Final

Rice-Specific

Groundwater Assessment Report

Prepared for

Central Valley Regional Water Quality Control Board

On Behalf of

California Rice Commission

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Executive Summary

This Groundwater Assessment Report (GAR) was developed on behalf of the California Rice Commission (CRC) to support development of the groundwater quality component of a rice-specific water quality Monitoring and Reporting Program (MRP). The CRC, a statutory organization representing about 2,500 rice farmers who farm approximately 550,000 acres of Sacramento Valley rice fields, is an approved Coalition Group under the Central Valley Regional Water Quality Control Board's (RWQCB) Irrigated Lands Regulatory Program (ILRP) *Conditional Waiver of Waste Discharge Requirements for Irrigated Lands* (Conditional Waiver).

Previously, the CRC's MRP focused on surface water quality; however, the RWQCB is developing a Long-Term Irrigated Lands Regulatory Program (LTILRP), which proposes to continue to address surface water quality and to add new groundwater quality monitoring and reporting requirements. The new requirements are proposed to be adopted as Waste Discharge Requirements (WDR) and an associated rice-specific MRP.

This GAR provides a rigorous review of regional settings of the rice farmlands in the Sacramento Valley, including agriculture and rice land use, soils and hydrogeology, and existing groundwater monitoring networks and data, and provides a detailed Conceptual Site Model (CSM) for the interpretation of the data reviewed. The GAR presents recommendations for a groundwater monitoring program, a data gap analysis, land use reporting, nutrient management planning, and annual reporting.

California Rice

Rice is primarily grown in eight Sacramento Valley counties (Butte, Colusa, Glenn, Placer, Sacramento, Sutter, Yolo, and Yuba) and is sometimes grown (on less than 1,000 acres) in Tehama County. Rice is also farmed in counties outside the Sacramento Valley; however, these acreages are generally small, and rice is a minor crop in these areas. Rice lands overlie 11 Sacramento Valley Groundwater Basin subbasins, including the Red Bluff, Corning, West Butte, East Butte, Sutter, North Yuba, South Yuba, North American, South American, Yolo, and Colusa subbasins.

Department of Water Resources (DWR) land use surveys identify approximately 587,975 acres that are potentially farmed in rice.[1] The amount of land annually farmed in rice is influenced by factors such as market conditions, weather, and drought water bank needs. The U.S. Department of Agriculture reports that 545,000 acres were grown in 2009 (USDA 2011). Rice is preferentially farmed on lands with low vertical hydraulic conductivity. Low rates of downward water (and thus solute) movement through the soil allows for maintenance of standing water, and avoids rapid seepage and deep percolation of applied water. This lengthens residence time within the upper soil strata during which uptake, transformation, and immobilization of applied fertilizers, herbicides, and pesticides can occur.

Technical Approach

To address the anticipated new groundwater monitoring requirements of the LTILRP, the CRC developed a rice-specific approach for analyzing rice farming's potential impact on groundwater quality and for developing associated monitoring and reporting requirements. The GAR relies on the following approach:

- Evaluation of existing, readily available data
- Review of the data in the context of a rice-specific CSM
- Analysis of the vulnerability of groundwater quality posed by rice farming

Evaluation of Available Data

Existing information and data were gathered and reviewed to provide a foundation for the CRC's proposed approach. Sources of information included applied materials and management practices, soil data, agronomic and

[1] Note that DWR land use survey data for rice may include wild rice.

soils literature, groundwater monitoring networks, and groundwater quality monitoring data. Two types of water quality data were evaluated: nitrogen data from rice-specific root-zone studies, and groundwater quality collected from monitoring well networks.

Four monitoring well networks were evaluated, including U.S. Geological Survey (USGS) Rice Wells, Shallow Domestic Wells, USGS GAMA[2] Wells, and the wells included in the Department of Pesticide Regulations (DPR) Groundwater Database. The well networks were chosen based on the following features:

- Location of wells in proximity to rice land use areas
- Availability of well construction information
- Availability of depth of sample information
- Monitoring of a broad range of chemical constituents (especially nutrients and pesticides)
- Inclusion of shallow wells to identify the quality of groundwater within the top 30 to 50 feet of the groundwater table (first encountered groundwater)
- Inclusion of deeper wells to assess historical vertical contaminant migration
- Peer-review and publication of results

Results of water quality samples from these networks were reviewed to assess the potential impact of rice fields on the underlying groundwater. The main groups of constituents evaluated include nutrients (nitrate), salinity indicators, general parameters, and pesticides. Table ES-1 summarizes the datasets.

TABLE ES-1
Summary of Water Quality Datasets

Dataset	Subsurface Zone	Summary
Linquist research	Root Zone	The Linquist (et al. 2011) research provides a good understanding of root-zone characteristics and the fate of applied nitrogen in rice fields characterized by a very broad range of soil physical properties.
USGS Rice Wells	Shallow groundwater (30 to 50 feet deep) located near rice fields	The USGS Rice Well network provides a sufficient spatial and temporal dataset on which to base conclusions about the influence of rice farming on groundwater quality. The USGS Rice Wells provide a substantial network of shallow wells considered to be representative of lands on which rice is farmed (rice lands). This well network was constructed in 1997 by USGS, who continues to monitor it. The network initially included 28 wells distributed throughout the Sacramento Valley rice lands. This dataset provides the best water quality data for shallow groundwater quality potentially affected by rice farming, and is therefore well suited for representative monitoring as well as trend monitoring for a wide range of constituents since 1997.
Shallow Domestic Wells	Shallow groundwater used for domestic supply (average top perforation is 112 feet and average bottom perforation is 149 feet below land surface) in eastern portion of the Sacramento Valley	The Shallow Domestic Wells provide additional shallow groundwater quality data to complement data from the USGS Rice Wells. Shallow Domestic Wells are not all located near rice fields and may have mixed land uses around them, but nevertheless can provide an understanding of groundwater quality upgradient and downgradient of rice lands (all sampled in 1996, and a subset in 2008).
USGS GAMA Middle Sacramento Valley Study Unit	Deep public groundwater supply wells (average top perforation is 197 feet and average bottom perforation is 340 feet below land surface)	The USGS GAMA Wells include deeper water supply wells and represent groundwater quality near rice fields and under the influence of prolonged rice farming on land in the region (sampled in 2006).

[2] GAMA is the Groundwater Ambient Monitoring and Assessment Program managed by the USGS.

Conceptual Site Model

A CSM was developed and applied to interpret the available information relative to assessment and management of rice fields as sources of pollution based on the information collected. The CSM is a framework for analyzing data related to subsurface hydrology and pollutant transport. The CSM helps describe the connections of rice fields to the broader environment. Independent lines of evidence can be developed to assess risk of groundwater quality degradation by rice farming. Ultimately, the CSM can be used as a tool to design targeted monitoring, field research, and adaptive management. The CSM includes the following main features:

- Physical-chemical conditions and dynamics pertaining to flooded fields and root zones
- Sources of water and pollutants
- Sinks (or “pools”) for water and pollutants (the pool terminology reflects that residence in a pool may vary, and that constituents move from one pool to another, and sometimes back again)
- Potential transformations and pathways for migration of water and pollutants

CSM analysis findings were assessed to identify physical and groundwater quality data that are characteristic of typical conditions related to rice agriculture, provide interpretations and conclusions about the impact of typical rice land use on groundwater, and apply the same conclusions to areas with similar physical conditions in other rice-farming areas for which monitoring data are not available.

Initial Vulnerability Analysis

The assessment evaluated hydrogeologic vulnerability, determined whether and where rice agriculture might pose a threat to groundwater quality, evaluated potential data gaps, and makes monitoring recommendations to fill these data gaps.

In 2000, the State Water Resources Control Board (SWRCB) created a statewide GIS dataset to support a groundwater vulnerability assessment. This map is referred to as the “initial hydrogeologically vulnerable areas” map. An overall groundwater assessment and monitoring methodology was established, and recommendations were made for future monitoring deemed necessary to address data gaps or other information needs to support CRC’s MRP efforts. In addition to the SWRCB initial Hydrogeologic Vulnerable Areas (HVAs) designations, Central Valley RWQCB staff identified the DPR Groundwater Protection Areas (GPAs) for consideration.

Following the review of the data within the context of the CSM, an analysis was performed to assess the vulnerability of groundwater quality due to rice-farming impacts. This analysis evaluated the sufficiency of the monitoring networks to support regional conclusions, evaluated constituents to determine those that may be of concern, and developed a refinement of the initial HVAs in light of the detailed review of soils, water quality, and rice root-zone data.

Results

The water quality results from the well networks were evaluated against water quality thresholds and water quality objectives as defined in the Basin Plan. A detailed evaluation was developed to assess temporal and spatial variation in groundwater quality. The following summarizes the evaluation of water quality:

- Nitrate was not detected in any USGS Rice Well at a level exceeding the maximum contaminant level (MCL). The results are consistent with geochemical understanding of rice root zone properties and are validated by the other USGS datasets reviewed.
- Most of the other constituents detected during monitoring are naturally occurring in the Sacramento Valley geologic formations, including valley fill sediments that make up the solid phase of aquifers. Where elevated concentrations of these constituents are observed, they are not likely to be a result of rice farming.
- Although some USGS Rice Wells do show elevated levels of salinity indicators, wells with high total dissolved solids (TDS) levels are located in areas with naturally high background TDS levels caused by local geology and mineral springs. There have been no confirmed detections of pesticides registered for use on rice.

Vulnerability Refinement

The vulnerability of groundwater to contamination is determined based on a combination of hydrogeologic conditions (soil, drainage, and geologic/hydrogeologic properties), observed groundwater quality conditions, and land use practices (rice management practices). The analysis presented in this GAR supports a rice-specific refinement of the initial SWRCB vulnerability designations. The analysis steps through a review of the geographic representation of the well networks, soil drainage classes, and, for limited data gap areas, additional soil property data. This additional analysis indicates that none of the initial HVA areas outside of Yuba County have rice-specific high vulnerability.

Data Gaps

This analysis has identified limited spatial and soils data gaps that would warrant additional analysis. The combination of results presented above provide the following observations related to groundwater monitoring data gaps in rice areas: (1) Yuba County includes almost half of the rice grown on HVAs, and no USGS Rice Wells are present in Yuba County, and (2) well-drained and moderately well-drained soils are not adequately represented by USGS Rice Wells throughout the rice-farming areas.

Therefore, the Yuba County area represents a data gap. In addition, the fringe areas of northern Glenn, eastern Sutter, and Placer counties are considered a data gap with regard to better drained soils and a low representation of monitoring wells in those areas.

To address both the Yuba County data gap and the fringe area data gap, it is recommended that a data gap analysis be focused on Yuba County. This recommendation is based on the fact that Yuba County rice lands are the largest contiguous area farmed in rice that overlies initial HVAs. If rice farming posed a risk to groundwater in "atypical" soil conditions, this area would be the most prone to impact. If impacts are not detected in this area, it is reasonable to deduct that similar areas are likewise protective of groundwater quality.

Conclusions

A detailed review of the soil properties of rice lands, nutrient management, and root-zone data indicated that rice farming poses a low risk to groundwater quality. This report has demonstrated that the data reviewed do not show impacts on groundwater quality from rice agriculture, and the scientific understanding of rice systems supports the reasonable assumption that rice agriculture has a very low potential to impact groundwater quality. In addition, no high-vulnerability areas due to rice agriculture were identified in this analysis. The analysis did identify one area as a data gap, in Yuba County. Further analysis of this area is recommended to determine its vulnerability designation.

Recommendations

Two types of groundwater monitoring are called for under the LTILRP, including Representative Monitoring for high-vulnerability areas and Regional and Temporal Trend Monitoring to provide an adequate record of actual regional groundwater quality distribution (spatial, regional trends) and of actual long-term groundwater quality changes (temporal trends) in irrigated lands regions. On the basis of the information reviewed for this GAR, no rice-specific groundwater quality impacts were identified, and there are no confirmed high-vulnerability areas; therefore, a rice-specific Representative Groundwater Monitoring Program is not triggered.

To fulfill the Regional and Temporal Trend Monitoring requirements, the GAR recommendations include Trend Monitoring at existing USGS Rice Wells, two new soil sampling sites, and a data gap assessment focused on rice lands in Yuba County and fringe areas on the Sacramento Valley margins.

The USGS Rice Well network has proven to be an excellent network for the purpose of assessing shallow groundwater quality underneath rice fields. A sub-sample of this network would be adequate for Trend Monitoring in rice fields. It is recommended that seven USGS Rice Wells be included in a Trend Monitoring

Program: 3, 8, 10, 15, 17, 18, and 21 (numbered according to the USGS 2001a report). These wells are chosen on the following basis:

- They are geographically (regionally) disperse and are located in the counties that have the most rice acreage. Colusa, Butte, Sutter, and Glenn counties together represent approximately 82 percent of the total rice lands in the Sacramento Valley and approximately 52 percent of the initial HVAs.
- Each is adequately representative of rice land use, as demonstrated in Appendix E-3.
- They are located on the four soil drainage classes on which 99 percent of the rice is grown, thus providing representation of groundwater quality under the primary types of soils on which rice is grown in the Sacramento Valley.
- USGS Rice Wells 3, 8, 17, and 18 include a record of trend monitoring since 1997.

To address a geographic data gap, it is recommended that soil pore water sampling be performed at two sites. One site should be sited in an area of well drained soil northwest of the Sutter Buttes, and another should be sited in Yolo County.

To address both the Yuba County data gap and the fringe area data gap, it is recommended that a data gap analysis be focused on Yuba County. This recommendation is based on the fact that Yuba County rice lands are the largest contiguous area farmed in rice that overlies initial HVAs.

Additional recommendations include coordination with the DPR, period land use reporting, and the implementation of requirements for grower nutrient management plans.

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Acronyms and Abbreviations

µg/L	microgram(s) per liter
µS/cm	microSiemen(s) per centimeter
µS/M	microSiemen(s) per meter
AGR	agricultural water supply (Basin Plan definition)
Basin Plan	*Water Quality Control Plan for the Sacramento River and San Joaquin River Basins*
bgs	below ground surface
bls	below land surface
BMO	Basin Management Objective
CDPH	California Department of Public Health
cm d^{-1}	centimeters per day
Conditional Waiver	Conditional Waiver of Waste Discharge Requirements for Irrigated Lands
CRC	California Rice Commission
CSM	Conceptual Site Model
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
CVHM	Central Valley Hydrologic Model
DPR	California Department of Pesticide Regulation
dS/m	deciSiemens per meter
DWR	California Department of Water Resources
EC	electrical conductivity
ECe	soil salinity
fasl	feet above sea level
fbsl	feet below sea level
Fe	iron
GAMA	Groundwater Ambient Monitoring and Assessment (USGS)
GAR	Groundwater Assessment Report
GPA	Groundwater Protection Area (DPR)
GPL	Groundwater Protection List (DPR)
GWMP	groundwater management plan
HVA	Hydrogeologically Vulnerable Area (SWRCB)
ILRP	Irrigated Lands Regulatory Program
in d^{-1}	inches per day
IND	industrial service supply (Basin Plan definition)
K	potassium

L/LOR	leaching and leaching or runoff GPA
LTILRP	Long-Term Irrigated Lands Regulatory Program
MAF	million acre feet
masl	meters above sea level
mbls	meters below land surface
MCL	maximum contaminant level
mg/L	milligram per liter
MRP	Monitoring and Reporting Program
MUN	domestic water supply (Basin Plan definition)
N	nitrogen
NAWQA	National Water Quality Assessment
NRCS	U.S. Department of Agriculture Natural Resources Conservation Service
P	phosphorus
pCi/L	picoCuries per liter
PCPA	Pesticide Contamination Prevention Act
PMCL	Primary Maximum Contaminant Level
PRO	industrial process supply (Basin Plan definition)
redox	oxidation-reduction
RL	Reporting Limit
RPP	Rice Pesticide Program
RWQCB	Regional Water Quality Control Board
S	sulfur
SGA	Sacramento Groundwater Authority
SMCL	Secondary Maximum Contaminant Level
SSURGO	NRCS Soil Survey Geographic
SVGB	Sacramento Valley Groundwater Basin
SWRCB	California State Water Resources Control Board
TDS	total dissolved solids
USEPA	US Environmental Protection Agency
USGS	United States Geological Survey
USGS Rice Well	Well installed for USGS 1997 National Water Quality Assessment (NAWQA) Program
WDR	Waste Discharge Requirement
WQO	water quality objective
WQS	water quality standard
Zn	zinc

SECTION 1

Introduction

This Groundwater Assessment Report (GAR) was developed on behalf of the California Rice Commission (CRC) to support development of a groundwater quality component of a rice-specific Monitoring and Reporting Program (MRP). The CRC is an approved Coalition Group under the Central Valley Regional Water Quality Control Board's (RWQCB) Irrigated Lands Regulatory Program (ILRP) *Conditional Waiver of Waste Discharge Requirements for Irrigated Lands* (Conditional Waiver).

Previously, the CRC's MRP focused on surface water quality; however, the RWQCB is developing a Long-Term Irrigated Lands Regulatory Program (LTILRP), which proposes to continue to address surface water quality and add new groundwater quality monitoring and reporting requirements. The new requirements are proposed to be adopted as Waste Discharge Requirements (WDR) and an associated rice-specific MRP. It is anticipated that this GAR will be a technical attachment to the MRP and will provide the basis for some of the RWQCB's findings.

1.1 Background of CRC Water Quality Efforts

The CRC is a statutory organization representing about 2,500 rice farmers who farm approximately 550,000 acres of Sacramento Valley rice fields. The CRC has actively led and participated in water quality management activities in rice fields since the 1980s. Early efforts were focused on retention and degradation of rice herbicides in rice fields to protect surface water quality. The ongoing Rice Pesticide Program (RPP) involved detailed in-field studies, extensive assessment and environmental monitoring, management practice pilot testing, development of new rice varietals to accommodate management practices, and outreach to promote widespread implementation.

The CRC has implemented the requirements of the ILRP Conditional Waiver since 2004. The current ILRP allows approved coalition groups to assist farmers in complying with the conditional waiver by performing monitoring and reporting, submitting required administrative fees imposed by the State Water Resources Control Board (SWRCB), and implementing outreach and education actions. The CRC Coalition Group is the only commodity-specific coalition group under the Conditional Waiver; other coalition groups are geographically (watershed) based. At the 2004 outset of the ILRP, the CRC worked collaboratively with RWQCB staff to develop MRP requirements based on analysis of rice-specific information and historical surface water quality monitoring results. Rice-specific information for development of the surface water program included the following:

- Rice cultural, irrigation, and drainage practices
- Timing and methods of pesticide and fertilizer application
- Soil conditions and management
- Water quality management practices
- Pesticide use permit conditions
- Sacramento Valley hydrology and hydrography

As the ILRP has evolved over the past 8 years, the CRC and RWQCB have consistently adapted this technical approach to refine monitoring and reporting activities in response to new data and changing conditions. This has included an expansion and iterative refinement of monitoring and coordination with related programs to encompass surface water parameters, sites, and sampling frequencies as needed to answer specific questions so that management and future monitoring can be adjusted accordingly.

1.2 Approach to Groundwater Assessment

To address the anticipated new groundwater monitoring requirements of the LTILRP, the CRC proposes a rice-specific approach for analyzing rice farming's potential impact on groundwater quality and for developing associated monitoring and reporting requirements. This rice-specific, technically based analysis is consistent with the approach used under the Conditional Waiver. The following approach was used in this assessment:

1. Existing information and data were gathered and reviewed to provide a foundation for the CRC's proposed approach. Several sources of information are readily available:

    - *Applied materials and management practices* are well characterized and are relatively uniform throughout rice farming in the Sacramento Valley.
    - *Soil data* characterize hydraulic conductivity and other physical properties of the soils underlying rice fields.
    - *Agronomic and soils literature* describes contaminant transformations, fate, and transport.
    - *Groundwater quality monitoring* pertinent to this evaluation has been conducted by numerous entities, including the US Geological Survey (USGS), California Department of Pesticide Regulation (DPR), counties, and water agencies. These monitoring data provide relevant information for the GAR.

2. A conceptual site model (CSM) was developed and applied to interpret the available information relative to assessment and control of rice fields as sources of pollution. Agronomic information, soil, hydrogeologic, and groundwater quality data, as well as groundwater quality management and monitoring programs, were reviewed to describe the current groundwater quality, assess the potential pathways for transport of contamination beneath rice fields, and determine if subsurface environments have been impacted by historical rice farming. This information was analyzed using the CSM, which provides a tool to describe potential sources, sinks, pathways, and transformations related to potential degradation of groundwater quality.

    CSM analysis findings were assessed to identify physical and groundwater quality data that are characteristic of typical conditions related to rice agriculture, provide interpretations and conclusions about the impact of typical rice land use on groundwater, and apply the same conclusions to areas with similar physical conditions in other rice-farming areas for which monitoring data are not available. The assessment also evaluated hydrogeologic vulnerability, determined whether and where rice agriculture might pose a threat to groundwater quality, evaluated potential data gaps, and makes monitoring recommendations to fill these data gaps.

3. An overall groundwater assessment and monitoring methodology is established, and recommendations are made for future monitoring deemed necessary to address data gaps or other information needs to support CRC's MRP efforts.

    The goal of these recommendations is to inform and refine future iterations of the MRP so that it can be an instrument for understanding and managing the impact of rice farming on groundwater quality. As new groundwater quality data become available and the analysis is refined, the additional information will be made available as addenda to this GAR, as appropriate and necessary to complete the discussion.

SECTION 2
Regional Setting

The description of the regional setting helps place rice farming in the proper physical context. Land use, geography, farm management, and physical characteristics of the Sacramento Valley rice lands are summarized to promote a common and reasonably thorough understanding of the environment being considered, and to support the assessment and interpretation of crop, soil, soil pore water, and groundwater data. Following this information is the description of a CSM for application in the evaluation of the potential impact of rice farming on groundwater quality.

2.1 Central Valley Agriculture

The Central Valley of California covers approximately 20,000 square miles and is one of the most productive agricultural regions in the world, with over 250 different types of crops grown (USGS 2009). The Central Valley is bounded on the west by the Coast Range and to the east by the Sierra Nevada range. The northern portion is drained by the Sacramento River and its tributaries, and is referred to as the Sacramento Valley. Much of the southern portion is drained by the San Joaquin River and its tributaries, and is referred to as the San Joaquin Valley. Farther south, the Tulare Basin is hydrographically closed (does not drain to the San Joaquin River) during normal water years. The areas drained by the two great rivers of the Central Valley form two relatively distinct groundwater basins, the Sacramento Valley Groundwater Basin (SVGB) and the San Joaquin Valley Groundwater Basin. The Sacramento and San Joaquin rivers meet in the Sacramento–San Joaquin Delta, terminating at San Francisco Bay. The Sacramento Valley is where all of the rice farming addressed in this GAR occurs, and therefore is the focus of this discussion.

Map 2-1 shows land uses in the Central Valley, including rice lands, other agricultural lands, dairies, and urban and commercial areas (maps are provided at the end of each section throughout this GAR). Within the context of groundwater quality protection, an understanding of the mosaic of land uses can support the development of crop-specific or regional approaches. The following are relevant observations about agricultural land uses within the Central Valley:

- Generally, similar crops are not grown contiguously, but are intermixed in a given township/section/range. Depending on the soil characteristics, water availability, and farm and market decisions made by land owners, some crops (field, truck, and hay) can be rotated perennially, annually, or even semiannually. Exceptions to this are where soil conditions over large areas narrow the range of crops that can be grown, such as rice, or where permanent crops such as trees are planted.
- Dairy land uses, which the RWQCB is regulating under its Dairy Program, are relatively concentrated. These uses are located primarily within the San Joaquin Valley and comprise a notable land use west of Chico in the Sacramento Valley.
- Lands with low hydraulic conductivity (because of fine textured soils or low-hydraulic conductivity layers), poor drainage, and tendency to alkalinity can be significantly more suitable for rice than for other crops. For example, rice is planted almost continuously (every spring) in much of the Colusa and Butte basins, where fine-textured (clay) soils predominate. These “rice lands” are contiguous across large geographic areas in the Sacramento Valley. Physiography and soils of rice lands are further described in Section 2.3.1.

2.2 Sacramento Valley Agriculture and Rice Land Use

The Sacramento Valley supports nearly 2 million acres of irrigated agriculture. According to 2011 crop reports from the nine counties, major crops include pasture (irrigated and dry), rice, tree fruit and tree nuts, wheat, hay/alfalfa, corn, tomatoes, safflower, beans, cotton, and barley. Dairy products are also an important commodity. Map 2-2 shows the mix of agricultural land uses in the Sacramento Valley. Again, rice lands are relatively contiguous across large geographic areas, and rice is the major agricultural crop, constituting about 23 percent of the irrigated acreage in the Sacramento Valley (DWR 2003a).

2.2.1 Geographic Extent of Rice-growing Areas Assessed in this Report

The focus of this report is the Sacramento Valley, and more specifically, the area of the valley where rice is cultivated. Rice is grown in the finer-grained soils in the central portion (about 5 percent) of the Sacramento Valley (USGS 2009). For purposes of the groundwater components of the rice-specific MRP, the geographic extent is defined as the nine rice-producing counties in the Sacramento Valley. Map 2-3 shows farmlands identified as rice lands by California Department of Water Resources (DWR) land use surveys and includes the boundaries of the DWR groundwater basins, along with towns and cities in the area.

Rice is primarily grown in eight Sacramento Valley counties (Butte, Colusa, Glenn, Placer, Sacramento, Sutter, Yolo, and Yuba) and is sometimes grown (on less than 1,000 acres) in Tehama County. Rice is also farmed in counties outside the Sacramento Valley; however, these acreages are generally small, and rice is a minor crop in these areas. Rice lands overlie 11 SVGB subbasins, including the Red Bluff, Corning, West Butte, East Butte, Sutter, North Yuba, South Yuba, North American, South American, Yolo, and Colusa subbasins.

DWR land use surveys identify approximately 587,975 acres that are potentially farmed in rice.[3] The amount of land annually farmed in rice is influenced by factors such as market conditions, weather, and drought water bank needs. The CRC reports annual acreage using the USDA published values. The most recent year for which published values are available is 2009. Total planted acreage in 2009 was 545,300 acres (USDA 2011). DWR land use surveys identify rice farmlands, including lands that are actively farmed in rice or are fallow but identifiable as rice lands. The land use surveys are performed periodically on a rotating basis for each county; all counties are not surveyed in a single year. The total acreage of rice identified by DWR is approximately 585,000 acres, which represents an upper bound of lands typically determined to be suitable for rice farming. Table 2-1 provides a summary of rice lands in each county. Map 2-4 shows the percent of rice land use by county for the portion of the county overlying the SVGB.

