MONTEREY COUNTY FOCUS AREA DOMESTIC WELL PROJECT REPORT

State Water Resources Control Board

Groundwater Ambient Monitoring and Assessment (GAMA) Program

Domestic Well Project

Groundwater Quality Report

2011

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Acronyms

AL	Action Level
µg/L	micrograms per liter
µmhos/cm	micromhos per centimeter
CDPH	California Department of Public Health
DWR	California Department of Water Resources
GAMA	Groundwater Ambient Monitoring and Assessment
GPS	global positioning satellite
LLNL	Lawrence Livermore National Laboratory
MBAS	methylene blue active substances
MCL	maximum contaminant level
mg/L	milligrams per liter
MTBE	methyl tert-butyl ether
NDMA	n-nitrosodimethylamine
NL	notification level
PCE	tetrachloroethylene
pCi/L	picocuries per liter
SMCL	secondary maximum contaminant level
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound

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Abstract

The Groundwater Ambient Monitoring and Assessment (GAMA) Domestic Well Project performed its sixth county focus area study in Monterey County, California. Private domestic wells were sampled between May 2 and June 30, 2011. GAMA staff collected water samples from 79 private domestic wells located in and near the cities of: Aromas, Bradley, Carmel, Carmel Valley, Castroville, Chualar, Gonzales, Greenfield, Lockwood, Prunedale, Royal Oaks, Soledad, and Watsonville.

Water samples were transported to a California Department of Public Health (CDPH)[1] accredited environmental laboratory and analyzed for chemical constituents commonly found in groundwater such as bacteria (total and fecal coliform), inorganic constituents (metals, major anions and general minerals), and volatile organic compounds (VOCs). Test results were compared against public drinking water standards established by the CDPH or EPA: primary maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), notification levels (NLs), and action level (AL) (in this order of availability). These water quality standards were used for comparison purposes only, since private domestic well water quality is not regulated by the State of California.

Groundwater samples from 50 wells had test results for at least one chemical constituent above a drinking water standard. Eleven constituents were above a primary MCL or AL including arsenic, cadmium, fecal coliform, fluoride, lead, nitrate, nitrite, perchlorate, thallium, total coliform, and uranium. Thallium was the most frequently detected above an MCL (18 wells), followed by total coliform (11 wells), nitrate (9 wells), and perchlorate (9 wells).

Seven constituents were reported at concentrations above a SMCL including aluminum, iron, manganese, pH, specific conductance, sulfate, and total dissolved solids. Manganese was the most frequently detected above a SMCL (13 wells). In addition, water samples were analyzed for hexavalent chromium in 13 selected wells and were detected above the draft MCL in 4 wells.

[1] The State Water Resources Control Board currently includes the Division of Drinking Water, but at the time of this project, this division was under the California Department of Public Health (CDPH).

In addition, Lawrence Livermore National Laboratory (LLNL) performed stable isotope analyses on all water samples. Isotopic information is useful for identifying potential sources and transport of nitrate in groundwater. The LLNL findings indicate that the wells sampled in this study are characterized by generally low nitrate concentrations (<45 milligrams per liter (mg/L) as NO_3) and low boron concentrations (<200 µg/L). The nitrate isotopic compositions ($\delta^{15}N$, $\delta^{18}O$) of the moderate-nitrate samples (>10 mg/L and < 45 mg/L as NO_3) fell within the overlapping range of soil nitrogen, animal manure, and wastewater; therefore, the source(s) of nitrate in these samples could not be clearly distinguished by nitrate isotopic composition. The high-nitrate samples (>45 mg/L as NO_3) were characterized by higher boron concentrations and $\delta^{11}B$ values, particularly to the groundwater in the Gonzales region the Salinas River valley.

Introduction

Groundwater is an essential part of California's water supply. More than 85 percent of community public water systems, serving roughly 30 million people, rely on groundwater for at least part of their drinking water supply (GAMA, 2013). Approximately two million California residents rely on either a private domestic well or a small water system not regulated by the state (GAMA, 2015). For these residents, there is little to no information readily available about the quality of their drinking water.

Groundwater is also an important water source for irrigation and industrial supply. Reliance on groundwater is expected to increase due, in part, to increased agricultural and industrial demand, drought, and population/land-use changes. Consequently, there are concerns about groundwater quality in California.

The State Water Resources Control Board created the Groundwater Ambient Monitoring and Assessment (GAMA) Program to address public concerns over groundwater quality. The primary objectives of the GAMA Program are to improve comprehensive statewide groundwater monitoring and to increase public availability of groundwater quality information. The data gathered by the GAMA Program highlight regional and local groundwater quality concerns and may be used to evaluate chemicals of concern in specific areas throughout the state. The GAMA Program consists of four current projects:

Domestic Well Project: The Domestic Well Project samples private wells from volunteer well owners on a county-by-county basis. Over 1,100 private wells (of the estimated 250,000 to 600,000 statewide) have been sampled in Yuba, El Dorado, Tehama, Tulare, San Diego, and Monterey county focus areas since 2002. This project has found that most of the well owners have not had their well sampled previously.

Analytical tests include common contaminants such as nitrate, trace metals, volatile organic compounds (VOCs), pesticides, and radionuclides at no cost to the well owner. The well owners receive the analytical test results and fact sheets, and the water quality data is placed on the GAMA Groundwater Information System GAMA, maintaining the privacy of the well owners.

Priority Basin Project: The Priority Basin Project assesses groundwater basins that account for over 95 percent of all groundwater used for public drinking. Groundwater is tested for common contaminants regulated by the California Department of Public Health (CDPH), and unregulated chemicals such as pharmaceuticals, chemicals of emerging concern, isotopes, and age-dating tracers, often at very low detection limits. To date, the U.S. Geological Survey (USGS) has sampled over 2,300 public supply wells and has developed a statistically unbiased assessment of the quality of California's drinking water aquifers.

Special Studies Project: Special Studies, with Lawrence Livermore National Laboratory (LLNL) as project lead, focuses on specific groundwater quality studies, using state of the art scientific techniques and methods that help researchers and public policy planners to better understand how groundwater contamination occurs and behaves. Studies have included sources of nitrate, wastewater mixing, groundwater recharge, trace detection of pharmaceutical compounds and personal care products, using low-level anthropogenic compounds as tracers, and isotopic composition as a contamination source tool. In addition, LLNL has pioneered the use of tritium-helium groundwater age-dating techniques, which are critical in understanding groundwater sources and flow.

GAMA Groundwater Information System: The GAMA Groundwater Information System integrates and displays water quality data on an on-line interactive, searchable map. Its analytical tools and reporting features help users assess groundwater quality and identify potential groundwater issues. The GAMA Groundwater Information System contains over 125 million data records from different sources such as, public water system source water quality, Department of Water Resources, Department of Pesticide Regulation, USGS National Water Information System, Irrigated Lands Regulatory Program, local domestic well studies, the GAMA Program's Priority Basin, Domestic Well, and Special Studies Projects, and data from well logs, water levels, and cleanup sites.

Background

Monterey County

Monterey County has a population of over 415,000 (Census Bureau 2010). It covers an area of 3,771 square miles and lies within the California Department of Water Resources (DWR) defined Southern Coast Ranges hydrogeologic province, encompassing 100 miles of Pacific coastline.

Monterey County is the third largest agricultural county in California. In Salinas Valley alone, more than 200,000 acres are irrigated by groundwater from over 1,700 wells. According to the Monterey County Water Resources Agency, of the approximate 527,000 acre-feet of groundwater are extracted each year, 91 percent is used for agriculture and nine percent is used for urban water supply. Division of Drinking Water groundwater quality data reveal that 55 percent of 711 public supply wells in the Central Coast hydrologic province between 1994 and 2000 were impaired by nitrate. Over pumping groundwater in Salinas Valley coastal aquifers has caused seawater intrusion as well, which has negatively affected groundwater quality (DWR, 2003).

Hydrogeologic Setting

There are 431 DWR-defined basins in California, which are grouped into 10 hydrologic regions. Monterey County is within the Central Coast hydrologic region and includes three basins and an additional five subbasins (Figure 1).

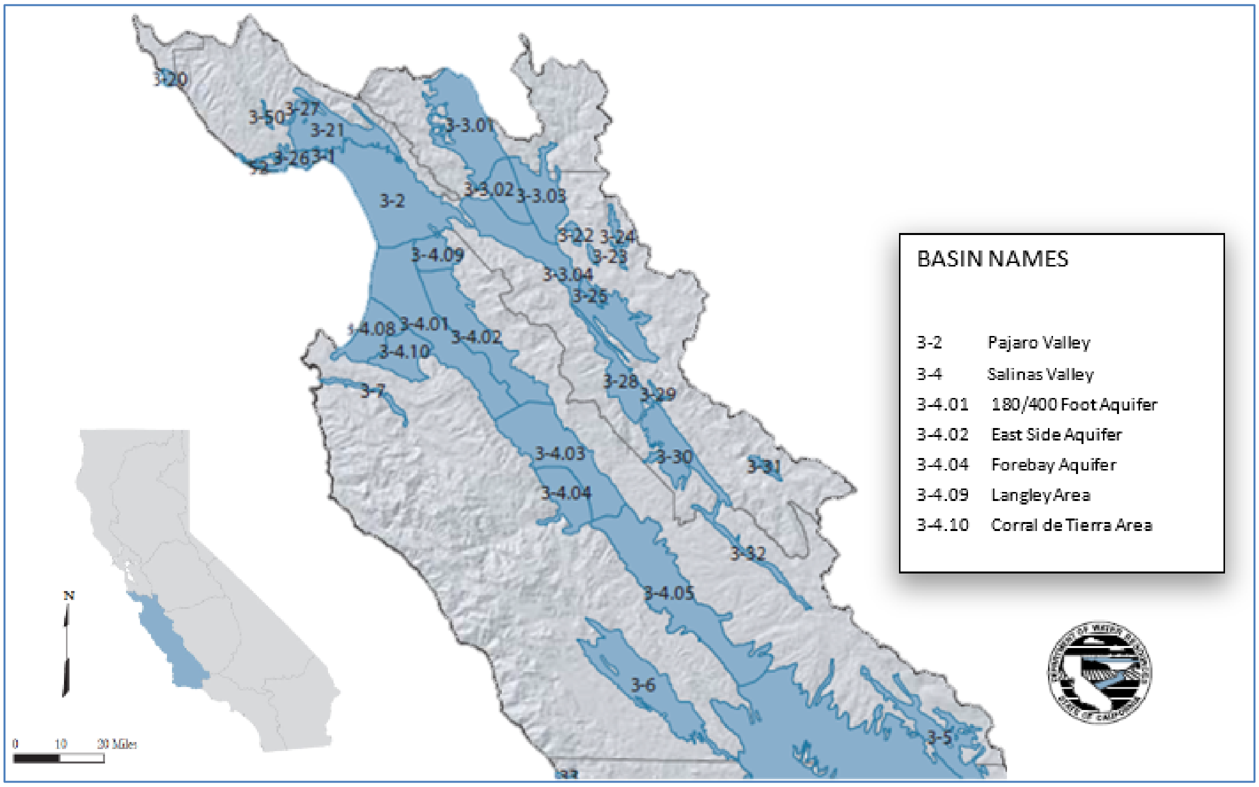


Figure 1. Area of the DWR-defined Central Coast Hydrologic Region, with basins from this report indicated in legend.

Domestic Well Monitoring and Sampling

Well Owner Participation and Procedures

Monterey County was selected due to the large number of private domestic wells and the availability of well owner information in electronic format. According to the 1990 U.S. Census, there were approximately 12,000 domestic wells in Monterey County. The Central Coast Regional Water Quality Control Board and Monterey County supplied databases of approximately 2,100 domestic wells owners for our use in this study.

Invitation brochures (also sent with Spanish translations) were mailed to the prospective well owners in early 2011. The invitation brochure provided information about the GAMA Domestic Well Project and invited well owners to participate in the program. Well owners who positively responded by mailing a signed brochure back to the State Water Board were subsequently contacted by GAMA Program staff to schedule a sampling appointment.

The private domestic well sampling was designed as a one-time sampling survey to help educate domestic well owners about the quality of their well water. The water quality results do not necessarily represent the ambient groundwater quality in the focus area, but instead offer (at no cost) water quality information for those specific wells.

After receiving the final analytical report from the laboratory, GAMA Program staff mailed individual well water test results to well owners. A summary of all sampling results in the focus area were provided to state and local health officials to assist well owners that may have questions about their test results.

Well Locations

Well locations are shown on Figure 2. Sixty-seven wells were located within a defined DWR basin: 39 within the Salinas Valley basin, 20 within the Pajaro Valley basin, five within the Carmel Valley basin, and three wells in the Lockwood Valley basin. Twelve wells sampled were located outside of DWR-defined basins.

