Health Organization, 1996). Fluoride has a maximum contaminant level in California (MCL-CA) of 2 mg/L, and fluoride concentrations in groundwater from trend wells sampled for this study were all less than 0.5 mg/L (fig. 21). Aluminum has a MCL-CA of 1,000  $\mu\text{g/L}$ , and aluminum concentrations in groundwater from trend wells sampled for this study were all less than 10  $\mu\text{g/L}$  (fig. 23). Selenium has an EPA maximum contaminant level (MCL-US) of 50  $\mu\text{g/L}$ , and the greatest concentration measured for selenium during this study was 15.6  $\mu\text{g/L}$ .

(fig. 31). Strontium has an EPA lifetime health advisory level (HAL-US) of 4,000  $\mu\text{g/L}$ , and groundwater from only one trend well had a strontium concentration as much as half of the HAL-US (fig. 32). Vanadium has a California Department of Public Health notification level (NL-CA) of 50  $\mu\text{g/L}$ , and vanadium concentrations in NSF study unit wells, where the step trend of decreased concentrations was indicated, were all less than 20  $\mu\text{g/L}$  (fig. 33).

## Comparison of the Three Evaluation Methods

The three evaluation methods differed in their findings of step trends for the water-quality constituents analyzed during this study. Thirty-three constituents exhibited step trends in groundwater from one or both of the study units, or from the combined study units, by at least one of the evaluation methods (tables 2A, B, C, D). As expected, the evaluation method with no threshold difference requirement yielded the greatest number of significant step trends, at 50. The evaluation method that applied the CI difference threshold resulted in slightly fewer step-trend findings, at 41. One reason for this, however, is that the four field-measured parameters for which eight step trends were indicated when no difference threshold was applied could not be evaluated by the CI difference threshold method. When the CI difference threshold could be applied, the finding of step trends with this difference threshold was the same as the findings with no difference threshold applied, with only three exceptions. The step trends indicated decreased concentrations of carbonate in the SALMON study unit and in the combined study units when no difference threshold was applied were not found when the CI difference threshold was applied. In contrast, the step trend of decreasing concentrations for iodide in the NSF study unit when the CI difference threshold was applied was not found when no difference threshold was applied. The evaluation method that applied the GRAC difference threshold resulted in 26 step trends, and it appeared to be effective at screening differences in constituent concentrations that did not represent meaningful changes.

This study showed that applying a difference threshold helped to identify step trends in groundwater quality by preventing small differences (analytical variability) from indicating a significant step trend. Judging from the one-to-one plots provided in figures 4–36, the GRAC difference threshold was generally effective at distinguishing meaningful differences in the paired samples from data scattered throughout the range of concentrations measured for nearly all of the constituents in this study. The effectiveness of the GRAC difference threshold was shown particularly clearly in the evaluations of the two isotopic constituents that exhibited step trends when no difference threshold was applied and when the CI difference threshold was applied.

By these evaluations, the isotopic ratio of oxygen in water ( $\delta^{18}\text{O-H}_2\text{O}$ ) increased in groundwater from both study units and in groundwater from the combined study units, and the isotopic ratio of carbon-13 in dissolved carbonates ( $\delta^{13}\text{C}$ ) decreased in groundwater from the SALMON study unit. The isotopes of water  $\delta^{18}\text{O-H}_2\text{O}$  and  $\delta^2\text{H-H}_2\text{O}$  usually co-vary, however, and stable isotopic compositions are not expected to change appreciably in groundwater unless the source of the groundwater recharge changes (Ingraham, 1998), so these step trends are considered to be unlikely. No paired differences for  $\delta^{18}\text{O-H}_2\text{O}$  or  $\delta^{13}\text{C}$  exceeded the GRAC difference threshold, so no step trends for  $\delta^{18}\text{O-H}_2\text{O}$  or  $\delta^{13}\text{C}$  were indicated by this evaluation method.

In contrast to the GRAC difference threshold, the CI difference threshold, as applied in this study, was usually not an effective threshold, as was evident by the nearly identical step-trend findings for the evaluations with no difference threshold and those using the CI difference threshold. The CI difference threshold appeared to be effective for some constituents, but only for sample pairs for which constituent concentrations were low relative to reporting levels. For example, all of the differences between arsenic concentrations that failed to exceed the CI difference threshold were for paired samples from wells where arsenic concentrations were less than 1  $\mu\text{g/L}$ . The maximum reporting level for arsenic used in this study was 0.2  $\mu\text{g/L}$ . For iron, which had a maximum reporting level used in this study of 6.4  $\mu\text{g/L}$ , the effective limit under which the CI difference threshold appeared effective was about 20  $\mu\text{g/L}$ . For manganese, with a maximum reporting level used in this study of 0.66, the effective limit was about 2  $\mu\text{g/L}$ .

There are various possible reasons why the CI difference threshold was less effective than the GRAC difference threshold. The CI difference threshold relies on the assumption that analytical variability observed during each of the two separate periods indicates the analytical variability between the periods. This is not a valid assumption based on what was observed during this study. Variability was often substantially different from one sampling period to the next, for trace elements, in particular (Kent, 2018, tables 11 and 13, <https://doi.org/10.5066/F7GH9GF5>). In addition, analytical bias was documented for several constituents during one sampling period, but not for the other. Another issue with confidence intervals is that if they surround a value close to zero, they can extend to negative values. This illogical outcome makes the confidence intervals effectively smaller, so that it is easier for difference thresholds based on confidence intervals to be exceeded. A threshold is ineffective if it is easily exceeded. It could be possible to overcome some of the problems with difference thresholds calculated using confidence intervals by assigning a significance level less than 0.05 or by calculating the confidence intervals in a different way.

## Implications for Water Managers

The step-trend changes in constituent concentrations identified in this study, while low to moderate in magnitude, will be of interest to water managers and stakeholders in the areas of the North San Francisco Bay and the Monterey Bay and Salinas Valley Basins GAMA-PBP study units. The most relevant findings for water managers in the area of the North San Francisco Bay study unit are the increasing step trend in sulfate concentrations and the decreasing step trend in arsenic concentrations. The most relevant findings for water managers in the area of the Monterey Bay and Salinas Valley Basins study unit are the increasing step trends in groundwater nitrate and iron concentrations. Future monitoring efforts may seek explanations for the observed changes. Such explanations are beyond the scope of the present study.

## References Cited

- Anderson, R.L., 1987, Practical statistics for analytical chemists: New York, Van Nostrand Reinhold Company Inc., 316 p.
- Awad, S., 2014, Analysing groundwater using the  $^{13}\text{C}$  isotope: Physics Procedia, v. 55, p. 35–40, accessed August 14, 2017, at <https://doi.org/10.1016/j.phpro.2014.07.006>.
- Balazs, C.L., Morello-Frosch, R., Hubbard, A.E., and Ray, I., 2012, Environmental justice implications of arsenic contamination in California's San Joaquin Valley—A cross-sectional, cluster-design examining exposure and compliance in community drinking water systems: Environmental Health, v. 11, no. 1, 12 p., <https://doi.org/10.1186/1476-069X-11-84>.
- Barlow, J.R.B., Kingsbury, J.A., and Coupe, R.H., 2012, Changes in shallow groundwater quality beneath recently urbanized areas in the Memphis, Tennessee area: Journal of the American Water Resources Association, v. 48, no. 2, p. 336–354, <https://doi.org/10.1111/j.1752-1688.2011.00616.x>.
- Belitz, K., Dubrovsky, N.M., Burow, K.R., Jurgens, B.C., and Johnson, T., 2003, Framework for a ground-water quality monitoring and assessment program for California: U.S. Geological Survey Water-Resources Investigations Report 2003–4166, 78 p., accessed January 10 2017, at <https://pubs.er.usgs.gov/publication/wri034166>.
- Belitz, K., Jurgens, B., Landon, M.K., Fram, M.S., Johnson, T., 2010, Estimation of aquifer scale proportion using equal area grids—Assessment of regional scale groundwater quality: Water Resources Research, v. 46, no. 11, 14 p., accessed January 10, 2017, at <https://doi.org/10.1029/2010WR009321>.
- Bexfield, L.M., 2008, Decadal-scale changes of pesticides in ground water of the United States, 1993–2003: Journal of Environmental Quality, v. 37, no. 5, supplement, p. S-226–S-239, <https://doi.org/10.2134/jeq2007.0054>.
- Bradford, G.R., 1963, Lithium survey of California's water resources: Soil Science, v. 96, no. 2, p. 77–81.
- California Department of Water Resources, 2003, California's groundwater: California Department of Water Resources Bulletin 118, 246 p., accessed August 3, 2018, at [https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Bulletin-118/Files/Statewide-Reports/Bulletin\\_118\\_Update\\_2003.pdf](https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Bulletin-118/Files/Statewide-Reports/Bulletin_118_Update_2003.pdf).
- California State Water Resources Control Board, 2003, Report to the Governor and Legislature—A comprehensive groundwater quality monitoring program for California: Assembly Bill 599, 121 p., accessed January 18, 2013, at [http://www.waterboards.ca.gov/gama/docs/final\\_ab\\_599\\_rpt\\_to\\_legis\\_7\\_31\\_03.pdf](http://www.waterboards.ca.gov/gama/docs/final_ab_599_rpt_to_legis_7_31_03.pdf).
- Davis, T.A., Olsen, L.D., Fram, M.S., and Belitz, K., 2014, Updated study reporting levels (SRLs) for trace-element data collected for the California Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project, October 2009–March 2013: U.S. Geological Survey Scientific Investigations Report 2014–5105, 52 p., accessed January 10, 2017, at <https://doi.org/10.3133/sir20145105>.
- Durfor, C.N., and Becker, E., 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water Supply Paper 1812, 364 p., <https://pubs.er.usgs.gov/publication/wsp1812>.
- Fram, M.S., Olsen, L.D. and Belitz, K., 2012, Evaluation of volatile organic compound (VOC) blank data and application of study reporting levels to groundwater data collected for the California GAMA Priority Basin Project, May 2004 through September 2010: U.S. Geological Survey Scientific Investigations Report 2012–5139, 94 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/sir20125139>.
- Goldrath, D.A., Kulongoski, J.T., and Davis, T.A., 2016, Groundwater-quality in the Monterey–Salinas shallow aquifer study unit, 2013—Results from the California GAMA Program: U.S. Geological Survey Data Series 987, 132 p., accessed January 10, 2017, at <https://doi.org/10.3133/ds987>.
- Harter, T., and Lund, J.R., 2012, Addressing nitrate in California's drinking water with a focus on Tulare Lake Basin and Salinas Valley groundwater: Davis, University of California, Center for Watershed Sciences, 78 p., accessed March 10, 2017, at <http://groundwaternitrate.ucdavis.edu/>.



- Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book. 4, chap. A3, 523 p., accessed January 10, 2017, at <http://pubs.usgs.gov/twri/twri4a3/>.
- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water Supply Paper 2254, 263 p., <https://pubs.er.usgs.gov/publication/wsp2254>.
- Ingraham, N.L., 1998, Isotope variations in precipitation, chap 3, in Kendall, C., and McDonnell, J.J., eds., Isotope tracers in catchment: Hydrology, p. 87–118, <https://doi.org/10.1016/B978-0-444-81546-0.50010-0>.
- Jones, S.A. and Joy, N., 2006, The inequity of the revised arsenic rule for very small community drinking water systems: Environmental Science and Policy, v. 9, no. 6, p. 555–562, <https://doi.org/10.1016/j.envsci.2006.05.003>.
- Keeling, C.D., 1979, The Suess Effect:  $^{13}\text{C}$ Carbon- $^{14}\text{C}$ Carbon interrelations: Environment International, v. 2, no. 4–6, p. 229–300, [https://doi.org/10.1016/0160-4120\(79\)90005-9](https://doi.org/10.1016/0160-4120(79)90005-9).
- Kent, R.H., 2018, Data sets for: Variations on a method for evaluating decadal-scale changes in the groundwater quality of two GAMA coastal study units 2004–2014, California GAMA Priority Basin Project: U.S. Geological Survey data release, <https://doi.org/10.5066/F7GH9GF5>.
- Kent, R., 2015, Groundwater quality data in 15 GAMA study units—Results from the 2006–10 initial sampling and the 2009–13 resampling of wells, California GAMA Priority Basin Project: U.S. Geological Survey Data Series 919, 219 p., accessed January 10, 2017, at <https://doi.org/10.3133/ds919>.
- Kent, R., and Landon, M.K., 2013, Trends in concentrations of nitrate and total dissolved solids in public supply wells of the Bunker Hill, Lytle, Rialto, and Colton groundwater subbasins, San Bernardino County, California—Influence of legacy land use: Science of the Total Environment, v. 452–453, p. 125–136, <https://doi.org/10.1016/j.scitotenv.2013.02.042>.
- Kent, R., and Landon, M.K., 2016, Triennial changes in groundwater quality in aquifers used for public supply in California—Utility as indicators of temporal trends: Environmental Monitoring and Assessment, v. 188, no. 610, 17 p., <https://doi.org/10.1007/s10661-016-5618-3>.
- Kent, R., Belitz, K., and Fram, M.S., 2014, Groundwater-quality data in seven GAMA study units—Results from initial sampling, 2004–2005, and resampling, 2007–2008, of wells—California GAMA Program Priority Basin Project: U.S. Geological Survey Data Series 795, 170 p., accessed January 10, 2017, at <http://dx.doi.org/10.3133/ds795>.
- Koterba, M.T., Wilde, F.D., and Lapham, W.W., 1995, Ground water data-collection protocols and procedures for the National Water-Quality Assessment Program—Collection and documentation of water-quality samples and related data: U.S. Geological Survey Open-File Report 95–399, 114 p., <https://pubs.er.usgs.gov/publication/ofr95399>.
- Kulongoski, J.T., and Belitz, K., 2004, Ground-water ambient monitoring and assessment program: U.S. Geological Survey Fact Sheet 2004–3088, 2 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/fs20043088>.
- Kulongoski, J.T., and Belitz, K., 2007, Ground-water quality data in the Monterey Bay and Salinas Valley Basins, California, 2005—Results from the California GAMA Program: U.S. Geological Survey Data Series 258, 84 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/ds258>.
- Kulongoski, J.T., and Belitz, K., 2011, Status and understanding of groundwater quality in the Monterey Bay and Salinas Valley Basins, 2005—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2011–5058, 60 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/sir20115058>.
- Kulongoski, J.T., Belitz, K., and Dawson, B.J., 2006, Ground-water quality data in the north San Francisco Bay hydrologic provinces, California, 2004—Results from the California Groundwater Ambient Monitoring and Assessment (GAMA) Program: U.S. Geological Survey Data Series Report 167, 100 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/ds167>.
- Kulongoski, J.T., Belitz, K., Landon, M.K., and Farrar, C., 2010, Status and understanding of groundwater quality in the north San Francisco Bay groundwater basins, 2004—California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2010–5089, 65 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/sir20105089>.
- Lindsey, B.D., and Rupert, M.G., 2012, Methods for evaluating temporal groundwater quality data and results of decadal-scale changes in chloride, dissolved solids, and nitrate concentrations in groundwater in the United States, 1988–2010: U.S. Geological Survey Scientific Investigations Report 2012–5049, 46 p., accessed February 27, 2017, at <https://pubs.er.usgs.gov/publication/sir20125049>.
- Lindsey, B.D., Johnson, T.D., and Belitz, K., 2016, Decadal changes in groundwater quality: U.S. Geological Survey Web Page, <https://nawqatrends.wim.usgs.gov/Decadal/>.

- Maloney, T.J., ed., 2005, Quality management system, U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 2005-1263, accessed December 6, 2013, at <https://pubs.er.usgs.gov/publication/ofr20051263>.
- Mathany, T.M., 2017 Groundwater-quality data in 12 GAMA study units—Results from the 2006–10 initial sampling period and the 2008–13 trend sampling period, California GAMA Priority Basin Project: U.S. Geological Survey Data Series Report 1038, 140 p., <https://doi.org/10.3133/ds1038>.
- McMahon, P.B., and Chapelle, F.H., 2008, Redox processes and water quality of selected principal aquifer systems: *Ground Water*, v. 46, no. 2, p. 259–271, <https://doi.org/10.1111/j.1745-6584.2007.00385.x>.
- Mueller, D.K., and Titus, C.J., 2005, Quality of nutrient data from streams and ground water sampled during water years 1992–2001: U.S. Geological Survey Scientific Investigations Report 2005-5106. 27p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/sir20055106>.
- Olsen, L.D., Fram, M.S., and Belitz, K., 2010, Review of trace-element field blank data collected for the California Groundwater Ambient Monitoring and Assessment (GAMA) Program, May 2004–January 2008: U.S. Geological Survey Scientific Investigations Report 2009-5220, 47 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/sir20095220>.
- Pirkey, K.D., and Glodt, S.R., 1998, Quality control at the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Fact-Sheet 026-98, 4 p., accessed January 10, 2017, at <https://pubs.er.usgs.gov/publication/fs02698>.
- Plummer, L.N., Michel, R.L., Thurman, E.M., and Glyn, P.D., 1993, Environmental tracers for age-dating young groundwater, *in* Alley, W. M., ed., *Regional Groundwater Quality*: New York, Van Nostrand Reinhold, p. 255–294.
- Pratt, J. W., 1959, Remarks on zeros and ties in the Wilcoxon signed rank procedures: *Journal of the American Statistical Association*, v. 54, no. 287, p. 655–667.
- RMC Water and Environment, 2013, Sonoma Valley salt and nutrient management plan final report: Prepared for the Sonoma Valley county Sanitation District in association with Todd Engineers and PlanTierra, Inc., various paging, accessed March 10, 2017, at [http://www.scwa.ca.gov/files/docs/projects/svgw/Sonoma\\_SNMP2013.pdf](http://www.scwa.ca.gov/files/docs/projects/svgw/Sonoma_SNMP2013.pdf).
- Rosen, M.R., and Lapham, W.W., 2008, Introduction to the U.S. Geological Survey National Water-Quality Assessment (NAWQA) of ground-water quality trends and comparison to other national programs: *Journal of Environmental Quality*, v. 37, supplement 5, p. S-190–S-198, <https://doi.org/10.2134/jeq2008.0049>.
- Rupert, M.G., 2008, Decadal-scale changes of nitrate in ground water of the United States, 1988–2004: *Journal of Environmental Quality*, v. 37, supplement 5, p. S-240–S-248, <https://doi.org/10.2134/jeq2007.0055>.
- U.S. Environmental Protection Agency, 2001, Technical fact sheet—Final rule for arsenic in drinking water: U.S. Environmental Protection Agency EPA 815-F-00-016, accessed August 10, 2017, at <https://nepis.epa.gov/Exe/ZyPdf.cgi?Dockey=20001XXE.txt>.
- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1–A9: accessed January 10, 2017, at <http://water.usgs.gov/owq/FieldManual/>.
- World Health Organization, 1996, Iodine in drinking-water—Background document for development of WHO Guidelines for drinking-water quality, *in* Guidelines for drinking-water quality, 2d ed., v. 2, Health criteria and other supporting information: Geneva, World Health Organization, accessed August 8, 2017, at [http://www.who.int/water\\_sanitation\\_health/dwq/chemicals/iodine.pdf](http://www.who.int/water_sanitation_health/dwq/chemicals/iodine.pdf).