TABLE 2-1
Rice Land Use per County Portion Overlying the SVGB

County	Total Acres within County Overlying SVGB [a,b]	Total Acres of Surveyed Rice Land[c]	Percent of Land Farmed in Rice (Surveyed/Total)	Planted Acres, 2009[d]
Butte	308,397	105,531	34.2%	106,400
Colusa	434,127	147,315	33.9%	150,400
Glenn	393,856	90,644	23.0%	85,700
Placer	135,049	21,355	15.8%	13,600
Sacramento	372,816	11,412	3.1%	0
Sutter	372,749	139,862	37.5%	115,300
Tehama	433,259	2,544	0.6%	0
Yolo	438,180	30,399	6.9%	35,900
Yuba	158,040	38,913	24.6%	38,000
Total Area	**3,046,743**	**587,975**	**22.4%**	**545,300**

[a] County boundaries source: CalAtlas 2009
[b] Groundwater basins source: DWR 2010
[c] Land use source: DWR 2010
[d] USDA 2011

3 Note that DWR land use survey data for rice may include wild rice.

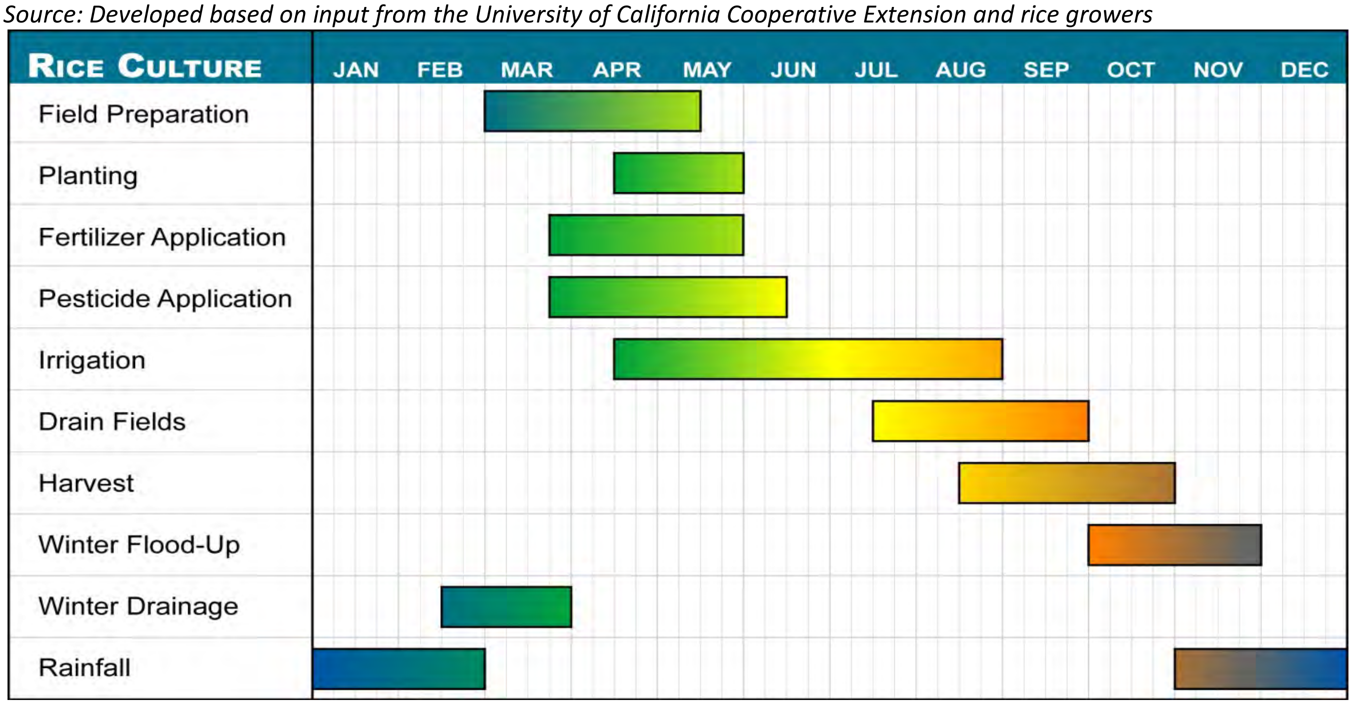
2.2.2 Rice Farm Management

Some management methods and techniques are unique to rice, but others are common with other crops. Understanding the similarities and differences between the rice-farming environment and environments surrounding other crops helps develop appropriate approaches for rice-specific data analysis and interpretation.

Most California rice is produced by direct seeding into standing water; limited acreage is drill-seeded (planted with ground equipment). A continuous flood is maintained after stand establishment (approximately April through September) until draining for harvest.[4] After harvest, about one-third to one-half of the fields is again flooded in the winter (from October through February). This land management regime results in flooded conditions during 5 to 10 months of the year, making rice fields prime and highly valued habitat for migratory waterfowl. Non-winter-flooded fields may also remain relatively moist if they are poorly drained. As mentioned previously, a large proportion of rice lands are planted with rice year after year. This results in farmers who specialize in rice production, and whose businesses are primarily dependent on rice crop success. When planted with rice, cultural practices vary slightly from field to field, but not to the degree that they often do for other crops, where larger planting time windows, alternative irrigation, pest management, and other practices are more easily and successfully accommodated.

Key events in the rice-farming cycle are field preparation, planting, fertilizer and pesticide (mainly herbicide) application, irrigation flooding, field drainage, harvest, winter flood-up, and winter drainage. Figure 2-1 illustrates the typical timeline for these key events.

FIGURE 2-1
Key Events in a Typical Rice Year
Source: Developed based on input from the University of California Cooperative Extension and rice growers



The following management practices and physical characteristics of the rice-growing environment are ***common to all cropping systems***:

- **Fertilizer management:** Seasonal (spring) field preparation, fertilization, and planting. Fertilizer rates are established in consideration of cropping history, yield goals, and soil test levels of nutrients. Application rates and methods are based on fertilizer response relationships developed through field research.

[4] Brief periods of field drainage are characteristic of some herbicide applications; however, this drain-down does not result in dry soil conditions. Drainage to surface water is addressed under the surface water component of the LTILRP.

- **Early season weed control:** Farmers combine herbicides and other cultural practices to control weeds, with early season control being more efficient and helpful to the crop. A rapidly established, vigorously growing crop outcompetes weeds for space, light, nutrients, and water. All operations are designed to produce this condition, which in turn minimizes the need to purchase and apply herbicide. Herbicides selection and timing are based on anticipated and observed field conditions, including levels of infestation. The more successful a farmer is in controlling weeds by other cultural methods, the less herbicide the farmer needs to purchase. The majority of weed control is by cultural methods other than herbicide application.
- **Integrated pest management:** Farmers target pesticides (including herbicides, insecticides, and fungicides) to control pests, but mainly when triggered by infestation above established thresholds (integrated pest management).
- **In-season nutrient supplement:** Farmers may apply supplementary, in-season nitrogen, mainly in response to evidence from leaf tissue analysis that this is needed. This in-season practice aids in targeting exact early season fertilizer application.
- **Seasonal water management:** Farmers irrigate the land seasonally (during the growing season) in amounts sufficient to deliver water that the standing, actively growing crop consumes.
- **Seasonal inputs and cycling:** To produce a crop of high yield and quality, concentrations of pollutants (nutrients, pesticides) in the root zone are periodically raised, then consumed, transformed, or degraded while detained there. When functioning properly, the concentrations of materials in runoff, or leaching from the root zone, are low enough to be protective of the environment, including surface and groundwater.
- **Harvest:** Seasonal (fall) harvest is followed by a generally fallow period until springtime.

The following management and physical characteristics are unique (or especially pronounced) in the rice-growing environment:

- **Nutrient management:** Rice nutrient management is based on technically developed guidelines that account for seasonal plant uptake and nutrient cycling. Fertilizer application is managed not only to achieve sufficient nutrient input at the most effective time during plant growth, but also to avoid over-fertilization. Over-fertilization can adversely impact rice crop yield while increasing the cost of farm inputs, and is therefore avoided.
- **Flooded fields:** Rice fields are flooded before planting and maintained in this condition until shortly before harvest. Flooding is the most significant component of weed control in rice, since the crop is more tolerant of standing water than most weeds. Depth of flooding is maintained at about 5 inches.
- **Seeding:** Presoaked rice seed is flown from airplanes into flooded fields to plant the crop.
- **Weed management:** Floodwater is often drained down to expose weeds before herbicide application or when a ground application is required, after which fields are reflooded until they need to be drained a few weeks before harvest. If a granular in-water, early season herbicide is used, no draindown is required.
- **Pesticide water holds:** For pesticide applications requiring a labeled water-hold, water is retained in fields without release to allow the pesticide to degrade to an acceptable level before release from the field. The holding period is determined by research and defined by the label (law) with some exception through the regulatory process of permit conditions.
- **Winter flood-up and rice straw decomposition:** Between one-third and one-half of rice fields are reflooded after harvest during the fall-winter seasons to facilitate rice straw decomposition and to provide habitat for waterfowl.
- **Maintaining saturated root zone and soil oxidation-reduction (redox) conditions:** The combination of low soil hydraulic conductivity and prolonged flooding in rice fields maintains most (all but the upper inch) of the root zone in a low redox condition for extended periods. This condition results in a slow or nonexistent transformation to nitrate, as described further in Section 2.5.1.

- **Focused, committed farmers:** Since many families have grown only or mainly rice for generations (often because of limitations of the land they farm), the rice-farming community and industry tends to be well-networked and heavily committed. Through mandatory pesticide use meetings and CRC water quality education and outreach, rice farmers are well apprised of water quality requirements and their important, on-the-ground role in protecting the environment.

A few relatively small acreages of atypical rice farming exist in the Sacramento Valley. Organic rice production does not exceed 25,000 acres. For organic rice culture, nutrients are supplied through three methods: (1) Rotation method with legumes, (2) Organic Materials Review Institute–certified chicken manure pellets (of which some is feather meal), and (3) a 3-year cycle of first year no fertilizer, second year with fertilizer, and third year without rice (fallow). Table 2-2 compares six variations in rice cultural practices with respect to the parameters that could influence the fate and transport of constituents. Because of these strong similarities, a single, unified CSM of applied materials, management practices, and root zone conditions is appropriate to describe all of the variations in rice production systems.

2.2.3 Applied Materials

The following describes rice farming as it has been practiced since the expansion of mineral fertilizer use and the advent of selective herbicides after the 1940s. The most recent, significant change in cultural practices relative to nutrient management in particular occurred in the early 1980s, when short-statured rice varieties became available and were widely planted. As was the case for other cereal crops, these varieties brought the heavy grain closer to the ground on a shorter stem, reducing the tendency of plants to become too tall and top heavy, causing them to fall over before harvest. This allowed more fertilizer (especially nitrogen) to be productively used by plants. As a result, more fertilizer needed to be applied to use other inputs (water, land, fuel) as efficiently as possible to produce grain. At the same time, flooding depth became shallower, field leveling more precise, and weed pressure shifted slightly, all as a result of the shorter rice plants.

The transition to short-stature rice happened rapidly in California, and by 1982 most fields were planted and managed in this manner; therefore, it is accurate to say that crop and water management have been relatively constant on rice lands over the past 30 years or so. This fact will aid in the interpretation of shallow groundwater quality data presented in later sections.

2.2.3.1 Nutrients and Minerals

Like most other farmland, rice acreage is fertilized annually. Fertilizer suppliers are a primary source of information regarding the rates of fertilizer application. Suppliers were consulted to determine the range of application rates commonly applied to rice in the Sacramento Valley (CH2M HILL 2004). The information obtained from the suppliers is summarized in Table 2-3. As shown, fertilizer may be applied to rice before planting (anhydrous and aqua ammonia, granular starter, zinc) and/or later in the season to correct deficiencies in an actively growing crop (topdressing).

TABLE 2-2
Comparison of Cultural Practices and Conditions among Major Rice Cropping System Variants in the Sacramento Valley

Cultural Practice or Condition	Conventional Rice Production on Basin Soils	Conventional Rice Production on Terrace Soils	Organic Rice Production	Rice Production in Rotation with Other Crops	Drill-seeded Rice	Rice Decomposition Fields
Seeding	Water-seeded	Same	Same	Same	Drilled	Similar
Fertility	Inorganic (primarily ammonia) N incorporated mainly pre-plant	Same	Organic (primarily organic and ammonia) N incorporated mainly pre-plant; some fields may use green manure (e.g., vetch) as a source of fertility	Same	Same	Similar
Weed control	Primarily through maintenance of a continuous and uniform flood; secondarily by tillage and timely application of selective herbicides	Same	Primarily through maintenance of a continuous and uniform flood; secondarily by rotation and tillage	Same, but rotation may also help to reduce weed pressure	Same	Similar
Irrigation configuration	Uniform, 5-inch-deep flood, retained by levees or "checks" and regulated by box weirs	Same	Same	Same	Same	Similar
Irrigation schedule	Maintained from pre-plant to 2 weeks before harvest; lowered to facilitate contact between a select few herbicides and weeds, sometime between 20 and 30 days after planting (Note that drawdown not required for all herbicides)	Same	Same	Same	Same but for a few days' delay in initial flood-up	Similar
Straw management	Considerable work is involved in preparing a field for decomposition of rice straw; the field is typically chopped, stomped and flooded for decomposition, then incorporated at planting; rice straw is occasionally baled and removed, or burned to diminish disease pressure	Same	Same	Same	Same	Mainly chopped and incorporated.
Winter flooding	About one-third to two-thirds of the acreage is winter flooded (see rice decomp)	Same	Same	Same	Same	Rice decomp fields are reflooded for various periods between harvest and drydown to allow for spring field work

TABLE 2-2
Comparison of Cultural Practices and Conditions among Major Rice Cropping System Variants in the Sacramento Valley

Cultural Practice or Condition	Conventional Rice Production on Basin Soils	Conventional Rice Production on Terrace Soils	Organic Rice Production	Rice Production in Rotation with Other Crops	Drill-seeded Rice	Rice Decomposition Fields
Soil properties	Deep, heavy clay soils with low rates of vertical hydraulic conductivity	Often other soil textures, but mostly underlain by restrictive layers (e.g., duripans) with similarly low rates of vertical hydraulic conductivity	Same	Often on more moderately textured, somewhat better-drained soils; conductivities may be higher	Same	Similar
Soil conditions during the growing season	Saturated with standing water cap, leading to reduced conditions throughout; brief drainage events for weed control do not result in drainage and aeration, so have a minor influence on geochemical condition.	Same	Same	Same; continuous flooding retains reduced soil conditions	Same	Similar
Plant growth	Approximately May through September: germination, seedling, tillering, panicle initiation, jointing, flowering, grain formation and filling, drydown, harvest; rooting in the upper 6 inches	Same	Same	Same	Same	Similar
Crop rotation	Mostly continuous rice year after year; when rotation occurs, similar in all other regards to non-rotated rice, except where the influence of rotation is specifically mentioned	Same	Same with a greater tendency to rotation where this is practicable	A minority of rice land lends itself to rotation with other crops and is the most frequently rotated	Same	Similar

Notes:

Same: Signifies that for this cropping system variant, there is no significant change in the cultural practice or condition relative to conventional rice production on basin soils (second column).

Similar: Signifies that for this cropping system variant, it may be similar to any of the other cited variants described with respect to this cultural practice or condition.

TABLE 2-3
Typical Fertilizer Components Applied to Rice in the Sacramento Valley

Material	Elemental Form	Typical Application Rate (lbs/ac) Low	High	Form and Application Timing
Aqua ammonium	N	80	120	Injected preplant
Starter fertilizer	[N-P-K-S-Zn]	150	200	Solid 16-20-0-13S + Zn starter blend
	N	24	32	
	P_2O_5	30	40	
	K_20	0	0	
	S	19.5	26	
	Zn	1	5	
Solid ammonium sulfate (NH_4SO_4)		0	200	Solid, topdressed to correct N deficiency if needed
	N	0	42	
	S	0	49	

Source: CH2M HILL 2004

K: Potassium
N: nitrogen
O: oxygen
P: phosphorus
S: sulfur
Zn: zinc

The most commonly needed nutrients for rice production in California are nitrogen, phosphorus, and zinc (UC-ANR 010). Potassium, sulfur, and iron are less commonly deficient in California rice soils (UC-ANR 2010). Nitrogen fertilizer is typically applied annually, and phosphorus is applied nearly as often. Zinc is applied on approximately 50 percent of fields annually, although the trend has been decreasing in recent years (UC-ANR 2010).

Nitrogen is essential for all commercial rice production in California. Typical nitrogen application rates for California rice are in the range of 100 to 200 pounds of nitrogen per acre, although some fields may require less than this range (UC-ANR 2010). Specific nitrogen requirements vary with soil type, rice variety, cropping history, planting date, herbicide use, and the kind and amount of crop residue incorporated during seedbed preparation. Winter flooding for straw decomposition and waterfowl management has greatly reduced nitrogen use in some rice fields. Most nitrogen is applied preplant and either incorporated (mixed into soil by tillage) or injected at 2 to 4 inches depth before flooding. Some nitrogen may be topdressed (aerial application of granular fertilizer, often ammonium sulfate) midseason (at panicle differentiation) to correct deficiencies and maintain plant growth and yield.

The following are the forms of nitrogen applied to rice:

- Most nitrogen applied to rice, as previously described, is added in inorganic (ammonium) form.
- Even where organic nitrogen sources are used, there can be a substantial inorganic component, and organic forms are most readily transported and taken up after mineralization (conversion to ammonium-N).
- The organic fertilizers (mainly from poultry operations) used in rice production are “hotter” than, for example, raw dairy manure (in that they contain ammonia-N and organic-N, which are transformed to inorganic nutrients relatively quickly).
- Green manures are typically leguminous. Being less rapidly decomposed than poultry manure, legumes are in effect a slower-release nitrogen source.

A third organic nitrogen pool is decomposing rice straw and weeds biomass. This organic load, which (as in other cereal and oilseed cropping systems) contains a strong proportion of carbon relative to nitrogen, places a net demand on applied nitrogen year after year. Nitrogen that is incorporated into microbial biomass feeding on these plant residues gradually releases as microbes die and their bodies decompose. Phosphorus is applied at a rate of 20 to 40 pounds per acre (UC-ANR 2010) and is incorporated into the seedbed before flooding. In most years, rice fields have P concentrations high enough that there is no critical need to apply phosphorus, and annual phosphorus fertilizer application is not required. Phosphorus deficiency symptoms are rarely seen (UC-ANR 2010). Phosphate fertilizer also may be topdressed when a deficiency occurs, usually at the early seedling stage.

Zinc deficiency, or “alkali disease,” is common in alkaline soils and areas where topsoil has been removed. If zinc is used, it is applied at 2 to 16 pounds per acre, preflood, and it is not incorporated into the soil. Zinc deficiencies most commonly occur in cool weather during stand establishment (early season).

Rice plants absorb sulfur (S) as sulfate (SO4), with the greatest uptake during the later stage of tillering. Sulfur occurs naturally in the soil in organic matter and minerals, as well as in irrigation water and rainfall. Ammonium sulfate is most commonly used in California when sulfur deficiency exists. This fertilizer contains 24 percent sulfur. It is commonly used for topdressing and occasionally as a starter fertilizer (UC-ANR 2010).

Iron deficiency is rare in California flooded rice soils. The principal cause of deficiency is alkaline soil conditions. Irrigation flooding causes reduced soil conditions and increases the solubility of iron compounds, particularly in acid soils. Thus, flooding normally liberates enough iron to supply the needs of the rice crop.

For the approximately 25,000 acres of organic rice, nutrient management is different than for the conventional rice farmers. Information was received from the two largest organic rice producers and handlers in California about the nutrient inputs for the organic rice. Three scenarios apply across the board to all organic rice production in California:

- Use of dry poultry manure. This substance is dry and similar in consistency to screened compost. The manure must meet Organic Materials Review Institute standards and show levels of N, P, and K on the label. The reason for dryness is to ensure consistency with the fertilizer standards.
- Use of pelletized processed manure with poultry feathers. This is a more refined input than dry poultry manure, and also more costly. Levels of N, P, and K are shown on the label.
- There are zero inputs when land is rotated from rice to fallow ground.

2.2.3.2 Nutrient Management Tools

Several tools are used by growers to determine nutrient status of the soil before planting and of the plant during the growing season:

- **Visual analysis.** Determinations of deficiency symptoms during the growing season are performed by visual analysis. If a deficiency is determined to exist, plant samples can be collected and analyzed to determine the cause and degree of deficiency.
- **Direct field methods.** These methods can be used to determine the severity of nitrogen deficiency in the field. Common methods for direct field analysis of nitrogen include the leaf color chart and the chlorophyll meter.
- **Soil testing.** Testing may not provide sufficiently accurate indications of available nitrogen and phosphorus levels, because it does not reflect nutrient levels under flooded conditions, and because nitrogen may be lost from the soil before flooding (for example, through denitrification) (UC-ANR 2010). In addition, the University of California currently does not recommend a soil test for determining available phosphorus status for rice (UC-ANC 2010). Development of a phosphorus budget may be more accurate in determining potential phosphorus needs, based on field inputs and outputs (Linquist and Ruark 2011).

2.2.3.3 Pesticides

Agricultural use of pesticides in California is regulated by DPR and the County Agricultural Commissioners. Growers, pesticide applicators, pest control advisors, and pest control operators report pesticide use to County

Agricultural Commissioners for inclusion in the DPR Pesticide Use Report. Appendix A lists pesticides registered for use on rice and 2010 usage data.

A review of sampled pesticides and their characteristics is given in Section 3.4. Sampling results compared to their thresholds is described in Section 5.4. Table 2-4 lists the pesticides registered for use on rice.

TABLE 2-4
Pesticides Registered for Use on Rice

Type	Name	CAS No.
Herbicides	Bensulfuron-methyl[a]	CAS No. 83055-99-6
	Bispyribac-sodium	CAS No. 125401-92-5
	Carfentrazone-ethyl	CAS No. 128639-02-1
	Clomazone[a]	CAS No. 81777-89-1
	Cyhalofop-butyl[a]	CAS No. 122008-85-9
	2,4-D	CAS No. 20940-37-8
	Glyphosate: diammonium salt	CAS No. 69254-40-6, CAS No. 38641-94-0, CAS No. 70901-12-1
	Halosulfuron	CAS No. 100784-20-1
	Orthosulfamuron[a]	CAS No. 213464-77-8
	Paraquat dichloride	CAS No. 1901-42-5
	Pendimethalin	CAS No. 40487-42-1
	Penoxsulam	CAS No. 219714-96-2
	Propanil[a]	CAS No. 709-98-8
	Thiobencarb[a,b]	CAS No. 28249-77-6
	Triclopyr TEA	CAS No. 57213-69-1
Insecticides	Carbaryl	CAS No. 63-25-2
	(s) or zeta-cypermethrin	CAS No. 52315-07-8
	Diflubenzuron	CAS No. 35367-38-5
	Lambda cyhalothrin	CAS No. 91465-08-6
	Malathion	CAS No. 121-75-5
Fungicides	Azoxystrobin	CAS No. 131860-33-8
	Propiconazole	CAS No. 60207-90-1
	Trifloxystrobin	CAS No. 141517-21-7
Algaecides	Copper sulfate (pentahydrate)	CAS No. 7758-99-8
	Sodium Carbonate Peroxyhydrate	CAS No. 15630-89-4

[a] Pesticides registered for use only on rice (also referred to as rice-specific pesticides)
[b] Thiobencarb is managed under a separate prohibition of discharge program and will not be included in the CRC WDR. Inclusion in this list is for demonstration purposes.

2.3 Physical Setting

The physical setting of this groundwater assessment is described in terms of soils and landforms, hydrogeology, and general groundwater quality.

2.3.1 Soils and Landforms of the Sacramento Valley and Sacramento Valley Rice Farmlands

The Sacramento Valley is ringed by the Coast, Cascade, and Sierra Nevada mountain ranges, which have weathered and eroded to fill the valley bottom with alluvial material. Over time, soils formed within these alluvial parent materials on the landscapes formed by these deposits, giving rise to a relatively wide variety of soils and soil conditions for irrigating and growing crops, such as rice. Before the advent of water resources projects, river flows would peak in response to intense precipitation and snowmelt, and rivers would overtop their banks. Sediments suspended in floodwater were conveyed away from the rivers and deposited along their flanks. Closest to the flooding source (the main stream channels), coarse sediments would settle into relatively well-drained, natural levees, but farther away, finer sediments settled in the bottom of broad basins. The Sutter, Butte, Colusa, and Natomas basins are examples of these landforms and contain most of California's rice fields. These basins are shown on aerial Maps 2-5 and 2-6.

Soils that developed on basin landforms typically have high proportions of clay- and silt-sized particles and poor internal drainage. Soil surface horizons typically have 30 to 60 percent clay and require greater energy for traditional cultivation than soils with lesser amounts of clay (UC-ANR 2010). Soils on terrace landforms typically have well-developed profiles, with loam or clay loam surface horizons, 10 to 35 percent clay content, and a dense clay layer in subsurface soils (UC-ANR 2010). Some terrace soils also have a cemented hardpan (duripan) underlying the clay layer, which impedes root penetration and the vertical percolation of water.

Rice is mainly grown on farmlands with soils favorable to the maintenance of standing water: specifically, clay soils with low vertical hydraulic conductivity. Soil features such as fine-textured or cemented layers with low vertical hydraulic conductivity are common over broad areas and are considered advantageous for flooded rice culture. Although deep ripping of restrictive layers might make these soils more suitable for nonflooded crops, it would also reduce suitability for rice planting.

A soil's natural drainage characteristics are classified by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) into natural drainage classes. This refers to the frequency and duration of wet periods under conditions similar to those at the time the soil developed. The factors considered to establish a given soils' classification are texture, saturated hydraulic conductivity, presence of free water in the profile, water table surface elevation, additional water from seepage, and rainfall; however, alteration of the water regime by humans, either through drainage or irrigation, is not a consideration for classification unless the alterations have significantly changed the morphology of the soil (USDA 1993).

In very poorly drained soils, water leaves the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded (USDA 1993).

In well drained soil, water leaves the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness (USDA 1993).

Map 2-7 shows the NRCS soil drainage classes in rice-growing areas. As shown in this map, the majority of rice lands overlie soils classified as poorly drained (300,000 acres), somewhat poorly drained (88,000 acres), and moderately well drained (105,000 acres), with smaller acreages overlying lands classified as well drained (87,000 acres), and very minor acreages classified as somewhat excessively drained (314 acres) and excessively drained (416 acres). A detailed analysis of drainage classes is presented in Section 6.

Soil properties as mapped in soil surveys may not fully reflect properties as they respond to contemporary management. For example, when lands are plowed and flooded annually to grow rice, a number of properties are systematically altered:

- Hydraulic conductivity declines due to repeated tillage of topsoil without subsoil tillage, often in marginally moist conditions that favor compaction. This change helps farmers retain irrigation water needed to control weeds and retain nutrients.
- Soil pH moderates (i.e., acid and alkaline soils become more neutral in pH) when soils become reduced after flooding. This tends to increase phosphorus availability in calcareous soils and moderates aluminum toxicity that might otherwise occur in more acid soils.

- Salinity is removed from the land in runoff and percolating water, mostly fairly early in the reclamation process, so that there is little residual salinity in established rice fields.
- Basin soils that have soils with high proportions of shrink-swell clays will crack when dried, which likely occurred historically before they were irrigated during dry summers. This has contemporary significance, since cracks that remain below plow depth might retain coarser material that settled there historically, providing limited cross section with hydraulic conductivity in excess of surrounding soil matrix. Under contemporary management, soil moisture is maintained at a high to very high level for most of the year by winter precipitation, summer irrigation, and off-season irrigation for rice decomposition (on one-third to one-half of acreage). Since the "shrink" phase only occurs upon drying, surface soils might crack to some degree in the early spring before flooding, but most rice lands remain moist enough at depth so that conditions for deep cracking no longer occur during years in which rice is planted.

Nevertheless, soil mapping data are helpful when understood in this dynamic context, and are reviewed here. Map 2-8 shows soil textures in the Sacramento Valley rice areas. A detailed discussion of hydrologic soil groups is provided in Appendix B, NRCS Definitions.

Soil hydraulic conductivity can be estimated from other soil properties, such as texture and bulk density (USDA 1993). Map 2-8 shows the predominant soil texture of mapping units in rice lands, and Map 2-9 shows hydraulic conductivity (which was based on the textural classes assuming medium bulk density). As shown on Map 2-8, rice is predominantly grown in soil textures classified as clay, silty clay, clay loam, and loam, with more minor acreages grown on soil textures classified as loamy sand and silty clay loam. As shown on Map 2-9, these soil textures translate to the majority of rice farmed on soil of low hydraulic conductivity, with acreages in the North Yuba, South Yuba, and North American groundwater subbasins grown on soil textures classified as moderately high hydraulic conductivity (in absence of duripan), and additional acreages in the valley fringes and along reaches of the Sacramento River classified as either moderately low or moderately high hydraulic conductivity.

Soil pH is mapped for rice lands on Map 2-10. With few exceptions, soils are in the range of pH 6 to 8.4. Some soils along the eastern margin of the Sacramento Valley (in the North Yuba and North American basins), and a few narrow bands along Sacramento River tributaries, are more acid (3.5 to 6). Some acreage in the northwestern valley, along with scattered, small tracts along the Feather River and in Yolo County, is mapped with pH in excess of 8.5.

Most of the Sacramento Valley has soil that is mapped with ECe (soil salinity) at less than 2 deciSiemens per meter (dS/m, or μmhos/cm, as expressed in the NRCS Soil Survey Geographic [SSURGO] database shown on Map 2-11). This land is non-saline. Extensive areas in the Colusa Basin and northward along tributaries are in the ECe 2 to 8 range, and some in western Glenn County is mapped 8 to 16. None of these more saline ranges could actually produce rice without first being reclaimed into the non-saline range.