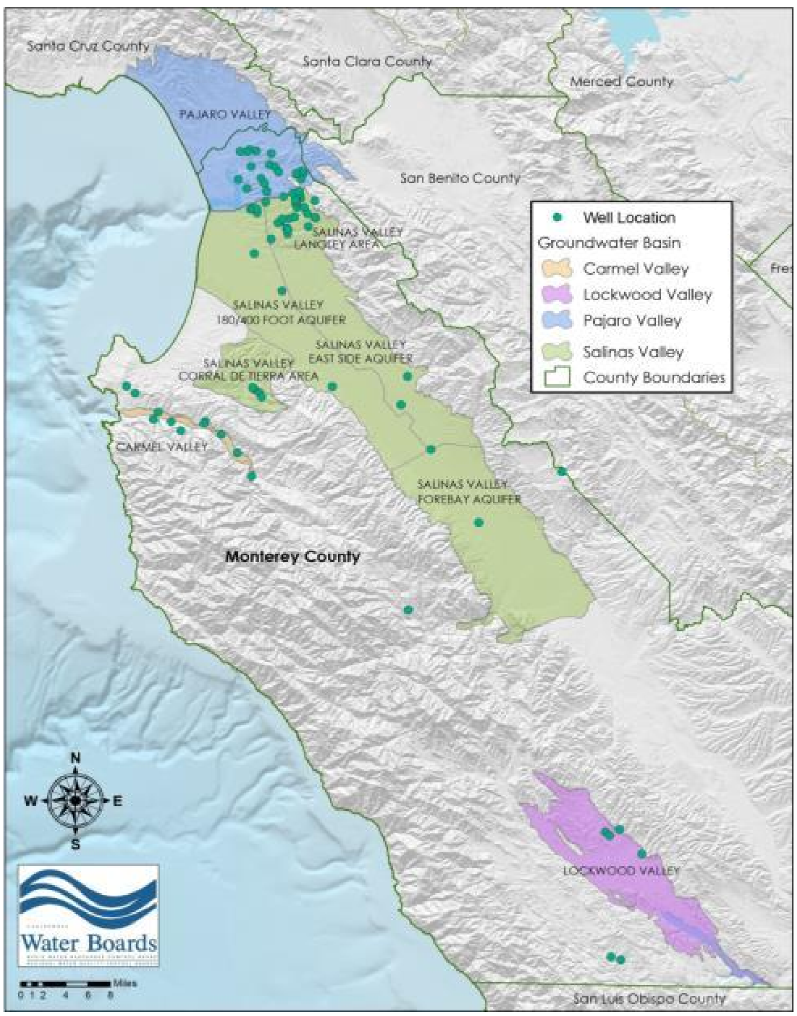


Figure 2. Locations of sampled domestic wells.

Well Construction Data

Well owners provided well construction information for 58 of the 79 wells, and some were accompanied with the well completion reports. A summary of well depths is included in Table 1.

Table 1. A summary of well depth intervals (where available) by number of wells.

Total Well Depth (feet)	Number of Wells
0-99	3
100-149	1
150-199	4
200-249	4
250-299	9
300-349	6
350-399	8
400-449	3
450-499	4
500-549	4
550-599	1
600-699	3
≥700	4

Data and Sample Collection

Samples were collected from 79 private domestic wells between May and June 2011. Prior to well sample collection, well construction information was obtained from either well owners or well completion reports (well logs). Additionally, field staff noted the presence and location of nearby septic systems, agricultural activities, and livestock. Well locations were recorded using a global positioning satellite (GPS) unit. During sample collection, GAMA Program staff collected field parameters such as water temperature, pH, and specific conductance.

Samples were collected as close to the wellhead as possible, most often from a faucet or hose bib near the pressure tank. Samples were collected in laboratory supplied containers, and immediately placed in an insulated cooler filled with ice. Duplicate samples were collected at approximately ten percent of the well locations to verify sample collection methods and as a quality control measure for laboratory analyses.

Collected water samples were then transported to the laboratory for analyses under strict chain-of-custody documentation.

Laboratory-supplied trip blanks were transported and analyzed along with the collected groundwater samples. The presence of trip blanks helped to determine whether cross-contamination occurred during transportation, processing, and/or storage.

Sample Analyses

Collected groundwater samples were sent to the accredited environmental laboratory for analyses. Samples were identified as either routine or non-routine.

Routine analyses included:

- Inorganic parameters (metals, major ions, and general minerals)
- Volatile organic compounds
- Bacterial indicators (total and fecal coliform)
- Perchlorate
- Radionuclides

Non-routine analyses included:

- Triazine Pesticides
- Thirty-six wells were selected for triazine pesticides analysis based upon land-use coverage provided by the California Department of Pesticide Regulation.
- Hexavalent chromium (Thirteen wells were selected for hexavalent chromium analysis based upon previously collected data from nearby wells.)
- N-nitrosodimethylamine (NDMA)

In addition, samples were also analyzed for several isotopic parameters including hydrogen and oxygen isotopes in water, oxygen and nitrogen isotopes in nitrate, and boron isotopes by LLNL. Isotopic composition data provides useful information to help determine the source(s) of contamination. Isotopic results are summarized in Appendix A.

Analytical Results

If preliminary analytical test results indicated that coliform bacteria were present, or if nitrate was detected above the MCL, GAMA Program staff immediately informed the well owner. Following receipt of the laboratory analyses report, well owners were mailed a written summary of the test results for their well water. Additionally, well owners were provided with easy to understand literature about chemical constituents, associated health effects, potential contamination sources, and available treatment options for their well water (including a Spanish translation).

Detections Above a Drinking Water Standard

Division of Drinking Water water quality standards were used for comparison purposes only, since private domestic well water quality is not regulated by the state. Water quality standards include primary maximum contaminant levels (MCLs), secondary MCLs (SMCLs), and notification levels (NLs).

- MCL is the maximum level of a contaminant that may have an adverse effect on the health of persons (Title 17 CCR and 22 CCR, California Regulations Related to Drinking Water)
- SMCL applies to any contaminant in drinking water that may adversely affect aesthetic or technical qualities of water such as the odor, color, staining or scaling (Title 17 CCR and 22 CCR, California Regulations Related to Drinking Water)
- NL is a precautionary measure for a contaminant to be considered for an MCL but has not yet completed the regulatory standard setting process. A NL is not a drinking water standard (Title 17 CCR and 22 CCR, California Regulations Related to Drinking Water)
- AL is a legally enforceable standard designed to protect public health by limiting copper and lead in drinking water (Title 17 CCR and 22 CCR, California Regulations Related to Drinking Water)

A summary of analytical results is included in Table 2.

Table 2. Summary of detections above drinking water standards

Wells Above Water Quality Standard	Number of Wells Analyzed	Constituent	Range of Detections	MCL[2]	SMCL
11	79	Total Coliform	Present or Absent	Present	
1	79	Fecal Coliform	Present or Absent	Present	
9	79	Nitrate (as NO_3)	47.2 - 238 mg/L	45 mg/L	
5	79	Nitrite (as N)	1.08 - 2.1 mg/L	1 mg/L	
1	79	Sulfate	1090 mg/L		500 mg/L
2	79	Fluoride	2.3 - 4.8 mg/L	2 mg/L	
9	79	Perchlorate	6.24 - 45.5 µg/L	6 µg/L	
5	79	Specific Conductance	1740 - 3060 µmhos/cm		1600 µmhos/cm
4	79	pH	6.34 - 8.12		6.5 to 8.5
5	79	Total Dissolved Solids	1070 - 2360 mg/L		1000 mg/L
1	79	Aluminum	545 µg/L		200 µg/L
8	79	Arsenic	14.2 - 63.6 µg/L	10 µg/L	
3	79	Cadmium	7.2 - 31.4 µg/L	5 µg/L	
13	79	Manganese	50.1 - 268 µg/L		50 µg/L
6	79	Iron	377 - 2980 µg/L		300 µg/L
1	79	Lead	33.2 µg/L	15 µg/L[3]	
18	79	Thallium	2.1 - 9.3 µg/L	2 µg/L	
1	79	Uranium	21 pCi/L	20 pCi/L	
4	13	Hexavalent Chromium	11.0 - 18.4 µg/L	10 µg/L[4]	4

mg/L = milligrams per liter, µg/L = micrograms per liter, µmhos/cm = micromhos per centimeter, pCi/L = picocuries per liter

[2] Water quality standards are used for reference purposes only because domestic well water is not regulated.

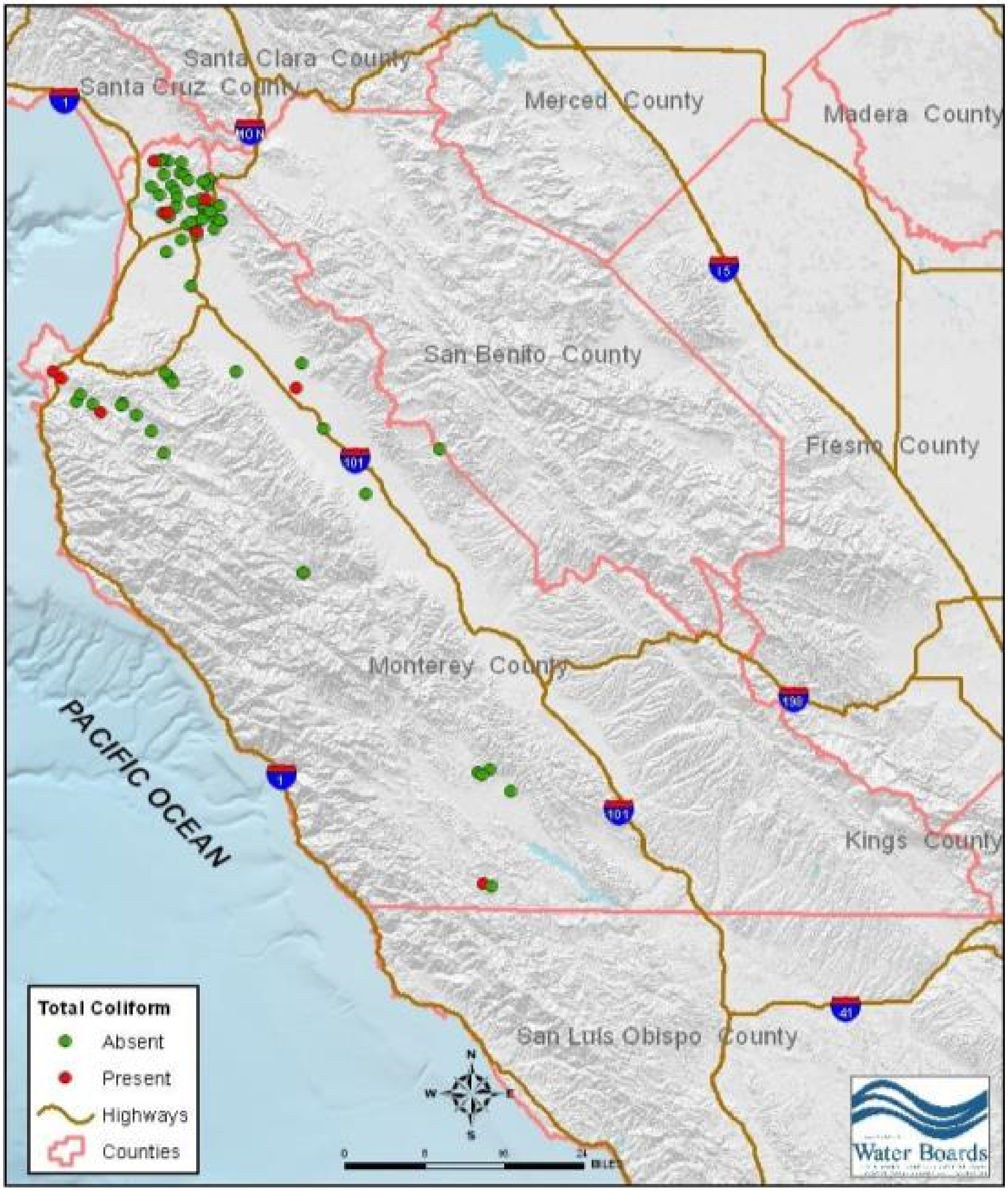
[3] US EPA Action Level

[4] Draft MCL at the time this report was published

Coliform Bacteria

Total coliform bacteria were present in 11 of 79 wells tested. Fecal coliform bacteria were present in 1 of 79 wells tested. Figure 3 shows the distribution of total coliform bacteria detected in sampled private domestic wells.

Figure 3. Total Coliform Analytical Results



General Minerals

General minerals detected in private domestic well samples are summarized in Table 3. General minerals listed in Table 3, except methylene blue active substances (MBAS, foaming agents in surfactants), naturally occur in groundwater. Leachate from septic systems, disposal of partially treated wastewater, and some agricultural activities can change the concentrations of these minerals in groundwater.

Many general mineral constituents do not have water quality standards; however, MBAS, total dissolved solids (TDS), and pH have established SMCLs. MBAS were detected in 26 wells at concentrations below the SMCL (0.5 milligrams per liter (mg/L)). TDS, an estimate of the concentration of all dissolved components in water, was above the SMCL (1,000 mg/L) in 5 wells. Specific Conductance (EC) values were reported above the SMCL (1,600 µmhos/cm) in 5 wells, pH was reported below 6.5, the U.S. Environmental Protection Agency (USEPA) SMCL in 4 wells.

Table 3. General mineral results.