**Table 1.** Sample dates, elevations, and construction information for the 50 trend wells that were sampled two times, approximately 9–10 years apart, in the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units.

[LSD, land surface datum; mm/dd/yyyy, month/day/year; NA, not applicable; NGVD 29, National Geodetic Vertical Datum of 1929; NWIS, National Water Information System; USGS, U.S. Geological Survey. **GAMA well identification number acronyms:** *Monterey Bay and Salinas Valley Basins study unit:* MSMB, Monterey Bay study area; MSPR, Paso Robles study area; MSSC, Santa Cruz study area; MSSV, Salinas Valley study area. *North San Francisco Bay study unit:* NSFVOL, Volcanic Highlands study area; NSFVP, Valley and Plains study area; NSFVG, Wilson Grove Formation Highlands study area; NSFVGFP, Wilson Grove Formation Highlands study area flow-path well]

GAMA well identification number	USGS station identification number (hyperlinked to data in the USGS NWIS)	Initial sample date (mm/dd/yyyy)	Triennial samples (supplement some initial data) date (mm/dd/yyyy)	Decadal sample date (mm/dd/yyyy)	Elevation of LSD (meters above NGVD 29) <sup>1</sup>	Well depth (meters below LSD)	Top of highest perforation (meters below LSD)	Bottom of lowest perforation (meters below LSD)
North San Francisco Bay study unit								
NSFVOL-05	<a href="#">382832122354301</a>	9/27/2004	NA	10/21/2014	305	155	101	155
NSFVOL-06	<a href="#">381120122262901</a>	9/28/2004	08/23/2007 <sup>2</sup>	11/18/2014	30	85	61	85
NSFVOL-14	<a href="#">381639122150801</a>	10/7/2004	08/27/2007, 10/19/2011	11/19/2014	42	127	17	127
NSFVOL-17	<a href="#">383501122302201</a>	10/20/2004	NA	9/16/2014	171	81	NA	NA
NSFVOL-18	<a href="#">383038122271301</a>	10/20/2004	11/28/2007 <sup>2,3,4</sup> , 10/26/2011	11/5/2014	61	204	41	201
NSFVOL-20	<a href="#">381906122274901</a>	11/4/2004	NA	11/20/2014	91	76	52	76
NSFVP-06	<a href="#">381934122403601</a>	9/1/2004	NA	10/22/2014	43	213	52	207
NSFVP-10	<a href="#">383034122590701</a>	9/13/2004	NA	9/17/2014	11	30	23	29
NSFVP-19	<a href="#">383630122512601</a>	9/16/2004	NA	9/16/2014	25	30	6	18
NSFVP-22	<a href="#">381422122352001</a>	9/20/2004	NA	11/19/2014	15	153	18	153
NSFVP-26	<a href="#">383916122473501</a>	9/27/2004	NA	9/15/2014	58	183	38	183
NSFVP-29	<a href="#">384238122541201</a>	9/28/2004	08/27/2007, 10/24/2011	9/15/2014	63	37	19	37
NSFVP-32	<a href="#">382553122232501</a>	10/7/2004	11/20/2007 <sup>2,4</sup>	11/4/2014	38	122	NA	NA
NSFVP-34	<a href="#">382307122311301</a>	10/18/2004	08/22/2007, 10/18/2011	10/20/2014	98	79	12	79
NSFVP-36	<a href="#">381153122185701</a>	10/19/2004	08/20/2007 <sup>2,4</sup> , 10/17/2011	11/18/2014	2	93	44	91
NSFVP-37	<a href="#">381808122293801</a>	10/19/2004	08/22/2007	10/20/2014	36	110	18	107
NSFVP-38	<a href="#">381544122263801</a>	10/20/2004	08/22/2007, 10/18/2011	10/21/2014	9	235	64	235
NSFVP-39	<a href="#">383148122292901</a>	10/21/2004	11/16/2007 <sup>2,4</sup> , 10/26/2011	10/23/2014	75	140	17	140
NSFVP-41	<a href="#">381932122172601</a>	10/21/2004	08/20/2007 <sup>2,4</sup> , 10/19/2011	11/6/2014	14	72	18	72
NSFVP-46	<a href="#">382720122245701</a>	11/3/2004	NA	11/4/2014	46	55	12	55
NSFVP-48	<a href="#">381440122191101</a>	11/4/2004	11/15/2007 <sup>2,4</sup>	11/5/2014	20	61	18	61
NSFWG-03	<a href="#">382318122511401</a>	9/21/2004	08/29/2007 <sup>2,3,4</sup> , 10/25/2011	9/18/2014	83	168	82	168
NSFWG-04	<a href="#">382153122480301</a>	9/22/2004	NA	11/3/2014	59	138	132	138
NSFWG-06	<a href="#">381524122573701</a>	9/23/2004	NA	11/3/2014	136	49	NA	NA
NSFWGFP-01	<a href="#">382345122490701</a>	10/5/2004	08/29/2007, 10/25/2011	9/17/2014	24	161	42	161



**Table 1.** Sample dates, elevations, and construction information for the 50 trend wells that were sampled two times, approximately 9–10 years apart, in the North San Francisco Bay and Monterey Bay and Salinas Valley Basins study units.—Continued

[LSD, land surface datum; mm/dd/yyyy, month/day/year; NA, not applicable; NGVD 29, National Geodetic Vertical Datum of 1929; NWIS, National Water Information System; USGS, U.S. Geological Survey. **GAMA well identification number acronyms:** *Monterey Bay and Salinas Valley Basins study unit:* MSMB, Monterey Bay study area; MSPR, Paso Robles study area; MSSC, Santa Cruz study area; MSSV, Salinas Valley study area. *North San Francisco Bay study unit:* NSFVOL, Volcanic Highlands study area; NSFVP, Valley and Plains study area; NSFVG, Wilson Grove Formation Highlands study area; NSFVGFP, Wilson Grove Formation Highlands study area flow-path well]

GAMA well identification number	USGS station identification number (hyperlinked to data in the USGS NWIS)	Initial sample date (mm/dd/yyyy)	Triennial samples (supplement some initial data) date (mm/dd/yyyy)	Decadal sample date (mm/dd/yyyy)	Elevation of LSD (meters above NGVD 29) <sup>1</sup>	Well depth (meters below LSD)	Top of highest perforation (meters below LSD)	Bottom of lowest perforation (meters below LSD)
Monterey Bay and Salinas Valley Basins study unit								
MSMB-02	<a href="#">363700121500001</a>	8/10/2005	NA	9/8/2014	12	69	57	66
MSMB-04	<a href="#">365218121490301</a>	8/17/2005	08/20/2008	8/4/2014	2	244	61	244
MSMB-09	<a href="#">365500121470001</a>	8/15/2005	NA	8/5/2014	30	142	60	136
MSMB-11	<a href="#">364616121451301</a>	8/18/2005	NA	8/20/2014	3	183	69	183
MSMB-13	<a href="#">363900121450001</a>	8/17/2005	NA	8/19/2014	58	170	96	163
MSMB-17	<a href="#">364500121440001</a>	8/9/2005	NA	8/20/2014	6	192	113	186
MSMB-20	<a href="#">365425121452201</a>	8/16/2005	NA	8/5/2014	8	54	31	45
MSMB-26	<a href="#">363955121401001</a>	8/11/2005	NA	8/14/2014	13	198	137	190
MSMB-28	<a href="#">363618121381901</a>	8/3/2005	08/21/2008 <sup>2,3,4,5</sup>	8/13/2014	18	149	126	142
MSMB-37	<a href="#">364100121360001</a>	9/1/2005	NA	8/21/2014	34	247	94	247
MSMB-38	<a href="#">363900121360001</a>	8/11/2005	NA	8/13/2014	21	192	110	186
MSPR-01	<a href="#">353041120394501</a>	7/19/2005	NA	8/11/2014	247	152	46	152
MSPR-03	<a href="#">353800120380001</a>	7/28/2005	11/14/2008 <sup>3,4,5</sup>	8/11/2014	229	207	79	201
MSPR-09	<a href="#">354805120453601</a>	7/18/2005	11/14/2008 <sup>3,4,5</sup>	9/10/2014	176	153	22	151
MSSC-04	<a href="#">370304122014201</a>	8/25/2005	NA	8/6/2014	140	110	47	108
MSSC-05	<a href="#">370349121594801</a>	8/30/2005	NA	8/7/2014	207	518	213	509
MSSC-06	<a href="#">365700121580001</a>	8/24/2005	08/18/2008	8/4/2014 <sup>7</sup>	12	70	34	61
MSSC-08	<a href="#">370150121565301</a>	9/15/2005	08/18/2008 <sup>8</sup>	8/6/2014	67	73	62	73
MSSC-10	<a href="#">365933121552601</a>	8/29/2005	NA	9/9/2014	55	165	116	158
MSSV-02	<a href="#">360000120540001</a>	8/4/2005	NA	8/12/2014	143	40	24	40
MSSV-03	<a href="#">360600121000001</a>	8/2/2005 <sup>6</sup>	NA	9/10/2014	110	43	27	43
MSSV-06	<a href="#">361100121070001</a>	8/2/2005	11/13/2008 <sup>3,4,5</sup>	8/18/2014	91	67	49	67
MSSV-07	<a href="#">361207121075501</a>	8/2/2005	NA	8/18/2014	91	65	40	62
MSSV-11	<a href="#">361900121160001</a>	7/25/2005	NA	9/8/2014	98	269	95	263
MSSV-16	<a href="#">362300121210001</a>	9/14/2005	NA	9/11/2014	84	244	61	241

<sup>1</sup>LSD is a datum plane that approximates land surface at each well. The altitude of the LSD is described in feet above the NGVD 29.