Linear extensibility is another soil property that was mapped to illustrate the predominance of shrink-swell clays in the soil (Map 2-12). Basin soils that historically received alluvium from flooding over the adjacent rivers' natural levees tend to have high levels of linear extensibility. The flattest bottom areas of these basins can have very high levels, but these areas are relatively limited. Likewise, higher landscape positions on the valley margins often have low proportions of shrink-swell clays and exhibit moderate to low linear extensibility as a result.

Due to the presence of clay lenses throughout the Sacramento Valley, perched water tables are likely to exist in some locales (however, detailed mapping of perched areas in the valley is not readily available); in these zones, lower rates of hydraulic conductivity beyond the root zone can contribute to poor drainage. Anecdotally, rice researchers describe piezometers installed beneath rice research sites in farmers' fields, in which the piezometers remain dry during most of the period during which the field above is flooded. This suggests that, for at least some fields, the connection between applied water and groundwater is extremely muted.

Historically (before rice growing areas were reclaimed), some of these areas accumulated salts and alkalinity, and were therefore unfavorable for farming. Relatively salt-tolerant crops such as barley, and later flooded crops such as rice, were used to reclaim these lands. During the reclamation process, farming income was accrued from the crop, which paid for the effort of irrigating with fresh water to leach and remove native salinity and alkalinity.

After initial reclamation (occurring decades ago), it is necessary to avoid a return to native saline and/or alkaline conditions. Continuous, flooded rice production is the means used to maintain reclamation and productivity of rice lands.

Low-lying flood bypasses are leased for farming, and a large proportion of these are planted with rice. Soils in these areas are frequently affected by wintertime flooding and can vary more widely in texture, but are generally poorly drained. In addition to rice, other crops (field corn, wild rice) are grown in some of these areas.

The predominance of features such as fine textures, low hydraulic conductivity, poor drainage, flood risk, and potential alkalinity on many lands planted with rice makes these lands unique in the following regard: rice is often not only the best, but practically the only crop that can be sustainably farmed. As a result, much of this land is continuously planted with rice. Geographic exceptions include areas such as the Sutter Basin, where soils are more versatile. Temporal exceptions are periods when rice acreage is reduced due to drought, water transfers, unseasonably late rains that maintain flooded conditions in the bypasses, and/or low commodity prices. In addition, many rice fields have been laser leveled and had permanent levees installed, making irrigation of other crops impractical.

Modern cropping system management (beyond the reclamation process previously described) influences soils in which rice is planted. California rice fields are tilled (usually with a disk harrow) annually in the spring before final field preparation and in advance of flooding, creating a relatively loose plow layer up to 1 foot deep, and a relatively dense plow pan immediately beneath. The latter is particularly pronounced because deeper layers of rice soils typically do not dry thoroughly before tillage, so that compaction from heavy equipment is enhanced. While compaction is considered an agronomic problem for many crops, it is helpful in maintaining flooded conditions in rice fields, and the tilled soil depth above it is sufficient for rooting.

Soil hydrology is controlled by annual flooding necessary to support the crop. About 350,000 acres are also flooded during wintertime to speed decomposition of straw. Although different in intensity and timing from historical, natural flooding, the subsurface conditions, including low levels of oxygen and chemically reducing conditions, would be similar. Production and incorporation of crop residues (roots, straw, and grain) contribute organic matter that is decomposed and cycled through soil organic matter pools, much as it would have been under native conditions. Soil fertility is controlled by addition of various forms of fertilizer, which are timed, placed, and dosed to coincide with crop demand (see previous discussion) and to avoid waste of and pollution by these materials.

Soil fertilization practices vary with the capacity of the soils to absorb nutrient elements in the form of positively charged ions (cations) and negatively charged ions (anions). Fine-textured soils of the Sacramento Valley would be expected to have relatively high cation exchange capacities, meaning that they adsorb cations, such as ammonium, potassium ($K+$), sodium, calcium, and so on. Adsorption to the negatively charged cation exchange sites on clay particles hinders leaching of cations through the soil profile and accumulation in groundwater. Certain clay minerals also fix ammonium and potassium within interlayer spaces, further reducing their mobility. Conversely, negatively charged ions, such as nitrate, are repelled by the negatively charged surfaces of clay particles and are more readily transported in solution through the soil profile and eventually make their way to the shallow groundwater.

2.3.2 Overview of Sacramento Valley Hydrogeology

The Sacramento Valley overlies one of the largest groundwater basins in the state, and wells developed in the sediments of the valley provide excellent (high-quality and relatively plentiful) water supply for irrigation, municipal, industrial, and domestic uses (DWR 2003a). The Red Bluff Arch near the northern end of the Central Valley separates the SVGB from the Redding Area groundwater basin. The SVGB extends from the Red Bluff Arch south to the Cosumnes River. The southern portion of the SVGB underlies the northern portion of the Delta. The SVGB is very productive and is considered the foremost groundwater basin (in terms of productivity) in California. The Sacramento Valley floor has a Mediterranean climate, with mild winters and hot, dry summers. Precipitation during an average year ranges from 13 to 26 inches in the Sacramento Valley rice-growing areas (USGS 2009).

DWR divides the SVGB into 17 subbasins according to groundwater characteristics, surface water features, and political boundaries (DWR 2003a). It is important to note that these individual groundwater subbasins have a high degree of hydraulic interconnection because the rivers (which are the primary method of defining the subbasin boundaries) do not act as barriers to groundwater flow. In most of the Sacramento Valley, streams are in direct hydraulic connection with the underlying aquifer; however, groundwater is free to flow underneath river systems because regional groundwater flow patterns within the aquifer respond to recharge and discharge at a much larger scale than the individual rivers and streams. Therefore, the SVGB functions primarily as a single laterally extensive alluvial aquifer, not as numerous discrete, smaller groundwater subbasins.

A sediment texture analysis was developed by the USGS for a three-dimensional model of the Central Valley (Central Valley Hydrologic Model [CVHM]) (USGS 2009). The results from this analysis showed significant heterogeneity in the texture of the sediments, with finer-grained sediments generally occurring in the Sacramento Valley. In the Sacramento Valley, fine-grained sediments are likely associated with nearby volcanic activity or relatively low energy drainage basins, and are interbedded with coarse-grained alluvial sediments near river channels, flood plains, and alluvial fans (DWR 2009).

The main source of fresh groundwater in the SVGB is the upper 1,000 feet of basin-fill deposits (USGS 2010). Hydrogeologic units containing fresh water along the eastern portion of the basin, primarily the Tuscan and Mehrten formations, are derived from sediments from the Sierra Nevada. Toward the southeastern portion of the Sacramento Valley, the Mehrten formation is overlain by sediments of the Laguna, Riverbank, and Modesto formations, which also originated in the Sierra Nevada. The primary hydrogeologic unit in the western portion of the SVGB is the Tehama formation, which was derived from the Coast Ranges. In most of the Sacramento Valley, these deeper units are overlain by younger alluvial and floodplain deposits. Geologic outcrops in the Sacramento Valley are shown in Map 2-13.

Prior to development, groundwater in both the confined and unconfined aquifers generally moved from recharge areas in the uplands surrounding the floor of the Sacramento Valley toward discharge areas in the lowlands along the valleys axis and the Delta. Under these conditions, groundwater flow was oriented primarily toward the Sacramento River. The main mechanisms for aquifer recharge were deep percolation of precipitation and seepage from stream channels. The eastern tributary streams to the Sacramento River carrying runoff from the Sierra Nevada and the Klamath Mountains provided the bulk of the recharge derived from streams. Most of this occurred as mountain-front recharge in the coarse-grained upper alluvial fans where streams enter the basin (USGS 2009).

Currently, recharge to the SVGB occurs primarily along the upper reaches of tributary streams where the rivers are losing water to the underlying aquifer, through deep percolation of applied water in irrigated areas (most of the valley floor), from mountain-front recharge (subsurface inflow), and from deep percolation of precipitation. Map 2-14 provides a conceptual representation of the major recharge areas to the shallow and deep aquifer systems of the SVGB. This map suggests that the majority of the valley floor constitutes a recharge zone for the shallow aquifer, while deep aquifer recharge occurs primarily through outcrops of the Tuscan Formation along the east side of the valley. In the rice agriculture areas of the Sacramento Valley, soils are predominantly composed of tight clays, as described in the previous section, which typically results in low rates of infiltration of precipitation and applied water. However, the ponded nature of rice field irrigation does result in moderate amounts of recharge to the shallow aquifer system.

Under current conditions, groundwater generally flows inward from the edges of the groundwater basin toward the Sacramento River and in a southerly direction parallel to the river. Depth to groundwater throughout most of the Sacramento Valley averages about 30 feet below ground surface (bgs), with shallower depths along the Sacramento River and greater depths along the basin margins. In addition, localized shallow groundwater levels (less than 10 feet deep) often occur beneath rice fields. Extremely shallow water levels seen in the vicinity of rice fields likely represent either perched groundwater or mounding beneath the rice fields resulting from irrigation flooding. Appendix C includes maps showing valley-wide regional groundwater elevation contours for spring and fall 2010 and 2011 for the shallow zone (less than 200-ft deep wells) and the intermediate zone (200- to 600-ft deep wells). Seasonal fluctuations in groundwater levels occur due to the recharge from precipitation and snowmelt runoff, associated fluctuations in river stages, and the pumping of groundwater to supply agricultural and municipal demands.

Groundwater level fluctuations reflect changes in the amount of groundwater stored in the aquifer system, which is driven by variability in the magnitude and timing affected by the amounts of aquifer recharge and discharge.

Discharge from the aquifer system occurs when groundwater is extracted by wells, discharged to streams, leaves the basin through subsurface outflow, is evapotranspired by phreatophytes, or discharges to the ground surface. In the Sacramento Valley, the low-lying Butte Sinks in the Sutter Basin constitutes an area of significant groundwater discharge.

In dry years, groundwater levels gradually decline in many areas because more water is discharged than recharged. During wet years, groundwater levels in the SVGB typically recover because more water is recharged than discharged (DWR 2003b).

The water budget (the components of inflow, outflow, and change in storage) of the SVGB is dominated by a large annual inflow volume of water falling as precipitation on the surrounding mountains and valley floor of the watershed. A portion of this water is consumed through evapotranspiration by vegetation and surface evaporation, and most of the remainder becomes runoff and groundwater recharge. Runoff to the Sacramento Valley Hydrologic Region is 22.4 million acre-feet (MAF) per year. Agricultural applied water is approximately 7.7 MAF per year in the SVGB (DWR 1998). A portion of this applied water, and the remaining 13.9 MAF per year of runoff, is potentially available to recharge the basin through deep percolation of water and to replenish groundwater storage depleted by groundwater pumping. Except during drought periods, most areas of the SVGB are “full,” and groundwater levels recover to pre-irrigation-season levels each spring. The term “full” means that there are no extensive areas of depressed groundwater levels in the basin except for localized conditions as described below. Historical groundwater level hydrographs suggest that even after extended droughts, groundwater levels in this basin recovered to pre-drought levels within 1 or 2 years after the return of normal rainfall.

As agricultural land use and water demands have intensified over time, groundwater levels in some areas have declined because increases in pumping have exceeded the quantity of local recharge to the groundwater system. This imbalance between pumping and recharge in portions of the valley has been the motivating force for development of supplemental surface supplies in several areas during the past 30 to 40 years. Examples include Yolo County’s construction of Indian Valley Dam on the North Fork of Cache Creek, South Sutter Water District’s construction of Camp Far West Reservoir on the Bear River, and Yuba County’s construction of New Bullards Bar Dam and Reservoir on the North Yuba River.

Today, groundwater levels are generally in balance valley-wide, with pumping matched by recharge from the various sources annually. Some locales show the early signs of persistent groundwater level declines, including northern Sacramento County, areas near Chico, and on the far west side of the Sacramento Valley in Glenn County, where water demands are met primarily, and in some locales exclusively, by groundwater.

In the SVGB, surface water and groundwater systems are strongly connected and are highly variable spatially and temporally. Generally, the major trunk streams of the valley (the Sacramento and Feather rivers) act as drains and are recharged by groundwater throughout most of the year. The exceptions are areas of depressed groundwater elevations attributable to groundwater pumping, inducing leakage from the rivers, and localized recharge to the groundwater system. In contrast, the upper reaches of tributary streams flowing into the Sacramento River from upland areas are almost all *losing* streams (they recharge the groundwater system). Some of these transition to *gaining* streams (they receive groundwater) farther downstream, closer to their confluences with the Sacramento River. Estimates of these surface water/groundwater exchange rates have been developed for specific reaches on a limited number of streams in the Sacramento Valley (USGS 1985), but a comprehensive valley-wide accounting has not been performed to date.

2.3.3 Overview of Sacramento Valley Groundwater Quality

Groundwater quality in the SVGB is generally good and adequate for municipal, agricultural, domestic, and industrial uses (DWR 2003a). However, some localized groundwater quality problems exist, as described below. Natural groundwater quality is influenced by streamflow and recharge from the surrounding Coast Ranges and Sierra Nevada. Runoff from the Sierra Nevada is generally of higher quality than runoff from the Coast Ranges because of the presence of marine sediments in the Coast Ranges. Therefore, groundwater quality tends to be better in the eastern half of the valley. Groundwater quality also varies from north to south, with the best water quality occurring in the northern portion of the Valley, and poorer water quality in the southwestern portion (USGS 1984). This geographic variation is caused by surface recharge through the valley floor, which tends to be more concentrated in constituents than inflows from the valley margins. Most recharge of shallow groundwater in the basin is from agricultural irrigation, which has the potential to concentrate materials over-applied to farmland via percolating water.

Calcium is the predominant cation and bicarbonate the predominant anion in the groundwater in the northern and eastern Sacramento Valley (USGS 2010). Groundwater on the west side generally has higher concentrations of sulfate, chloride, and total dissolved solids (TDS) than groundwater on the east side. Groundwater in the center of the SVGB is generally more geochemically reduced and contains higher concentrations of dissolved solids than groundwater on the east side (USGS 2010).

TDS consist of inorganic salts and small amounts of organic matter, and are strongly correlated with electrical conductivity (EC, also referred to as specific conductance). EC and TDS are both used as indicators of salinity levels in groundwater. The California secondary drinking water standard for TDS is recommended at 500 milligrams per liter (mg/L) (taste and odor threshold). The non-regulatory agricultural water quality goal is 450 mg/L.[5] Generally, TDS levels are between 200 and 500 mg/L in most of the Sacramento Valley. Along the eastern boundary of the valley, TDS concentrations tend to be less than 200 mg/L, indicative of the low salinity of Sierra Nevada runoff. In the southern half of the valley, the TDS levels are higher because of the local geology, and large areas have TDS concentrations exceeding 500 mg/L. TDS concentrations as high as 1,500 mg/L have been reported in a few areas (USGS 1991). Areas that have high TDS concentrations include the south-central part of the SVGB south of Sutter Buttes, in the area between the confluence of the Sacramento and Feather Rivers. The area west of the Sacramento River, between Putah Creek and the Delta, also has elevated TDS levels. The areas around Maxwell, Williams, and Arbuckle have high concentrations of chloride, sodium, and sulfate (DWR 1978). TDS in this region averages about 500 mg/L, but concentrations exceeding 1,000 mg/L have been reported. The source of salinity in the Maxwell and Putah Creek areas is associated with mineral springs in the hills to the west. High salinity around the Sutter Buttes is believed to be caused by upwelling of saline water from underlying marine sediments (USGS 1984).

Nitrates found in groundwater have various sources, including fertilizers, wastewaters, and natural deposits. In irrigation water, nitrate can be an asset because of its value as a fertilizer; however, problems associated with plant toxicity can arise from concentrations exceeding 30 mg/L (as N) (USGS 1991). The drinking water primary maximum contaminant limit for the protection of human health is 10 mg/L-N (NO2+NO3-N). In the SVGB, the background NO2+NO3-N concentration is estimated to be less than or equal to 3 mg/L (USGS 1984). Two areas of elevated (greater than 5.5 mg/L) NO2+NO3-N concentrations have been identified: one in northern Yuba and southern Butte counties (in the Gridley-Marysville area) and another in northern Butte and southern Tehama counties (in the Corning-Chico area). Approximately 25 to 33 percent of samples from these areas have concentrations exceeding the maximum contaminant level (MCL) of 10 mg/L NO2+NO3-N. Elevated NO2+NO3-N concentrations in these areas are associated with shallow wells and are thought to be the result of a combination of fertilizers and septic systems. The latter is especially an issue in Butte County, where 150,000 of its 200,000 residents rely on individual septic systems (DWR 2009).

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[5] *Water Quality for Agriculture*, published by the Food and Agriculture Organization of the United Nations in 1985, contains recommended goals protective of various agricultural uses of water, including irrig+ation of various types of crops and stock watering. This goal is for salt-sensitive crops, considering a number of different factors, including climate, precipitation, and irrigation management.

Iron and manganese are naturally occurring elements that often co-occur in the valley-fill sediments. Findings from the USGS Groundwater Ambient Monitoring and Assessment (GAMA) Middle Sacramento Valley Study showed that iron or manganese concentrations are present at high concentrations in about 27 percent of the primary aquifers and at moderate concentrations in about 6 percent (USGS and SWRCB 2011). This indicates that groundwater in the major aquifers of the Sacramento Valley is affected by the presence of the surrounding naturally occurring minerals throughout the deep sediments.

Other naturally occurring groundwater quality impairments occur in specific areas of the valley. Groundwater near the Sutter Buttes is impaired because of the local volcanic geology. Hydrogen sulfide is a problem for wells in geothermal areas in the western part of the region (DWR 2009).

2.3.4 Initial Designation of Hydrogeologically Vulnerable Areas

In 2000, the SWRCB created a statewide GIS dataset to support a groundwater vulnerability assessment. This map is referred to as the "initial hydrogeologically vulnerable areas" map. A brief SWRCB description of the dataset noted that where published hydrogeologic information suggested the presence of soil or rock conditions, causing the area to potentially be more vulnerable to groundwater contamination, these areas were designated in the dataset. SWRCB used data from DWR and USGS publications to identify areas where geologic conditions may be more likely to allow recharge at rates substantially higher than in lower permeability or confined areas of the same groundwater basin. For example, groundwater resources underlying designated (i.e., published) recharge, rapid infiltration, or unconfined areas were considered categorically more vulnerable to potential contaminant releases than groundwater underlying areas of slower recharge, lower infiltration rates, or intervening low permeability deposits (i.e., confining layers) (SWRCB 2000).

In addition to the SWRCB initial Hydrogeologically Vulnerable Areas (HVA) designations, Central Valley RWQCB staff identified the DPR Groundwater Protection Areas (GPAs) for consideration. DPR, under its Groundwater Protection Program, identifies leaching, runoff, and leaching or runoff conditions for GPAs. The purpose of the designations is to inform agricultural pesticide users of vulnerable areas where unmitigated use of certain pesticides is likely to contaminate groundwater. RWQCB staff identified the "leaching" and "leaching or runoff" GPAs for consideration as vulnerable.

Map 2-15 shows the HVAs and "leaching" and "leaching or runoff" (L/LOR) GPAs in the nine rice-growing counties of the Sacramento Valley. This map shows that most of the identified vulnerable areas are located in alluvial plains by the mainstem rivers of the valley and their floodplain areas. These are generally zones where surface water recharges groundwater. The map also shows that significant portions of the SWRCB initial HVA lands intersect with DPR GPAs.

GIS analysis was used to calculate the acres of rice lands located in the initial HVAs and the GPAs. Map 2-16 shows the rice land use areas that are located in the HVAs and DPR leaching GPAs. Rice land use data were intersected with the initial HVAs, resulting in a total of 48,164 acres of rice lands located in initial HVAs. Similarly, rice land use data were intersected with the DPR L/LOR GPAs, resulting in a total of 1,905 acres of rice lands located in DPR leaching areas and 56 acres in DPR leaching or runoff GPAs.

Yuba County and the Yuba groundwater basins have the most rice land located in high vulnerability areas. This is consistent with the type of soils that predominate in this region. The hydrologic vulnerability of certain rice-growing areas will be discussed in the context of groundwater quality results and will be related to potential additional monitoring needs.

2.4 Groundwater Beneficial Use

Approximately 31 percent of the Sacramento Valley region's urban and agricultural water needs are met by groundwater (DWR 2003a). Although surface water supplies provide the majority of agricultural applied water in the Sacramento Valley, groundwater provides approximately 10 to 15 percent of the total water for agricultural irrigation, depending on water year type.

Beneficial uses of groundwater are designated in the *Water Quality Control Plan for the Sacramento River and San Joaquin River Basins* (Basin Plan). Unless otherwise designated, all groundwater in the Sacramento Valley is considered suitable, or at a minimum potentially suitable, for municipal and domestic water supply (MUN), agricultural supply (AGR), industrial service supply (IND), and industrial process supply (PRO). The Basin Plan specifies exceptions to each beneficial use designation on the basis of quality or yield characteristics (Central Valley RWQCB 1998)

Municipal, industrial, and agricultural water demands in the region total approximately 8 MAF, and groundwater provides about 2.5 MAF of this total (DWR 2009). The portion of the water diverted for irrigation but not actually consumed by crops or other vegetation becomes recharge to the groundwater aquifer or flows back to surface waterways and contributes to surface supplies either within or downstream of the Sacramento Valley.

Groundwater well yields are generally good and range from one hundred to several thousand gallons per minute in the coarser aquifer materials. Municipal and irrigation wells are typically screened deeper in the aquifer (200 to 600 feet bgs) than the domestic wells in the SVGB (100 to 250 feet bgs).

2.5 Conceptual Site Model of Pollutant Sources and Sinks in Rice Fields

The CSM is a framework for analyzing data related to subsurface hydrology and pollutant transport. The CSM helps describe the connections of rice fields to the broader environment. Through use of the CSM, interrelated processes and potential transport pathways can be described, facilitating interpretation of data in a stepwise manner. Independent lines of evidence can be developed to assess risk of groundwater quality degradation by rice farming. Ultimately, the CSM can be used as a tool to design targeted monitoring, field research, and adaptive management.

As described previously, rice cultivation is contiguous over large geographic areas and has been conducted in a consistent manner over about three decades. Cultural practices, while variable in their details, are similar in their main features across most rice fields in the Sacramento Valley.

Figure 2-2 illustrates the rice-specific CSM, which includes the following main features:

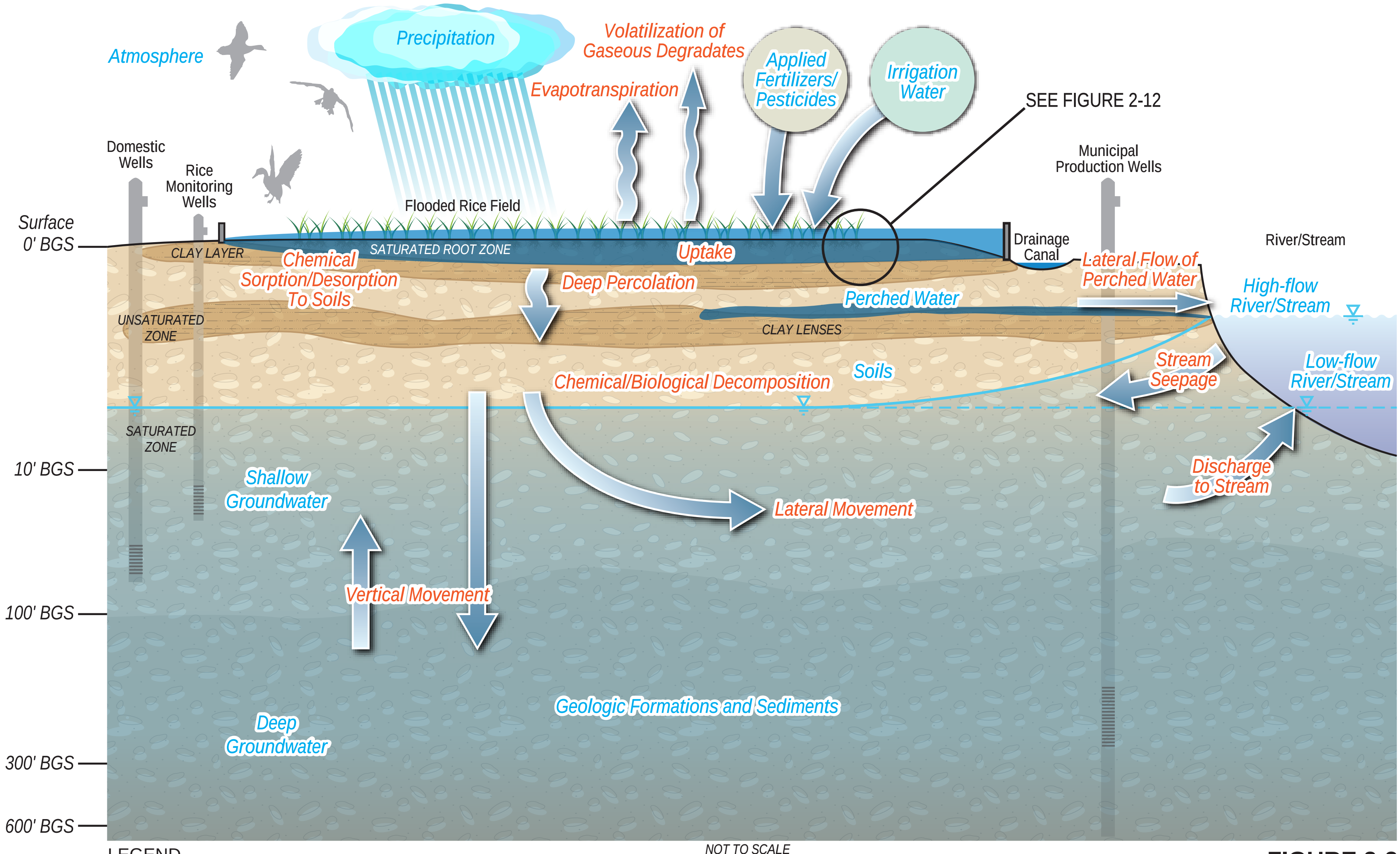
- Physical-chemical conditions and dynamics pertaining to flooded fields and root zones
- Sources of water and pollutants
- Sinks (or “pools”) for water and pollutants (the pool terminology reflects that residence in a pool may vary, and that constituents move from one pool to another, and sometimes back again)
- Potential transformations and pathways for migration of water and pollutants

The physical setting for soils and subsurface characteristics are described in Section 2.3. Rice-specific CSM features are summarized below.

2.5.1 Root Zone Conditions and Dynamics

Root zone conditions and dynamics relevant to rice farming include soils with low vertical hydraulic conductivity, a saturated root zone, and soil oxidation-reduction (redox) conditions.

- **Soils with low vertical hydraulic conductivity:** Rice is preferentially farmed on lands with low vertical hydraulic conductivity. Low rates of downward water (and thus solute) movement through the soil allows for maintenance of standing water where rapid seepage and deep percolation of applied water are avoided. This lengthens residence time during which uptake, transformation, and immobilization of applied fertilizers, herbicides, and pesticides can occur. Recent research measured saturated hydraulic conductivities ranging from 0.001 inches per day (in d^{-1}) to 0.029 in d^{-1} soils at nine out of ten sites evaluated in the Sacramento Valley. One site had soil with a coarse-loamy texture and a saturated hydraulic conductivity of 0.685 in d^{-1} (Linquist et al. 2011). Broader studies of water budgets in rice fields suggest that vertical recharge rates from rice fields may be even lower than predominant vertical hydraulic conductivity rates would suggest. One reason for this could be the poor drainage present at the bottom of the root zone.



LEGEND

- Pathways and Transformations
- Sources and Sinks

The features on this diagram are intended to be broadly representative of physical and chemical conditions encountered in a typical rice field, and are not intended to represent exact conditions in every rice field.