Constituent	Range of Detections	Public Drinking Water Standard	Water Quality Standard Type (mg/L)	Number of Wells Above Standard	Number of Wells Tested
Total Alkalinity as CaCO3	16 – 490 mg/L	NA	NA	0	79
Calcium	2.39 – 409 mg/L	NA	NA	0	79
Magnesium	1.53 – 152 mg/L	NA	NA	0	79
Potassium	0.826 - 22.6 mg/L	NA	NA	0	79
Sodium	13.4 – 334 mg/L	NA	NA	0	79
MBAS	0.03 - 0.17 mg/L	0.5 mg/L	SMCL	0	79
Hardness (Total) as CaCO3	12 – 550 mg/L	N/A	NA	0	79
pH	6.34 - 8.12	6.5-8.5	SMCL	4	79
Total Dissolved Solids (TDS)	157 – 2360 mg/L	1,000 mg/L	SMCL	5	79
Specific Conductance (EC)	237 – 3060 µmhos/cm	1,600 µmhos/cm	SMCL	5	79

mg/L = milligrams per liter, N/A = No drinking water standards established for this constituent

Major Ions

Major ion detections are summarized on Table 4. Perchlorate, nitrate, nitrite, fluoride, and sulfate were detected above a drinking water standard. Reported results are as follows:

- Nitrate detections ranged from 0.16 to 238 mg/L. Nine wells were reported with concentrations above the MCL (45 mg/L as NO_3). Nitrate results are shown on Figure 4.
- Nitrite detections ranged from 0.12 to 2.1 mg/L. Five wells were reported with results above the MCL (1.0 mg/L as N).
- Fluoride was reported above the MCL of 2 mg/L in 2 wells
- Sulfate was reported above the SMCL of 500 mg/L in 1 well.
- Perchlorate was detected above the MCL of 6 micrograms per liter (µg/L) in 9 wells. Perchlorate results are shown on Figure 5.

Table 4. Major ions results.

Constituent	Range of Detected Values (mg/L)	Public Drinking Water Standard (mg/L)	Water Quality Standard Type	Number of Wells Above Standard	Number of Wells Tested
Boron	0.02-0.786	1	NL	0	79
Bromide	0.04-3.2	N/A	NA	0	79
Chloride	4.4-291	500	SMCL	0	79
Fluoride	0.1-4.8	2	MCL	2	79
Nitrate (as NO_3)	0.16-238	45	MCL	9	79
Nitrite (as N)	0.12-2.1	1	MCL	5	79
Perchlorate	0.0006-0.0455	0.006	MCL	9	79
Sulfate	2.4-1090	500	SMCL	1	79
Phosphorous	0.03-0.87	NA	NA	0	79

mg/L = milligrams per liter, N/A = No drinking water standards established for this constituent

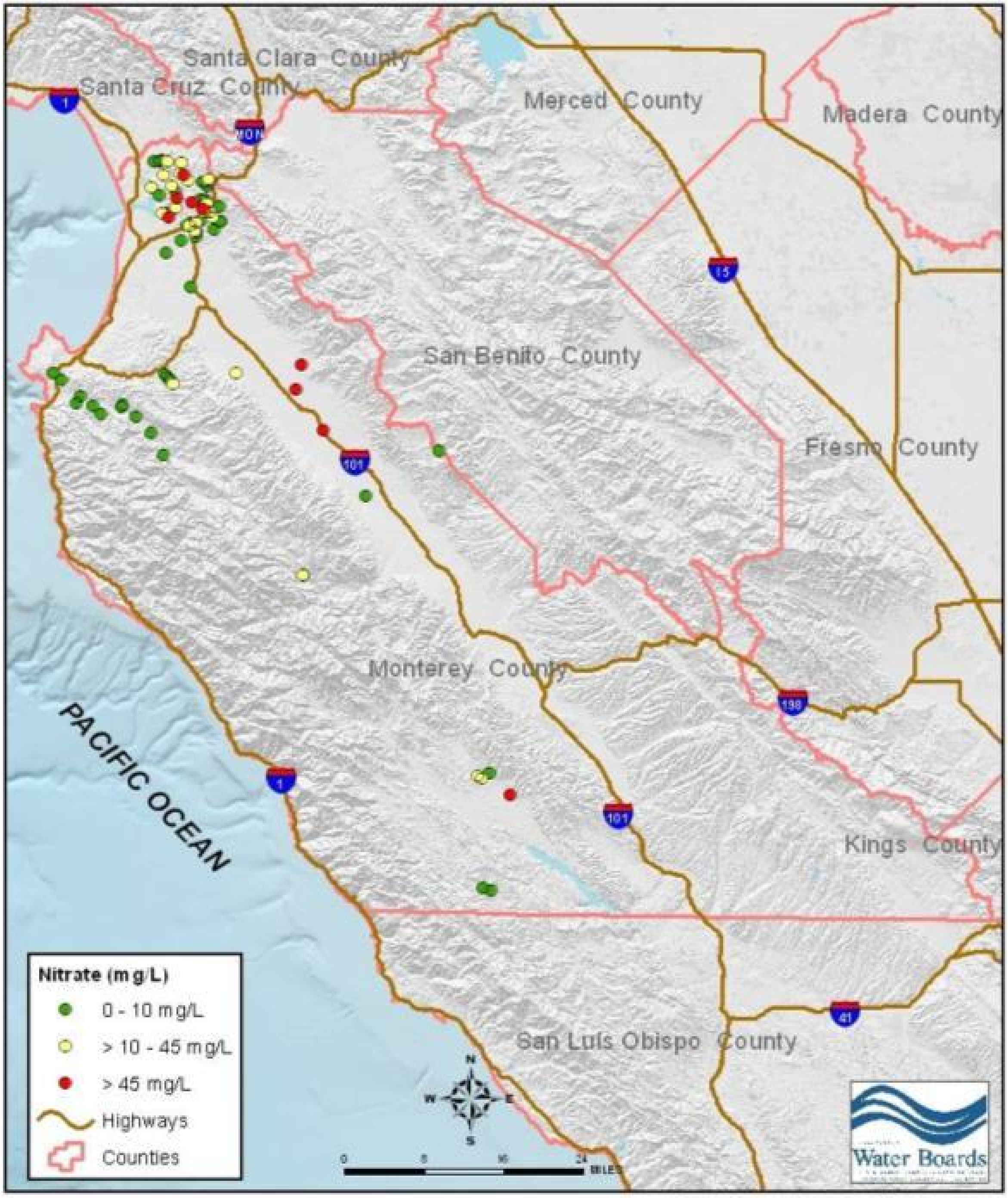


Figure 4. Nitrate Analytical Results

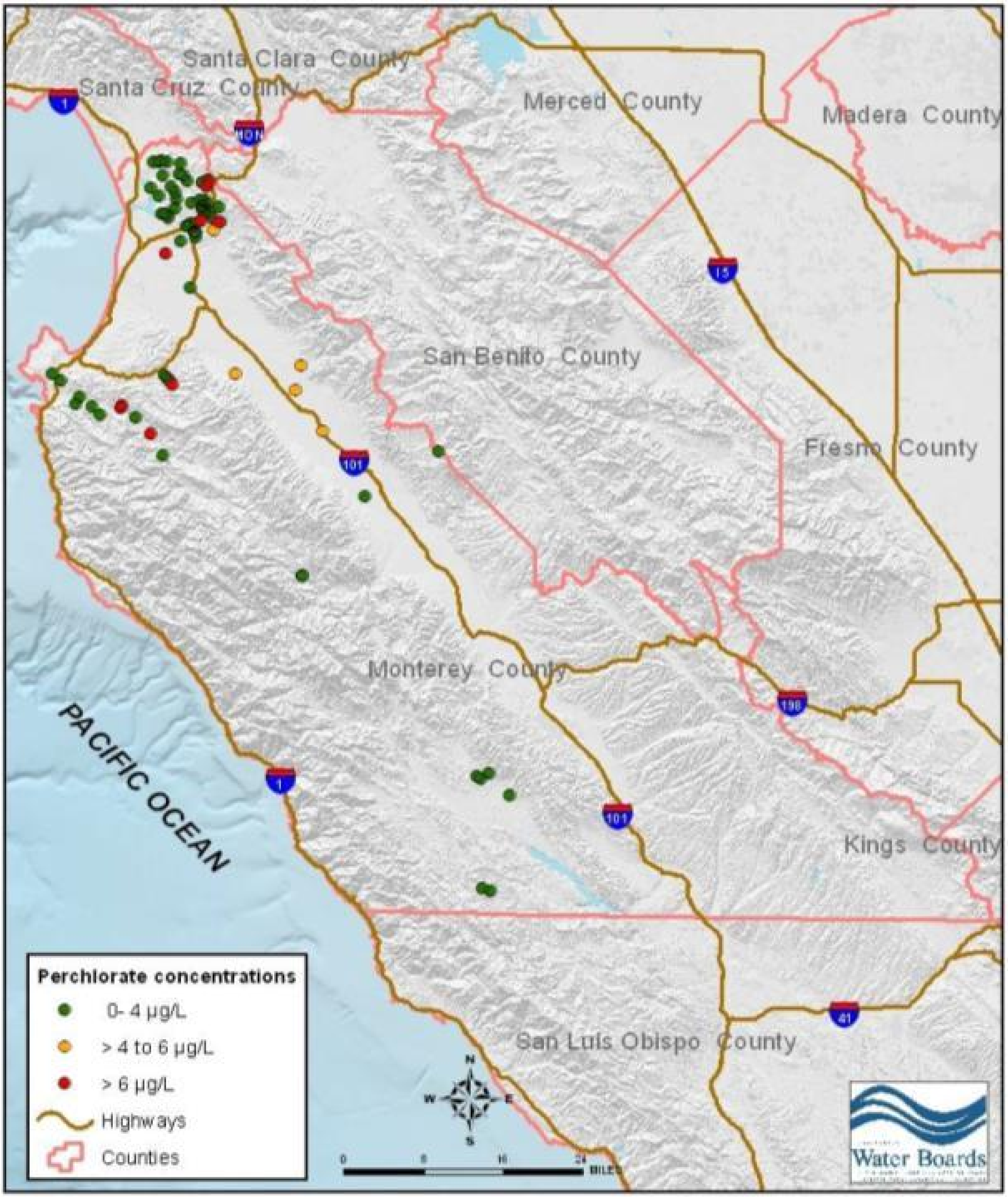


Figure 5. Perchlorate Analytical Results

Metals

Reported metals concentrations detected in private domestic wells are shown in Table 5. Aluminum, arsenic, cadmium, iron, lead, manganese, and thallium were reported at concentrations above their respective water quality standard. Hexavalent chromium was reported above the draft MCL in 4 of the 13 wells sampled for non-routine analyses. Results in this report for hexavalent chromium are compared to the draft MCL of 10 µg/L (as of 2011).

Reported results are summarized as follows:

- Aluminum was detected in 35 of 79 wells tested, at concentrations ranging from 19.6 to 545 µg/L. One well was reported with concentrations above the SMCL of 200 µg/L.
- Arsenic was detected in 33 of 79 wells tested, at concentrations ranging from 0.6 to 63.6 µg/L. Eight wells were reported with concentrations above the MCL of 10 µg/L. Arsenic concentrations are shown on Figure 6.
- Cadmium was detected in 16 of 79 wells tested, at concentrations ranging from 0.9 to 31.4 µg/L. Three wells were reported with detections above the MCL of 5 µg/L.
- Hexavalent chromium was detected above the draft MCL of 10 µg/L in 4 of the 13 wells tested.
- Iron was detected in 59 of the 79 wells tested, at concentrations ranging from 13.5 to 2980 µg/L. Reported detections were above the SMCL of 300 µg/L in 6 wells.
- Lead was detected in 16 of the 79 wells tested, at concentrations ranging from 1.3 to 33.2 µg/L. A detection above the USEPA Action Level (AL) of 15 µg/L was reported in one well.
- Manganese was detected in 51 of the 79 wells tested, at concentrations ranging from 1.3 to 268 µg/L. Thirteen wells were reported with detections above the SMCL of 50 µg/L. Manganese concentrations are shown on Figure 7.
- Thallium was detected in 38 of the 79 wells tested, at concentrations ranging from 0.9 to 9.3 µg/L. Eighteen wells were reported with detections above the MCL of 2 µg/L. Thallium concentrations are shown in Figure 8.

Table 5. Metals results.