<sup>2</sup>This sample, collected to evaluate triennial trends, was used as the initial carbon isotope sample for this well.

<sup>3</sup>This sample, collected to evaluate triennial trends, was used as the initial major ion and trace element sample for this well.

<sup>4</sup>This sample, collected to evaluate triennial trends, was used as the initial nutrient sample for this well.

<sup>5</sup>This sample, collected to evaluate triennial trends, was used as the initial perchlorate sample for this well.

<sup>6</sup>Inorganic constituents were sampled September 12, 2005, at this well.

<sup>7</sup>Sample for analysis of volatile organic compounds collected August 6, 2014, at this well.

<sup>8</sup>Sample only analyzed for carbon isotopes and stable isotopes of water.

**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Water temperature	00010	50	8	10	32	<b>0.010 ▼</b>
Dissolved oxygen	00300	44	4	23	17	0.674
Field specific conductance	00095	49	1	27	21	<b>0.040 ▲</b>
Lab specific conductance <sup>1</sup>	90095	34	0	25	9	<b>0.010 ▲</b>
Total dissolved solids	70300	34	0	16	18	0.427
Field pH	00400	35	1	12	22	<b>0.006 ▼</b>
Lab pH	00403	34	0	22	12	0.293
Alkalinity	29801	32	0	17	15	0.308
Bicarbonate	63786	34	0	16	16	0.614
Carbonate	63788	32	8	5	19	<b>0.002 ▼</b>
Total nitrogen	62854	34	3	16	15	0.478
Nitrate <sup>1</sup>	00631	34	10	14	10	0.260
Nitrite	00613	34	28	2	4	0.461
Ammonia	00608	34	20	8	6	0.545
Orthophosphate	00671	34	0	28	6	<b>0.002 ▲</b>
Perchlorate	61209	43	39	3	1	0.312
Calcium <sup>1</sup>	00915	34	0	24	10	<b>0.007 ▲</b>
Magnesium <sup>1</sup>	00925	34	0	25	9	<b>0.001 ▲</b>
Potassium <sup>1</sup>	00935	34	0	17	17	0.885
Sodium <sup>1</sup>	00930	34	0	25	9	<b>0.007 ▲</b>
Bromide	71870	34	2	12	20	0.266
Chloride	00940	34	0	25	9	0.083
Iodide	71865	34	2	12	20	0.073
Sulfate	00945	34	0	23	11	<b>0.011 ▲</b>
Fluoride <sup>1</sup>	00950	32	1	9	22	<b>0.002 ▼</b>
Silica <sup>1</sup>	00955	34	0	6	28	<b>&lt;0.001 ▼</b>
Aluminum <sup>1,2</sup>	01106	34	22	11	1	<b>0.003 ▲</b>
Antimony	01095	34	28	2	4	0.430
Arsenic	01000	34	3	8	23	<b>0.004 ▼</b>
Barium <sup>1</sup>	01005	34	0	20	14	<b>0.046 ▲</b>
Boron <sup>1</sup>	01020	34	0	18	16	0.638
Cadmium <sup>1</sup>	01025	34	22	4	8	0.296
Chromium	01030	34	22	7	5	0.520
Copper	01040	34	22	7	5	0.658
Iron <sup>2</sup>	01046	34	9	19	6	<b>0.006 ▲</b>
Lead	01049	34	21	4	9	0.116

**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Lithium	01130	34	0	24	10	0.024 ▲
Manganese <sup>1</sup>	01056	34	7	18	9	0.030 ▲
Molybdenum	01060	34	0	25	29	0.939
Nickel <sup>1</sup>	01065	34	1	22	11	0.669
Selenium <sup>1</sup>	01145	34	14	9	11	0.488
Strontium <sup>1</sup>	01080	34	0	22	12	0.092
Thallium	01057	34	31	1	2	0.588
Uranium <sup>1</sup>	22703	34	6	13	15	0.824
Vanadium	01085	34	1	14	19	0.758
Zinc <sup>1</sup>	01090	34	25	5	4	0.683
Carbon disulfide	77041	50	41	5	4	0.664
Chloroform (trichloromethane)	32106	50	38	8	4	0.260
Methyl <i>tert</i> -butyl ether (MTBE)	78032	50	45	1	4	0.180
Tetrachloroethene (PCE)	34475	50	45	1	4	0.168
Trichloroethene (TCE)	39180	50	45	2	3	0.668
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	49	46	3	0	0.083
Atrazine	39632	49	46	1	2	0.548
Simazine	04035	49	40	2	7	0.093
δ <sup>2</sup> H of water	82082	48	0	27	21	0.587
δ <sup>18</sup> O of water	82085	48	0	42	6	<0.001 ▲
δ <sup>13</sup> C of dissolved carbonates	82081	30	0	10	20	0.111
Carbon-14 (modern carbon)	49933	30	0	14	16	0.504
Tritium	07000	49	15	4	30	<0.001 ▼

**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	50	50	0	0	NA
Dissolved oxygen	00300	44	27	8	9	0.719
Field specific conductance	00095	49	40	8	1	<b>0.021 ▲</b>
Lab specific conductance <sup>1</sup>	90095	34	25	8	1	<b>0.023 ▲</b>
Total dissolved solids	70300	34	30	3	1	0.325
Field pH	00400	35	33	0	2	0.157
Lab pH	00403	34	32	1	1	0.983
Alkalinity	29801	32	29	3	0	0.083
Bicarbonate	63786	34	29	3	0	0.083
Carbonate	63788	32	22	1	9	<b>0.011 ▼</b>
Total nitrogen	62854	34	17	10	7	0.389
Nitrate <sup>1</sup>	00631	34	18	11	5	0.123
Nitrite	00613	34	30	2	2	0.976
Ammonia	00608	34	31	1	2	0.540
Orthophosphate	00671	34	15	16	3	<b>0.007 ▲</b>
Perchlorate	61209	43	41	1	1	0.987
Calcium <sup>1</sup>	00915	34	28	5	1	0.095
Magnesium <sup>1</sup>	00925	34	25	8	1	<b>0.018 ▲</b>
Potassium <sup>1</sup>	00935	34	30	4	0	<b>0.046 ▲</b>
Sodium <sup>1</sup>	00930	34	30	3	1	0.325
Bromide	71870	34	20	4	10	0.158
Chloride	00940	34	22	7	5	0.494
Iodide	71865	34	23	4	7	0.326
Sulfate	00945	34	18	13	3	<b>0.013 ▲</b>
Fluoride <sup>1</sup>	00950	32	31	0	1	0.317
Silica <sup>1</sup>	00955	34	32	0	2	0.157
Aluminum <sup>1,2</sup>	01106	34	28	6	0	<b>0.014 ▲</b>
Antimony	01095	34	33	1	0	0.317
Arsenic	01000	34	27	2	5	0.268
Barium <sup>1</sup>	01005	34	27	5	2	0.210
Boron <sup>1</sup>	01020	34	26	4	4	0.926
Cadmium <sup>1</sup>	01025	34	31	1	2	0.588
Chromium	01030	34	32	2	0	0.157
Copper	01040	34	30	1	3	0.340
Iron <sup>2</sup>	01046	34	21	11	2	<b>0.011 ▲</b>
Lead	01049	34	26	1	7	<b>0.037 ▼</b>

**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	34	28	5	1	0.095
Manganese <sup>1</sup>	01056	34	22	8	4	0.198
Molybdenum	01060	34	26	4	4	0.853
Nickel <sup>1</sup>	01065	34	20	6	8	0.483
Selenium <sup>1</sup>	01145	34	25	3	6	0.330
Strontium <sup>1</sup>	01080	34	30	4	0	<b>0.046 ▲</b>
Thallium	01057	34	34	0	0	NA
Uranium <sup>1</sup>	22703	34	23	6	5	0.687
Vanadium	01085	34	16	7	11	0.351
Zinc <sup>1</sup>	01090	34	25	5	4	0.808
Carbon disulfide	77041	50	43	4	3	0.636
Chloroform (trichloromethane)	32106	50	44	4	2	0.434
Methyl <i>tert</i> -butyl ether (MTBE)	78032	50	48	1	1	0.989
Tetrachloroethene (PCE)	34475	50	47	0	3	0.083
Trichloroethene (TCE)	39180	50	46	2	2	1.000
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	49	49	0	0	NA
Atrazine	39632	49	48	0	1	0.317
Simazine	04035	49	48	0	1	0.317
δ <sup>2</sup> H of water	82082	48	48	0	0	NA
δ <sup>18</sup> O of water	82085	48	48	0	0	NA
δ <sup>13</sup> C of dissolved carbonates	82081	30	30	0	0	NA
Carbon-14 (modern carbon)	49933	30	2	12	16	0.459
Tritium	07000	49	24	3	22	<b>&lt;0.001 ▼</b>