FIGURE 2-2
Conceptual Site Model in Sacramento Valley Rice Fields
Rice-Specific Groundwater Assessment Report

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- **Saturated root zone:** The root zone (from the surface down to below the depth of rooting) of a rice field is saturated from 5 to 10 months of the year. Plant roots and farm practices (tillage, fertilization, and irrigation) influence the form of soil N in these layers of the soil. The saturated root zone influences redox conditions. The prolonged maintenance of a saturated root zone is unique to flooded crops, of which rice is the only major example in California.
- **Soil oxidation-reduction (redox) conditions:** In rice fields, the combination of low soil hydraulic conductivity and prolonged saturation maintains most of the root zone (below the first inch or so) in a low redox condition. This condition prevails from planting in around mid-April, through early September, and is reestablished at fall flood-up (October) and extending through pre-plant (April) in fields where wintertime flooding is practiced.

  The nature and speed of biological and chemical transformations are dependent on the redox state of the soil, which in turn depends on the degree of soil wetness. Thus, soil aeration helps determine predominant chemical species present in the soil, and their availability, mobility, and possible toxicity (Brady and Weil, 2002). Oxygen diffuses very slowly through water, and aerobic soil microbes rapidly reduce oxygen and other substances. In this way, reduced ions quickly come to predominate when soils become saturated. Regardless of the form of applied N, it can be transformed in numerous ways (see Figure 2-3). Transformations of particular interest, and conditions that favor them, are as follows:

  - At higher redox potentials (in aerated soils), ammonium is readily transformed to nitrate. Thus, in well-aerated soils, the half-life of ammonium may be relatively brief, and ammonium concentrations correspondingly low, even if the predominate form of applied N is organic N or inorganic ammonium.
  - At intermediate redox potentials (in wet soil), conditions favor rapid conversion of nitrate (that is not taken up by plants) to N_2 and nitrous oxide gases. Denitrification can significantly reduce soil pore water concentrations of nitrate.
  - Under prolonged saturation, prevailing anaerobic conditions and resulting low redox potentials prevent nitrification of ammonium, so that available soil N is almost exclusively present as ammonium.
  - In temperate mineral soils such as those in the Central Valley, net negative charge predominates in soil particles, so that positively charged ions (such as ammonium, potassium, calcium, etc.) tend to bond with varying strength to the solid phase, removing them from the soil solution. This retards their movement relative to the already slow downward liquid flux. For the same reason, negatively charged ions (such as nitrate), tend to remain in solution, and move along more or less with soil solution.

Mobility of N is therefore minimized by rice field physical conditions and management during most of the year. Literature and field trials that evaluate N mobility in rice soils confirm these summary points, and are reviewed in Appendix D.

2.5.2 Sources

Sources of water and pollutants include applied materials, irrigation water, natural ecology, surface water, and precipitation.

- **Applied materials:** Applied chemicals, including fertilizers and pesticides. Application rates, application methods, and physical/chemical properties of applied materials are key considerations in assessing risk to groundwater quality (see Section 2.2.3). In addition, plant residues (rice and weed roots, straw, and unharvested grain) remain after harvest, adding organic matter to the soil.
- **Irrigation water:** Sacramento Valley rice farmers use mainly surface water for irrigation. The quality of this water is generally high (low levels of salinity; DWR 2009, USGS 2000), having been derived from melting snow that enters the rivers by managed reservoir discharge. Flows and water quality of the Sacramento Valley rivers and streams are influenced by yearly climate variations, runoff from agriculture, urban and mining areas, and operation of water projects (USGS 2000).

- **Natural geology:** Local geologic formations contribute dissolved minerals to groundwater, influencing natural background water quality conditions. Sacramento Valley geologic formations have volcanic and marine origins, which can contain high levels of salinity and other naturally occurring constituents, as described in Section 2.3.3.
- **Surface water:** Flowing water in rivers, streams, canals, and wetlands can recharge groundwater during periods of high stream stage.
- **Precipitation:** Precipitation is a source of high-quality water onto the land. It can influence seasonal fluctuations in groundwater levels and soil moisture.

2.5.3 Sinks

Potential sinks for water and pollutants include plants, soils, shallow and deep groundwater, surface water, and atmosphere.

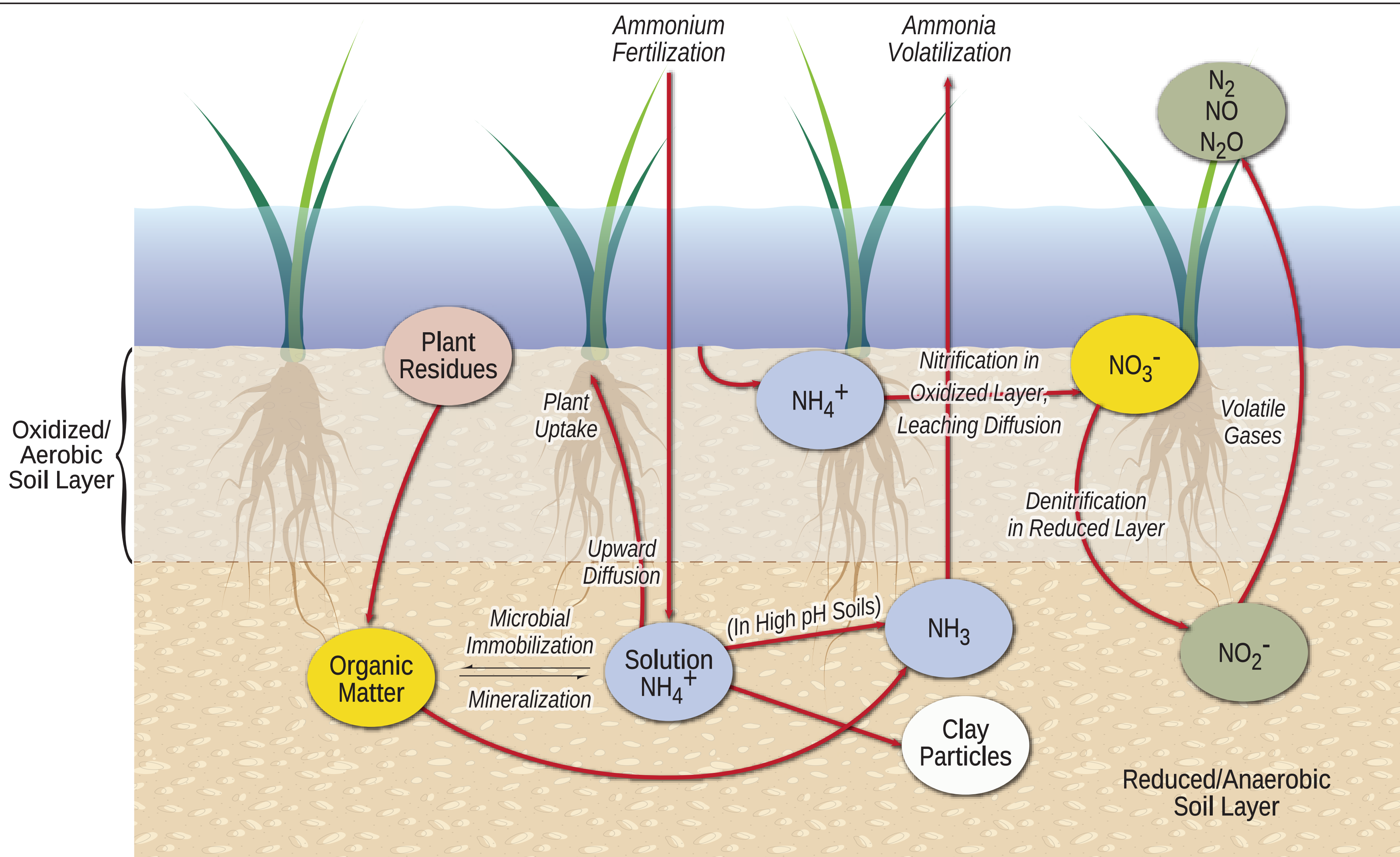
- **Plants:** Plants can take up applied nutrients and pesticides. When applications are properly timed and balanced with uptake, the risk of mobilization out of the root zone is low. Sacramento Valley research has shown that pore water concentrations of NO_3 at a depth of 4.9 feet bgs and deeper are negligible (Linquist et al. 2011). It can be concluded that uptake, storage, transformation, and losses in the root zone control concentrations of nitrate in percolating water to these low levels.
- **Soils:** Soil particles can act as sinks for chemicals that adsorb to their surface, as discussed previously. Inorganic and organic soil colloids readily adsorb some inorganic and organic constituents. When constituents interact strongly with the solid phase (through sorption or fixation), they are predominantly not in the soil solution, but can still be taken up by plants when roots deplete zones around them and set up local concentration gradients that drive desorption. This has the effect of retarding transport of sorbed constituents, effectively lengthening the residence time of these constituents in the root zone, and increasing the proportion that are taken up or transformed by root zone processes.
- **Shallow and deep groundwater:** Water and pollutants that are not used by plants, adsorbed by soil particles, or transformed have the potential to travel beyond the root zone. However, their rate of travel toward groundwater is capped at the slow rate of percolating water. Shallow groundwater underlying most rice fields in the Sacramento Valley can be found between 6.5 and 15 feet bgs. The shallow groundwater zone transitions to a deeper groundwater zone that is the predominant source of groundwater used for agricultural and municipal purposes.
- **Surface water:** Surface water can also be a sink for pollutants and water (at low stream stages) because of the hydraulic connection between the surface water and shallow groundwater in the Sacramento Valley. These potential pathways are described below.
- **Atmosphere:** Ammonia volatilization and nitrification-denitrification, for example, result in loss of soluble constituents from the soil to the atmosphere.

The sources and sinks described above are hydraulically connected in varying degrees, with a major nexus in the root zone. This is of great practical significance for water quality management, because it is the root zone that can best be controlled by farming practices.

2.5.4 Pathways and Transformations

Potential pathways and transformations of water and pollutants in a rice field include plant uptake, decomposition, chemical adsorption to soils, seepage from surface water, discharge to surface water, evapotranspiration, lateral movement, and vertical movement.

- **Plant uptake:** Rice plants and weeds use water and solutes to grow, providing a pathway from the root zone to the plant (a sink for solutes) and to the atmosphere (the sink for water).
- **Decomposition:** Chemicals can be degraded by biological or physical means, sometimes into a form that is more environmentally benign or less mobile.



Source: Modified from Figure 4.2, UC-ANR 2010.

NOT TO SCALE

FIGURE 2-3
Nitrogen Transformations in Flooded Soils
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- **Chemical adsorption/desorption to/from soils:** Adsorption and desorption affect the contaminant concentration in nearby pore water. Where soils have significant clay content and the dominant inorganic N form is ammonium, the balance of these processes tends to retard movement of N and reduce the rate of transport to something significantly less than the rate of mass flow of water through the soil. This has the effect of eliminating inorganic N transport in most flooded soils as a significant threat to groundwater quality. Pesticide properties that influence their behavior in a subsurface environment include half-life, soil sorption coefficient, water solubility, and vapor pressure (Kerle et al. 2007). Additional factors that influence pesticide fate and transport in soil and groundwater include the application rate, formulation, and method; soil properties including temperature, pH, soil texture, organic matter content, redox potential, and moisture content; and sunlight (Kerle et al. 2007). The modern California pesticide registration process favors materials that are less mobile in groundwater environments due to greater tendency to be adsorbed, and/or materials that are active at very low application rates, limiting the concentrations in the first place.
- **Seepage from surface water:** Seepage from agricultural drains, natural and managed wetlands, creeks, sloughs, and rivers can contribute water and pollutants to a groundwater system. Seasonal fluctuations in the groundwater table and surface water levels drive the movement of water from surface water into groundwater (and vice versa). During high river flows or wetland inundations, the stage in the surface water system may become higher than the groundwater level, and the difference in pressure drives seepage into the groundwater system.
- **Discharge to surface water:** Groundwater systems, particularly those with perched or high water tables, can seasonally discharge to surface water. During low river flows, the groundwater table may be higher than the stage in the river, thus driving the discharge of groundwater into surface water via lateral subsurface flow movement.
- **Evapotranspiration:** Evapotranspiration is the combination of evaporation of water from water, soil, and plant surfaces in rice fields.
- **Lateral movement:** When water and chemicals reach the water table, they move laterally from areas of high pressure (piezometric head) to areas of lower pressure. This results in the horizontal movement of groundwater through the subsurface. Rates of horizontal movement depend on the horizontal hydraulic conductivity, the effective porosity of the subsurface soil and aquifer materials, and the magnitude of the horizontal hydraulic gradient within the aquifer. Note that discharges to surface water are covered under the surface water component of the LTILRP.
- **Vertical movement:** Differences in vertical pressure (piezometric head) between shallow groundwater zones and deeper groundwater zones drive the vertical movement of water and contaminants. Rates of vertical movement depend on the vertical hydraulic conductivity of the subsurface environment, the effective porosity of subsurface materials, and the magnitude of the vertical gradient within the soil and aquifer. Depending on these properties, portions of shallow groundwater may travel to deeper groundwater zones and vice versa. When water moves into deeper zones, it might become further diluted by the presence of additional water. Measurements and calculations of vertical movement out of rice fields have generally shown extremely low rates.

2.5.5 Application of the CSM

This rice-specific CSM provides a framework to help answer likely questions concerning the potential for groundwater contamination to occur as a result of rice farming:

- Where would impacts to groundwater quality from rice farming be expected to occur, and in which areas can they be shown to be absent?
- In what locations, media, at what frequencies, and for what parameters is monitoring needed to answer outstanding questions?

The CSM, in conjunction with available data, will be used to locate the applicability of the following conditions:

- Weak source condition: Where risk of transport from the root zone to the shallow groundwater is low, for a given set of characteristic parameters (constituent of concern, soil conditions, and management practices), it can be concluded that the low risk applies to all similar conditions.
- Strong source condition: Where risk of transport from the root zone to the shallow groundwater is high, for a given set of typical conditions (constituent of concern, soil conditions, and management practices), it can be concluded that the high risk applies to all similar conditions.
- Rice agriculture's primary characteristics relevant to groundwater quality in the Sacramento Valley (weak sources of nitrate and other pollutants, high quality of underlying groundwater, and consistent land management practices over the preceding 30 years) suggest the following LTILRP goals:
  - Confirm the identification of rice agriculture being a weak source of pollutants.
  - Identify exceptions to the model where they exist and the implications of these exceptions.
  - Where geographic or practice exceptions constitute a significant pollutant source, identify means to weaken these sources and apply them.

In general, the hypothesis is that shallow groundwater quality would be characteristic of the impacts of rice land use. This leads to three general cases:

1. Where rice farming is suspected to be a major contributor to groundwater pollution, shallow groundwater quality data should demonstrate this impact. Areas with similar subsurface and cultural conditions should be evaluated carefully to see whether they show the same type of pattern and problem.
2. Where shallow groundwater beneath rice lands is found to be of high quality, it could be concluded that rice farming not impacting groundwater. Areas with similar soils, hydrogeology, and crop management practices could be reasonably concluded to have the same low risk.
3. Where non-rice-farming sources are present, their contribution to groundwater quality degradation (if any) needs to be evaluated before assuming that rice farming is a source.
   - Where rice farming in such an area conforms to case 1, rice fields in the area should be evaluated carefully to see whether they are causing the contamination.
   - Where rice farming in such an area conforms to case 2, rice fields in the area are probably not a significant source.

SECTION 3

Review of Existing Monitoring Networks

Groundwater quality in the rice-growing areas is best understood by reviewing existing groundwater quality data from groundwater monitoring networks. Data from historical and current monitoring networks were reviewed to determine which were applicable for this analysis and to identify significant gaps in monitoring of groundwater quality in the Sacramento Valley's rice-growing region.

This section describes the monitoring networks most applicable to the GAR and focuses on the main network characteristics evaluated. The well networks were chosen based on the following features:

- Location of wells in proximity to rice land use areas
- Availability of well construction information
- Availability of depth of sample information
- Monitoring a broad range of chemical constituents (especially nutrients and pesticides)
- Shallow wells to identify the quality of groundwater within the top 20 to 30 feet of the groundwater table
- Deeper wells to assess historical vertical contaminant migration
- Peer-review and publication of results

Wells of different depths serve distinct data needs. Shallow wells were preferred to deeper wells for the purpose of identifying the quality of shallow groundwater beneath and downgradient of rice fields because these are most likely to exhibit the influence of rice field sources of pollutants. Deeper wells were reviewed to assess the potential for contaminants to migrate vertically to the deeper zones of the aquifer.

3.1 USGS Rice Monitoring Wells

The USGS installed 28 monitoring wells in the Sacramento Valley rice-growing areas as part of a 1997 National Water Quality Assessment (NAWQA) Program land use study (USGS 2001a).

3.1.1 Purpose of Network

The purpose of the study was to assess shallow groundwater quality and to determine if any effects on water quality could be attributed to rice agriculture, among other human activities (USGS 2001a). The data collected from these 28 "USGS Rice Wells" were selected by USGS to be representative of shallow groundwater conditions in the vicinity of the rice farmlands among which they are located.

Subsequent to this initial study, the network has continued to be used for further monitoring. Of the original 28 monitoring wells drilled by the USGS, 23 wells currently remain in the network. Some were destroyed or damaged and are no longer in use. A few damaged wells were repaired or replaced with new wells. The 23 current wells are sampled annually for water levels. A subset of 5 wells is sampled every 2 years for water quality (Rice Wells 1, 3, 8, 17, and 18). A summary technical memorandum is provided in Appendix E-1.

3.1.2 Description of Network

The original 28 USGS Rice Wells were sited by USGS according to the guidelines for the selection and installation of wells described in *Guidelines and Standard Procedures for Studies of Ground-water Quality: Selection and Installation of Wells, and Supporting Documentation* (USGS 1997). The following criteria were used to select well locations:

- Located in deposits that make up the SVGB
- Surrounded by at least 75 percent rice farmland within 500 meters (1,640 feet)

The USGS performed a GIS analysis to select the locations for well installation. DWR land use data showing lands farmed in rice was divided into 30 equal-area grids. A computer program randomly selected and ordered sites located in each of the 30 cells. The USGS contacted landowners and obtained permission for well drilling on private lands or within county rights-of-way. In cases where permission could not be obtained near the randomly selected points, the search was expanded to other locations within the cell or adjacent cells. Seven wells were located in rights-of-way areas next to rice fields, and the remaining 21 USGS Rice Wells were located adjacent to rice fields along field roads or rice equipment areas, or in farm or home yards surrounded by rice fields. Map 3-1 shows the locations of the current and original wells of the USGS Rice Wells monitoring network. These wells are primarily located in the northwestern part of the Sacramento Valley rice land use area.

The USGS Rice Wells were constructed to sample shallow groundwater characteristic of rice land use impacts. The sampling depth of the original USGS Rice Wells ranged between 28.9 and 49.9 feet bgs. Detailed well construction information is given in Table 3-1. The technical memorandum provided as Appendix E-1 includes a graphic (Figure 2) showing the well depths, screened intervals, and average depths to water level measured over the period of record. Appendix E-2 shows an example of USGS Rice Well construction. Each well is adequately representative of rice land use, as demonstrated in Appendix E-3.

The USGS analyzed groundwater samples for 6 field measurements (including pH and temperature), 29 inorganic constituents, 6 nutrient constituents, dissolved organic carbon, 86 pesticides, tritium (hydrogen-3), deuterium (hydrogen-2), and oxygen-18.

3.2 Shallow Domestic Wells

The USGS conducted a groundwater quality study on the southeastern side of the Sacramento Valley in 1996 as part of the NAWQA Program and referred to this as the NAWQA Sacramento subunit area. This program focused on sampling existing shallow domestic wells.

3.2.1 Purpose of Network

The NAWQA Sacramento subunit area, which comprises about 1,700 square miles and includes intense agricultural and urban development, was chosen for the program because it had the largest amount of groundwater use in the SVGB. The objective of a study-unit survey was to assess the overall water quality in the aquifers that supply the highest amount of drinking water within the study basin. For this study, 29 shallow domestic and 2 monitoring wells were sampled (USGS 2001b). The data from this network provide additional information on groundwater quality in shallow groundwater in and around rice land use areas. These wells were sampled twice by the NAWQA program: once in 1996 and again in 2008.

3.2.2 Description of Network

For the purposes of this GAR, this network is referred to as Shallow Domestic Wells. This well network is shown on Map 3-2. Generally, the network extends from Butte County to Sacramento County to the east of the Sacramento River. The 31 wells sampled ranged from approximately 70 to 260 feet deep. Detailed well construction information is given in Table 3-2.

USGS analyzed groundwater samples from these wells for 6 field measurements, 14 inorganic constituents, 6 nutrient constituents, organic carbon, 86 pesticides, 87 volatile organic compounds, tritium (hydrogen-3), radon-222, deuterium (hydrogen-2), and oxygen-18.

TABLE 3-1
USGS Rice Wells Construction Details

Report Well ID	USGS Well ID	DWR Well Number	Number of Samples Collected at the Well (1997–2010)	Latitude	Longitude	Land Surface Altitude (fasl)	Well depth (fbls)	Screened Interval (fbls)	Average Depth to Water Level (fbls)	Subbasin	County	Status
1	384330121293901	010N004E13F001M	9	38°43'30.42"N	121°29'43.59"W	22.0	49.9	35.1–44.9	19.6	North American	Sacramento	Current
2	385314121401701	012N003E18H001M	2	38°53'12.90"N	121°40'21.88"W	22.0	49.9	40.0–44.9	4.0	Sutter	Sutter	Current
3	385431121451401	012N002E09B002M	9	38°54'30.56"N	121°45'18.24"W	22.0	28.9	19.0–24.0	3.7	Sutter	Sutter	Current
4	385528121532001	012N001E05C001M	1	38°55'30.19"N	121°53'25.14"W	23.0	35.1	24.9–29.9	3.9	Colusa	Yolo	Abandoned
5	385720121282401	013N004E24Q001M	1	38°57'20"N	121°28'24"W	66.9	47.9	38.1–43.0	13.1	North American	Sutter	Abandoned
6	390416121433601	014N002E10R001M	2	39°04'15.43"N	121°43'39.14"W	36.1	44.0	34.1–39.0	1.3	Sutter	Sutter	Current
7	390832121463601	015N002E20D001M	2	39°08'32.69"N	121°46'38.78"W	41.0	35.1	24.9–29.9	5.0	Sutter	Sutter	Current
8	390856122044301	015N002W16R001M	9	39°08'54.05"N	122°04'45.38"W	55.1	35.1	24.9–29.9	2.3	Colusa	Colusa	Current
9	391059122043601	015N002W03E001M	2	39°10'59.40"N	122°04'41.10"W	48.9	35.1	24.9–29.9	2.1	Colusa	Colusa	Current
10	391653122101401	017N003W35M001M	2	39°16'54.46"N	122°10'18.83"W	74.1	35.1	24.9–29.9	2.6	Colusa	Colusa	Current
11	391947122094501	017N002W14G001M	2	39°19'44.4"N	122°9'46.79"W	80.1	35.1	24.9–29.9	3.4	Colusa	Colusa	Current
12	392328121571501	018N001W27B001M	2	39°23'27.50"N	121°57'19.11"W	67.9	33.5	23.6–28.5	2.8	West Butte	Glenn	Current
13	392358121450301	018N002E21G001M	1	39°23'57.38"N	121°45'00.52"W	81.0	43.0	27.9–38.1	3.6	East Butte	Butte	Abandoned
14	392524122113401	018N003W09R001M	1	39°25'22.92"N	122°11'37.58"W	96.1	37.1	26.9–32.2	3.8	Colusa	Glenn	Abandoned
15	392542121452501	018N002E09L001M	2	39°25'35.40"N	121°45'41.96"W	86.0	35.1	24.9–29.9	4.1	East Butte	Butte	Current
16	392545122015201	018N002W12G002M	2	39°25'44.41"N	122°01'56.53"W	78.1	35.1	24.9–29.9	6.7	Colusa	Glenn	Current
17	392604121531801	018N001E08D001M	9	39°26'05.43"N	121°53'18.16"W	71.9	38.4	28.5–33.5	4.2	West Butte	Glenn	Current
18	392810122080901	019N003W25R001M	9	39°28'14.87"N	122°08'12.71"W	97.1	38.4	28.5–33.5	4.4	Colusa	Glenn	Current
19	392824122091401	019N003W25E001M	2	39°28'22.76"N	122°09'51.42"W	98.1	35.1	24.9–29.9	2.4	Colusa	Glenn	Current
20	392848121523901	019N001E20R001M	1	39°28'47.46"N	121°52'43.45"W	83.0	48.6	33.5–43.6	4.9	West Butte	Glenn	Current
21	392924121504801	019N001E22B001M	2	39°29'24.94"N	121°50'51.37"W	86.0	35.1	24.9–29.9	1.3	East Butte	Butte	Current
22	392931122031701	019N002W23E001M	2	39°29'29.75"N	122°03'21.01"W	80.1	35.4	25.6–30.5	2.0	Colusa	Glenn	Current
23	393119121521001	019N001E09C001M	1	39°31'19.16"N	121°52'12.66"W	90.9	45.9	36.1–41.0	5.9	West Butte	Glenn	Abandoned
24	393230121422201	020N002E35J002M	2	39°32'29.95"N	121°42'27.88"W	124.0	35.1	24.9–29.9	3.3	East Butte	Butte	Current
25	393235122055301	020N002W32J001M	2	39°32'34.52"N	122°05'56.82"W	107.9	35.1	24.9–29.9	2.8	Colusa	Glenn	Current
26	393353122013501	020N002W25A001M	2	39°33'52.51"N	122°01'39.34"W	96.1	35.1	24.9–29.9	1.6	Colusa	Glenn	Current
27	393538122053201	020N002W16D001M	1	39°35'37.92"N	122°05'40.19"W	125.0	35.4	25.6–30.5	5.1	Colusa	Glenn	Current
28	393630121455401	020N002E08A001M	2	39°36'29.27"N	121°45'56.86"W	136.2	35.1	24.9–29.9	5.3	East Butte	Butte	Current

Source: USGS 2001a

fasl: feet above sea level
fbls: feet below land surface

TABLE 3-2
Shallow Domestic Wells Construction Details

Report Well ID	USGS Well ID	DWR Well Number	Land Surface Altitude (fasl)	Well depth (fbls)	Screened Interval (fbls)	1996 Depth to Water Level (fbls)	2008 Depth to Water Level (fbls)	Subbasin	County
1	381923121255001	006N005E33Q001M	18.0	158.1	138.1–158.1	57.1	—	South American	Sacramento
2	382855121221601	007N005E01R001M	45.9	259.8	194.9–259.8	93.5	80	South American	Sacramento
3	383304121192501	008N006E16B002M	75.1	149.9	100.1–149.9	82.7	90.8	South American	Sacramento
4	383350121254301	008N005E09H001M	32.5	48.9	26.9–46.9	24.0	29.4	South American	Sacramento
5	383352121254002	008N005E09H003M	31.8	208.0	192.9–208	36.7	37.5	South American	Sacramento
6	383801121333801	009N004E17J002M	27.9	149.9	139.1–149.9	14.2	25.7	Yolo	Sacramento
7	383914121124901	009N007E09B001M	271.0	250.0	125–250	158[a]	158.3	North American	Sacramento
8	384301121195101	010N006E16P001M	139.1	230.0	210–230	160.1	153.7	North American	Sacramento
9	384330121265601	010N005E17H001M	57.1	240.2	211.9–240.2	98.1	—	North American	Sacramento
10	384455121292101	010N004E01K001M	40.0	162.1	140.1–160.1	55.4	48.9	North American	Sutter
11	384736121411501	011N003E18N001M	28.9	223.1	199.1–214.9	19.0[b]	—	Sutter	Sutter
12	384949121233501	011N005E02M001M	85.0	180.1	120.1–180.1	90.9	81.8	North American	Placer
13	385432121213001	012N005E12A001M	110.9	109.9	69.9–100.1	51.2	39.1	North American	Placer
14	385432121451401	012N002E09A001M	22.0	154.9	140.1–154.9	3.0	3.3	Sutter	Sutter
15	385546121312801	013N004E33J001M	47.9	154.9	100.1–154.9	16.7	38.0	North American	Sutter
16	385550121352201	013N003E36L001M	35.1	55.1	44–55.1	8.5	14.0	Sutter	Sutter
17	385718121290401	013N004E24N001M	63.0	212.9	80.1–212.9	11.2	—	North American	Sutter
18	385914121215801	013N005E12Q002M	125.0	107.0	96.1–107	47.6	48.7	North American	Placer
19	390301121391001	014N003E20H003M	44.0	125.0	67.9–125	14.4	29.0	Sutter	Sutter
20	390333121250701	014N005E16Q001M	100.1	234.9	204.1–234.9	93.2	84.3	South Yuba	Yuba
21	390342121415501	014N002E13L002M	37.1	89.9	59.1–89.9	2.3	5.1	Sutter	Sutter
22	390743121273601	015N005E30C001M	86.0	200.1	160.1–200.1	60.0	—	South Yuba	Yuba
23	390756121411901	015N002E24J001M	47.9	85.0	36.1–85	7.5	10.0	Sutter	Sutter
24	390945121354601	015N003E12M001M	60.0	69.9	40–69.9	19.0	—	North Yuba	Yuba
25	390954121394302	015N003E08F002M	57.1	115.2	69.9–115.2	22.3	20.4	Sutter	Sutter
26	391016121411701	015N002E01R001M	57.1	53.1	27.9–53.1	7.2	10.1	Sutter	Sutter
27	391806121484501	017N001E25D001M	76.1	89.9	60–89.9	32.8	30.1	East Butte	Sutter
28	392121121393401	017N003E05L001M	94.2	95.1	60–95.1	7.2	8.3	East Butte	Butte
29	392209121320301	018N004E33L001M	110.9	140.1	ND	17.4	—	North Yuba[c]	Butte
30	392636121324501	018N004E05M001M	180.1	113.8	94.2–113.8	52.5	55.0	North Yuba[c]	Butte
31	392945121350001	019N003E13P001M	149.9	171.9	159.1–171.9	24.6	27.4	East Butte	Butte

Source: USGS 2001b, USGS 2011.

fasl: feet above sea level   fbls: feet below land surface

[a] The USGS 2001b report shows a value of 57.7 fbls for this measurement; however, raw data obtained from the USGS database (USGS 2011) show 158 fbls, which is more consistent with the measurement for 2008.
[b] Water level was measured on April 2, 1985.
[c] According to an updated 2012 DWR Bulletin 118 map posted online after this GAR analysis was performed, this well is now within the North Yuba Subbasin. Future analyses will include this well as such.