Constituent	Range of Detected Values	Public Drinking Water Standard	Standard Type	Number of Wells Above Standard	Number of Wells Tested
Aluminum	19.6 - 545 µg/L	200 µg/L	SMCL	1	79
Antimony	4.3 µg/L	6 µg/L	MCL	0	79
Arsenic	0.6 - 63.6 µg/L	10 µg/L	MCL	8	79
Barium	4.1 - 379 mg/L	1,000 µg/L	MCL	0	79
Beryllium	0.6 - 2 µg/L	4 µg/L	MCL	0	79
Boron	20 - 786 mg/L	1,000 µg/L	NL	0	79
Cadmium	0.9 - 31.4 µg/L	5 µg/L	MCL	3	79
Chromium (Total)	0.5 - 47 µg/L	50 µg/L	MCL	0	79
Hexavalent Chromium	11.0 - 18.4 µg/L	10 µg/L[5]	MCL	4	79
Cobalt	0.2 - 4.4 µg/L	N/A	NA	0	79
Copper	1 - 199 mg/L	1,000 µg/L	SMCL	0	79
Iron	13 - 2980 µg/L	300 µg/L	SMCL	6	79
Lead	1.3 - 33.2 µg/L	15 µg/L	AL	1	79
Manganese	1.3 - 268 µg/L	50 µg/L	SMCL	13	79
Mercury	0.05 - 0.7 µg/L	2 µg/L	MCL	0	79
Molybdenum	0.5 - 125 µg/L	N/A	NA	0	79
Nickel	0.8 - 8.9 µg/L	100 µg/L	MCL	0	79
Selenium	3.1 - 38.1 µg/L	50 µg/L	MCL	0	79
Silver	0.5 - 0.9 µg/L	100 µg/L	SMCL	0	79
Thallium	0.9 - 9.3 µg/L	2 µg/L	MCL	18	79
Vanadium	0.1 - 35.6 µg/L	50 µg/L	NL	0	79
Zinc	2.3 - 2850 mg/L	5,000 µg/L	SMCL	0	79

µg/L = micrograms per liter, N/A = No drinking water standards established for this constituent

[5] Draft MCL at the time this report was published

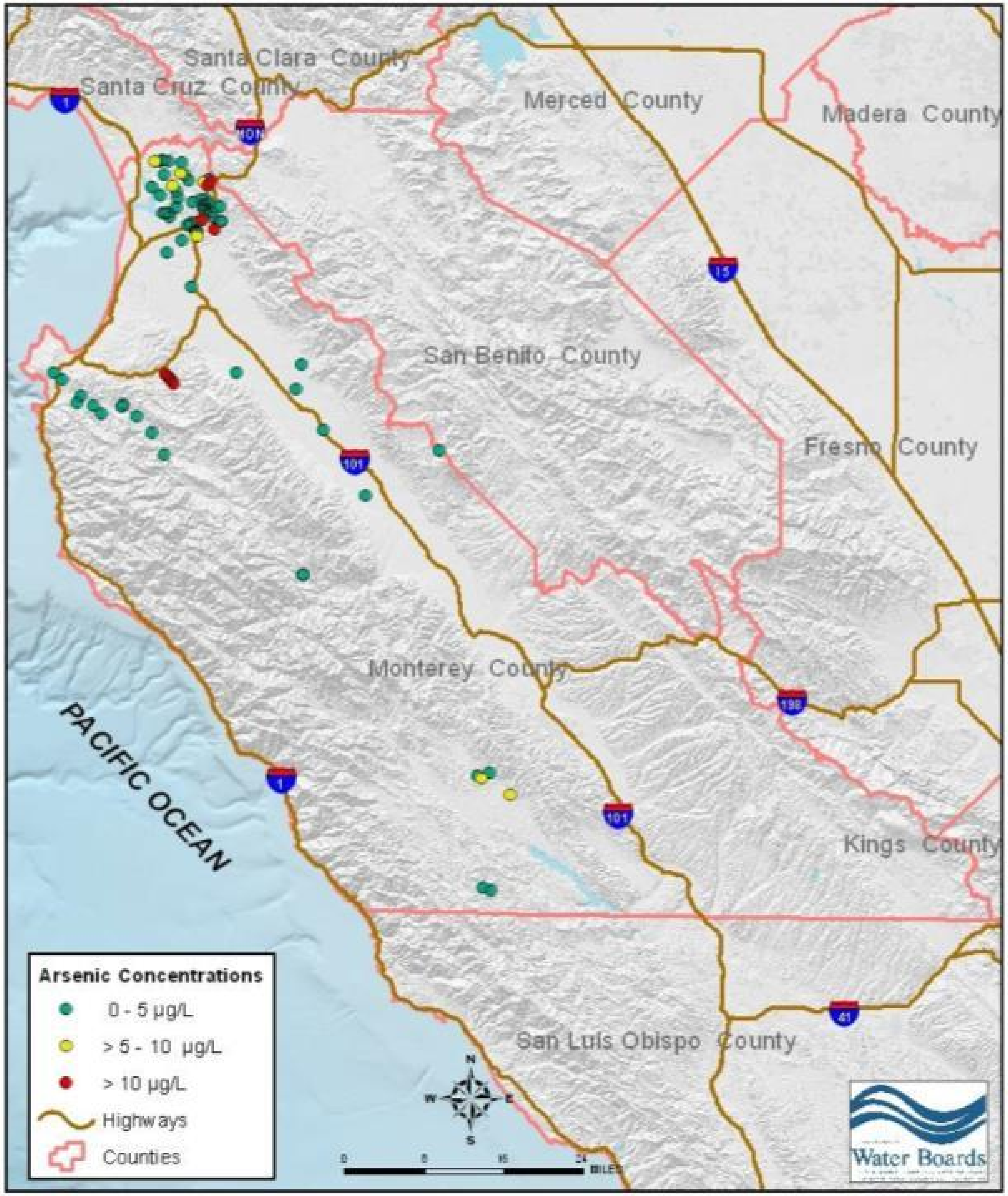


Figure 6. Arsenic Analytical Results

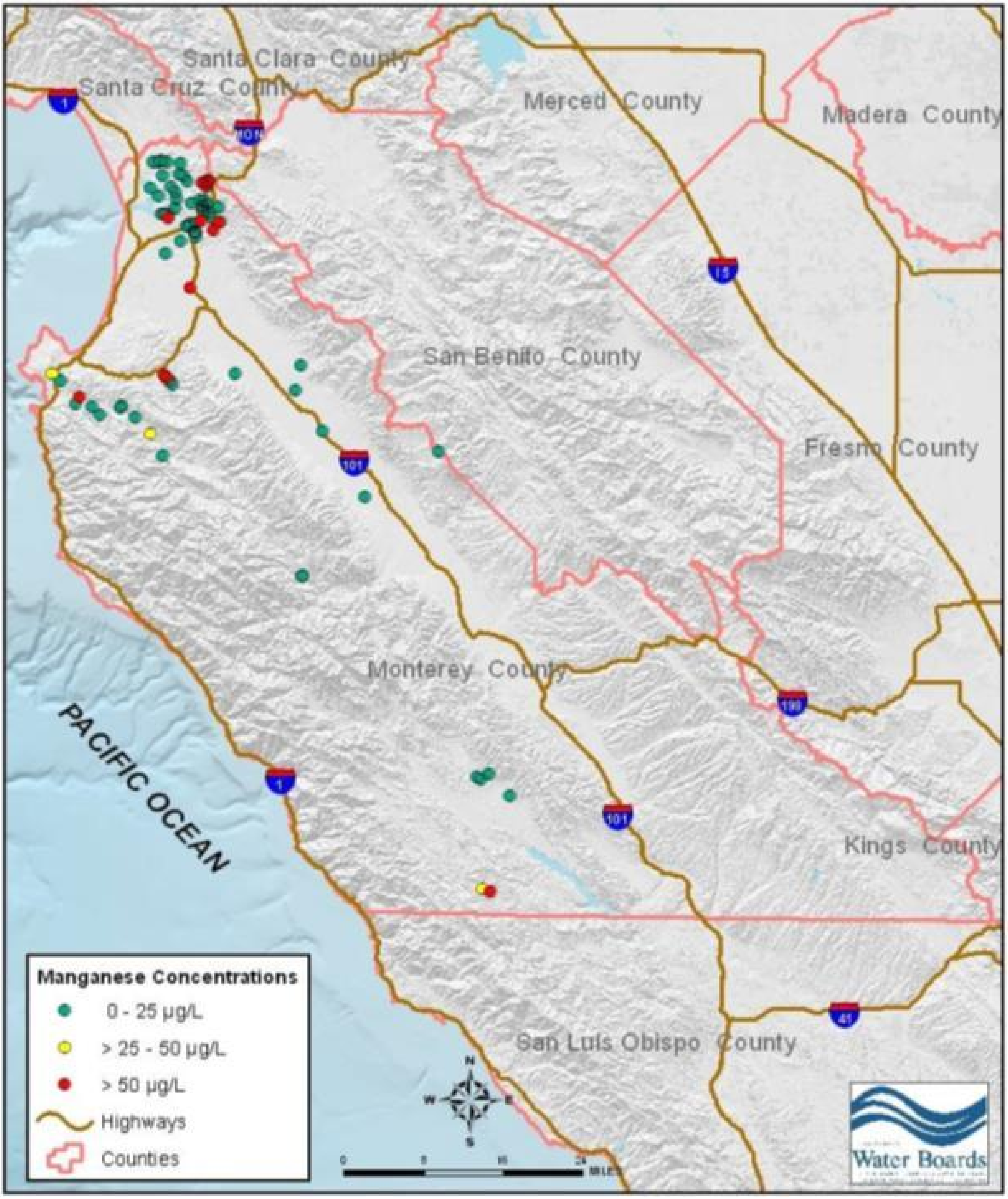


Figure 7. Manganese Analytical Results

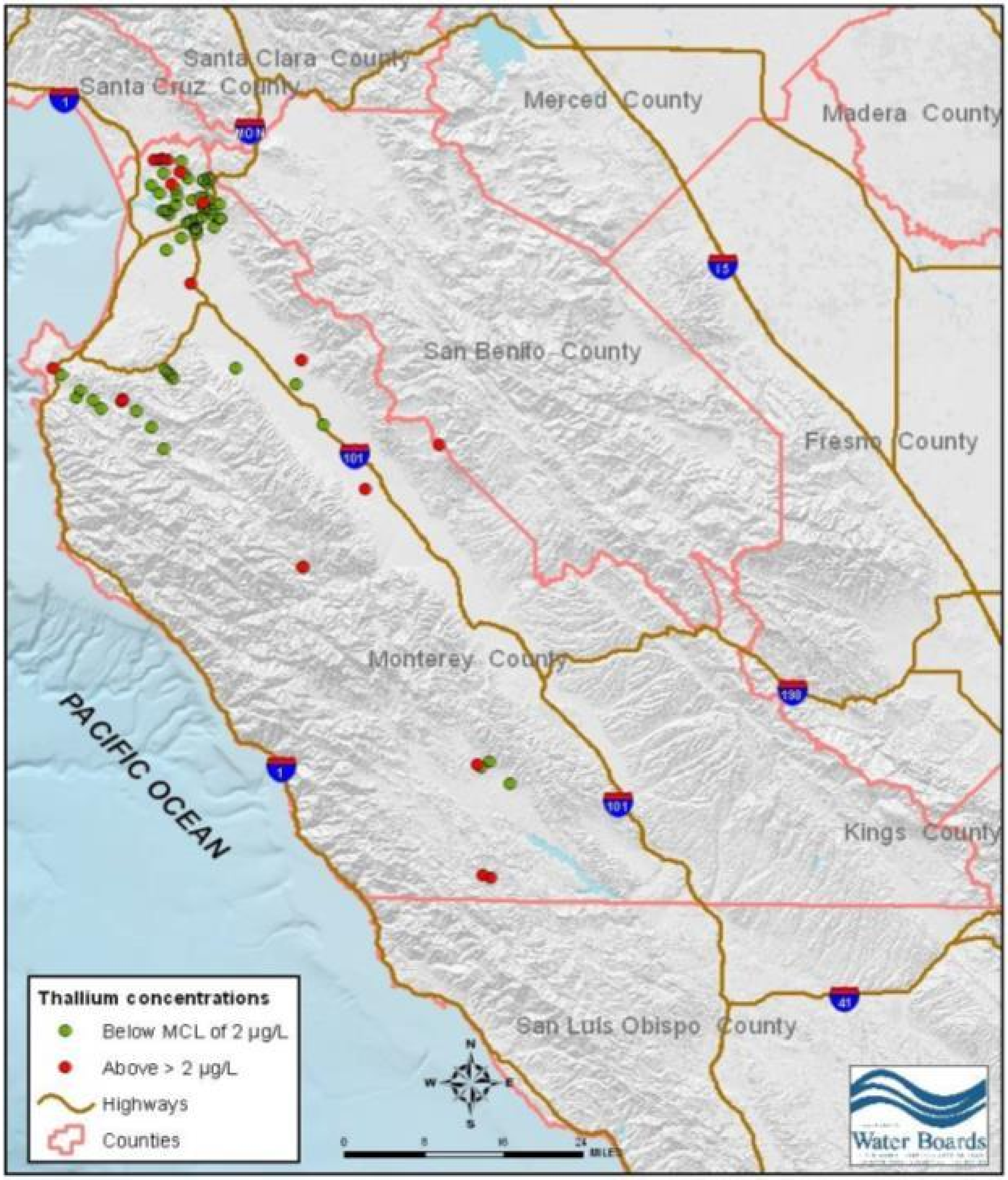


Figure 8. Thallium Analytical Results

Radionuclides

Radionuclide analyses included gross alpha particle activity, gross beta, combined radium (activity of radium-226 and radium-228), tritium, and uranium. Results summarized below and shown in Table 6. Uranium concentrations were reported above the public drinking water standard of 20 pCi/L in 1 well.

Table 6. Radionuclide results.

Constituent	Range of Detected Values (pCi/L)	Public Drinking Water Standard (pCi/L)	Water Quality Standard Type	Number of Wells Above Standard	Number of Wells Tested
Gross alpha	3.31 to 12.19	15	MCL	0	79
Gross beta	4.43 to 18.27	50	MCL	0	79
Radium 226+228	0.74 to 4.9	5	MCL	0	79
Tritium	ND	20,000	MCL	0	79
Uranium	5.7 to 21	20	MCL	1	79

pCi/L = picocuries per liter, ND= Not Detected

Pesticides and Pesticides Degradates

Thirty-six private domestic wells were analyzed for pesticides degradates, atrazine, cyanazine, hexazinone, metribuzin, prometon, prometryn, and simazine. No pesticides or pesticide degradates were detected in the private domestic wells tested.

Volatile Organic Compounds

Volatile organic compounds and gasoline oxygenates were not detected above an MCL in any of the sampled wells. The most frequently detected VOC (above a laboratory detection limit) was chloroform, followed by 1,1,-dichloroethane, tetrachloroethene (PCE), chloroethane, toluene, acetone, methyl tert-butyl ether (MTBE), trichlorofluoromethane (Freon 11), carbon disulfide, trichlorotrifluoroethane (CFC-113), and bromoform. Results are summarized in Table 7.

Table 7. Volatile organic compounds results.