**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	50		No results for field parameters		
Dissolved oxygen	00300	44		No results for field parameters		
Field specific conductance	00095	49		No results for field parameters		
Lab specific conductance <sup>1</sup>	90095	34	0	25	9	<b>0.010 ▲</b>
Total dissolved solids	70300	34	0	16	18	0.427
Field pH	00400	35		No results for field parameters		
Lab pH	00403	34	0	22	12	0.293
Alkalinity	29801	32	0	17	15	0.308
Bicarbonate	63786	34	0	16	16	0.614
Carbonate	63788	32	25	1	5	0.095
Total nitrogen	62854	34	12	14	8	0.244
Nitrate <sup>1</sup>	00631	34	14	13	7	0.166
Nitrite	00613	34	28	2	4	0.461
Ammonia	00608	34	22	7	5	0.546
Orthophosphate	00671	34	8	22	4	<b>0.003 ▲</b>
Perchlorate	61209	43	42	0	1	0.317
Calcium <sup>1</sup>	00915	34	0	24	10	<b>0.007 ▲</b>
Magnesium <sup>1</sup>	00925	34	0	25	9	<b>0.001 ▲</b>
Potassium <sup>1</sup>	00935	34	1	16	17	0.878
Sodium <sup>1</sup>	00930	34	0	25	9	<b>0.007 ▲</b>
Bromide	71870	34	10	9	15	0.290
Chloride	00940	34	0	25	9	0.083
Iodide	71865	34	18	4	12	0.051
Sulfate	00945	34	0	23	11	<b>0.011 ▲</b>
Fluoride <sup>1</sup>	00950	32	10	4	18	<b>0.002 ▼</b>
Silica <sup>1</sup>	00955	34	0	6	28	<b>&lt;0.001 ▼</b>
Aluminum <sup>1,2</sup>	01106	34	23	11	0	<b>&lt;0.001 ▲</b>
Antimony	01095	34	30	1	3	0.340
Arsenic	01000	34	8	5	21	<b>0.002 ▼</b>
Barium <sup>1</sup>	01005	34	0	20	14	<b>0.046 ▲</b>
Boron <sup>1</sup>	01020	34	3	16	15	0.590
Cadmium <sup>1</sup>	01025	34	23	4	7	0.403
Chromium	01030	34	28	4	2	0.415
Copper	01040	34	24	5	5	0.975
Iron <sup>2</sup>	01046	34	17	14	3	<b>0.006 ▲</b>
Lead	01049	34	22	3	9	0.067



**Table 2A.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the combined study units.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	34	0	24	10	0.024 ▲
Manganese <sup>1</sup>	01056	34	11	16	7	0.029 ▲
Molybdenum	01060	34	7	12	15	0.897
Nickel <sup>1</sup>	01065	34	14	11	9	0.986
Selenium <sup>1</sup>	01145	34	16	8	10	0.486
Strontium <sup>1</sup>	01080	34	0	22	12	0.092
Thallium	01057	34		No qualifying replicates to establish CI		
Uranium <sup>1</sup>	22703	34	16	11	7	0.273
Vanadium	01085	34	4	11	19	0.555
Zinc <sup>1</sup>	01090	34	25	5	4	0.808
Carbon disulfide	77041	50		No qualifying replicates to establish CI		
Chloroform (trichloromethane)	32106	50	42	5	3	0.485
Methyl <i>tert</i> -butyl ether (MTBE)	78032	50		No qualifying replicates to establish CI		
Tetrachloroethene (PCE)	34475	50		No qualifying replicates to establish CI		
Trichloroethene (TCE)	39180	50		No qualifying replicates to establish CI		
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	49	48	1	0	0.317
Atrazine	39632	49	48	0	1	0.317
Simazine	04035	49		No qualifying replicates to establish CI		
δ <sup>2</sup> H of water	82082	48	0	27	21	0.587
δ <sup>18</sup> O of water	82085	48	0	42	6	<0.001 ▲
δ <sup>13</sup> C of dissolved carbonates	82081	30	0	10	20	0.111
Carbon-14 (modern carbon)	49933	30	0	14	16	0.504
Tritium	07000	49	19	2	28	<0.001 ▼

<sup>1</sup>Data-quality assessment summaries published by the QSB found measurement bias or variability at the NWQL for this constituent during one or both sampling periods.

<sup>2</sup>Project field-blank results indicate a potential positive bias in initial period concentrations for this constituent.

**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Water temperature	00010	25	3	6	16	0.092
Dissolved oxygen	00300	19	2	13	4	<b>0.025 ▲</b>
Field specific conductance	00095	25	0	15	10	<b>0.028 ▲</b>
Lab specific conductance <sup>1</sup>	90095	18	0	16	2	<b>0.002 ▲</b>
Total dissolved solids	70300	18	0	8	10	0.306
Field pH	00400	19	1	12	6	0.376
Lab pH	00403	18	0	8	10	0.327
Alkalinity	29801	16	0	9	7	0.278
Bicarbonate	63786	16	0	9	7	0.278
Carbonate	63788	16	7	5	4	0.745
Total nitrogen	62854	18	2	6	10	0.295
Nitrate <sup>1</sup>	00631	18	6	5	7	0.350
Nitrite	00613	18	15	0	3	0.084
Ammonia	00608	18	9	5	4	0.482
Orthophosphate	00671	18	0	14	4	0.064
Perchlorate	61209	26	26	0	0	NA
Calcium <sup>1</sup>	00915	18	0	12	6	<b>0.005 ▲</b>
Magnesium <sup>1</sup>	00925	18	0	13	5	<b>0.011 ▲</b>
Potassium <sup>1</sup>	00935	18	0	9	9	0.557
Sodium <sup>1</sup>	00930	18	0	13	5	0.053
Bromide	71870	18	2	6	10	0.316
Chloride	00940	18	0	16	2	<b>0.011 ▲</b>
Iodide	71865	18	2	6	10	0.089
Sulfate	00945	18	0	11	7	0.064
Fluoride <sup>1</sup>	00950	16	1	3	12	<b>0.008 ▼</b>
Silica <sup>1</sup>	00955	18	0	1	17	<b>&lt;0.001 ▼</b>
Aluminum <sup>1,2</sup>	01106	18	8	9	1	<b>0.007 ▲</b>
Antimony	01095	18	18	0	0	NA
Arsenic	01000	18	1	3	14	<b>0.012 ▼</b>
Barium <sup>1</sup>	01005	18	0	11	7	<b>0.048 ▲</b>
Boron <sup>1</sup>	01020	18	0	10	8	0.777
Cadmium <sup>1</sup>	01025	18	16	0	2	0.158
Chromium	01030	18	15	2	1	0.564
Copper	01040	18	11	4	3	0.822
Iron <sup>2</sup>	01046	18	4	10	4	0.069
Lead	01049	18	9	3	6	0.261

**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Lithium	01130	18	0	14	4	<b>0.012 ▲</b>
Manganese <sup>1</sup>	01056	18	2	9	7	0.239
Molybdenum	01060	18	0	6	12	0.184
Nickel <sup>1</sup>	01065	18	1	15	2	<b>0.010 ▲</b>
Selenium <sup>1</sup>	01145	18	12	0	6	<b>0.015 ▼</b>
Strontium <sup>1</sup>	01080	18	0	13	5	0.112
Thallium	01057	18	16	1	1	0.968
Uranium <sup>1</sup>	22703	18	4	5	9	0.369
Vanadium	01085	18	1	4	13	0.081
Zinc <sup>1</sup>	01090	18	5	5	8	0.402
Carbon disulfide	77041	25	20	2	3	0.742
Chloroform (trichloromethane)	32106	25	19	4	2	0.437
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	22	1	2	0.564
Tetrachloroethene (PCE)	34475	25	24	0	1	0.317
Trichloroethene (TCE)	39180	25	24	0	1	0.317
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	24	23	1	0	0.317
Atrazine	39632	24	23	0	1	0.317
Simazine	04035	24	21	0	3	0.083
δ <sup>2</sup> H of water	82082	24	0	14	10	0.310
δ <sup>18</sup> O of water	82085	24	0	22	2	<b>&lt;0.001 ▲</b>
δ <sup>13</sup> C of dissolved carbonates	82081	18	0	8	10	0.586
Carbon-14 (modern carbon)	49933	18	0	9	9	0.845
Tritium	07000	25	7	3	15	<b>0.003 ▼</b>