3.3 USGS GAMA Wells for Middle Sacramento Valley Study

As part of the SWRCB-funded GAMA Program, the USGS conducted several groundwater quality studies throughout the state. The GAMA Priority Basin Assessment project was developed in response to the Groundwater Quality Monitoring Act of 2001 (AB 599) and is conducted by the USGS in cooperation with the SWRCB. AB 599 is a public mandate to monitor the quality of groundwater used for public supply. For the purposes of this GAR, these wells are referred to as USGS GAMA Wells.

3.3.1 Purpose of Network

As part of the GAMA Priority Basin Assessment project, groundwater monitoring in the SVGB was divided into three study units: the Southern, Middle, and Northern Sacramento Valley Study Units. The Middle Sacramento Valley Study Unit encompasses most of the rice-growing areas in the valley and is described here. The Middle Sacramento Valley Study was designed to provide a spatially unbiased assessment of raw groundwater quality within the study unit. The study did not attempt to evaluate the quality of water delivered to consumers, which is treated after extraction (USGS 2008).

3.3.2 Description of Network

The defined study unit comprising the USGS GAMA Wells covers approximately 2.1 million acres between Tehama and Sacramento counties. Samples were collected from 108 wells in Butte, Colusa, Glenn, Sutter, Tehama, Yolo, and Yuba counties (USGS 2008):

- Seventy-one wells were selected using a randomized grid-based method to provide statistical representation of the study unit.
- Fifteen wells were selected to evaluate changes in water chemistry along groundwater flow paths.
- Twenty-two were the USGS Rice Wells (described separately in Section 3.1).

This network description focuses on the deeper USGS GAMA wells that were sampled for this program (86 total), most of which are production wells. The locations of the USGS GAMA wells are shown on Map 3-3. The network was divided into two regions: east of the Sacramento River (ESAC area) and west of the Sacramento River (WSAC area). The perforated intervals are summarized in Table 3-3.

TABLE 3-3
USGS GAMA Wells: Maximum, Minimum, and Average Perforation Depths for Middle Sacramento Valley Study Unit

	Top of Perforation (feet below land surface)	Bottom of Perforation (feet below land surface)
Minimum	0.0	56.1
Maximum	580.1	879.9
Average	195.2	340.2

The GAMA groundwater samples were analyzed for a large number of synthetic organic constituents, constituents of special interest (perchlorate, *N*-nitrosodimethylamine [NDMA], and 1,2,3-trichloropropane [1,2,3-TCP]), inorganic constituents (nutrients, major and minor ions, and trace elements), radioactive constituents, and microbial indicators. Naturally occurring isotopes (tritium, carbon-14, and stable isotopes of hydrogen, oxygen, nitrogen, and carbon) and dissolved noble gases also were measured to help identify the sources and ages of the sampled groundwater.

This network provides data representing conditions in the deeper aquifer zone. Correlating groundwater data with overlying land use helps to assess the potential of surface-applied nutrients and pesticides to migrate to the deeper aquifer layers.

3.4 California Department of Pesticide Regulation Data

DPR performs monitoring and obtains pesticide sampling data from other agencies, including the California Department of Public Health (CDPH), USGS, and DWR. These data are incorporated into the DPR Well Inventory Database. DPR implements the Well Inventory Database to fulfill its obligations under the Pesticide Contamination Prevention Act (PCPA) as part of its Groundwater Protection Program.

DPR began addressing pesticide contamination of groundwater in the early 1980s in response to the discovery of groundwater contamination resulting from legal application of the non-rice soil fumigant and nematocide dibromochloropropane (DBCP). Reports of additional pesticides in groundwater led to the passage of the PCPA in 1985. The purpose of the PCPA is to prevent further pollution by agricultural pesticides of groundwater used for drinking water supplies. It established a program that required DPR to implement the following program of study:

- Obtain environmental fate and chemistry data for agricultural pesticides before they can be registered for use in California
- Identify agricultural pesticides with the potential to pollute groundwater
- Sample wells for presence of agricultural pesticides in groundwater
- Obtain, report, and analyze the results of well sampling for pesticides conducted by public agencies
- Formally review detected pesticides to determine whether their continued use can be allowed
- Adopt use modifications to protect groundwater from pollution if the formal review indicates that continued use can be allowed

3.4.1 Purpose of Network

The records included in the DPR Well Inventory Database were collected by the various agencies consistent with their own programs and obligations. The database is a central statewide clearinghouse for pesticide data. The following briefly describes the purpose of each of the datasets included in the database:

- DPR performs monitoring based on its evaluation of pesticide risk and historical data, and to address data gaps and follow-up data needs.
- CDPH regulates public (municipal) water systems, which are required to monitor their drinking water supply wells and report the results directly to CDPH. The list of analytes in public supply sampling includes those that are required by regulation and those identified by the municipal supplier for analysis. Well water quality monitoring data are reported to CDPH by municipal water suppliers, and the pesticide data are reported to DPR by CDPH.
- DPR coordinates with USGS to incorporate the results of its pesticide groundwater analysis into the statewide database.

3.4.2 Description of Network

DPR provided the query results of its Well Inventory Database through the period December 2009 (DPR 2011a).The DPR Well Inventory Database contains over 6,700 records of pesticide samples taken at 1,145 well sites in the eight rice-growing counties. The earliest record dates to October 1983. Well depths are not included in the database because such information is considered confidential under California law. Likewise, precise location data are confidential; therefore, the location of each well is provided as the centroid of section in which the well is located. Map 3-4 shows the centroid locations of all wells within the DPR Well Inventory Database that were sampled for pesticides registered for use on rice. The network of wells included in the DPR Well Inventory Database is geographically extensive and includes sampling locations in the eight rice-growing counties, including many locations where rice farm lands do not predominate.

Parameters sampled include those identified by DPR for priority assessment and those selected for evaluation by other agencies. DPR maintains the Groundwater Protection List (GPL) pursuant to California Code of Regulations Title 3, Section 6800[b]. DPR publishes annual reports evaluating pesticide active ingredients and use information, and identifies pesticides with data exceeding Specific Numerical Values. The GPL includes two sections: (a) those pesticides detected in groundwater or soil pursuant to Section 13149 of the Food and Agriculture Code and (b) those pesticides identified pursuant to Section 13145(d) of the Food and Agricultural Code. No pesticides registered for use on rice are included in part (a) of the list. Some pesticides registered for use on rice are included on part (b) of the list. Table 3-4 lists the pesticides registered for use on rice, indicates whether the pesticide is included on the GPL, and identifies if USGS or DPR sampling results for the pesticide are included in the DPR Well Inventory Database.

TABLE 3-4
DPR Section 6800 Pesticides Registered for Use on Rice

Chemical Name	Type	Registered Uses	Sampling included in DPR Well Inventory Database
Azoxystrobin	Fungicide	Widely use by multiple crops	Yes (2011)
Bensulfuron methyl	Herbicide	Rice use only	No
Bispyribac-sodium	Herbicide	Rice, turf, golf courses (originally rice-specific)	No
Carbaryl	Insecticide (OP)	Multiple crops and home use	Yes
Clomazone	Herbicide	Rice use only	No
2,4-D, dimethylamine salt	Herbicide (fenoxy)	Multiple crops and home use	Yes
Halosulfuron-methyl	Herbicide	Rice, schools, turf, other crops, and residential	No
Malathion	OP insecticide	Multiple crops and residential, very limited current use on rice	Yes
Penoxsulam	Herbicide	Rice herbicide, turf, tree nuts, aquatic site	No
Propanil	Herbicide	Rice use only	Yes
Thiamethoxam	Seed treatment insecticide	Multiple crops with the possibility of dry seed rice acres only if used; no reported use to date	No
Thiobencarb*	Herbicide	Rice use only	Yes
Triclopyr, triethylamine salt	Herbicide	Rice herbicide, turf, residential, lawns, aquatic	Yes

* Thiobencarb is regulated under the Basin Plan's Rice Pesticide Program.

3.5 County Monitoring Networks

Each county containing Sacramento Valley rice-growing areas has adopted a Groundwater Management Plan (GWMP) with specific monitoring networks and objectives. Appendix F describes each county plan. DWR or USGS perform most monitoring activities. A brief summary of overall groundwater quality in the basins is also presented. Information about these wells and the sampled data are not always published or readily available, so that data from these networks were excluded from this GAR.

3.5.1 Butte County

The Butte County Groundwater Quality Trend Monitoring Program, in place since 2001, has annually recorded measurements for temperature, pH, and EC on 10 wells throughout the county. According to Butte County, the county's groundwater monitoring program is a work in progress and requires expansion to adequately cover the entire basin geographically before additional constituents can be considered for monitoring. The data collected each July and August at the peak of irrigation season are establishing baseline levels across the county so that future changes in water quality can be detected, and to help guide further investigation and monitoring (Butte County Department of Water and Resource Conservation 2011).

The first samples under this GWMP were collected in July and August 2003 in 10 wells. In 2010, the Butte County Department of Water and Resource Conservation sampled the 13 wells within the county's monitoring grid during August for the groundwater quality trend monitoring program. The sampled parameters (especially EC and TDS) encompass the basic characteristics to consider when evaluating water for evidence of saline intrusion. Overall, the water quality sampling results indicate that groundwater in the basin is of high quality, free of saline intrusion, and is in good health (Butte County Department of Water and Resource Conservation 2011).

3.5.2 Sutter County

Groundwater monitoring in Sutter County is achieved by several efforts. Sutter County itself does not maintain any groundwater monitoring wells. The county samples groundwater in Robbins, where groundwater is its only public water supply system. All groundwater monitoring wells are sampled by DWR or USGS.

Additionally, the Feather Water District currently monitors groundwater levels in four wells. Sutter Extension Water District monitors groundwater levels in its basins at the beginning and end of irrigation season and may monitor saltwater intrusion in the future.

According to the Sutter County GWMP, groundwater samples have been collected for analysis in a total of 133 wells. DWR has sampled 34 of these wells in Sutter County, 14 of which are nested multiple-completion monitoring wells. USGS has sampled 94 of these wells, and the remaining wells were sampled by water purveyors who have shared their data. Water quality sampling for these wells conducted by DWR is expected to occur every 3 years or as funds are available. The water quality data are disseminated on the DWR Water Data Library (online) (Sutter County 2012).

According to the Sutter County GWMP, a review of historical and current water quality data for the development of the GWMP showed that specific conductance values are generally acceptable for agricultural and domestic uses in parts of the county, while in other areas, elevated values for EC could be found in the shallow aquifers near the Sacramento River and in the aquifers deeper than 900 feet bgs. The high salinity could not be attributed to any source. In addition, near the Sutter Buttes and Yuba City, nitrate concentrations in several wells were reported to exceed the MCL. Some of these populated areas have septic systems that might be contributing to the higher nitrate concentrations in groundwater (Sutter County 2012).

3.5.3 Yuba County

In Yuba County, monitoring is currently in place for groundwater elevation, groundwater quality, inelastic subsidence, and groundwater and surface water interaction. Monitoring wells from DWR and several other sources are used for the monitoring program. Yuba County Water Agency compiles groundwater quality data collected by the following entities:

- DWR Central District
- California Water Service Company (City of Marysville)
- Olivehurst Public Utility District
- Linda County Water District
- City of Wheatland
- SWRCB
- Beale Air Force Base
- Ostram Road Landfill
- Yuba County Department of Environmental Health
- Member units participating in groundwater substitution transfers under the Yuba Accord (EC measurements only)

According to the GWMP, DWR samples 10 to 13 wells annually for water quality, and has sampled an additional 62 wells in the North and South Yuba Subbasins at least once since the 1940s. Groundwater level and quality data (including nitrate) in the Yuba basins are summarized in a hydrogeology report prepared by the county that analyzed data from 1965 to 1989 (historical) and 1998 to 2007 (recent) (Yuba County Water Agency 2008). The report concluded that the basin's groundwater generally does not seem to pose a health risk with respect to nitrate. In the North Yuba Subbasin, higher levels of nitrate concentrations were found: two wells showed nitrate (as NO3-N) levels from 14 to 30 mg/L (as opposed to zero to about 7 mg/L in other wells). These levels are relatively high but still under the US Environmental Protection Agency (USEPA) drinking standard of 45 mg/L (Yuba County Water Agency 2008).

According to more recent water quality data, groundwater in the Yuba Basin met all state and federal Primary MCLs (PMCLs), indicating that groundwater is of good to excellent quality for drinking purposes (Yuba County Water Agency 2008).

3.5.4 Placer County

In Placer County, monitoring wells from DWR, USGS, City of Roseville, and City of Lincoln are used for a groundwater monitoring program. According to the 2007 Western Placer County GWMP, DWR conducted groundwater elevation measurements starting before 1950. DWR's program collects spring and fall groundwater level data from more than 32 wells throughout Placer County. Starting in 2000, the City of Lincoln began collecting extensive groundwater elevation measurements from production and monitoring wells within its service area. (City of Roseville et al. 2007)

Because most wells in the basin are used for agricultural purposes (which are usually not monitored as often as drinking water wells), an extensive record of water quality data is not available. More recently public water supply wells have been constructed in the Western Placer County GWMP area, and water quality data are available for these wells. The City of Roseville and City of Lincoln have compiled available historical water quality data for constituents monitored as required by Department of Health Services under California Code of Regulations Title 22.

The 2007 Western Placer County GWMP provides this general characterization of water quality in the county:

- The groundwater quality in the upper (or shallower) aquifer system is regarded as superior to that of the lower (or deeper) aquifer system.
- The lower aquifer system contains higher concentrations of TDS, iron, manganese, and in some cases arsenic than the upper aquifer.
- In general, at depths of approximately 1,200 feet or greater (actual depth varies throughout the basin), the TDS concentration can exceed 2,000 mg/L.

3.5.5 Sacramento County

Monitoring wells maintained by DWR and several other entities are used for the monitoring program in the North Area Groundwater Basin, which spans northern Sacramento County. The Sacramento Groundwater Authority (SGA) compiles groundwater quality data collected by the following entities: SGA member agencies, DWR, USGS, and California State University Sacramento.

SGA has installed its own monitoring wells in the basin through a DWR Local Groundwater Assistance Grant. The GWMP does not list the depth or location of any of these water quality monitoring wells. The SGA takes the following actions to monitor and manage groundwater quality (SGA 2008):

- Coordinates with member agencies to verify that uniform protocols are used when collecting water quality data.
- Maintains the existing SGA monitoring well network for purposes of groundwater quality monitoring.
- Coordinates with the USGS to continue to obtain water quality data from NAWQA wells.
- Coordinates with member agencies and other local, state, and federal agencies to identify where wells may exist in areas with sparse groundwater quality data. Identifies opportunities for collecting and analyzing water quality samples from those wells.
- Assesses the adequacy of the groundwater quality monitoring well network in the Biennial Basin Management Report.

The description of water quality in the SGA GWMP is based on data used to populate the region's Data Management System (developed specifically to support SGA efforts) and on contaminant information tracked by the Central Valley RWQCB and the Sacramento County Environmental Management Department. The Data Management System now includes available groundwater quality data from monitoring between 1991 and 2006 for approximately 260 public supply wells.

California Code of Regulations Title 22 water quality reporting is required by CDPH for each well of the public drinking water supplies. Tests have shown that nitrate levels in public supply wells are generally not of concern in the North Area Basin. Of the 185 samples from public supply wells tested during 2005 and 2006, the average nitrate concentration was 9.3 mg/L, with a maximum observed concentration of 33 mg/L (nitrate as nitrate; MCL is 45 mg/L) (SGA 2008).

3.5.6 Yolo County

According to the 2006 Yolo County GWMP, the groundwater quality monitoring network in Yolo County consists of 232 wells, which includes 57 shallow wells and 33 intermediate wells (Yolo County Flood Control and Water Conservation District 2006). These are monitored by several entities, including the Yolo County Flood Control and Water Conservation District.

The district monitors 30 of the wells, all of which are privately owned. None of these 30 wells is regulated (generally not used as public drinking water wells). The monitoring program samples the shallow aquifer (usually less than 220 feet deep) and has often found low-quality water that exceeds drinking water and/or irrigation standards for several parameters, including nitrate.

During development of the 2006 Yolo County GWMP, groundwater quality data was reviewed; the review found that while variable throughout the county, nitrate concentrations were generally increasing in the shallow and intermediate-depth aquifers. A detailed description of groundwater quality by subbasin and aquifer depth is provided in 2006 Yolo County GWMP Appendix F.

3.5.7 Colusa County

In Colusa County, DWR and USGS monitoring wells are used for a groundwater monitoring program. Colusa County does not maintain a special groundwater monitoring network. The monitoring program is not yet well developed. According to the Colusa County GWMP, baseline data should be obtained for specific conductance, nitrates, manganese, arsenic, and boron (Colusa County 2008).

According to the Colusa County GWMP, a general review of groundwater quality data from USGS and DWR wells showed that specific conductance is generally acceptable for agricultural and domestic use in the county except for two areas: in the marine sediment deposits in the foothills of the Coast Ranges, and in an area of anomalously high specific conductance north of Highway 20 between Colusa and Williams. Nitrate concentrations typically meet drinking water standards except in isolated areas for which the source is probably the result of inadequate sanitary seals or point sources such as septic systems (Colusa County 2008).

3.5.8 Glenn County

The monitoring program in Glenn County includes select domestic and irrigation wells from water districts, private owners, and municipal and industrial water suppliers. Wells selected for the groundwater quality monitoring network are different from those for the groundwater level monitoring network. The groundwater quality network was established during the summer of 2003. In most cases, the only water quality parameters measured are temperature and salinity. Some districts, such as Glenn Colusa Irrigation District, have monitored for other constituents as well; the district's GWMP indicates that serious groundwater quality problems occur between Maxwell and Arbuckle with high concentrations of sodium, chloride, and sulfate. The suspected sources of high salinity are mineral springs in contact with marine sediments (GCID 1995).

SECTION 4
Shallow Groundwater Level Data and Apparent Age

This section provides information on shallow groundwater levels under rice fields and the apparent age of the shallow groundwater. This data review used information provided in the two USGS reports that describe data from the USGS Rice Wells and the Shallow Domestic wells (USGS 2001a, 2001b).

4.1 Shallow Groundwater Levels

Groundwater elevations directly beneath land-use areas for rice are very shallow and are influenced by rice-farming flooding events. Groundwater is often perched above clay lenses beneath rice-growing soils. A review of typical depths to water in the USGS Rice Wells and the Shallow Domestic Wells sampled by the USGS provides information on the vertical distance that nutrients and fertilizers applied at the land surface would have to travel before reaching shallow groundwater.

Map 4-1 shows the depth to water levels for all shallow USGS Rice Wells and Shallow Domestic Wells as monitored by the USGS in 1997 and 2010 for the Rice Wells and in 1996 for the Domestic Wells. Generally, the wells located in the Sacramento River alluvial plain show depths to water of less than 10 feet, with most levels at 5 feet or less below the land surface in rice-growing areas. Wells drilled in the North Yuba and South Yuba basins and in the North American Basin, on the eastern fringe of the SVGB, show deeper water levels, with depths ranging from 15 to more than 150 feet below land surface.

A groundwater depth-to-water trend for all actively monitored USGS Rice Wells is graphed on in Figure 4-1 (see Map 3-1 for the location of these wells).

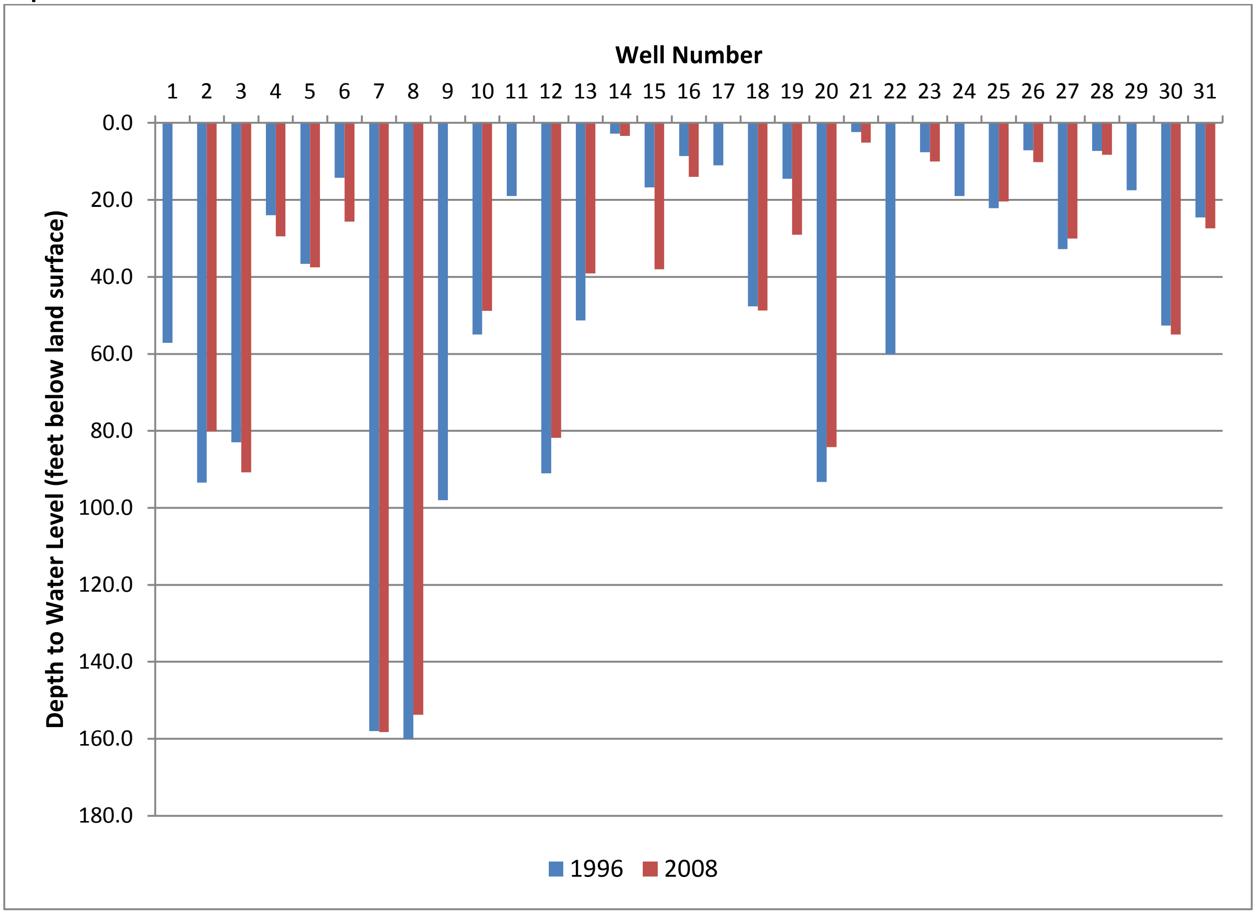
Water levels in thirteen of the USGS Rice Wells were very shallow, at less than 5 feet below the land surface. Excluding Well 1, the other seven Rice Wells showed depths to water of less than 10 feet, ranging from 1.3 feet to 9.4 feet below land surface. Well 1 depth to groundwater is deeper, ranging from 11.5 feet to about 29 feet. Well 1 also exhibits seasonal variations in groundwater levels. The water levels are shallower in the winter months and deeper in the summer months. This variation correlates with the climatic variations in the valley and shows the response to recharge in the shallow groundwater zone. Seasonal variations are slightly less for the wells that have shallower groundwater levels than Well 1. Figure 4-2 shows the depth to water levels for USGS Shallow Domestic Wells as monitored by the USGS in 1996 and 2008. See Map 3-2 for the location of these wells. Only two monitoring events with a 12-year interval have occurred, and this limited data prevents observation of water level trends for these wells. Of the 31 wells, depth to water levels were prominently deeper for Wells 7 and 8, ranging from 153.7 feet to 160 feet below land surface. Depth to water levels for all the other wells were less than 100 feet below land surface. A few wells had depths to water of 10 feet or less (wells 14, 21, 23, 26, and 28). These wells are mostly located in the Sutter Basin, which is an area of shallow groundwater.

4.2 Apparent Age of Shallow Groundwater

Apparent age of groundwater can be determined by measuring the concentration of certain radioactive chemicals with a known half-life. This information helps provide a better understanding of when the groundwater contained in a particular water quality sample was recharged, and therefore often provides for a more comprehensive interpretation of groundwater quality sampling results.

Tritium, a naturally occurring and manmade radioactive isotope of hydrogen with a half-life of 12.43 years, can be used to determine whether groundwater has been recharged since the early 1950s when atmospheric testing of hydrogen bombs began. This atmospheric testing resulted in the production of tritium levels up to 3 orders of magnitude higher than natural background concentrations (USGS 2001a). USGS measured tritium in the USGS Rice Wells and Shallow Domestic Wells to establish the apparent age of shallow groundwater.

FIGURE 4-2
Depth to Water Levels at USGS Shallow Domestic Wells



Tritium was detected in all of the USGS Rice Wells at concentrations ranging from 1 to 47 picoCuries per liter (pCi/L) with a median of 18.5 pCi/L. Groundwater that originated as precipitation and recharged before the 1950s should have a tritium concentration of about 1 pCi/L in 1997 (the date of the sampling event described in USGS 2001a). Current tritium concentrations in rainfall are about 44 pCi/L. Tritium concentrations measured in the USGS Rice Wells in 1997 indicate that all but one of the wells sampled yield groundwater that was at least partially recharged since 1950. This shows that the shallow groundwater sampled by the USGS Rice Wells is representative of rice growing practices, since the recharged water dates from about 60 years ago, after the development and spread of irrigated rice cultivation in the Sacramento Valley.

Tritium (hydrogen 3) was measured and detected in 18 of 22 domestic wells. The concentrations of tritium measured in groundwater samples from the USGS Shallow Domestic Wells in the upper part of the southeastern Sacramento Valley aquifer ranged from 4 to 67 pCi/L, with four wells not containing any measurable tritium. These results indicate that most of this groundwater was at least partially recharged in the last 45 years. However, it is possible that some wells contain a mixture of old and younger groundwater.