Constituent	Range of Detected Values (µg/L)	Public Drinking Water Standard (µg/L)	Water Quality Standard Type	Number of Wells Above Standard	Number of Wells Above Standard
1,1-Dichloroethane	0.08-0.1	NA	N/A	0	79
Chloroform	0.1 - 1	80	MCL	0	79
Tetrachloroethene (PCE)	0.2	5	MCL	0	79
Chloroethane	0.1	NA	N/A	0	79
Toluene	0.2	150	MCL	0	79
Acetone	0.7 - 2.3	NA	N/A	0	79
MTBE	0.2	13	MCL	0	79
Carbon disulfide	0.1	160	NL	0	79
Trichlorofluoromethane (Freon 11)	0.9	150	MCL	0	79
Trichlorotrifluoroethane (CFC-113)	0.5	1,200	MCL	0	79
Bromoform	0.3	80	MCL	0	79

µg/L = microgram per liter, N/A = No drinking water standards established

Stable Isotopes

LLNL performed specialized stable isotope analyses on all 79 samples. The isotopic evidence is useful for identifying potential contaminant sources and transport of nitrate in groundwater. A summary of the results is included as Appendix A.

Potential Contamination Sources and Possible Health Effects

Sixteen chemical constituents were detected above water quality standards. Eight of the 16 occurred in over five percent of the tested wells. The focus of the GAMA Domestic Well Project is not to identify potential contaminating source(s). Informative fact sheets for specific chemical constituents, including their associated health effects are located on the GAMA Program website.

Additional information for private domestic well owners is available on the GAMA Well Owner Resources website.

References

The California Department of Public Health Division of Drinking Water moved to the California State Water Resources Control Board on July 1, 2014. Since this paper was published before this transfer, and hence all Division of Drinking Water websites are therefore no longer valid, the references were updated to the paper's update date. All websites that were valid on original publish date are retained if possible.

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Appendix A – LLNL Isotopic Analysis Summary

The following summary was provided by LLNL. A detailed investigative report will be published at a future date.

Stable Isotopes of Hydrogen/Oxygen in Water

All 79 private domestic wells sampled in this focus area were analyzed for water isotopic composition. Figure A1 displays the location of sampled wells and the isotopic composition of oxygen (as $\delta^{18}O$ - H_2O) in water collected from these wells.

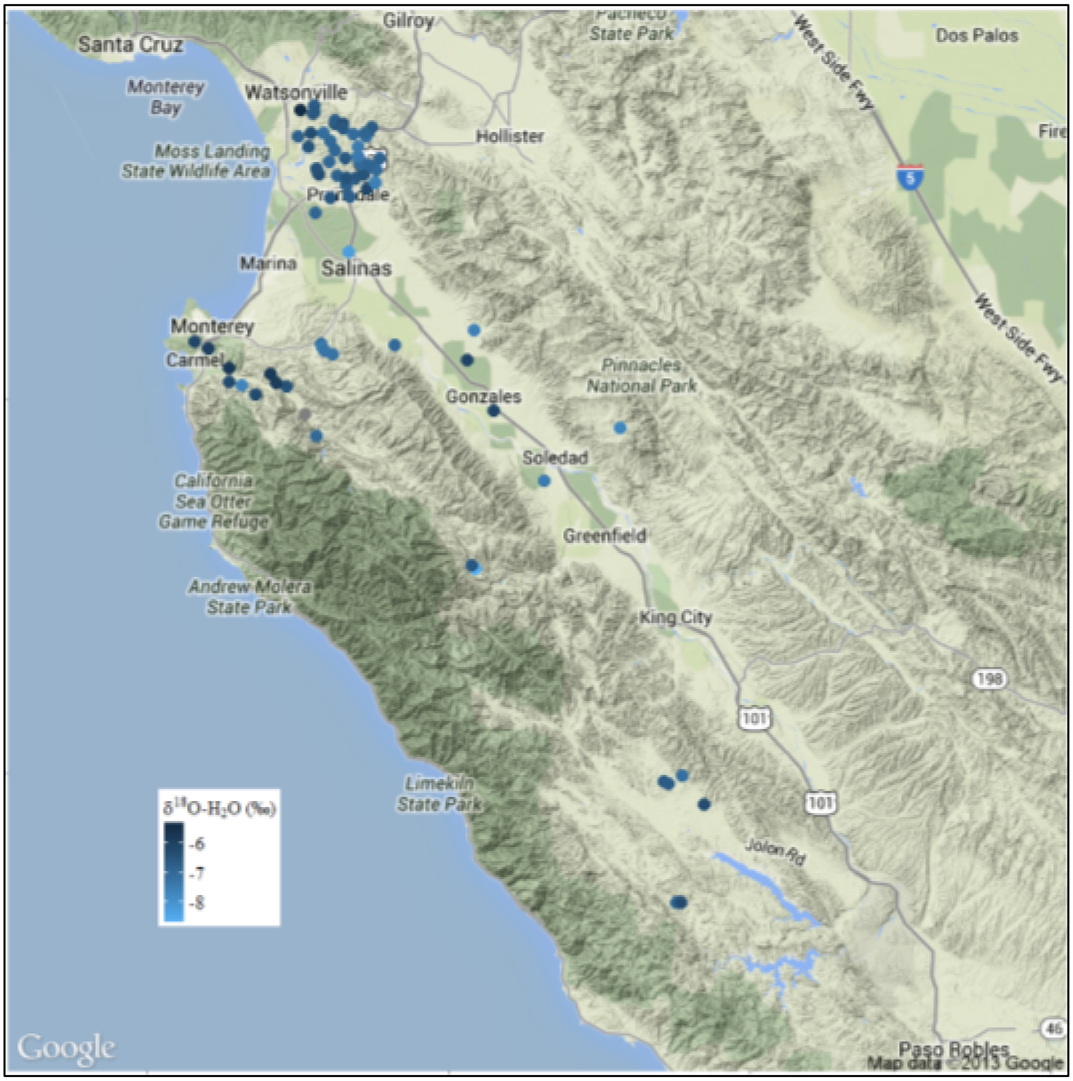

Figure A1. Isotopic composition of oxygen (as δ18O - H2O) of sampled wells in Monterey County

The isotopic composition of oxygen and hydrogen in private domestic well water in Monterey County, shaded to reflect groundwater basins, is plotted as δD-H2O versus δ18O-H2O in Figure A2. Also shown is the Global Mean Water Line (GMWL; Craig, 1961), a linear relationship between the stable isotopic composition of oxygen (δ18O) and of deuterium (δD) observed in precipitation on a global scale. In California, where strong gradients exist in water isotopic composition (from north to south and from the mountains to the coast) and where water isotopic composition is further affected by irrigation under semi-arid conditions, water isotopic composition is helpful in to determining the source of water before and after recharge.

On this plot, samples fall on or below the GMWL. The groundwater samples falling on or close to the GMWL have isotopic compositions consistent with recharge from local precipitation. A subset of samples falls below the GMWL and appear to define a shallower trend with considerable scatter. These samples are consistent with evaporation prior to recharge, perhaps associated with irrigation.

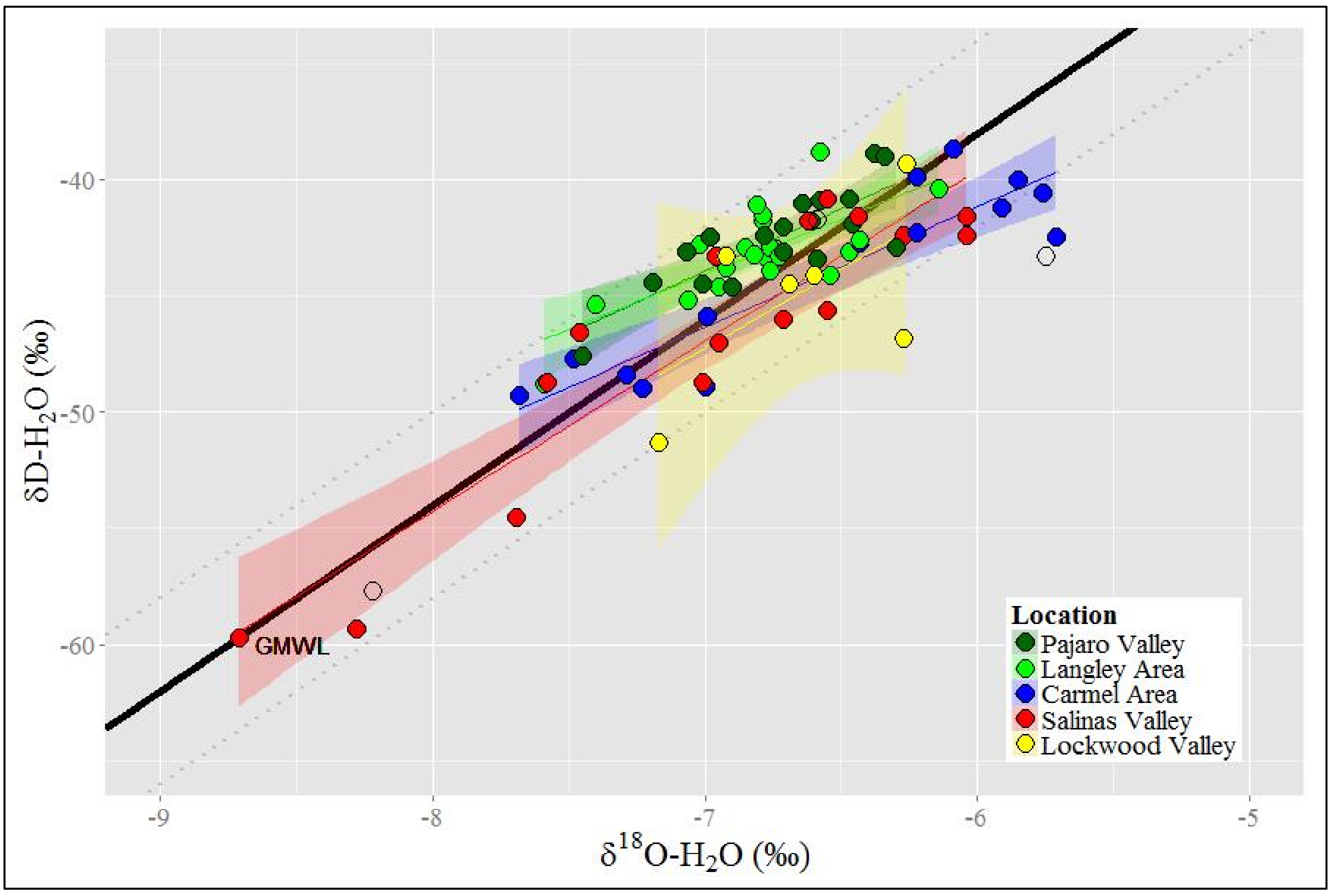

Figure A2. Water isotopic composition (δD, δ18O) of sampled wells in Monterey County. Groundwater basins are indicated by the shaded color area.

Stable Isotopes of Nitrogen and Oxygen in Nitrate

A variety of nitrate fractionation processes lead to distinctive isotopic signatures for different nitrate sources. As a result, isotope values of nitrogen and oxygen can be useful in identifying the origin of groundwater nitrate (Kendall, 1998 and Xue et al., 2009).

The isotopic composition of dissolved nitrate was measured in 37 samples for this study and covers the range δ15N = -3.6 to 17.0 and δ18O = -5.0 to 16.8 (Figure A3). Most of these samples (25 out of 37) have dissolved nitrate isotopic compositions consistent with soil nitrogen (δ15N = 3 to 8 per mille (‰), δ18O = -2 to 5‰) and have concentrations below the MCL (<45 mg/L as NO3). One sample is depleted in both δ15N (-3.6‰) and δ18O (-2‰), a composition consistent with nitrate derived from nitrification of ammonia fertilizer. Several samples (11 of 37) have enriched δ15N signatures, indicating either input from septic wastewater or animal manure sources and/or isotopic fractionation of NO3 nitrogen due to denitrification. Samples with the most enriched δ15N signature (>12‰) have low nitrate concentrations (<10 mg/ L as NO3), and for at least three of these samples, the isotopic evidence from both nitrate and water analyses suggests that denitrification is occurring. The isotopic range for wastewater and animal manure overlaps that of natural soil nitrogen, and the samples with high nitrate concentrations in this overlapping range are more likely to have an anthropogenic source.