**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	25	25	0	0	NA
Dissolved oxygen	00300	19	13	5	1	0.081
Field specific conductance	00095	25	22	3	0	0.083
Lab specific conductance <sup>1</sup>	90095	18	13	5	0	<b>0.026 ▲</b>
Total dissolved solids	70300	18	17	1	0	0.317
Field pH	00400	19	19	0	0	NA
Lab pH	00403	18	16	1	1	0.968
Alkalinity	29801	16	15	1	0	0.317
Bicarbonate	63786	16	15	1	0	0.317
Carbonate	63788	16	14	1	1	0.964
Total nitrogen	62854	18	11	3	4	0.317
Nitrate <sup>1</sup>	00631	18	11	3	4	0.500
Nitrite	00613	18	17	0	1	0.317
Ammonia	00608	18	17	1	0	0.317
Orthophosphate	00671	18	9	7	2	0.134
Perchlorate	61209	26	26	0	0	NA
Calcium <sup>1</sup>	00915	18	17	1	0	0.158
Magnesium <sup>1</sup>	00925	18	14	4	0	<b>0.046 ▲</b>
Potassium <sup>1</sup>	00935	18	17	1	0	0.317
Sodium <sup>1</sup>	00930	18	17	1	0	0.317
Bromide	71870	18	13	1	4	0.200
Chloride	00940	18	13	4	1	0.164
Iodide	71865	18	13	1	4	0.148
Sulfate	00945	18	9	8	1	<b>0.013 ▲</b>
Fluoride <sup>1</sup>	00950	16	16	0	0	NA
Silica <sup>1</sup>	00955	18	17	0	1	0.317
Aluminum <sup>1,2</sup>	01106	18	13	5	0	<b>0.026 ▲</b>
Antimony	01095	18	18	0	0	NA
Arsenic	01000	18	14	1	3	0.364
Barium <sup>1</sup>	01005	18	15	2	1	0.519
Boron <sup>1</sup>	01020	18	15	1	2	0.611
Cadmium <sup>1</sup>	01025	18	18	0	0	NA
Chromium	01030	18	18	0	0	NA
Copper	01040	18	16	0	2	0.158
Iron <sup>2</sup>	01046	18	12	5	1	0.110
Lead	01049	18	12	1	5	0.136

**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	18	16	2	0	0.158
Manganese <sup>1</sup>	01056	18	11	3	4	0.901
Molybdenum	01060	18	14	1	3	0.364
Nickel <sup>1</sup>	01065	18	13	4	1	0.221
Selenium <sup>1</sup>	01145	18	14	0	4	<b>0.046 ▼</b>
Strontium <sup>1</sup>	01080	18	17	1	0	0.317
Thallium	01057	18	18	0	0	NA
Uranium <sup>1</sup>	22703	18	12	3	3	0.896
Vanadium	01085	18	7	2	9	<b>0.036 ▼</b>
Zinc <sup>1</sup>	01090	18	12	3	3	0.896
Carbon disulfide	77041	25	21	2	2	0.932
Chloroform (trichloromethane)	32106	25	22	2	1	0.597
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	23	1	1	0.977
Tetrachloroethene (PCE)	34475	25	24	0	1	0.317
Trichloroethene (TCE)	39180	25	24	0	1	0.317
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	24	24	0	0	NA
Atrazine	39632	24	24	0	0	NA
Simazine	04035	24	23	0	1	0.317
δ <sup>2</sup> H of water	82082	24	24	0	0	NA
δ <sup>18</sup> O of water	82085	24	24	0	0	NA
δ <sup>13</sup> C of dissolved carbonates	82081	18	18	0	0	NA
Carbon-14 (modern carbon)	49933	18	2	8	9	0.896
Tritium	07000	25	12	2	11	<b>0.011 ▼</b>

**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	25		No results for field parameters		
Dissolved oxygen	00300	19		No results for field parameters		
Field specific conductance	00095	25		No results for field parameters		
Lab specific conductance <sup>1</sup>	90095	18	0	16	2	<b>0.002 ▲</b>
Total dissolved solids	70300	18	0	8	10	0.306
Field pH	00400	19		No results for field parameters		
Lab pH	00403	18	0	8	10	0.327
Alkalinity	29801	16	0	9	7	0.278
Bicarbonate	63786	16	0	9	16	0.278
Carbonate	63788	16	13	1	2	0.564
Total nitrogen	62854	18	7	6	5	0.598
Nitrate <sup>1</sup>	00631	18	9	4	5	0.426
Nitrite	00613	18	15	0	3	0.084
Ammonia	00608	18	10	5	3	0.335
Orthophosphate	00671	18	5	10	3	0.103
Perchlorate	61209	26	26	0	0	NA
Calcium <sup>1</sup>	00915	18	0	12	6	<b>0.005 ▲</b>
Magnesium <sup>1</sup>	00925	18	0	13	5	<b>0.011 ▲</b>
Potassium <sup>1</sup>	00935	18	1	8	9	0.542
Sodium <sup>1</sup>	00930	18	0	13	5	0.053
Bromide	71870	18	8	3	7	0.262
Chloride	00940	18	0	16	2	<b>0.011 ▲</b>
Iodide	71865	18	9	1	8	<b>0.022 ▼</b>
Sulfate	00945	18	0	11	7	0.064
Fluoride <sup>1</sup>	00950	16	3	2	11	<b>0.008 ▼</b>
Silica <sup>1</sup>	00955	18	0	1	17	<b>&lt;0.001 ▼</b>
Aluminum <sup>1,2</sup>	01106	18	9	9	0	<b>0.003 ▲</b>
Antimony	01095	18	18	0	0	NA
Arsenic	01000	18	3	2	13	<b>0.009 ▼</b>
Barium <sup>1</sup>	01005	18	0	11	7	<b>0.048 ▲</b>
Boron <sup>1</sup>	01020	18	3	8	7	0.678
Cadmium <sup>1</sup>	01025	18	17	0	1	0.317
Chromium	01030	18	18	0	0	NA
Copper	01040	18	12	3	3	0.937
Iron <sup>2</sup>	01046	18	8	7	3	0.136
Lead	01049	18	9	3	6	0.261



**Table 2B.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the North San Francisco Bay study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material.]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	18	0	14	4	<b>0.012 ▲</b>
Manganese <sup>1</sup>	01056	18	3	9	6	0.213
Molybdenum	01060	18	7	3	8	0.131
Nickel <sup>1</sup>	01065	18	8	9	1	<b>0.023 ▲</b>
Selenium <sup>1</sup>	01145	18	12	0	6	<b>0.015 ▼</b>
Strontium <sup>1</sup>	01080	18	0	13	5	0.112
Thallium	01057	18	No qualifying replicates to establish CI			
Uranium <sup>1</sup>	22703	18	13	3	2	0.578
Vanadium	01085	18	2	3	13	0.055
Zinc <sup>1</sup>	01090	18	12	3	3	0.896
Carbon disulfide	77041	25	No qualifying replicates to establish CI			
Chloroform (trichloromethane)	32106	25	22	2	1	0.597
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	No qualifying replicates to establish CI			
Tetrachloroethene (PCE)	34475	25	No qualifying replicates to establish CI			
Trichloroethene (TCE)	39180	25	No qualifying replicates to establish CI			
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	24	24	0	0	NA
Atrazine	39632	24	24	0	0	NA
Simazine	04035	24	No qualifying replicates to establish CI			
δ <sup>2</sup> H of water	82082	24	0	14	10	0.310
δ <sup>18</sup> O of water	82085	24	0	22	2	<b>&lt;0.001 ▲</b>
δ <sup>13</sup> C of dissolved carbonates	82081	18	0	8	10	0.586
Carbon-14 (modern carbon)	49933	18	0	9	9	0.845
Tritium	07000	25	10	1	14	<b>0.002 ▼</b>

<sup>1</sup>Data-quality assessment summaries published by the QSB found measurement bias or variability at the NWQL for this constituent during one or both sampling periods.

<sup>2</sup>Project field-blank results indicate a potential positive bias in initial period concentrations for this constituent.

**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Water temperature	00010	25	5	4	16	<b>0.040 ▼</b>
Dissolved oxygen	00300	25	2	10	13	0.236
Field specific conductance	00095	24	1	12	11	0.407
Lab specific conductance <sup>1</sup>	90095	16	0	9	7	0.570
Total dissolved solids	70300	16	0	8	8	0.796
Field pH	00400	16	0	0	16	<b>&lt;0.001 ▼</b>
Lab pH	00403	16	0	14	2	<b>0.007 ▲</b>
Alkalinity	29801	16	0	8	8	0.717
Bicarbonate	63786	16	0	7	9	0.796
Carbonate	63788	16	1	0	15	<b>&lt;0.001 ▼</b>
Total nitrogen	62854	16	1	10	5	0.052
Nitrate <sup>1</sup>	00631	16	4	9	3	<b>0.025 ▲</b>
Nitrite	00613	16	13	2	1	0.514
Ammonia	00608	16	11	3	2	0.799
Orthophosphate	00671	16	0	14	2	<b>0.007 ▲</b>
Perchlorate	61209	17	13	3	1	0.303
Calcium <sup>1</sup>	00915	16	0	12	4	<b>0.006 ▲</b>
Magnesium <sup>1</sup>	00925	16	0	12	4	<b>0.021 ▲</b>
Potassium <sup>1</sup>	00935	16	0	8	8	0.642
Sodium <sup>1</sup>	00930	16	0	12	4	0.070
Bromide	71870	16	9	6	10	0.221
Chloride	00940	16	0	9	7	0.756
Iodide	71865	16	0	6	10	0.501
Sulfate	00945	16	0	12	4	0.088
Fluoride <sup>1</sup>	00950	16	0	6	10	0.088
Silica <sup>1</sup>	00955	16	0	5	11	<b>0.015 ▼</b>
Aluminum <sup>1,2</sup>	01106	16	14	2	0	0.158
Antimony	01095	16	10	2	4	0.453
Arsenic	01000	16	2	5	9	0.313
Barium <sup>1</sup>	01005	16	0	9	7	0.570
Boron <sup>1</sup>	01020	16	0	8	8	0.717
Cadmium <sup>1</sup>	01025	16	6	4	6	0.612
Chromium	01030	16	7	5	4	0.625
Copper	01040	16	11	3	2	0.703
Iron <sup>2</sup>	01046	16	5	9	2	<b>0.029 ▲</b>
Lead	01049	16	12	1	3	0.271