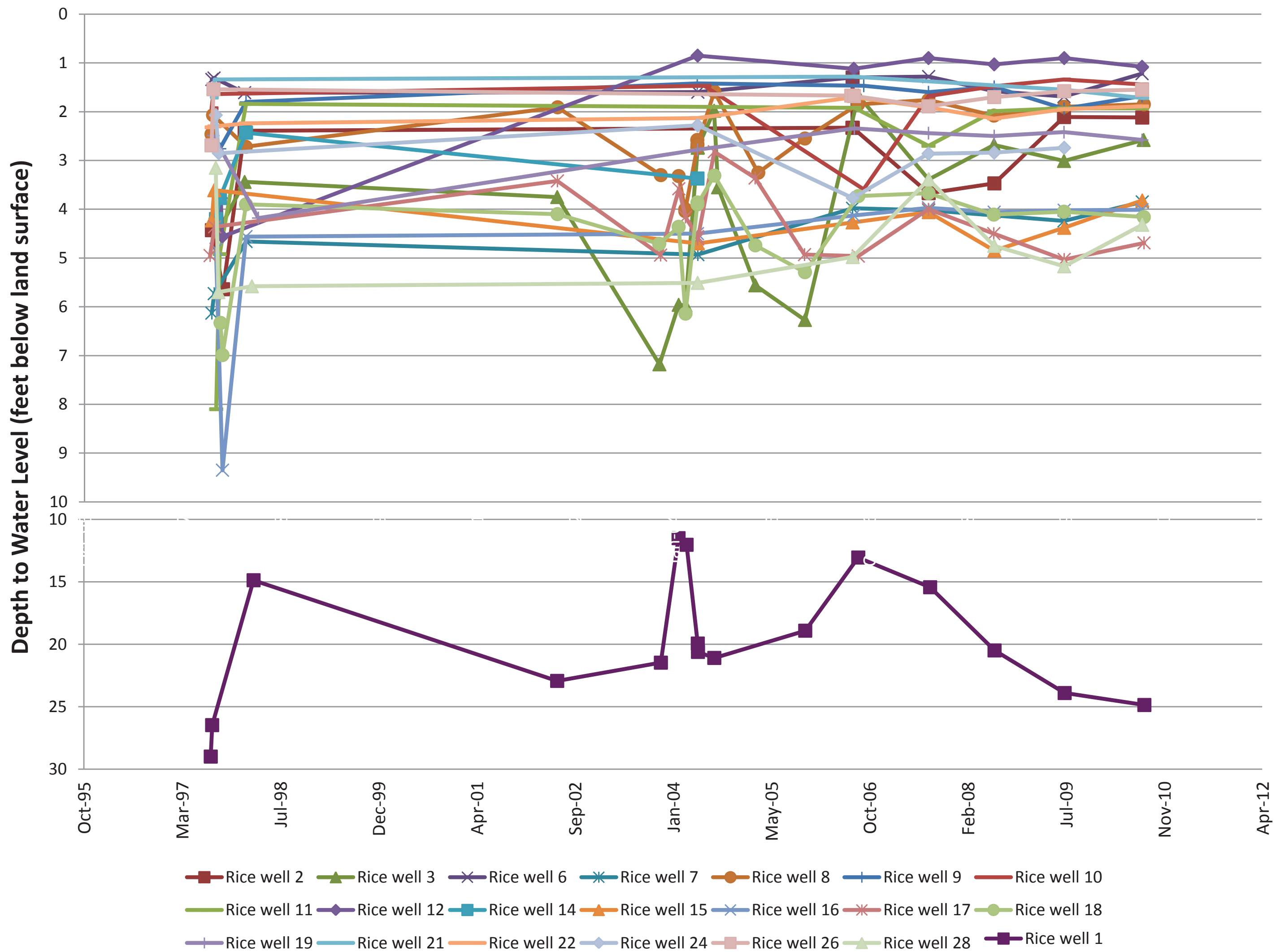


FIGURE 4-1
Depth to Water Trend at Actively Monitored USGS Rice Wells
Rice-Specific Groundwater Assessment Report

SECTION 5

Water Quality Data and Interpretation

A review of groundwater quality data for the sampled wells from the networks described in Section 3 is presented here. Results were grouped by major constituent type, and each dataset was evaluated. Results were compared to water quality thresholds to assess documented groundwater quality conditions in rice-growing areas. Results were also reviewed in the context of land use and the adequacy of well locations for groundwater monitoring in rice-growing areas. The following grouping of parameters is presented in the following discussion:

- Nitrogen
- Salinity indicators (specific conductance and TDS)
- General parameters (including minerals, metals, and trace elements)
- Pesticides

5.1 Water Quality Thresholds

The Basin Plan specifies water quality standards (WQSs) for groundwater. WQSs comprise designated beneficial uses and numeric and/or narrative water quality objectives (WQOs) developed to be protective of designated beneficial uses. For groundwater, WQOs are relevant to the protection of designated beneficial uses, but do not require improvement over naturally occurring background water concentrations.

5.1.1 Nitrate and Salinity Standards

Nitrogen is present in water bodies in the following forms that are measured to characterize water quality: nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3), and organic (TKN minus NH_3). The sum of the concentrations of the mentioned compounds is referred to as total nitrogen.

Nitrate concentration data were gathered from 1996 to 2010 from USGS Rice Wells, Shallow Domestic Wells, and GAMA Well networks. These samples were reported as NO_2^--N + NO_3^--N. This reporting convention for nitrate in groundwater is common. In Sacramento Valley groundwater, nitrite can be considered to be negligible and therefore the data reported as NO_2^--N + NO_3^--N represent nitrate concentrations.

Nitrogen is of particular concern when assessing water quality impacts from agriculture as it, along with phosphorus, is frequently applied to fields in fertilizer. As set forth by the EPA's Safe Drinking Water Act and the National Primary Drinking Water Standards (NPDWS), the federal MCL standards for nitrogen compounds are as follows (USEPA 2012, CDPH 2012):

- Nitrate + nitrite as N: 10 mg/L (the applicable MCL for this data review)
- Nitrate as NO_3^-: 45 mg/L
- Nitrite as N: 1 mg/L

CDPH regulations match these limits under Title 22 of the California Code of Regulations section 63341. Health issues of concern at concentrations exceeding the standards set forth by federal and state regulations are caused by both the nitrate and nitrite forms of nitrogen in water (CDPH 2012).

Nitrate concentrations at or exceeding 3 mg/L are generally thought to be caused by anthropogenic sources; otherwise, concentrations are assumed to be naturally occurring (USGS 2001a). Nitrate occurs naturally in groundwater from leached soils or bedrock, and it does not generally react with soil or sediments and tends to move with groundwater due to its high solubility in water and its generally stable condition; ammonia is less mobile and subject to sorption and conversion to nitrate under oxidized conditions (USGS 1996). Anthropogenic groundwater nitrate sources include synthetic fertilizer, animal manure, wastewater treatment plant effluent and biosolids, and septic systems (Esser et al. 2002).

Salinity is indicated either as total dissolved solids (TDS, in mg/L), or as the water source's conductivity (the ability of water to conduct an electrical current). When soluble salts dissolve in water, the resulting ions behave as conductors. Therefore, electrical conductivity (EC in microSiemens per centimeter [µS/cm], referred to as specific conductance when normalized to 25°C) measured in the field is an indirect measurement of salinity. The relationship between EC and TDS is variable in natural waters due to variations in water composition: different ions affect the EC electrode differently. For example, water high in sulfate will yield a lower value of EC than a water low in sulfate but at the same TDS. In addition, field EC instrument error or miscalibration can add uncertainty to the correlation with TDS.

Salinity in groundwater is often caused by the dissolution of soluble minerals, the presence of seawater deposited with marine sediments in particular geologic formations, and the presence of mineral springs. In the Sacramento Valley, these processes are responsible for elevated salinity levels in groundwater in the vicinity of the Sutter Buttes, where there are documented saline water intrusions from marine sediments (USGS 1984). Below are the federal and state secondary drinking water standards for salinity, which conservatively protect taste and odor.[6] Table 5-1 shows the Secondary MCLs (SMCLs) for EC and TDS.

TABLE 5-1
Salinity Indicator Standards

Salinity Indicator	Recommended Limit	Upper Limit	Criteria Type	Criteria Agency
Specific conductance/ electrical conductivity/EC	900 µS/cm at 25°C	1,600 µS/cm at 25°C	SMCL	CDPH
TDS	500 mg/L (State non-regulatory agriculture recommended limit: 450 mg/L)	1,000 mg/L	SMCL	CDPH, USEPA

mg/L: milligrams per liter
µS/cm: microSiemens per centimeter
PMCL: Primary MCL
SMCL: Secondary MCL

5.1.2 MUN Standards

As established in the Basin Plan, at a minimum, groundwaters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the MCLs specified in the following provisions of Title 22 of the California Code of Regulations:

- Tables 64431-A (inorganic chemicals) and 64431-B (fluoride) of Section 64431
- Table 64444-A (organic chemicals) of Section 64444
- Tables 64449-A (SMCLs-Consumer Acceptance Limits) and 64449-B (SMCLs-Ranges) of Section 64449

At a minimum, water designated MUN shall not contain lead in excess of 0.015 mg/L. To protect all beneficial uses, the RWQCB may adopt limits more stringent than MCLs.

The following MCLs are included as part of this rice-specific review:

- PMCLs for inorganic chemicals (Table 64431-A)
- PMCLs for organic chemicals that are registered for use on rice (selected from Table 64444-A)
- SMCLs (Tables 64449-A and Tables 64449-A)

These tables are provided in Appendix G. The Basin Plan includes language that enables the RWQCB to make exceptions to the default beneficial uses. These exceptions were adopted consistent with the criteria in SWRCB

[6] *Water Quality for Agriculture*, published by the Food and Agriculture Organization of the United Nations, contains recommended goals protective of various agricultural uses of water, including irrigation of various types of crops and stock watering. This goal is for salt-sensitive crops, considering a number of different factors, including climate, precipitation, and irrigation management. (Ayers and Wescot 1985)

Resolution No. 88-63, Sources of Drinking Water Policy. The following water-based criteria are pertinent to this GAR:

- "The total dissolved solids (TDS) exceed 3,000 mg/l (5,000 µmhos/cm, electrical conductivity) and it is not reasonably expected by the Regional Water Board [for the groundwater] to supply a public water system, or
- There is contamination, either by natural processes or by human activity (unrelated to a specific pollution incident), that cannot reasonably be treated for domestic use using either Best Management Practices or best economically achievable treatment practices"

5.1.3 AGR Standards

The RWQCB is currently undertaking a process to develop a Basin Plan amendment for Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS). Through this process, water quality goals may be developed and adopted as site-specific WQOs. As part of the ongoing implementation of the LTILRP, groundwater quality results may be reevaluated in the context of CV-SALTS requirements.

5.2 Nitrate

Nitrate is a priority of the LTILRP; therefore, a primary purpose of this GAR is to review existing data to determine if rice farming adversely impacts nitrate concentrations in groundwater. For this reason, nitrate is discussed separately from other constituents in its own section.

5.2.1 Nitrate Water Quality Thresholds

Groundwater samples taken from the USGS Rice Wells, Shallow Domestic Wells, and GAMA Wells networks described in Section 4 were reviewed for nitrate detections. Map 5-1 shows mapped maximum concentrations measured in the three well networks. The data were grouped in relation to the MCL as follows:

- Less than 0.5 MCL (or less than 5 mg/L of NO2+NO3-N)
- Between 0.5 MCL and MCL (or between 5 mg/L and 10 mg/L of NO2+NO3-N)
- Above MCL (or above 10 mg/L of NO2+NO3-N)

Ammonium is also briefly discussed because it is a potential source of nitrate when nitrification occurs in oxidizing soils.

5.2.2 Nitrate in USGS Rice Wells

Figure 5-1 shows the full dataset for all 28 USGS Rice Wells. Figure 5-2 shows the nitrate trends in the five USGS Rice Wells that were sampled nine times from 1997 through 2010.

FIGURE 5-1
Nitrate Concentrations in USGS Rice Wells

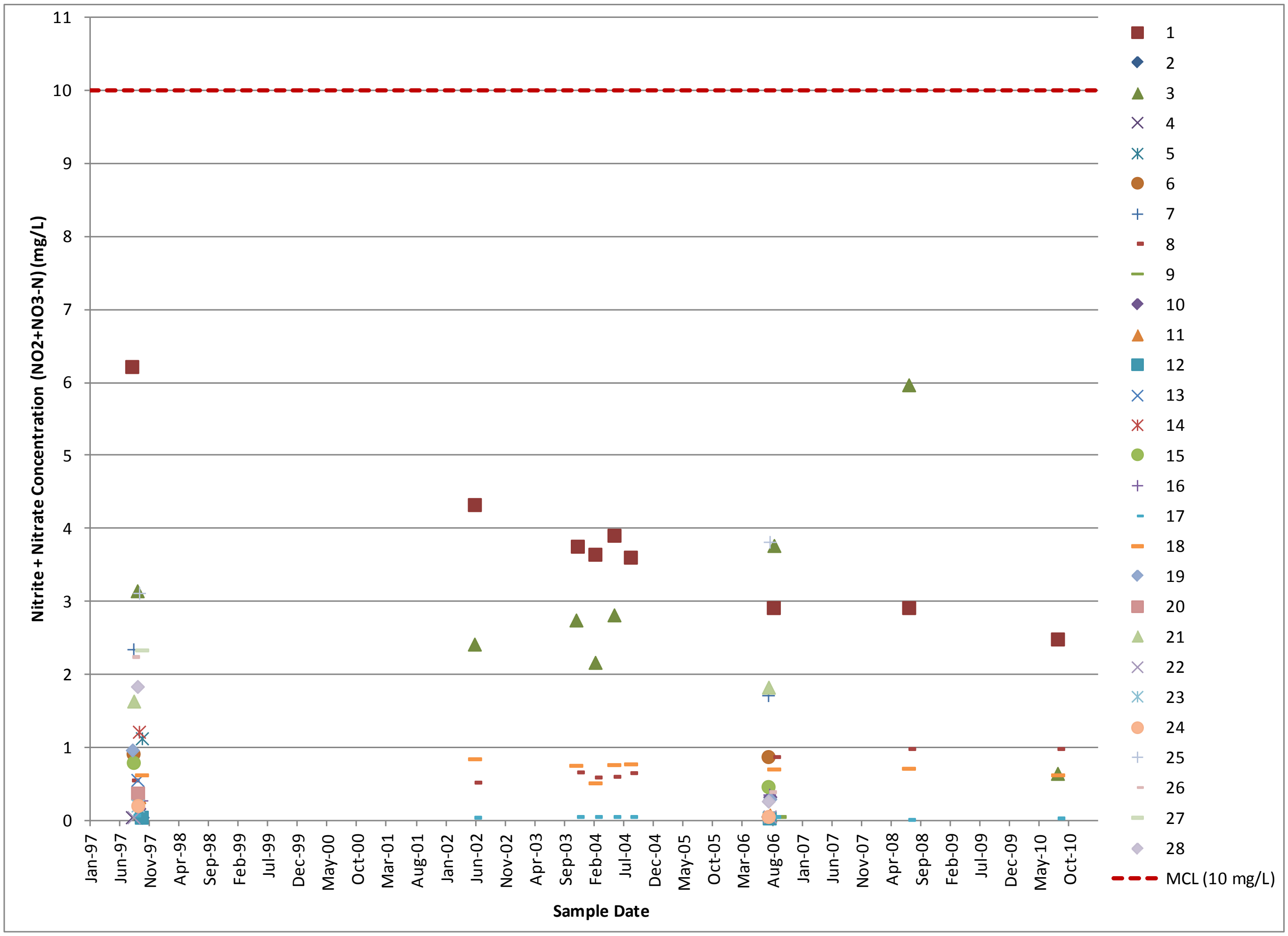
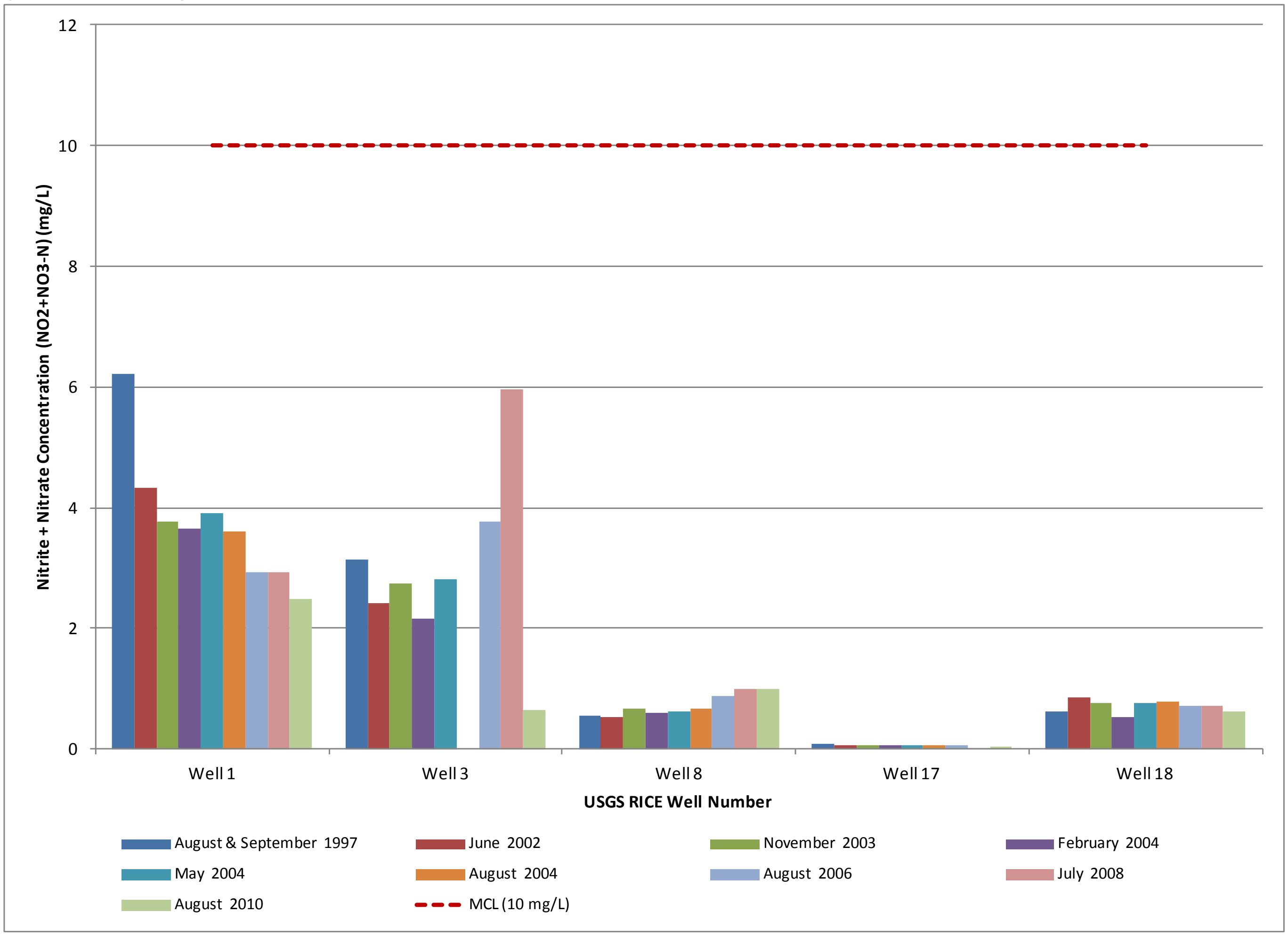


FIGURE 5-2

Nitrate Trends in Select USGS Rice Wells

Note: For Well 17, 7 out of the 9 samples were below the laboratory detection limit. The other 2 samples showed a detection of less than 0.1 mg/L.



The following summarizes the nitrate water quality data collected at the USGS Rice Wells:

- For the entire period of record, no USGS Rice Well had an NO2+NO3-N level above the 10 mg/L MCL.
- Two USGS Rice Wells had single nitrate readings above 5 mg/L but below the MCL (Well 1 in 1997 and Well 3 in 2008). The maximum concentration detected in a USGS Rice Well was 6.22 mg/L in Well 1. The most recent results for Wells 1 and 3 show concentrations less than 5 mg/L. Further evaluation of Well 1 showed it to be located at the edge of rice fields, yet surrounded by other land uses and urban areas. Therefore, this well may be influenced by other land uses in addition to rice farming. Also, a redox conditions analysis performed by the USGS showed that this well had oxic conditions (containing water with chemistry indicating oxidizing chemical conditions). This water would be less likely to come from rice fields (which are usually reduced due to prolonged flooding) and may explain the higher levels of nitrate in this well (USGS 2001a).
- The five USGS Rice Wells sampled nine times provide a multiyear trend monitoring dataset. Wells 1, 17, and 18 show decreasing trends in nitrate levels. Well 3 had a spike in nitrate concentration in 2008, but a subsequent sample in 2010 had a level of 0.65 mg/L. Well 8 shows slight increase over time, but all values are below 1 mg/L, which is much lower than the MCL and lower than the 3 mg/L threshold for naturally occurring nitrate; therefore, this should not be considered as an upward trend.
- Eighty-four percent of the USGS Rice Wells samples had nitrate concentrations below 3 mg/L, which is the level generally considered to be indicative of potential impacts by human activities. Therefore, it can be assumed that the nitrate levels in these wells are naturally occurring (USGS 2001a).

- Well 5, the only other well besides Well 1 to show oxic conditions, had a nitrate concentration of 1.1 mg/L, well below the MCL.
- Concentrations of ammonia (measured as N) were either not detected or were below 1 mg/L for all USGS Rice Wells. This is expected, given the relatively low mobility of ammonium in soils and the slow percolation rates out of rice fields. Therefore, ammonia is not a constituent of concern in the shallow groundwater under rice fields.

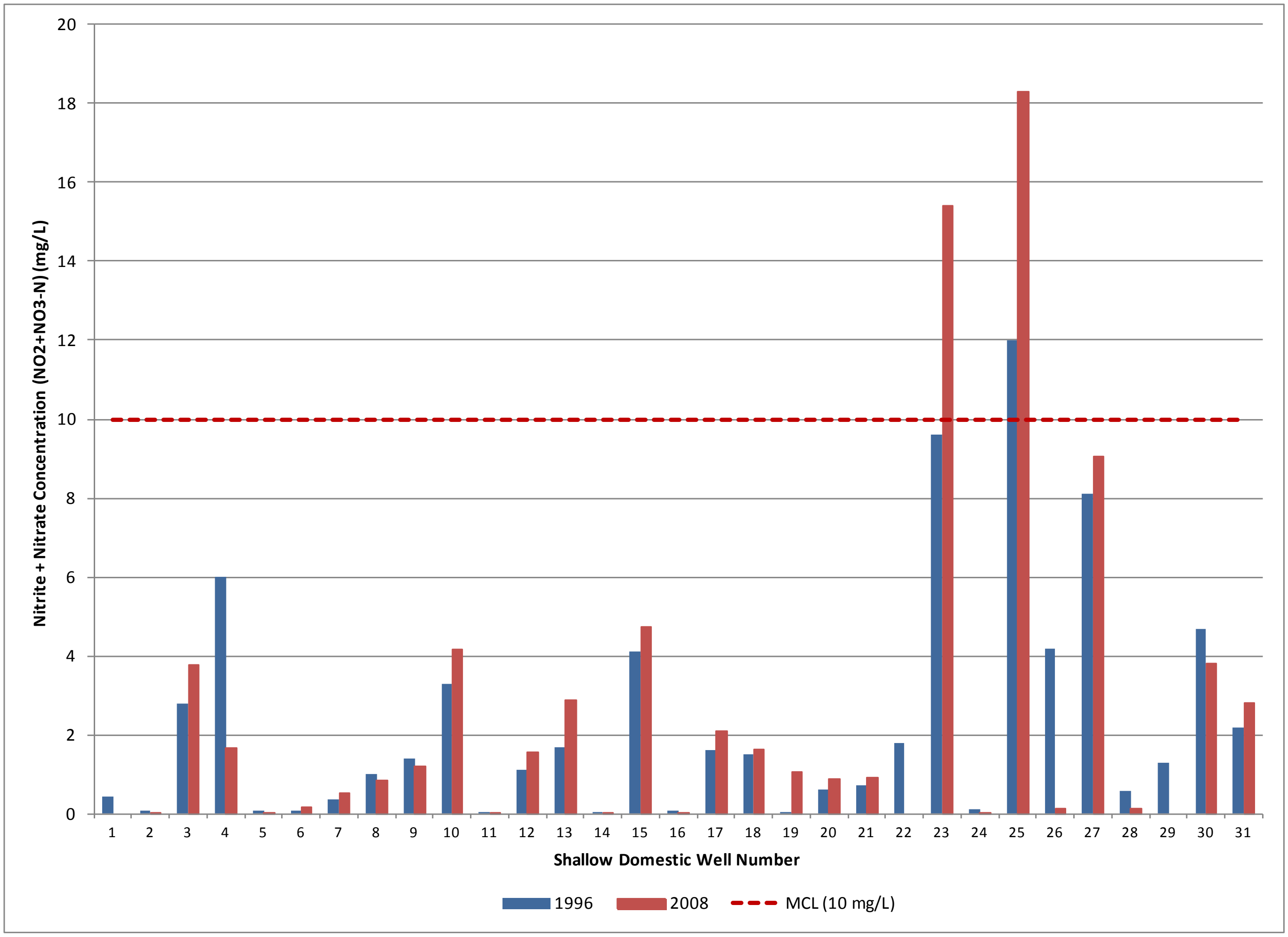
Appendix E-3 provides satellite maps showing land use surrounding each of the USGS Rice Wells and provides an additional description of the representativeness of these wells for rice farming impact assessment.

5.2.3 Nitrate in Shallow Domestic Wells

Figure 5-3 shows the results of the two sampling events (1996 and 2008) conducted at Shallow Domestic Wells.

FIGURE 5-3

Nitrate Concentration in Shallow Domestic Wells



The following summarizes the nitrate water quality data collected at the Shallow Domestic Wells:

- Of 31 shallow domestic wells, 29 had nitrate results below the MCL.
- Two Shallow Domestic Wells (Wells 23 and 25) had nitrate concentrations above the MCL. These wells are located in the northeastern Sutter County area in the Sutter Groundwater Basin, and both show an increase in nitrate concentrations of approximately 6 mg/L in 2008 relative to the 1996 sampling event. This area is downgradient of Yuba City and directly upgradient of Sutter County rice fields. Therefore, these wells are not likely impacted by rice.

- Two Shallow Domestic Wells (Wells 4 and 27) located in north Sutter County had nitrate concentrations above half the MCL, but below the MCL values (Well 4 at 6 mg/L, and Well 27 at 8.1 mg/L). Well 4 is located in northern Sacramento County in an area of no rice production. Well 27 is located adjacent to a rice field, but is also surrounded by field crops and deciduous fruit and nut trees (as seen on Maps 2-2 and 3-2).