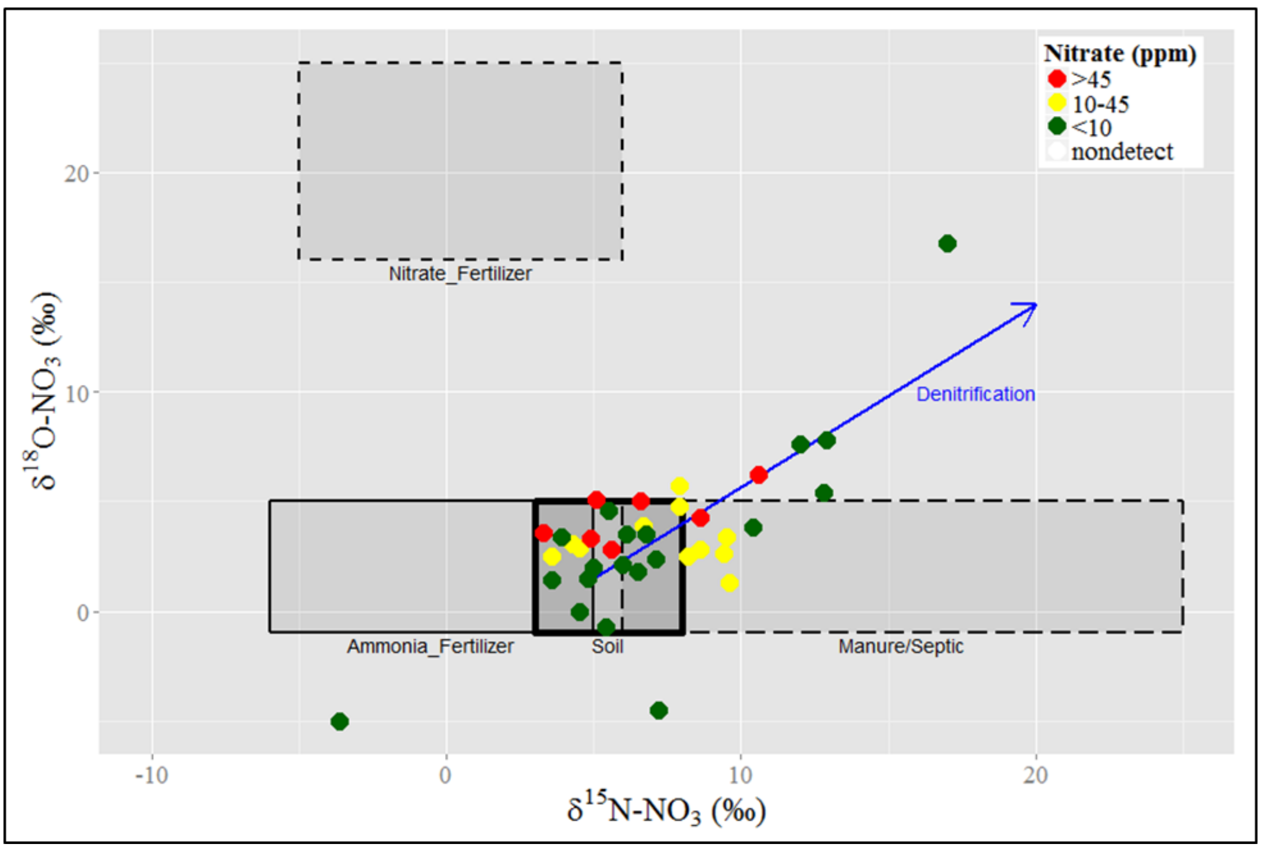

Figure A3. Nitrate isotopic composition (δ18O, δ15N) of sampled wells in Monterey County. Gray boxes represent fields of isotopic composition from Kendall (1998) and Xue et al (2009).

Nitrate and water isotopic composition also provide evidence for denitrification. In general, the isotopic composition of oxygen (δ18O-NO3) in nitrate that is produced by nitrification of ammonium is correlated with the oxygen isotope composition of oxygen (δ18O-H2O) in local water, This correlation is due to incorporation of local water and atmospheric oxygen during the production of nitrate from ammonium. Oxygen isotopic compositions in nitrate and water for Monterey County private domestic wells are shown in Figure A4, which also shows the predicted correlation between nitrate and water δ18O predicted for nitrate produced by nitrification of ammonium in water collected in the same well. The range reflects uncertainty in local pore water δ18O values in the unsaturated zone where nitrification is most likely to occur. Most samples have nitrate and water δ18O values that are consistent with nitrification of ammonium in the presence of local water. Three low-nitrate, enriched δ15N samples fall significantly above the line, a pattern consistent with denitrification.

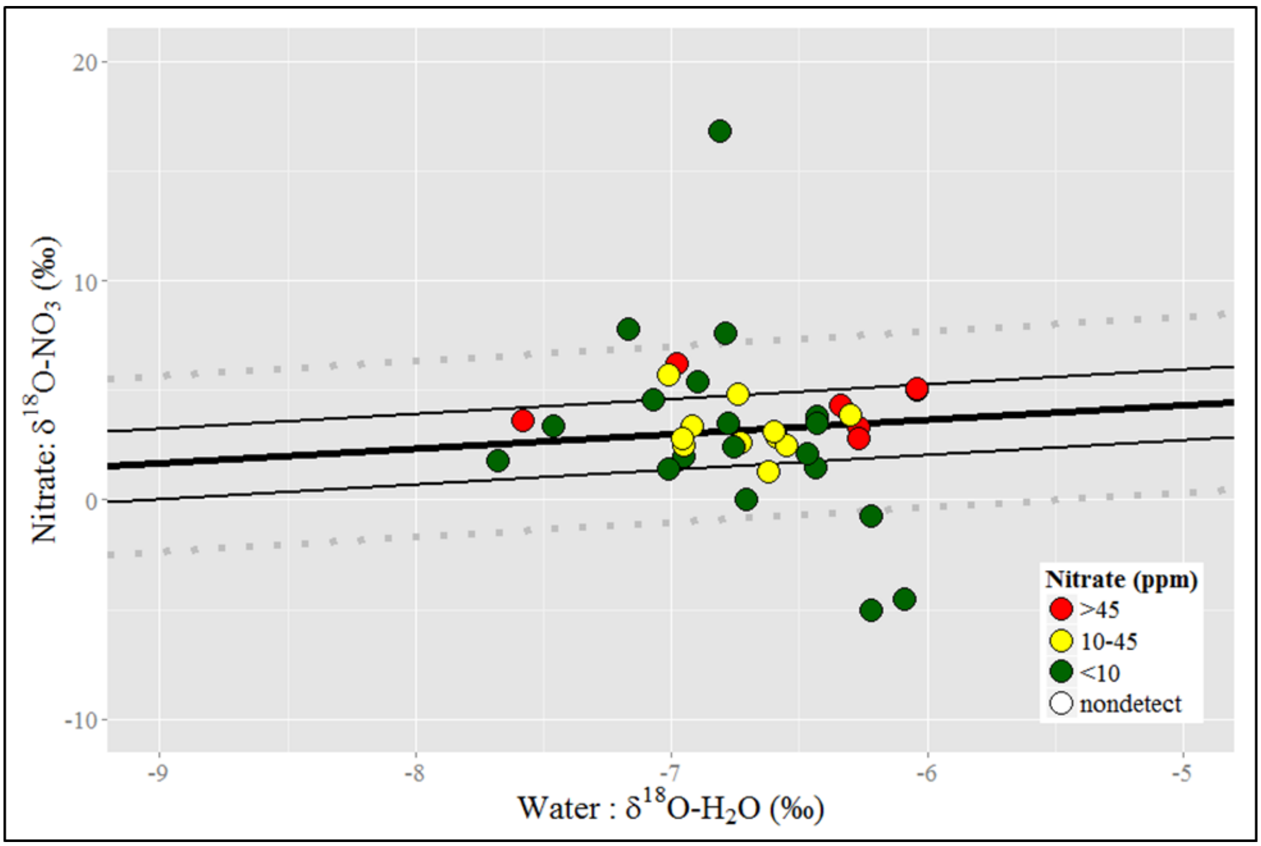

Figure A4. Isotopic composition of oxygen in nitrate and water in the wells sampled in Monterey County. The predicted relation between δ18O in nitrate produced by nitrification and water is shown as a solid lined with additional lines at ±1.6 and 4.0‰ to account for a range of δ18O values that may occur in unsaturated zone pore waters where nitrification is likely to occur.

Stable Isotopes of Boron

Boron is a ubiquitous dissolved chemical element in natural waters due to its high solubility, natural occurrence in continental crust, and anthropogenic use in fertilizers, consumer products, and other non-natural sources. The two stable isotopes of boron, 10B and 11B (natural abundances ≈ 19.9 and ≈ 80.1 atom percent, respectively), undergo isotopic fractionation due to a variety of chemical processes related to boron speciation. The isotopic composition of dissolved boron in groundwater is helpful in determining the source(s) of boron, which in turn can be used to infer the source(s) of other co-migrating contaminants such as nitrate.

Groundwater samples from 76 private domestic wells (out of the 79 in this project) were analyzed for boron isotopic composition ($\delta^{11}B$) (Figure A5). Boron concentrations are not available for all samples because the amount of boron required for isotopic analysis is less than the detection limit for boron by ion chromatography (20 to 50 µg/L).

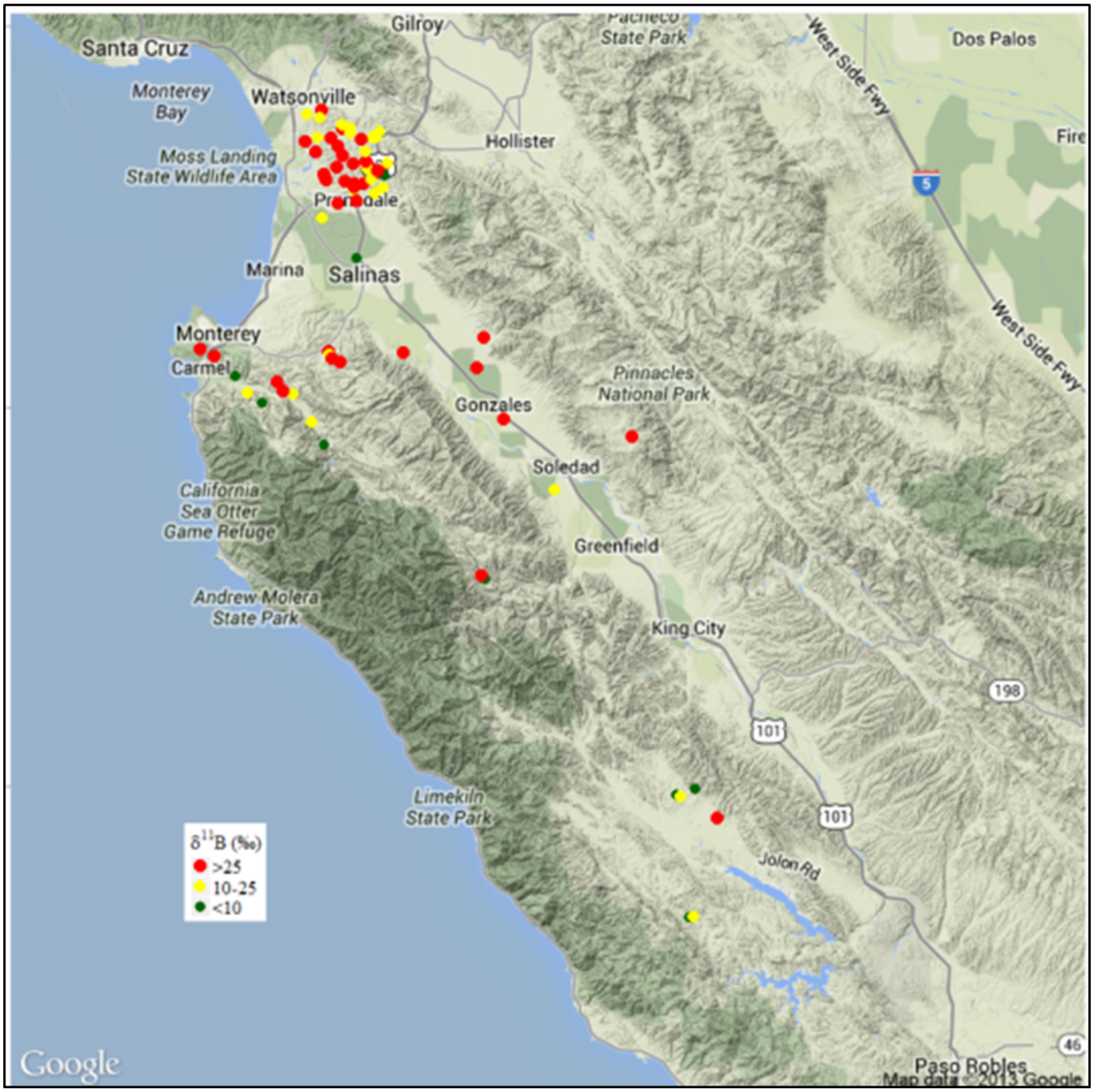

Figure A5. Locations and boron isotopic composition of 76 of the 79 sampled wells in Monterey County.

Measurements of $\delta^{11}B$ vary from -2.46 to +37.23 ‰, with one outlier (MON 153) at -25.11 ‰ (Figure A5). Well samples with low or non-detectable boron are within the range of boron concentrations observed in ambient groundwaters (5-10 µg/L) and have a wide range in boron isotopic composition (Figure A9). This range in boron isotopic composition may reflect mixing between different natural sources, e.g. between atmospheric precipitation (with $\delta^{11}B$ between +30 and +40‰) and groundwater influenced by water-rock interaction (with $\delta^{11}B$ between 0 and +10 ‰).

Well samples with higher concentrations of boron show two distinct trends in boron isotopic composition (Figure A6). Well samples following the lower trend have nitrate concentrations below the 45 mg/L (NO_3 MCL), and an inverse correlation between boron isotopic composition and boron concentration (i.e., decreasing $\delta^{11}B$ with increasing concentration). Well samples following the upper trend have high nitrate concentrations and enriched boron isotopic composition ($\delta^{11}B$ close to 30 ‰) that does not vary with boron concentration. These patterns are useful in source attribution and are discussed in the following section.