**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation-the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	No difference threshold			p value and trend direction (if applicable)
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	
Lithium	01130	16	0	10	6	0.501
Manganese <sup>1</sup>	01056	16	5	9	2	<b>0.019▲</b>
Molybdenum	01060	16	0	9	7	0.278
Nickel <sup>1</sup>	01065	16	0	7	9	0.179
Selenium <sup>1</sup>	01145	16	2	9	5	0.453
Strontium <sup>1</sup>	01080	16	0	9	7	0.301
Thallium	01057	16	15	0	1	0.317
Uranium <sup>1</sup>	22703	16	2	8	6	0.422
Vanadium	01085	16	0	10	6	0.301
Zinc <sup>1</sup>	01090	16	9	4	3	0.666
Carbon disulfide	77041	25	21	3	1	0.308
Chloroform (trichloromethane)	32106	25	19	4	2	0.416
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	23	0	2	0.157
Tetrachloroethene (PCE)	34475	25	21	1	3	0.288
Trichloroethene (TCE)	39180	25	21	2	2	0.966
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	25	23	2	0	0.157
Atrazine	39632	25	23	1	1	0.977
Simazine	04035	25	19	2	4	0.416
δ <sup>2</sup> H of water	82082	24	0	13	11	0.909
δ <sup>18</sup> O of water	82085	24	0	20	2	<b>&lt;0.001▲</b>
δ <sup>13</sup> C of dissolved carbonates	82081	12	0	2	10	<b>0.041▼</b>
Carbon-14 (modern carbon)	49933	12	0	5	7	0.209
Tritium	07000	24	8	1	15	<b>&lt;0.001▼</b>

**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	25	25	0	0	NA
Dissolved oxygen	00300	25	14	3	8	0.108
Field specific conductance	00095	24	18	5	1	0.108
Lab specific conductance <sup>1</sup>	90095	16	12	3	1	0.302
Total dissolved solids	70300	16	13	2	1	0.564
Field pH	00400	16	14	0	2	0.158
Lab pH	00403	16	16	0	0	NA
Alkalinity	29801	16	14	2	0	0.157
Bicarbonate	63786	16	14	2	0	0.158
Carbonate	63788	16	8	0	8	<b>0.005 ▼</b>
Total nitrogen	62854	16	15	0	1	0.074
Nitrate <sup>1</sup>	00631	16	7	8	1	<b>0.015 ▲</b>
Nitrite	00613	16	13	2	1	0.514
Ammonia	00608	16	14	0	2	0.158
Orthophosphate	00671	16	6	9	1	<b>0.020 ▲</b>
Perchlorate	61209	17	15	1	1	0.966
Calcium <sup>1</sup>	00915	16	11	4	1	<b>0.026 ▲</b>
Magnesium <sup>1</sup>	00925	16	11	4	1	0.162
Potassium <sup>1</sup>	00935	16	13	3	0	0.084
Sodium <sup>1</sup>	00930	16	13	2	1	0.564
Bromide	71870	16	7	3	6	0.156
Chloride	00940	16	9	3	4	0.886
Iodide	71865	16	10	3	3	0.928
Sulfate	00945	16	9	5	2	0.239
Fluoride <sup>1</sup>	00950	16	15	0	1	0.317
Silica <sup>1</sup>	00955	16	15	0	1	0.317
Aluminum <sup>1,2</sup>	01106	16	15	1	0	0.317
Antimony	01095	16	15	1	0	0.317
Arsenic	01000	16	13	1	2	0.564
Barium <sup>1</sup>	01005	16	12	3	1	0.271
Boron <sup>1</sup>	01020	16	11	3	2	0.656
Cadmium <sup>1</sup>	01025	16	13	1	2	0.617
Chromium	01030	16	14	2	0	0.158
Copper	01040	16	14	1	1	0.964
Iron <sup>2</sup>	01046	16	9	6	1	<b>0.041 ▲</b>
Lead	01049	16	14	0	2	0.158

**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on replicate acceptability criteria			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	16	12	3	1	0.302
Manganese <sup>1</sup>	01056	16	11	5	0	<b>0.026 ▲</b>
Molybdenum	01060	16	12	3	1	0.271
Nickel <sup>1</sup>	01065	16	7	2	7	0.143
Selenium <sup>1</sup>	01145	16	11	3	2	0.656
Strontium <sup>1</sup>	01080	16	13	3	0	0.084
Thallium	01057	16	16	0	0	NA
Uranium <sup>1</sup>	22703	16	11	3	2	0.611
Vanadium	01085	16	9	5	2	0.405
Zinc <sup>1</sup>	01090	16	13	2	1	0.564
Carbon disulfide	77041	25	22	2	1	0.532
Chloroform (trichloromethane)	32106	25	22	2	1	0.564
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	25	0	0	NA
Tetrachloroethene (PCE)	34475	25	23	0	2	0.157
Trichloroethene (TCE)	39180	25	22	2	1	0.564
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	25	25	0	0	NA
Atrazine	39632	25	24	0	1	0.317
Simazine	04035	25	25	0	0	NA
δ <sup>2</sup> H of water	82082	24	24	0	0	NA
δ <sup>18</sup> O of water	82085	24	24	0	0	NA
δ <sup>13</sup> C of dissolved carbonates	82081	12	12	0	0	NA
Carbon-14 (modern carbon)	49933	12	1	4	7	0.195
Tritium	07000	24	12	1	11	<b>0.003 ▼</b>

**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Water temperature	00010	25		No results for field parameters		
Dissolved oxygen	00300	25		No results for field parameters		
Field specific conductance	00095	24		No results for field parameters		
Lab specific conductance <sup>1</sup>	90095	16	0	9	7	0.570
Total dissolved solids	70300	16	0	8	8	0.796
Field pH	00400	16		No results for field parameters		
Lab pH	00403	16	0	14	2	<b>0.007▲</b>
Alkalinity	29801	16	0	8	8	0.717
Bicarbonate	63786	16	0	7	0	0.796
Carbonate	63788	16	13	0	3	0.084
Total nitrogen	62854	16	4	9	3	0.037▲
Nitrate <sup>1</sup>	00631	16	5	9	2	0.017▲
Nitrite	00613	16	13	2	1	0.514
Ammonia	00608	16	12	2	2	0.891
Orthophosphate	00671	16	3	12	1	<b>0.008▲</b>
Perchlorate	61209	17	16	0	1	0.317
Calcium <sup>1</sup>	00915	16	0	12	4	<b>0.006▲</b>
Magnesium <sup>1</sup>	00925	16	0	12	4	<b>0.021▲</b>
Potassium <sup>1</sup>	00935	16	1	16	17	0.642
Sodium <sup>1</sup>	00930	16	0	12	4	0.070
Bromide	71870	16	2	6	8	0.293
Chloride	00940	16	0	9	7	0.756
Iodide	71865	16	9	3	4	0.752
Sulfate	00945	16	0	12	4	0.088
Fluoride <sup>1</sup>	00950	16	7	2	7	0.092
Silica <sup>1</sup>	00955	16	0	5	11	<b>0.015▼</b>
Aluminum <sup>1,2</sup>	01106	16	14	2	0	0.158
Antimony	01095	16	12	1	3	0.371
Arsenic	01000	16	5	3	8	0.179
Barium <sup>1</sup>	01005	16	0	9	7	0.570
Boron <sup>1</sup>	01020	16	0	8	8	0.717
Cadmium <sup>1</sup>	01025	16	6	4	6	0.612
Chromium	01030	16	10	4	2	0.418
Copper	01040	16	12	2	2	1.000
Iron <sup>2</sup>	01046	16	9	7	0	<b>0.009▲</b>
Lead	01049	16	13	0	3	0.084



**Table 2C.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria for the Monterey Bay and Salinas Valley Basins study unit.—Continued

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; CI, confidence intervals; GAMA-PBP, USGS Groundwater Ambient Monitoring and Assessment Program-Priority Basin Project; H, hydrogen; n, number of wells with paired results for constituent; NA, not applicable; NWQL, USGS National Water Quality Laboratory; O, oxygen; p value, calculated probability of the obtained Wilcoxon-Pratt test result if the null hypothesis is true; QSB, USGS Quality Systems Branch; <, less than; ▲, increasing trend or ▼, decreasing trend with p value less than 0.05, considered statistically significant indication of step trend; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	n	Difference threshold based on confidence intervals			
			Number of wells with no change	Number of wells with increase	Number of wells with decrease	p value and trend direction (if applicable)
Lithium	01130	16	0	10	6	0.501
Manganese <sup>1</sup>	01056	16	8	7	1	<b>0.026 ▲</b>
Molybdenum	01060	16	0	9	7	0.278
Nickel <sup>1</sup>	01065	16	6	2	8	0.104
Selenium <sup>1</sup>	01145	16	4	8	4	0.433
Strontium <sup>1</sup>	01080	16	0	9	7	0.301
Thallium	01057	16	No qualifying replicates to establish CI			
Uranium <sup>1</sup>	22703	16	3	8	5	0.377
Vanadium	01085	16	2	8	6	0.422
Zinc <sup>1</sup>	01090	16	13	2	1	0.564
Carbon disulfide	77041	25	No qualifying replicates to establish CI			
Chloroform (trichloromethane)	32106	25	20	3	2	0.628
Methyl <i>tert</i> -butyl ether (MTBE)	78032	25	No qualifying replicates to establish CI			
Tetrachloroethene (PCE)	34475	25	No qualifying replicates to establish CI			
Trichloroethene (TCE)	39180	25	No qualifying replicates to establish CI			
2-Chloro-4-isopropylamino-6-amino- s-triazine	04040	25	24	1	0	0.317
Atrazine	39632	25	24	0	1	0.317
Simazine	04035	25	No qualifying replicates to establish CI			
δ <sup>2</sup> H of water	82082	24	0	13	11	0.909
δ <sup>18</sup> O of water	82085	24	0	20	4	<b>&lt;0.001 ▲</b>
δ <sup>13</sup> C of dissolved carbonates	82081	12	0	2	10	<b>0.041 ▼</b>
Carbon-14 (modern carbon)	49933	12	0	5	7	0.209
Tritium	07000	24	9	1	14	<b>&lt;0.001 ▼</b>

<sup>1</sup>Data-quality assessment summaries published by the QSB found measurement bias or variability at the NWQL for this constituent during one or both sampling periods.