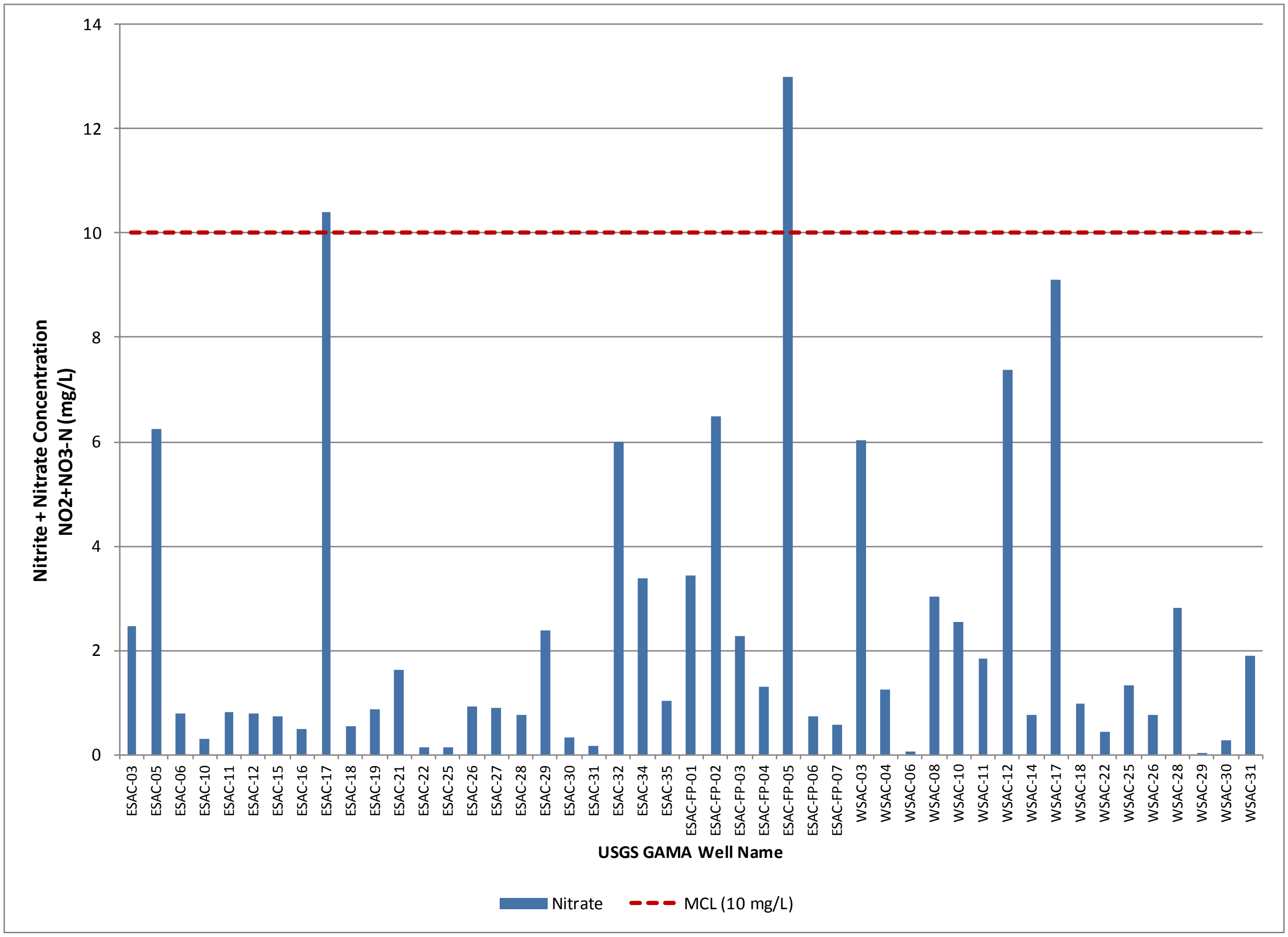
For comparison, Well 24 is directly downgradient of Yuba County rice fields and shows no nitrate impact on groundwater.

5.2.4 Nitrate in USGS GAMA Wells

Map 5-1 shows the location and NO2+NO3-N concentration of deep GAMA Wells sampled in 2006 relative to the MCL, and Figure 5-4 shows these concentrations at each respective well.

FIGURE 5-4

Nitrate Concentrations in USGS GAMA Wells



The following summarizes the results:

- Two of 60 deep GAMA wells had concentrations above the MCL. These wells were further evaluated as follows: One well is located in Yolo County outside of rice-growing areas. The other well is located in southern Butte County, upgradient of the North Yuba Groundwater Basin and directly upgradient of rice fields. It is also in an area where higher nitrate concentrations have been repeatedly observed (see Section 2.3.3). Because of their locations, the nitrate concentration of both wells does not seem to be attributable to rice farming.
- Six GAMA Wells (five grid wells and one flow-path well), including the two wells exceeding the MCL, had nitrate concentrations between half the MCL and the MCL. Four of these wells are located upgradient of rice-farming areas: two wells in Glenn County, one well in Sutter County, and one well in Colusa County. Of the

remaining two wells, one in Glenn County is located in a wide area of non-rice land use, and one is located in Colusa County at the edge of rice land use. These two wells may have some rice influence, but are also influenced by non-rice land uses. In general, these deeper groundwater quality observations are not indicative of rice-growing land use impacts.

- Concentrations of ammonia (measured as N) were either not detected or below 1 mg/L for all GAMA wells. Therefore, ammonia is not a constituent of concern in the deeper groundwater near rice fields.

5.3 Salinity Indicators

Rice plants have a low salinity tolerance of about 430 mg/L of TDS in irrigation water (or an effective soil EC of about 1.8 dS/m, which relates to approximately 1.2 dS/m in irrigation water [Dickey and Nuss 2002]). Rice farmers do not apply irrigation water specifically for leaching. Rather, the high-quality source water, combined with maintenance of a standing irrigation flood and likely seasonal surface water connectivity, prevent accumulation of salinity in the root zone. Where high salinity concentrations are detected in shallow groundwater, it is improbable that they result from rice farming; instead, they likely result from historical deposits of alkalinity or non-rice sources (Dickey and Nuss 2002). In the Sutter Basin, high salinity is likely caused by natural upwelling of connate saline water from depth.

Table 5-2 provides a summary of salinity indicators detection in the three USGS well networks. A detailed discussion of exceedances is provided in the following subsections.

TABLE 5-2
Drinking Water Quality Standards for Salinity and Observed Detections in USGS Wells

Indicator	Unit of Drinking Water Standard	Minimum Detection	Maximum Detection	Water Quality Threshold (SMCL TO, Table 64449-B)	Number of Wells with at Least One Sample Exceeding Upper Limit
USGS Rice Wells					
Specific Conductance	µS/cm at 25°C	267	13,800	Recommended: 900 Upper Limit: 1,600 Short Term: 2,200	7
TDS	mg/L	166	8,734	Recommended: 500 Upper Limit: 1,000 Short Term: 1,500	6
Shallow Domestic Wells					
Specific Conductance	µS/cm at 25°C	139	2,490	Recommended: 900 Upper Limit: 1,600 Short Term: 2,200	2
TDS	mg/L	126	1,330	Recommended: 500 Upper Limit: 1,000 Short Term: 1,500	2
USGS GAMA Wells					
Specific Conductance	µS/cm at 25°C	206	2,380	Recommended: 900 Upper Limit: 1,600 Short Term: 2,200	4
TDS	mg/L	166	1,330	Recommended: 500 Upper Limit: 1,000 Short Term: 1,500	2

mg/L: milligrams per liter
µS/cm: microSiemens per centimeter
MCL: Maximum Contaminant Level
PMCL: Primary MCL
SMCL: Secondary MCL

5.3.1 Specific Conductance

Specific conductance is a field measurement. The field measurements observed for each of the three USGS datasets are presented below.

5.3.1.1 Specific Conductance in USGS Rice Wells

Figure 5-5 shows the minimum and maximum specific conductance observations in USGS Rice Wells. Figure 5-6 shows the trends in USGS Rice Wells.

FIGURE 5-5
Minimum and Maximum Specific Conductance Observed in USGS Rice Wells

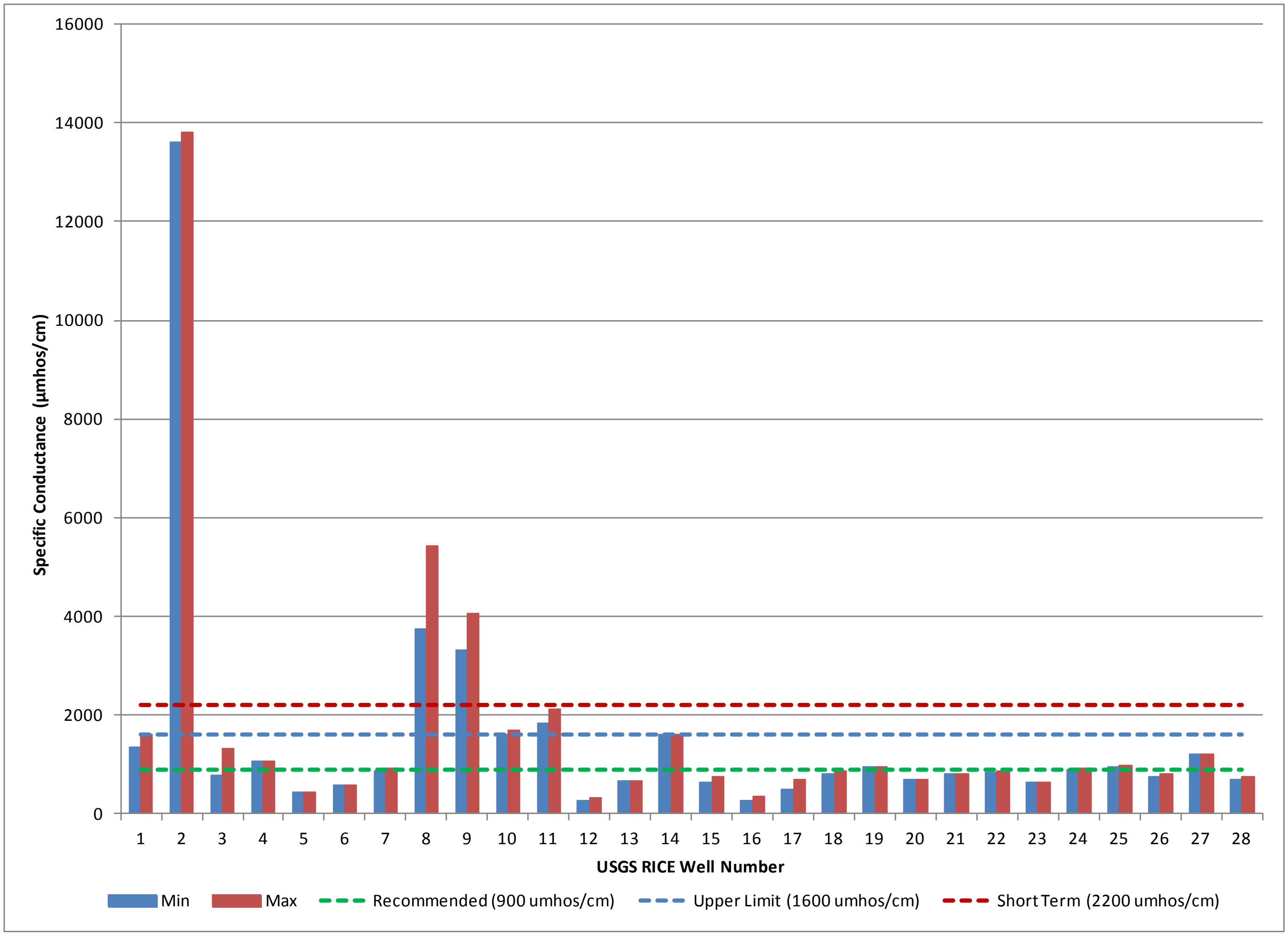
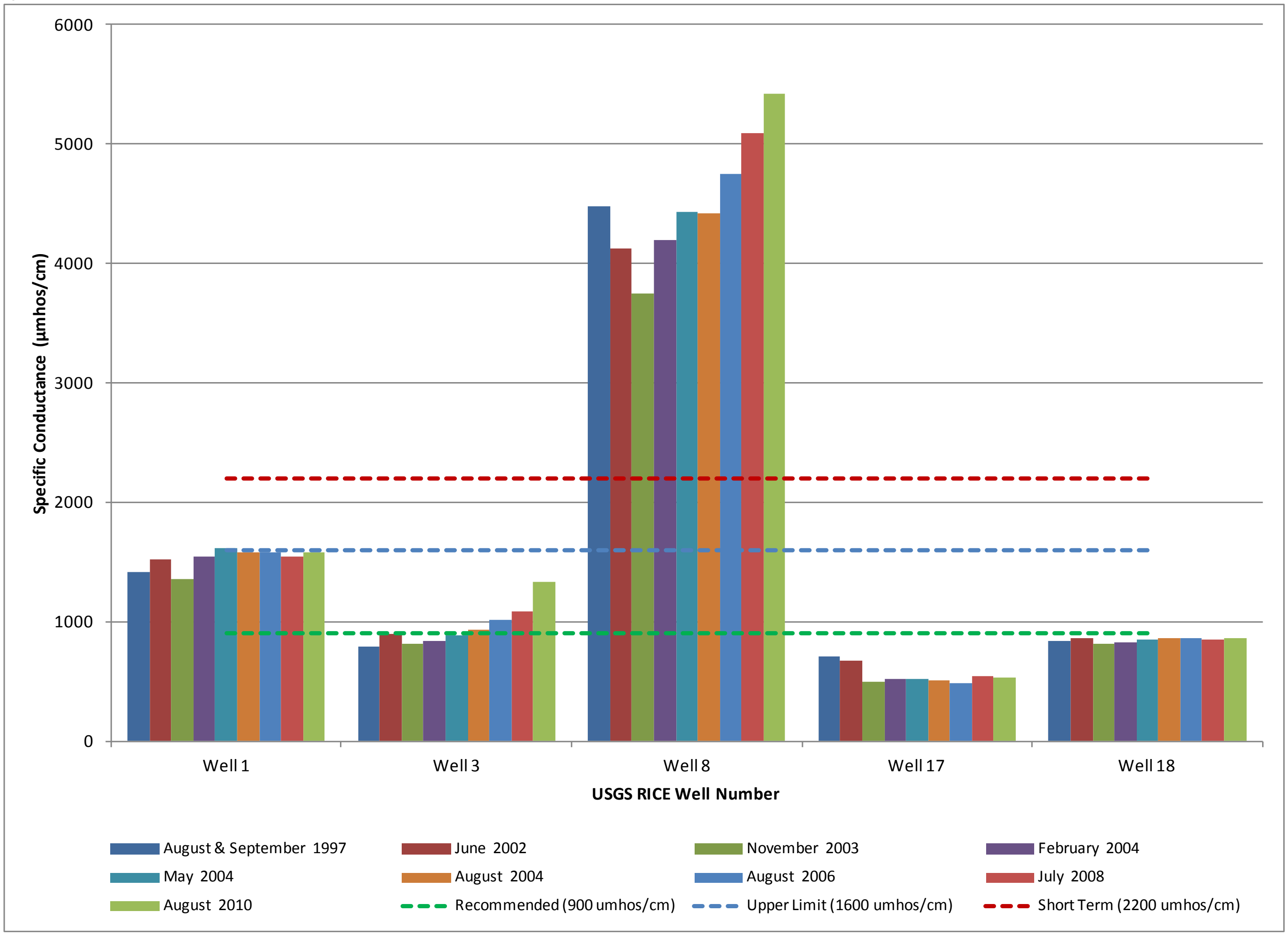


FIGURE 5-6
Specific Conductance Trends in USGS Rice Wells



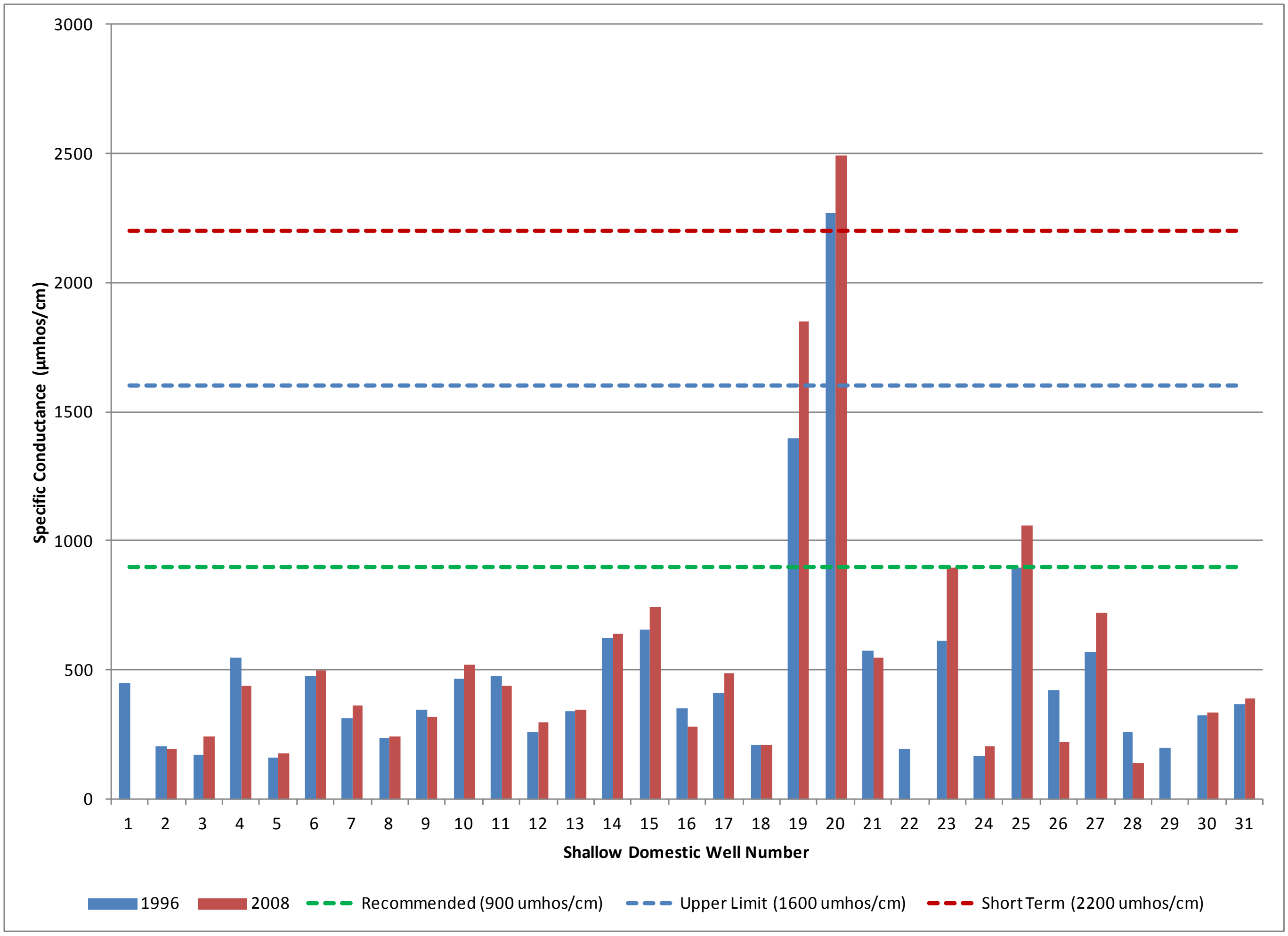
The following summarizes the specific conductance measurements observed in USGS Rice Wells:

- In 21 of 28 USGS Rice Wells, specific conductance was below the upper limit SMCL. In 25 of the 28 wells, specific conductance was less than the short-term PMCL.
- A maximum observed specific conductance of 13,800 µmhos/cm was observed in Well 2, located south of the Sutter Buttes. Two additional wells had specific conductance above the short-term SMCL; Well 8 and Well 9 had maximum observed specific conductance of 5,420 and 4,060 µmhos/cm, respectively.
- As shown in Figure 5-6, specific conductance values fluctuate between sampling events for Wells 3 and 8. Well 3 shows a slight increase in specific conductance over time. Differences of 1,000 µmhos/cm are observed, both in the increasing and decreasing direction for Well 8, with an increasing trend shown for the last 6 sampling events.

5.3.1.2 Specific Conductance in Shallow Domestic Wells

Figure 5-7 shows the specific conductance observations in Shallow Domestic Wells.

FIGURE 5-7
Specific Conductance Observations in Shallow Domestic Wells



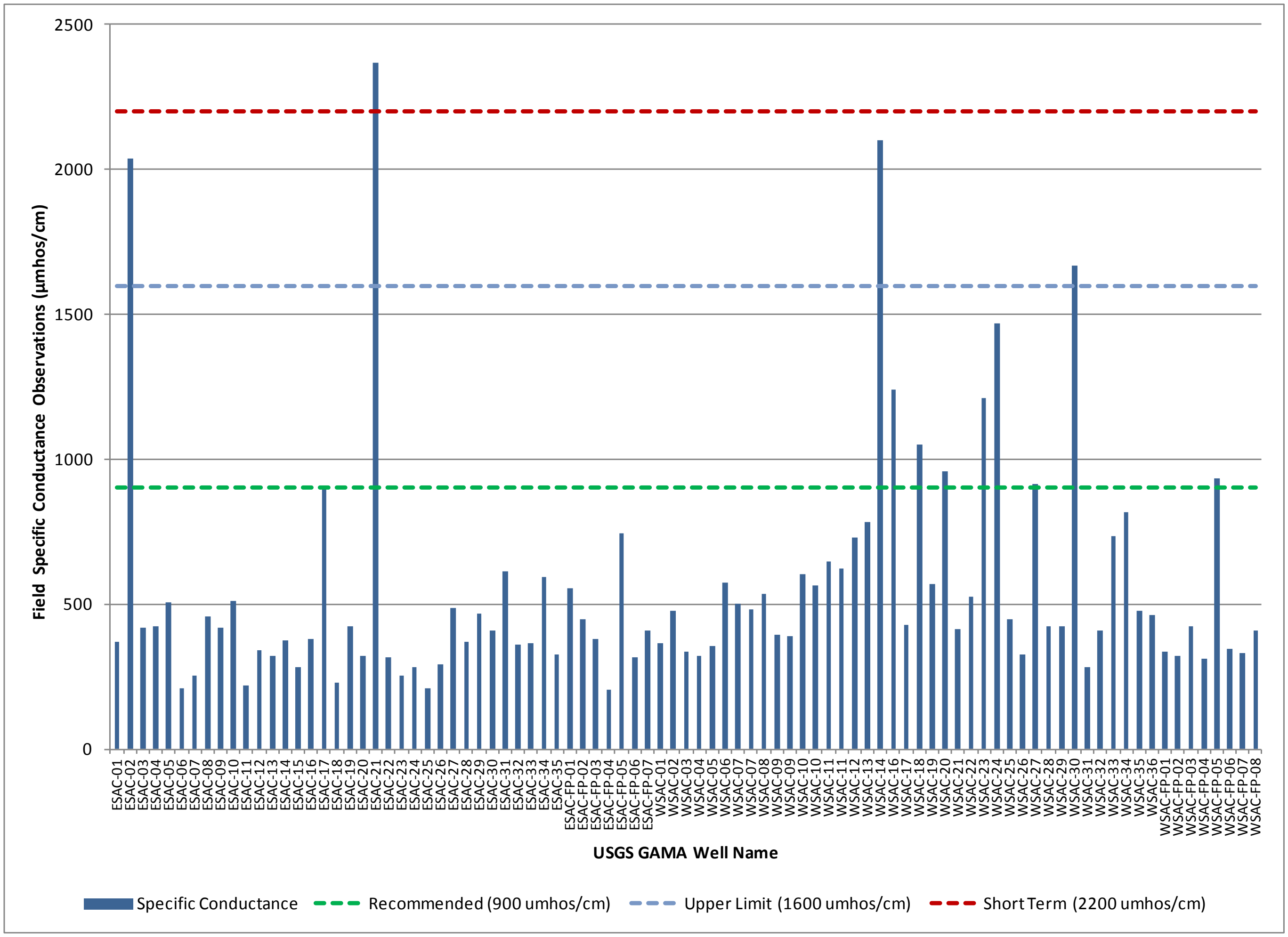
The following summarizes the specific conductance observations in Shallow Domestic Wells:

- In 29 of 31 wells, the specific conductance observations were below the upper limit SMCL.

5.3.1.3 Specific Conductance in USGS GAMA Wells

Figure 5-8 shows the specific conductance observations in USGS GAMA Wells.

FIGURE 5-8
Specific Conductance Observations in USGS GAMA Wells



The following summarizes the specific conductance observations recorded for USGS GAMA Wells:

- In 80 of 84 wells, observed specific conductance below the upper limit SMCL. Only one well had an observed specific conductance above the short-term SMCL.

5.3.2 TDS

Map 5-2 shows the TDS results from the USGS Rice Wells, Shallow Rice Wells, and USGS GAMA Wells.

5.3.2.1 TDS in USGS Rice Wells

Figure 5-9 shows the minimum and maximum observed TDS concentration in each USGS Rice Well for the period 1997 through 2010. Figure 5-10 shows the trends of the five wells sampled nine times.

FIGURE 5-9
Minimum and Maximum TDS Concentrations in USGS Rice Wells

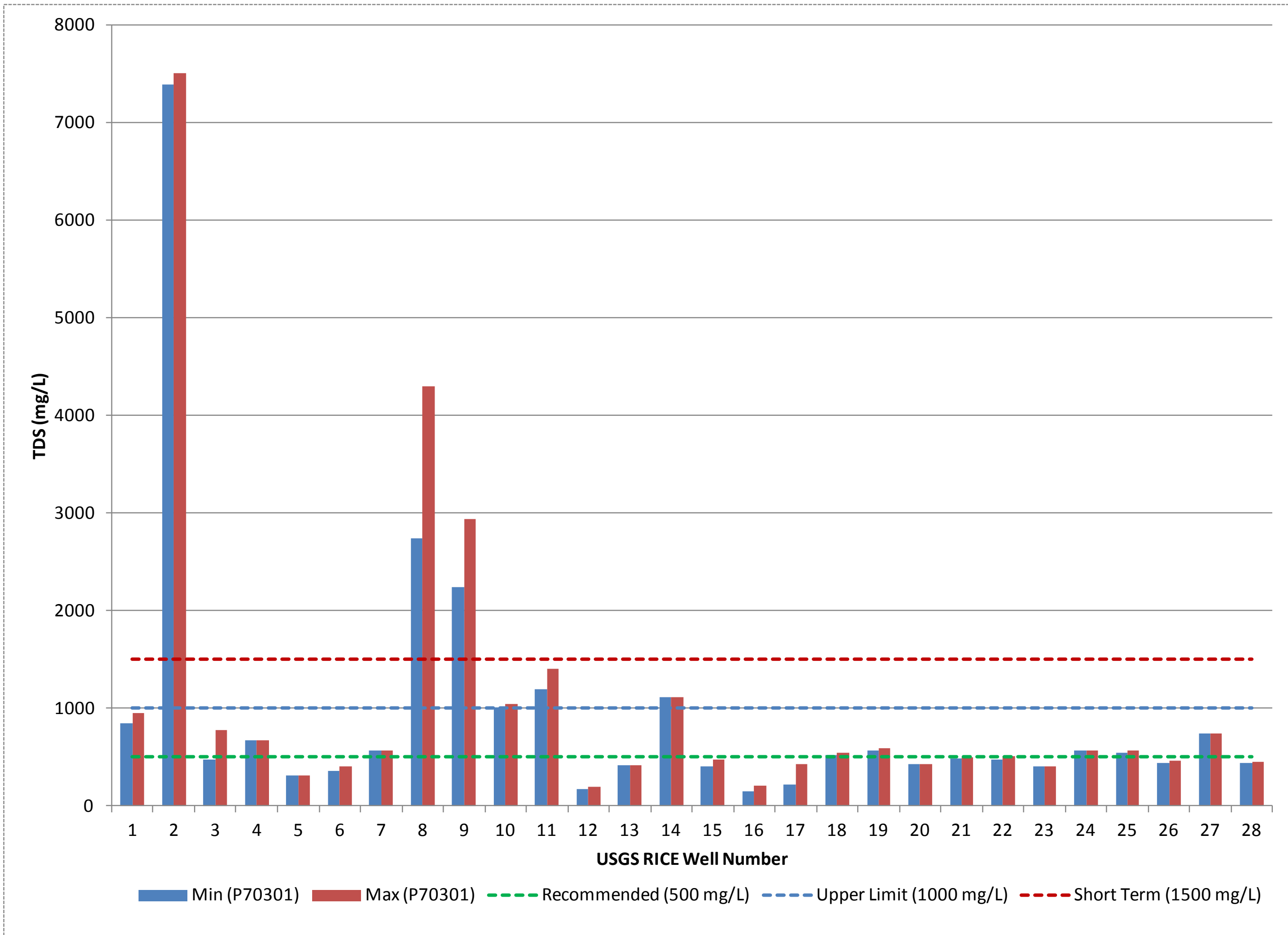
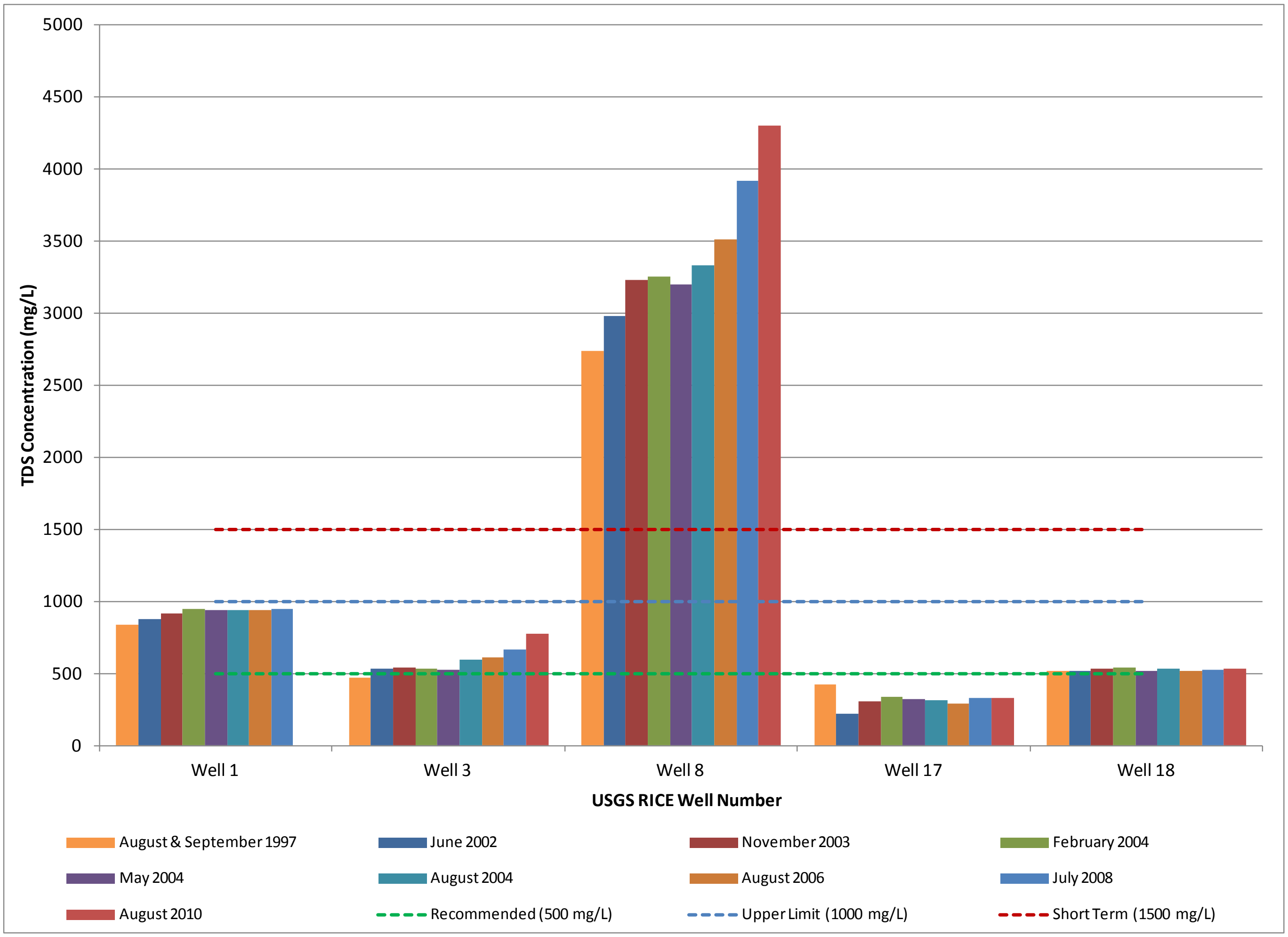