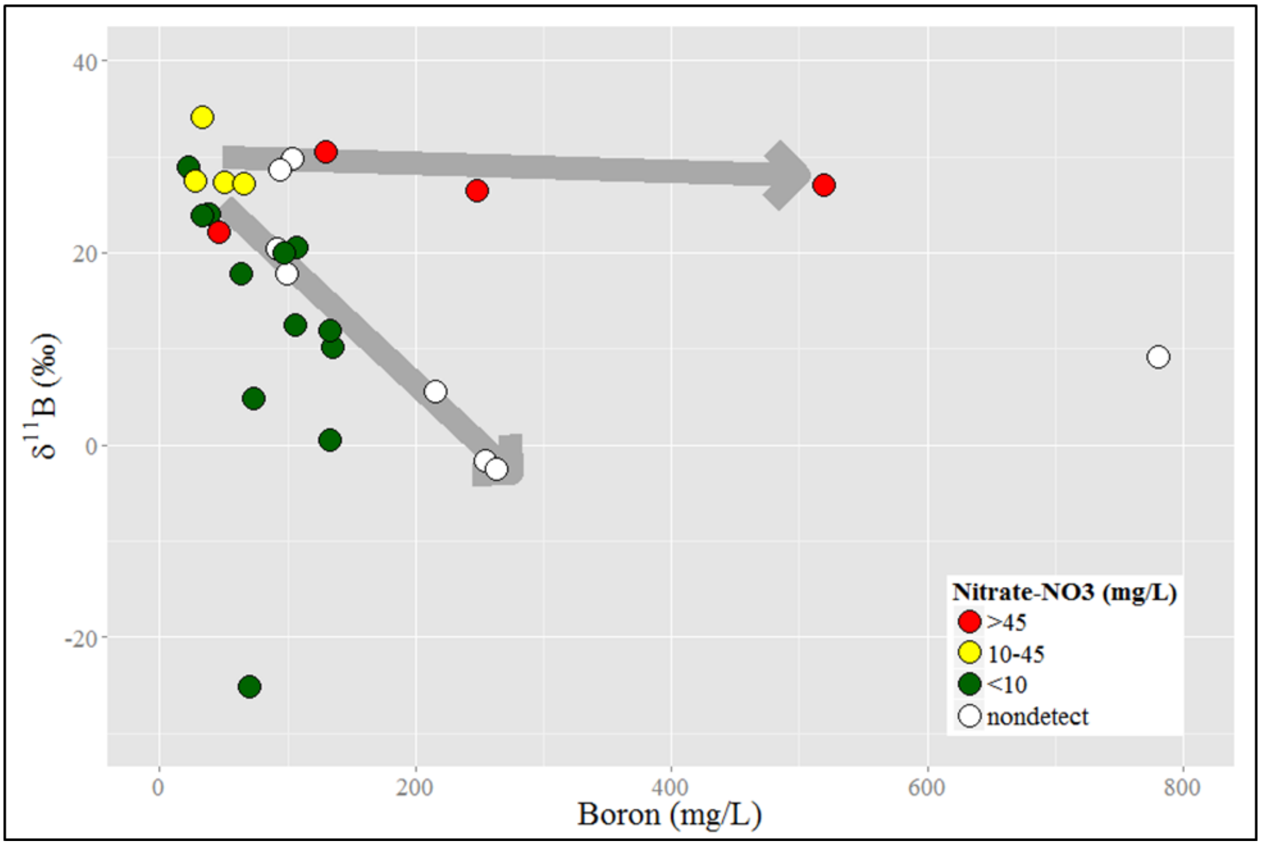

Figure A6. Boron concentration and isotopic composition results of sampled wells in Monterey County. Only samples in which boron was detected are shown

Boron isotopic composition as a nitrate source indicator

If the only sources of boron to shallow Monterey County groundwaters were contaminant sources high in nitrate, then a clear correlation between boron and nitrate would be observed. In this study, however, well samples with low nitrate (<45 mg/Las NO_3) have a range of boron concentration that does not correlate with nitrate concentration (Figure A7), strongly suggesting that natural sources of boron also contribute significantly to the boron content in Monterey County aquifers. Samples with high nitrate (> 45 mg/Las NO_3), however, do show a correlation between nitrate and boron concentration (Figure A7), suggesting that boron may be useful in nitrate source attribution for these samples.

The isotopic composition of boron and nitrate (Figure A8) are consistent with the interpretation that high nitrate wells are impacted by anthropogenic sources for both boron and nitrate (Figure A8a), and that low nitrate wells are significantly impacted by natural sources of both boron and nitrate (Figure A8b).

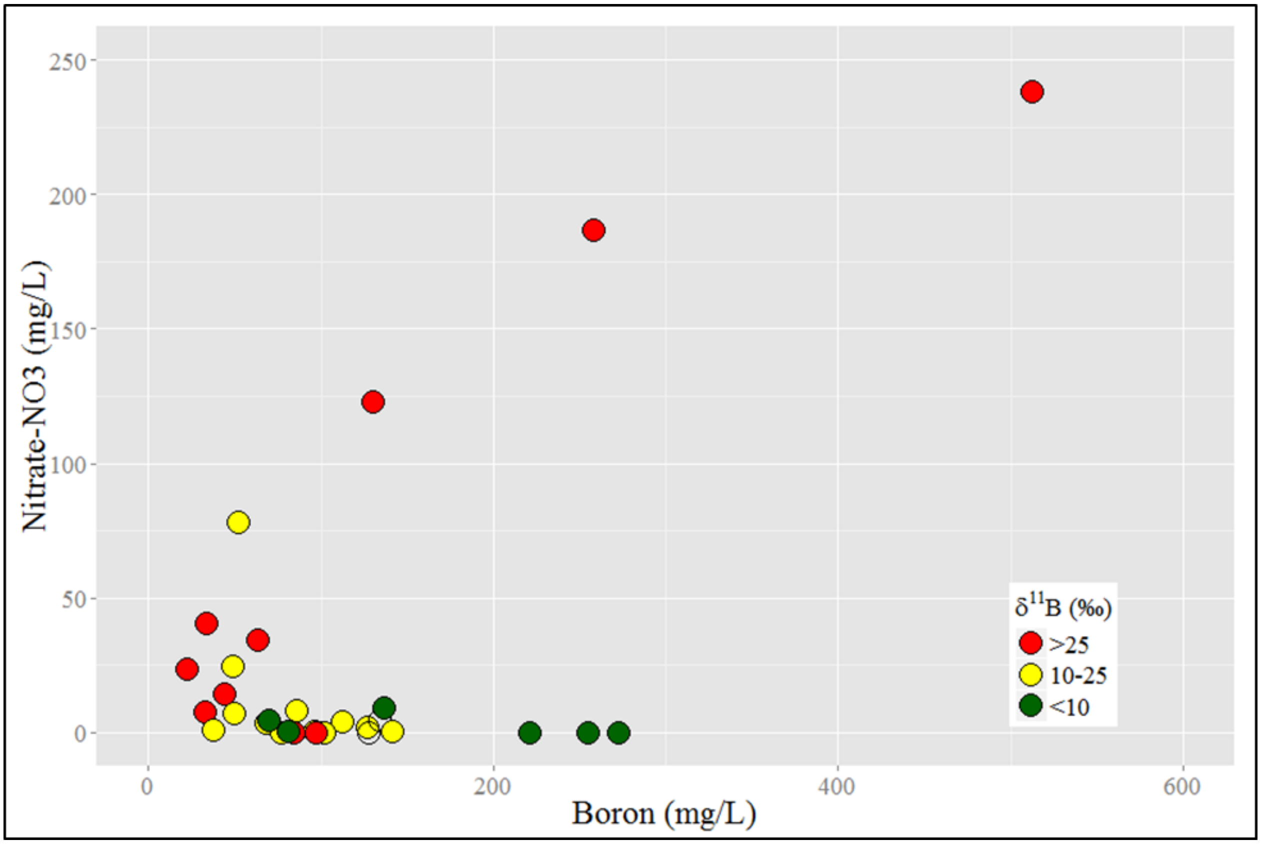

Figure A7. Boron and nitrate results of sampled wells in Monterey County. Only samples in which both boron and nitrate were detected are shown.

Low-nitrate groundwater samples: Water-rock interaction in the form of bedrock weathering and soil development contributes significantly to the boron content of groundwater. The boron isotopic composition of crustal rock is highly variable and is dependent on rock type (Palmer and Swihart, 1996; and references therein). Crystalline bedrock and most sedimentary rock types, however, have significantly lower δ11B values than the calculated boron isotopic compositions (+28 to +36 ‰) for precipitation in Monterey County. Mixing between low-boron isotopically enriched precipitation and high-boron isotopically-depleted groundwater (which has been affected by water-rock interactions) is consistent with the patterns observed in low-nitrate private domestic wells in Monterey County (Figure A6 and Figure A8b). The isotopic composition of nitrate in these low-nitrate waters is also consistent with natural sources and falls in a soil source field, with the exception of a few high NO3 - δ15N samples that have isotopic compositions (including their relationship to local water isotopic composition) that is consistent with denitrification (Figures A3, A4, and A8b).

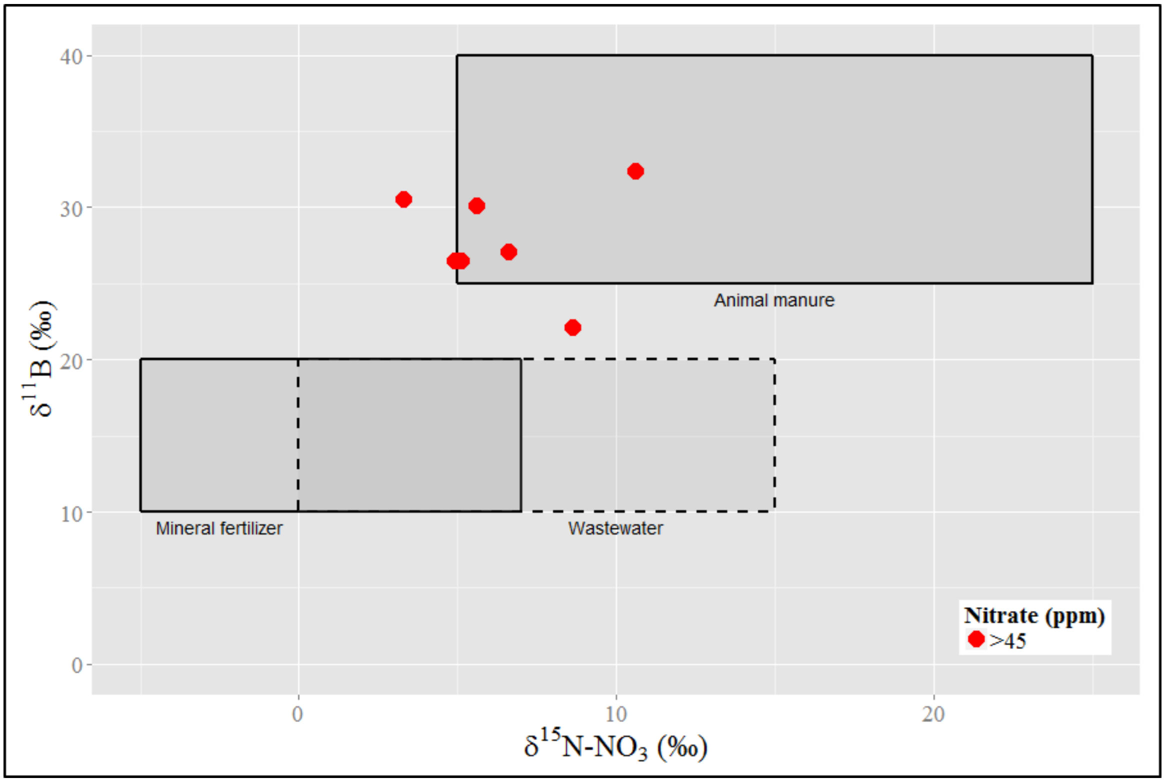

Figure A8a. Boron and nitrate isotopic compositions of sampled wells in Monterey County. The upper panel shows high-nitrate samples and anthropogenic source fields.

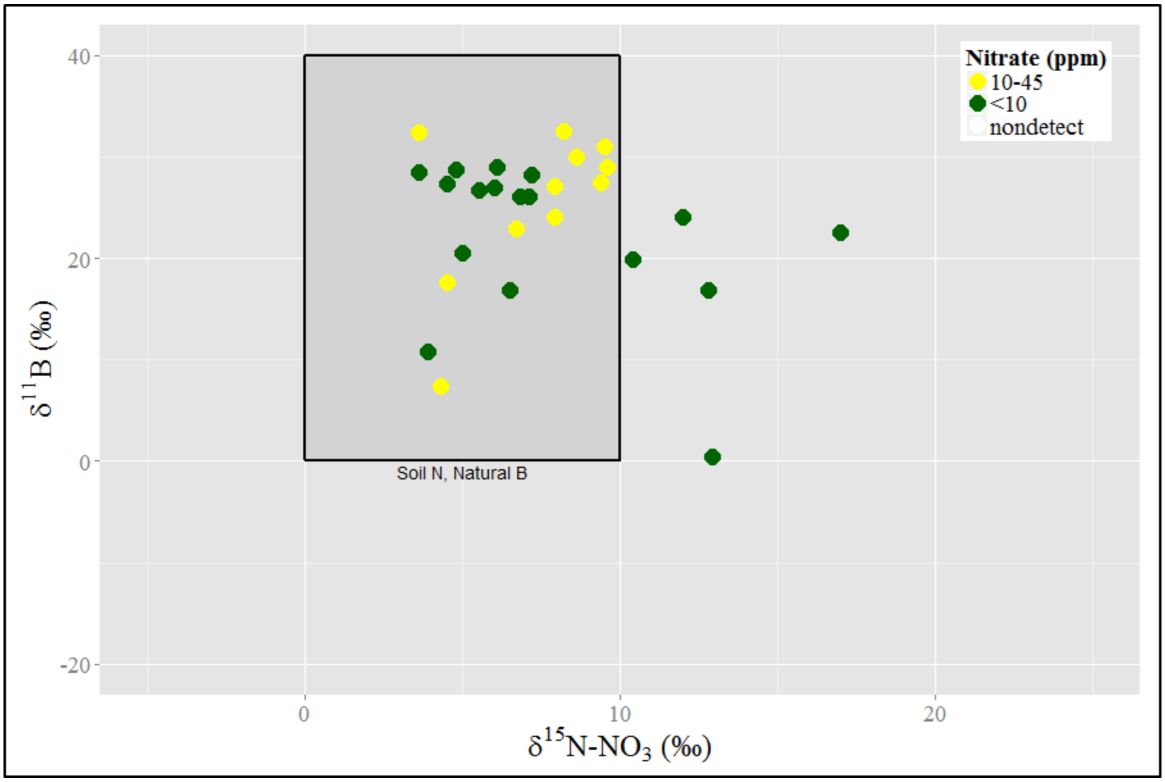

Figure A9b. Boron and nitrate isotopic compositions of sampled wells in Monterey County. The lower panel shows low-nitrate samples and natural source fields.