<sup>2</sup>Project field-blank results indicate a potential positive bias in initial period concentrations for this constituent.

**Table 2D.** Constituents detected in at least 10 percent of the samples collected during initial sampling or resampling of trend wells, the number of paired results, number increased, number decreased, and p values from Wilcoxon signed-rank test with Pratt correction using different threshold criteria: Summary of statistical evaluation results for constituents exhibiting step trends in this report.

[The five-digit United States Geological Survey (USGS) parameter code is used to uniquely identify a specific constituent or property.

**Abbreviations:** C, carbon; NSF, North San Francisco Bay; O, oxygen; ▲, increase; ▼, decrease; —, no step trend. Double entry divided by a forward slash (/) indicates a change in the step-trend finding before (in front of slash) and after (under slash) additional quality-control interpretation; δ, standard delta notation—the ratio of a heavier isotope to more common lighter isotope of that element, relative to a standard reference material]

Constituent	USGS parameter code	No difference threshold			Replicate criteria threshold			Confidence intervals threshold		
		Combined study units	NSF study unit	SALMON study unit	Combined study units	NSF study unit	SALMON study unit	Combined study units	NSF study unit	SALMON study unit
Water temperature	00010	▼	—	▼	—	—	—	No results for field parameters		
Dissolved oxygen	00300	—	▲	—	—	—	—	No results for field parameters		
Field specific conductance	00095	▲	▲	—	▲	—	—	No results for field parameters		
Lab specific conductance <sup>2</sup>	90095	▲ / —	▲ / —	—	▲ / —	▲ / —	—	▲ / —	▲ / —	—
Field pH	00400	▼	—	▼	—	—	—	No results for field parameters		
Lab pH	00403	—	—	▲	—	—	—	—	—	▲
Carbonate	63788	▼	—	▼	▼	—	▼	—	—	—
Total nitrogen	62854	—	—	—	—	—	—	—	—	▲
Nitrate <sup>1</sup>	00631	—	—	▲	—	—	▲	—	—	▲
Orthophosphate	00671	▲	—	▲	▲	—	▲	▲	—	▲
Calcium <sup>1</sup>	00915	▲	▲	▲	— / ▲	—	▲	▲	▲	▲
Magnesium <sup>1</sup>	00925	▲ / —	▲ / —	▲ / —	▲ / —	▲ / —	—	▲ / —	▲ / —	▲ / —
Potassium <sup>1</sup>	00935	—	— / ▼	—	▲ / —	—	—	—	— / ▼	—
Sodium <sup>1</sup>	00930	▲ / —	— / ▼	—	—	—	—	▲ / —	— / ▼	—
Chloride	00940	—	▲	—	—	—	—	—	▲	—
Iodide	71865	—	—	—	—	—	—	—	▼	—
Sulfate	00945	▲	—	—	▲	▲	—	▲	—	—
Fluoride <sup>1</sup>	00950	▼	▼	— / ▼	—	—	—	▼	▼	— / ▼
Silica <sup>2</sup>	00955	▼ / —	▼ / —	▼ / —	—	—	—	▼ / —	▼ / —	▼ / —
Aluminum <sup>1,2</sup>	01106	▲	▲	—	▲	▲	—	▲	▲	—
Arsenic	01000	▼	▼	—	—	—	—	▼	▼	—
Barium <sup>1</sup>	01005	▲ / —	▲ / —	—	—	—	—	▲ / —	▲ / —	—
Iron <sup>2</sup>	01046	▲	—	▲	▲	—	▲	▲	—	▲
Lead	01049	—	—	—	▼	—	—	—	—	—
Lithium	01130	▲	▲	—	—	—	—	▲	▲	—
Manganese <sup>1</sup>	01056	▲ / —	—	▲ / —	—	—	▲ / —	▲ / —	—	▲ / —
Nickel <sup>1</sup>	01065	—	▲ / —	—	—	—	—	—	▲ / —	—
Selenium <sup>1</sup>	01145	—	▼	—	—	▼	—	—	▼	—
Strontium <sup>1</sup>	01080	—	—	—	▲	—	—	—	—	—
Vanadium	01085	—	—	—	—	▼	—	—	—	—
δ <sup>18</sup> O of water	82085	▲	▲	▲	—	—	—	▲	▲	▲
δ <sup>13</sup> C of dissolved carbonates	82081	—	—	▼	—	—	—	—	—	▼
Tritium	07000	▼	▼	▼	▼	▼	▼	▼	▼	▼

<sup>1</sup>Data-quality assessment summaries published by the QSB found measurement bias or variability at the NWQL for this constituent during one or both sampling periods.

<sup>2</sup>Project field-blank results indicate a potential positive bias in initial period concentrations for this constituent.

**Table 3.** Constituents for which one of three circumstances indicate step-trend results are inconclusive.

[CaCO<sub>3</sub>, calcium carbonate; HAL-US, Environmental Protection Agency lifetime health-advisory level; MCL-CA, California maximum contaminant level; mg/L, milligram per liter; NL-CA, California notification level; NSF, North San Francisco Bay; SALMON, Monterey Bay and Salinas Valley Basins; USGS, U.S. Geological Survey; µg/L, microgram per liter; =, equal to; >, greater than]

Constituent	Step-trend findings before data adjustment	Bias period	Bias direction	Bias magnitude (percent)
Circumstance 1: Analytical bias documented by the USGS Quality Systems Branch (QSB), which may have contributed to step-trend finding. After adjusting the data for the documented bias the step-trend findings for these constituents were no longer significant.				
Magnesium	Increase in both study units and combined	Initial	Negative	5.5
Magnesium	Increase in both study units and combined	Decadal	Positive	9.0
Potassium	Increase in combined study units	Initial	Positive	6.0
Potassium	Increase in combined study units	Decadal	Positive	8.0
Sodium	Increase in combined study units	Decadal	Positive	8.0
Silica	Decrease in both study units and combined	Initial	Positive	7.0
Barium	Increase in NSF study unit and combined	Initial	Negative	7.0
Manganese	Increase in SALMON study unit and combined	Initial	Negative	8.0
Nickel	Increase in NSF study unit	Decadal	Positive	17.0
Constituent	Step-trend finding	Correlated constituent	Step-trend finding for correlated constituent	
Circumstance 2: The step-trend finding is not consistent with the evaluated results of a different, generally correlated water-quality constituent.				
Field-measured specific conductance	Increase in NSF study unit and combined	Total dissolved solids	None	
Laboratory-measured specific conductance	Increase in NSF study unit and combined	Total dissolved solids	None	
Field-measured pH	Decrease in SALMON study unit and combined	Laboratory-measured pH	Increase in SALMON study unit	
Laboratory-measured pH	Increase in SALMON study unit	Field-measured pH	Decrease in SALMON study unit and combined	
Isotopic ratio of oxygen-18 in water (δ <sup>18</sup> O)	Increase in both study units and combined	Isotopic ratio of deuterium in water (δ <sup>2</sup> H)	None	
Constituent	Step-trend finding	Maximum concentration	Benchmark for water quality	
Circumstance 3: Constituent concentrations observed in this study are negligible relative to their potential effect on water quality.				
Carbonate	Decrease in SALMON study unit and combined	3.3 mg/L	Alkalinity range=38–391 mg/L as CaCO <sub>3</sub> , median=159	
Iodide	Decrease in NSF study unit	0.26 mg/L	>1 mg/L (World Health Organization, 1996)	
Fluoride	Decrease in NSF study unit and combined	0.5 mg/L	MCL-CA=2 mg/L	
Aluminum	Increase in NSF study unit and combined	7 µg/L	MCL-CA=1,000 µg/L	
Selenium	Decrease in NSF study unit	15.6 µg/L	MCL-US=50 µg/L	
Strontium	Increase in combined study units	2,214 µg/L	HAL-US=4,000 µg/L	
Vanadium	Decrease in NSF study unit	18 µg/L (in NSF study unit)	NL-CA=50 µg/L	



ISSN 2328-031X (print)  
ISSN 2328-0328 (online)  
<https://doi.org/10.3133/sir20185088>

Publishing support provided by the U.S. Geological Survey  
Science Publishing Network, Sacramento Publishing Service Center

For more information concerning the research in this report, contact the

Director, California Water Science Center  
U.S. Geological Survey  
6000 J Street, Placer Hall  
Sacramento, CA 95819  
<https://ca.water.usgs.gov>