High-nitrate samples

The three samples with the highest nitrate concentrations (>100 mg/L as NO_3) are all located in the Gonzales region of the Salinas River Valley and have high boron concentrations (Figure A7). These samples have boron isotopic compositions that fall within an enriched and restricted $\delta^{11}B$ range of +26.54 to +30.51‰ (Figure A9) and have nitrate isotopic compositions that are enriched in ^{15}N (Figure A8a). Both animal manure and septic system discharge have similarly enriched similar $\delta^{15}N$ values, and so nitrate isotopic composition alone is not useful in differentiating between human waste and other animal wastes. The isotopic composition of boron in residential wastewaters, however, is generally depleted (-5 to +5‰) and is not consistent with the compositions observed in high nitrate groundwaters in Monterey County. The high nitrate and boron concentrations along with the enriched nitrate and boron isotopic compositions in these waters strongly suggest that animal manure is a significant source of nitrate to these wells. The association of an enriched boron isotopic composition wit high nitrate concentration is not restricted to the highest nitrate groundwaters, but also applies to waters with nitrate above 45 mg/L as NO_3 and to a lesser extent to waters with nitrate concentration above 10 mg/L as NO_3 (Figure A9).

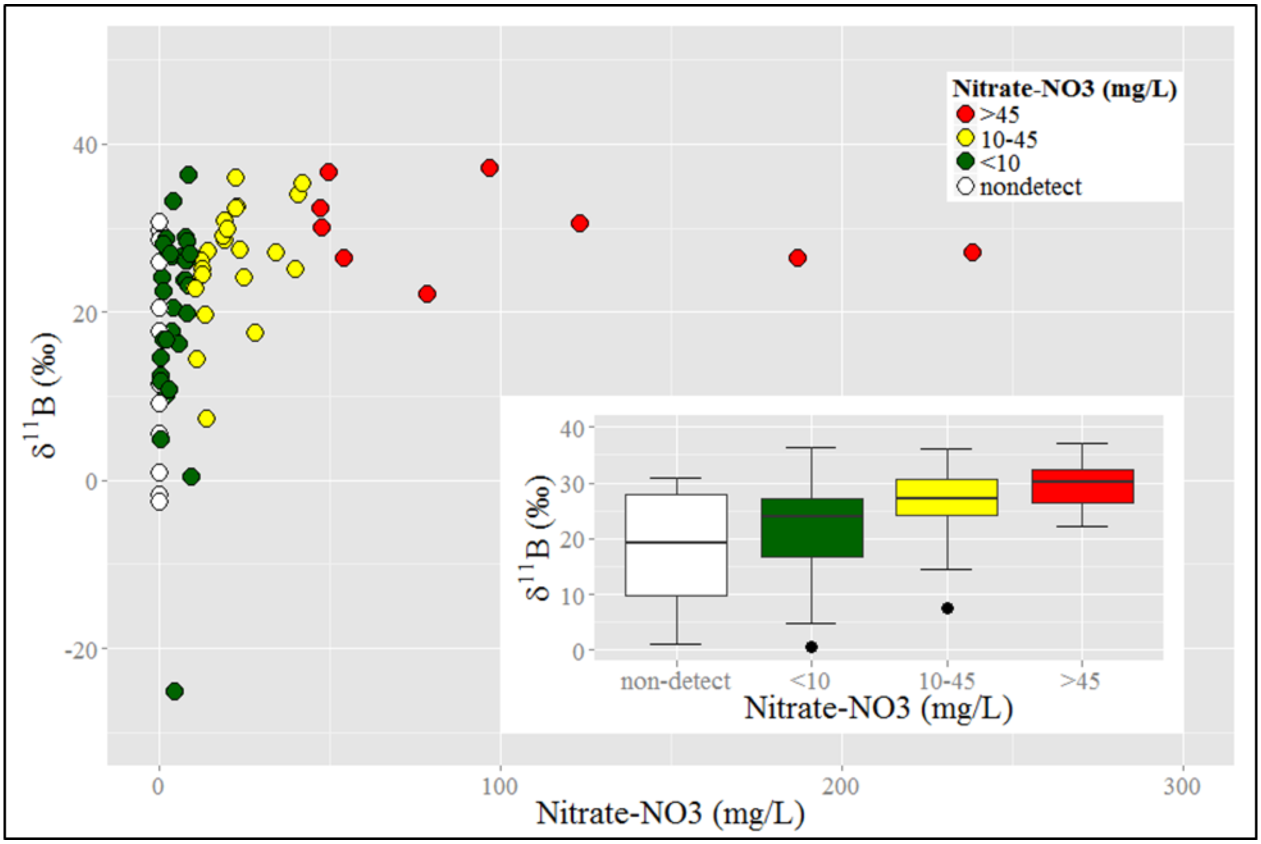

Figure A10. Boron isotopic composition vs. nitrate concentration of sampled wells in Monterey County.

Preliminary Conclusions of Measured Stable Isotopic Compositions

The Monterey County groundwater aquifers accessed by the wells sampled in this study are characterized by generally low nitrate concentrations (<45 mg/L as NO_3) and low boron concentrations (<200 µg/L). Nine of the 79 wells have nitrate concentrations higher than the MCL of 45 mg/L as NO_3. The nitrate isotopic compositions ($\delta^{15}N$, $\delta^{18}O$) of the high-nitrate samples (>10 mg/L) fall within the overlapping range of soil nitrogen, animal manure, and wastewater. Therefore, the source(s) of nitrate in these samples cannot be distinguished by nitrate isotopic composition alone. The high-nitrate samples, however, are also characterized by higher boron concentrations and $\delta^{11}B$ values varying from +22 to +31 ‰, possibly revealing a significant contribution of animal manure nitrate and boron, particularly to the groundwater in the Gonzales region the Salinas River valley.

Extrapolations to groundwater quality countywide cannot be made since the distribution and number of private domestic wells sampled was limited, a direct reflection of voluntary participation of well owners. Regional extrapolations of nitrate-contaminated groundwater in the Gonzales area can be made, though, as likely due to animal manure applications on agricultural lands. Ultimately, a more comprehensive study is necessary to better define groundwater quality in the area.

Table A1. Stable isotope results.

Sample ID	NO3 (mg/L)	B (µg/L)	δD-H2O (‰)	δ18O-H2O (‰)	δ15N-NO3 (‰)	δ18O-NO3 (‰)	δ11B (‰)
MON100	3.89	110	-47	-7.0	5.0	2.0	20.57
MON101	24.5	45	-43	-6.7	7.9	4.8	24.09
MON102	7.42	29	-43	-6.8	6.1	3.5	28.98
MON103	3.62	73	-40	-6.1	-	-	17.80
MON104	40.7	25	-43	-6.8	-	-	34.05
MON105	41.9	ND	-44	-6.5	-	-	35.39
MON106	ND	98	-43	-6.5	-	-	17.81
MON107	22.6	ND	-45	-7.0	8.2	2.5	32.54
MON108	23.3	20	-43	-6.7	9.4	2.6	27.46
MON109	49.4	ND	-44	-6.9	-	-	36.69
MON110	14.2	44	-43	-6.9	-	-	27.34
MON111	0.9	40	-42	-6.8	12.0	7.6	24.09
MON112	7.24	42	-43	-7.0	-	-	23.90
MON113	ND	220	-45	-7.1	-	-	5.61
MON114	ND	87	-49	-7.6	-	-	20.48
MON115	8.5	ND	-46	-7.0	-	-	36.32
MON116	7.74	ND	-48	-7.5	-	-	23.89
MON117	12	ND	-49	-7.2	-	-	26.20
MON118	3.75	ND	-48	-7.3	-	-	33.21
MON119	3.7	ND	-43	-6.8	-	-	26.56
MON120	2.16	ND	-45	-7.4	-	-	27.25
MON121	0.16	ND	-48	-7.5	-	-	14.62
MON122	12.3	ND	-42	-6.7	-	-	25.18
MON123	1.82	137	-42	-6.5	-	-	10.15
MON124	4.42	126	-41	-6.6	-	-	-
MON125	5.77	ND	-34	-5.4	-	-	16.23
MON126	39.8	ND	-39	-6.4	-	-	25.18
MON127	ND	ND	-41	-6.6	-	-	11.55
MON128	13.5	ND	-42	-6.6	-	-	19.69
MON129	ND	124	-44	-7.2	-	-	-
MON130	8.27	ND	-42	-6.8	-	-	23.14
MON131	1.1	ND	-41	-6.8	17.0	16.8	22.52
MON132	96.5	ND	-39	-6.6	-	-	37.23
MON133	18.8	ND	-39	-7.1	-	-	28.64
MON134	7.89	ND	-45	-7.0	3.6	1.4	28.43
MON135	47.2	ND	-43	-7.0	10.6	6.2	32.39
MON136	22.4	ND	-42	-6.8	-	-	36.02
MON137	12.6	ND	-43	-6.7	-	-	24.50
MON138	1.29	ND	-45	-6.9	12.8	5.4	16.80
MON139	78.2	52.4	-39	-6.3	8.6	4.3	22.15
MON140	28.1	ND	-43	-6.6	4.5	2.9	17.63

Sample ID	NO_3 (mg/L)	B (µg/L)	δD-H_2O (‰)	$\delta^{18}O$-H_2O (‰)	$\delta^{15}N$-NO_3 (‰)	$\delta^{18}O$-NO_3 (‰)	$\delta^{11}B$ (‰)
MON141	7.94	ND	-44	-6.8	7.1	2.4	26.08
MON142	18.4	ND	-42	-6.6	9.6	1.3	29.03
MON144	53.8	ND	-42	-6.3	4.9	3.3	26.47
MON146	ND	ND	-41	-5.9	-	-	25.96
MON147	1.76	ND	-49	-7.7	6.5	1.8	16.80
MON148	19	ND	-44	-6.9	9.5	3.4	30.97
MON149	6.29	ND	-43	-7.1	5.5	4.6	26.65
MON150	0.31	101	-43	-5.8	-	-	12.45
MON151	8.17	92.6	-43	-6.4	10.4	3.8	19.93
MON152	ND	250	-49	-7.0	-	-	-1.63
MON153	4.48	71.3	-42	-6.2	-3.6	-5.0	-25.11
MON154	6.16	ND	-40	-6.2	5.4	-0.7	-
MON155	ND	102	-41	-5.8	-	-	29.72
MON156	ND	87	-40	-5.9	-	-	28.63
MON157	238	514	-42	-6.0	6.6	5.0	27.09
MON158	123	133	-49	-7.6	3.3	3.6	30.51
MON159	34.1	56.3	-49	-7.0	7.9	5.7	27.12
MON161	ND	272	-60	-8.7	-	-	-2.46
MON162	ND	786	-59	-8.3	-	-	9.16
MON164	22.4	ND	-46	-6.6	3.6	2.5	32.37
MON165	19.8	ND	-43	-7.0	8.6	2.8	29.95
MON167	2.33	ND	-46	-6.7	4.5	0.0	27.31
MON168	187	253	-42	-6.0	5.1	5.1	26.54
MON169	10.5	ND	-43	-6.3	6.7	3.9	22.90
MON170	13.7	ND	-44	-6.6	4.3	3.1	7.42
MON171	9.15	140	-51	-7.2	12.9	7.8	0.46
MON172	47.4	ND	-47	-6.3	5.6	2.8	30.16
MON173	ND	ND	-43	-6.9	-	-	1.00
MON174	ND	ND	-55	-7.7	-	-	30.80
MON176	0.48	135	-39	-6.3	-	-	11.86
MON177	2.88	ND	-47	-7.5	3.9	3.4	10.75
MON178	1.78	ND	-42	-6.4	4.8	1.5	28.76
MON179	7.5	ND	-43	-6.4	6.8	3.5	26.07
MON180	0.94	ND	-39	-6.1	7.2	-4.5	28.17
MON181	0.44	78.6	-43	-5.7	-	-	4.81
MON182	11	ND	-45	-6.7	-	-	14.48
MON183	3.14	ND	-41	-6.6	-	-	27.00
MON184	8.96	ND	-41	-6.5	6.0	2.1	26.96