FIGURE 5-10
TDS Trends Observed in USGS Rice Wells



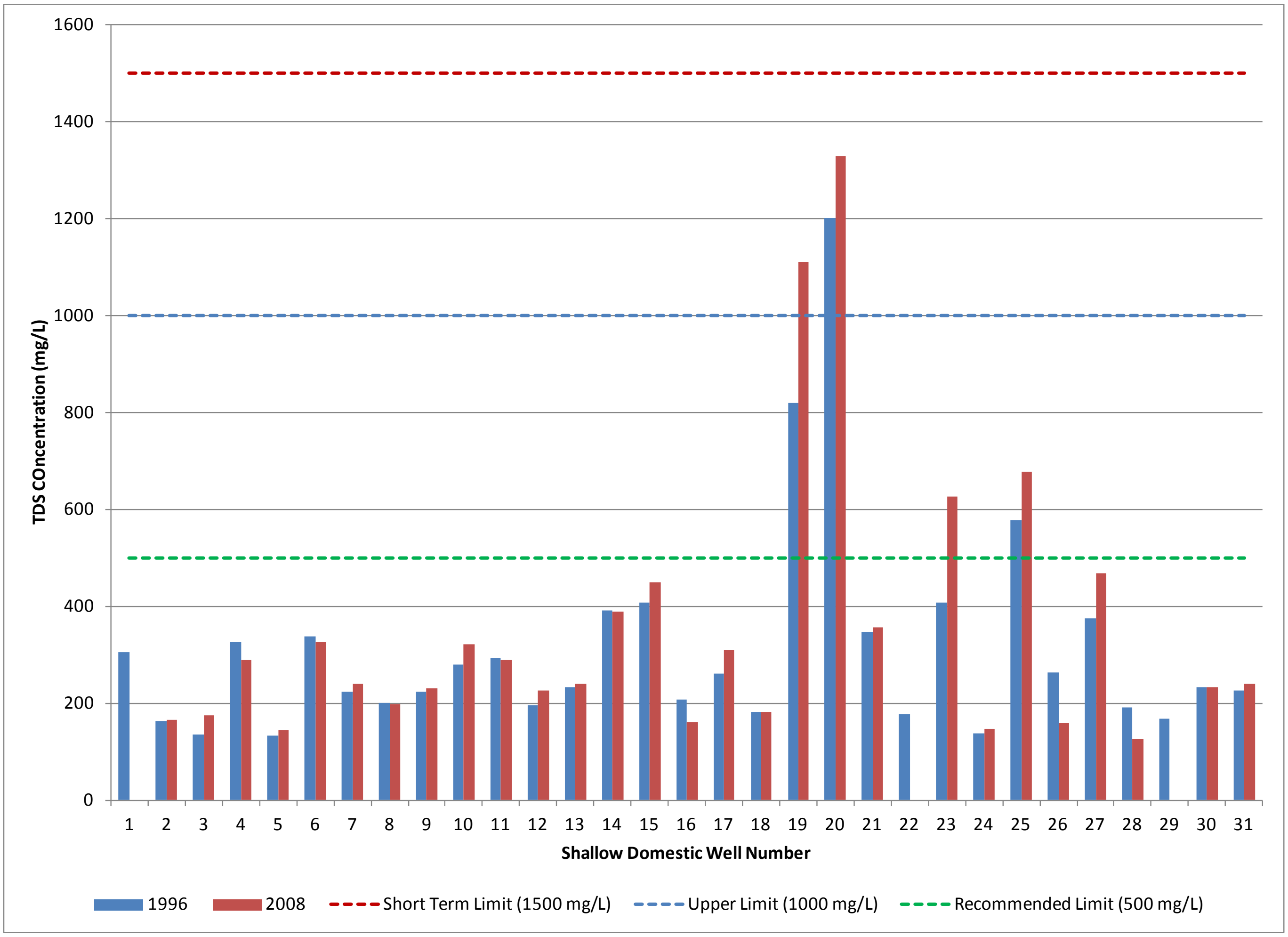
The following summarizes the TDS results of the USGS Rice Wells:

- In 22 of 28 USGS Rice Wells, the maximum observed TDS concentration was less than 1,000 mg/L.
- Three wells had maximum observed TDS concentrations between 1,000 mg/L and the 1,500 mg/L upper limit SMCL, and three wells had maximum observed TDS concentrations above 1,500 mg/L.
- The maximum observed TDS concentration was detected at USGS Rice Well 2, located in the southern Sutter Groundwater Subbasin in Sutter County (see Maps 3-1 and 5-2), with a concentration of 7,510 mg/L (brackish water). This well exceeds the 3,000 mg/L drinking water quality threshold. This well is located south of the Sutter Buttes, which is an area where high TDS levels in deeper wells are also generally found (USGS 2001a). The source of high TDS levels in Well 2 is inconclusive at this time, but cannot reasonably be attributed to rice land use. Indeed, the presence of high TDS in deeper units suggests that near-surface irrigation is unlikely to be the source of salinity in this area.
- USGS Rice Wells 8 and 9 also showed TDS concentrations above 2,000 mg/L. This area, between Arbuckle and Maxwell in Colusa County, has high levels of TDS as identified in past reports (see Section 2.3.3).
- As shown in Figure 5-10, TDS trends within four of five wells are very consistent. The exception to this is Well 8, which shows an apparent upward TDS trend. Well 3 also shows a slightly fluctuating and increasing trend in TDS concentrations. Rice farming is not believed to be the cause for this upward trend; a more regional analysis, such as performed under CV-Salts would be appropriate for this area.

5.3.2.2 TDS in Shallow Domestic Wells

Figure 5-11 shows the TDS results of sampling conducted at Shallow Domestic Wells in 1996 and 2006.

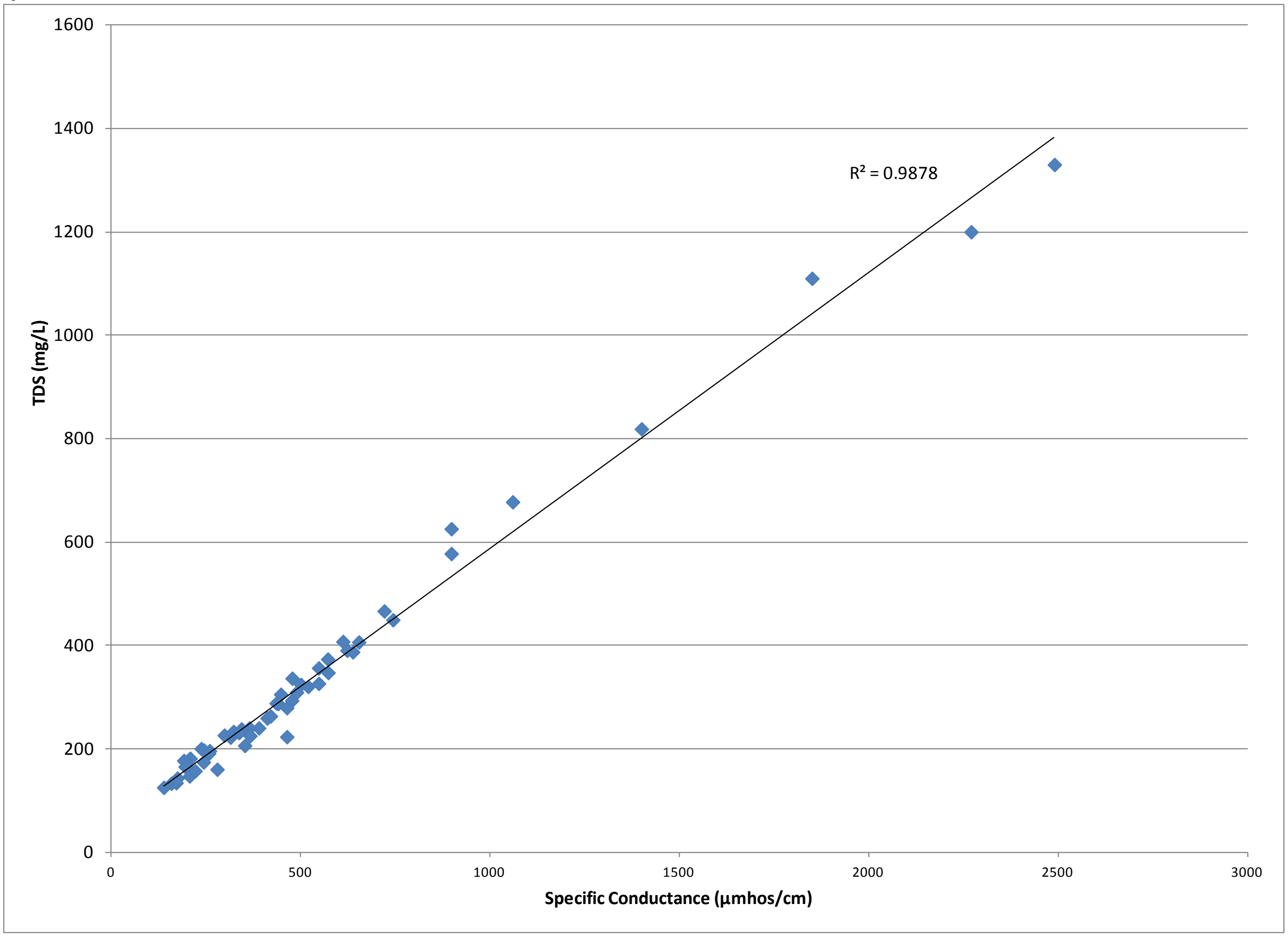
FIGURE 5-11
TDS Concentrations in Shallow Domestic Wells



The following summarizes the results of TDS sampling in Shallow Domestic Wells:

- Maximum observed TDS concentrations were less than 1,000 mg/L in 29 of 31 Shallow Domestic Wells.
- Wells 19 and 20 had concentrations greater than 1,000 mg/L.
- Figure 5-12 shows the specific conductance versus TDS plot for the Shallow Domestic Well dataset. As shown, there is a strong correlation between the two parameters, as expected.

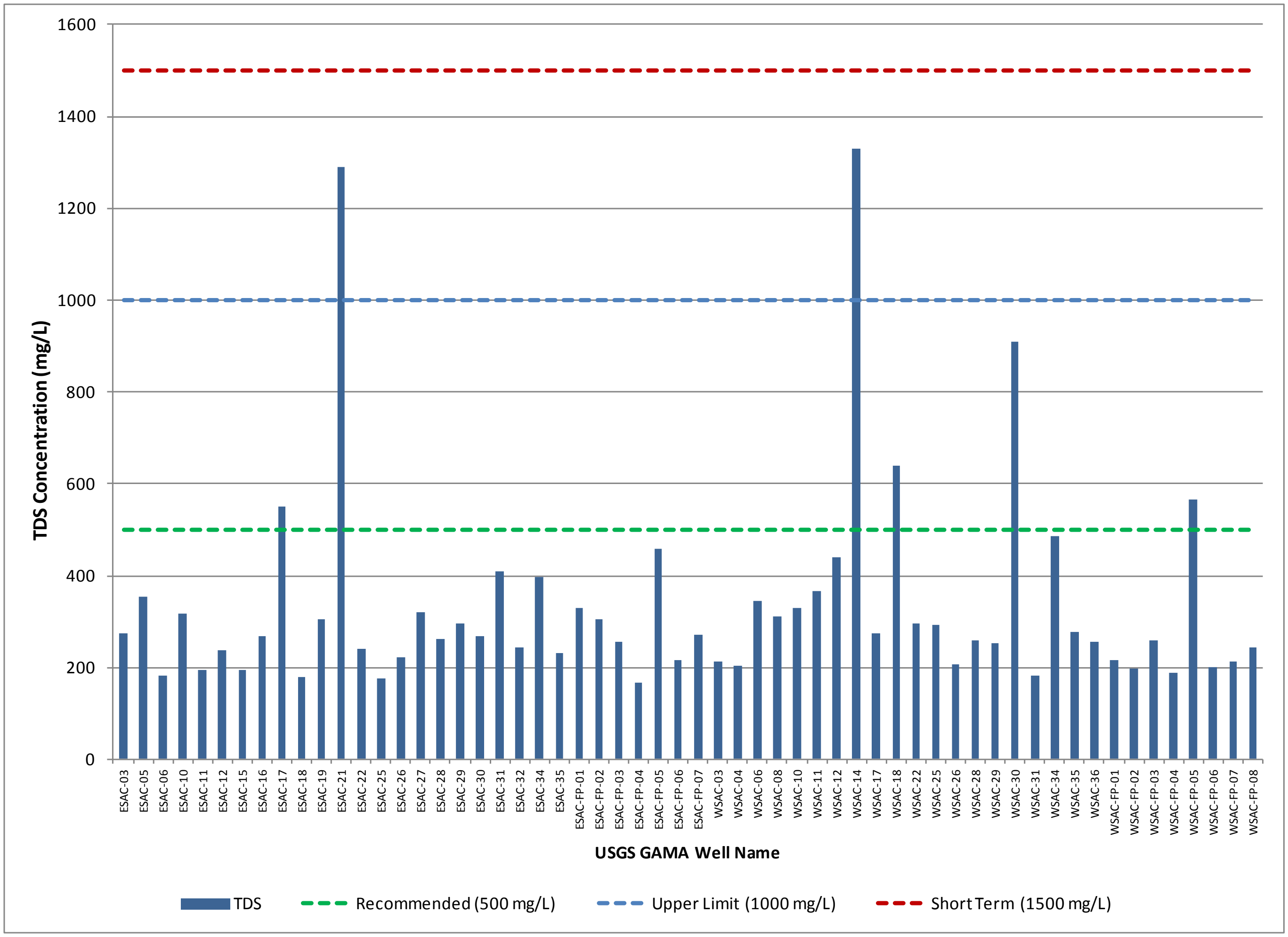
FIGURE 5-12
Specific Conductance vs. TDS in Shallow Domestic Wells



5.3.2.3 TDS in USGS GAMA Wells

Figure 5-13 shows the TDS results of sampling conducted at USGS GAMA Wells.

FIGURE 5-13
TDS Concentrations in USGS GAMA Wells



The following summarizes the TDS results for USGS GAMA Wells:

- In 56 of 58 USGS GAMA Wells, TDS was less than the upper limit.
- A maximum observed TDS concentration of 1,330 mg/L was observed at Well WSAC-14.
- These results are consistent with the known low-salinity quality of deep groundwater in the SVGB.
- Specific conductance and TDS are well correlated for this dataset.

5.4 General Parameters

General parameters in the well samples were evaluated at the request of the Central Valley RWQCB. This evaluation is included to provide an overview of the general water quality conditions of the wells sampled in the three USGS datasets.

5.4.1 Thresholds for General Parameters

The results of each of the USGS Rice Wells were compared to applicable water quality thresholds, which are listed in Table 5-3. Those parameters that were observed above established thresholds were further reviewed for each dataset, in a similar level of detail for all parameters. Field data generally include pH, temperature, dissolved oxygen, specific conductance, and TDS.

TABLE 5-3
Drinking Water Standards for General Parameters

Constituent	Drinking Water Standard	Unit of Drinking Water Standard	Type of Standard	Source*
Metals				
Aluminum (Al)	1,000 200	µg/L	PMCL SMCL	CDPH (1989) CDPH (1994)
Barium (Ba)	1,000	µg/L	PMCL	CDPH (1977)
Beryllium (Be)	4	µg/L	PMCL	CDPH (1994)
Cadmium (Cd)	5	µg/L	PMCL	CDPH (1994)
Chromium (Cr)	50	µg/L	PMCL	CDPH (1977)
Copper (Cu)	1,300	µg/L	PMCL	CDPH (1991)
Iron (Fe)	300	µg/L	SMCL	CDPH
Iron(II) (FeII)	300	µg/L	SMCL	CDPH
Lead (Pb)	15	µg/L	PMCL	CDPH (1995)
Manganese (Mn)	50	µg/L	SMCL	CDPH
Nickel (Ni)	100	µg/L	PMCL	CDPH (1994)
Silver (Ag)	100	µg/L	SMCL	CDPH
Thallium (Tl)	2	µg/L	PMCL	CDPH (1994)
Vanadium (V)	50 500	µg/L µg/L	NL RL	CDPH (2000)
Zinc (Zn)	5,000	µg/L	SMCL	CDPH
Non-metals				
Antimony (Sb)	6	µg/L	PMCL	CDPH (1994)
Arsenic (As)	10	µg/L	PMCL	CDPH (2008)
Boron (B)	1,000 10,000	µg/L	NL RL	CDPH
Chloride (Cl)	250	mg/L	SMCL	CDPH
Fluoride (F)	2	mg/L	PMCL	CDPH (1998)
Selenium (Se)	50	µg/L	PMCL	CDPH (1994)
Sulfate (S)	250	mg/L	SMCL	CDPH

* Where dates are not listed in this column, no adoption date is provided on the CDPH table on the agency's web site.

RL: reporting limit
µg/L: micrograms per liter
PMCL: Primary MCL
SMCL: Secondary MCL

5.4.2 General Parameters Detected Above MCLs

In the three USGS datasets reviewed, the following parameters were found to have one or more results that exceeded the applicable water quality thresholds:

- Arsenic
- Barium
- Cadmium
- Chloride
- Iron
- Manganese
- Salinity measurements (specific conductance and TDS)
- Sulfate

Tables 5-4 through 5-6 provide additional detail for the USGS Rice Wells, Shallow Domestic Wells, and USGS GAMA wells, respectively. In summary, the general parameters show low concentrations in the Shallow Domestic Wells with very few drinking water standard exceedances. In general, naturally occurring parameters are found in groundwater where they have been mobilized in aquifer sediments. For example, constituents such as Fe and Mn are quite mobile in reduced aquifer zones, which may then be sources of soluble Fe and Mn. Volumetrically, these aquifers dwarf overlying soils, so it is likely that naturally occurring loads from soil could result in elevated concentrations in groundwater. This is consistent with what is found in the literature regarding sources of these constituents in Sacramento Valley groundwater. Further discussion and summary of naturally occurring constituents appears in Section 6.3.2.

TABLE 5-4
General Parameters Detected Above MCLs in USGS Rice Wells

Metal and Non-metals Constituents	Units	Minimum Detection	Maximum Detection	Water Quality Threshold	Type of Threshold	Number of Wells With at Least One Sample Exceeding Upper Limit of Threshold
Arsenic	µg/L	0.38	15.25	10	PMCL Table 64431-A	3
Barium	µg/L	10.2	5,901.6	1,000	PMCL Table 64431-A	1
Cadmium	µg/L	E 0.01	7.43	5	PMCL Table 64431-A	3
Chloride	mg/L	2.27	4,772.20	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL (Table 64449-B)	1
Iron	µg/L	3.40	5,337.50	300	SMCL Table 64431-A	4
Manganese	µg/L	0.2	3,422.4	50	SMCL Table 64431-A	21
Sulfate	mg/L	5.05	2,628.63	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL (Table 64449-B)	4

TABLE 5-5
General Parameters Detected Above MCLs in Shallow Domestic Wells

Metal and Non-metals Constituents	Units	Minimum Detection	Maximum Detection	Water Quality Threshold	Type of Threshold	Number of Wells with at least one sample exceeding Upper Limit of Threshold
Arsenic	µg/L	0.46	46	10	PMCL Table 64431-A	9
Barium	µg/L	11	572	1,000	PMCL Table 64431-A	0
Cadmium	µg/L	0.02	0.05	5	PMCL Table 64431-A	0
Chloride	mg/L	1.03	683	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL Table 64449-B	1
Iron	µg/L	3	1,600	300	SMCL Table 64431-A	5
Manganese	µg/L	0.1	1,090	50	SMCL Table 64431-A	6
Sulfate	mg/L	1	255	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL (Table 64449-B)	0

TABLE 5-6
General Parameters Detected Above MCLs in USGS GAMA Wells

Metal and Non-metals Constituents	Unit of Detection & Drinking Water Standard	Minimum Detection	Maximum Detection	Water Quality Threshold	Type of Threshold	Number of Wells with at least one sample exceeding Upper Limit of Threshold
Arsenic	µg/L	0.24	80.6	10	PMCL Table 64431-A	10
Barium	µg/L	0.008	0.461	1,000	PMCL Table 64431-A	0
Cadmium	µg/L	0.02	3.54	5	PMCL Table 64431-A	0
Chloride	mg/L	1.79	626	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL (Table 64449-B)	1
Iron	µg/L	3	355	300	SMCL Table 64431-A	1
Manganese	µg/L	0.1	568	50	SMCL Table 64431-A	14
Sulfate	mg/L	0.18	12.6	Recommended: 250 Upper Limit: 500 Short Term: 600	SMCL (Table 64449-B)	0

5.4.2.1 Arsenic

Arsenic is a naturally occurring element present in some areas in Sacramento Valley geology. Rice farmers do not add materials that contribute arsenic to the environment. A PMCL of 10 µg/L has been established for arsenic. Map 5-3 shows the mapped maximum observed arsenic results for the three USGS datasets.

Arsenic in USGS Rice Wells

Figure 5-14 shows all of the arsenic results from the USGS Rice Wells for the period 1997 through 2010. Figure 5-15 shows the minimum and maximum arsenic observation for each well. Figure 5-16 shows the arsenic trends in the five wells that were sampled at greatest frequency.

FIGURE 5-14
Arsenic Observations in USGS Rice Wells

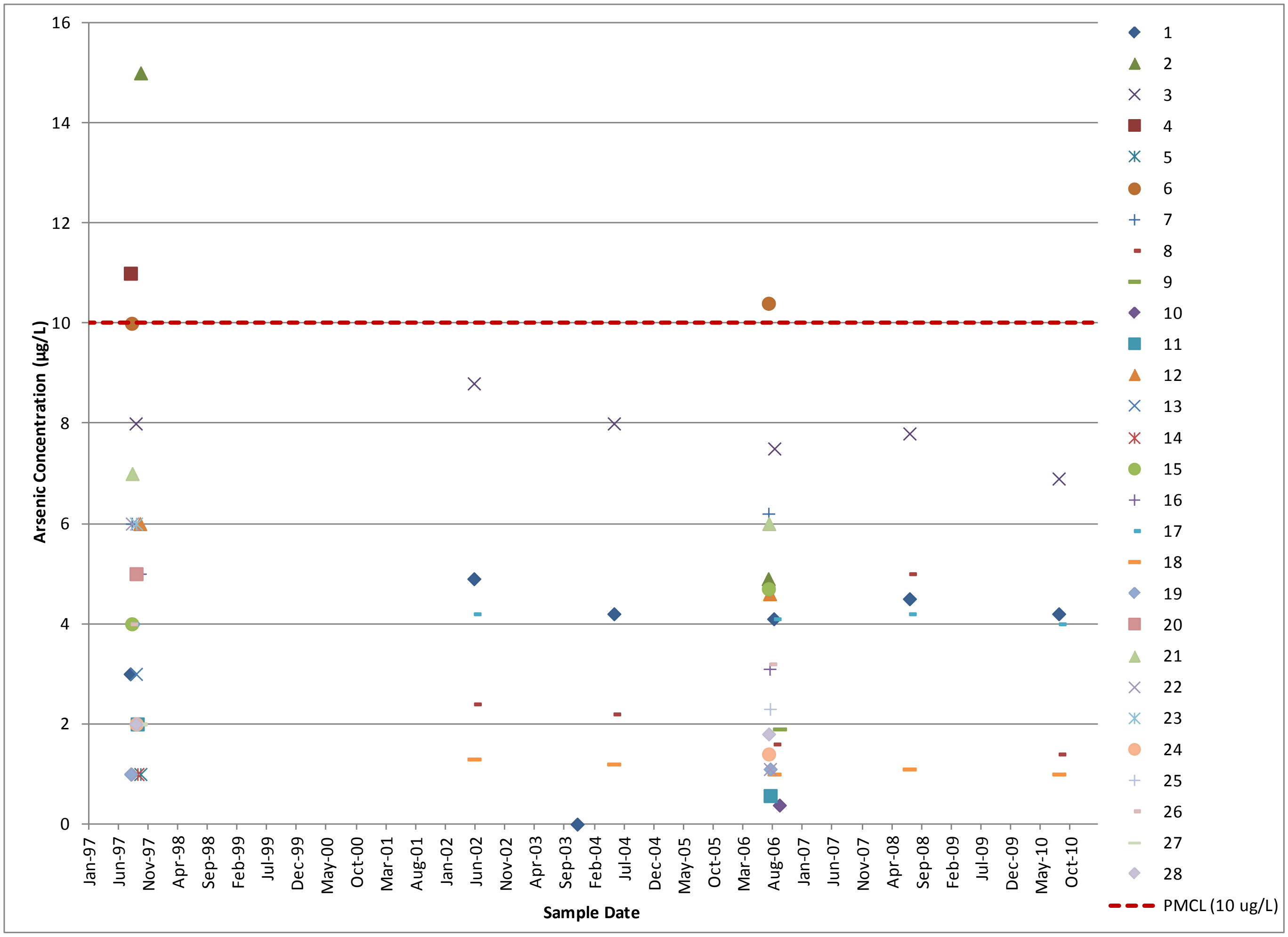


FIGURE 5-15
Arsenic Minimum and Maximum Observations in USGS Rice Wells

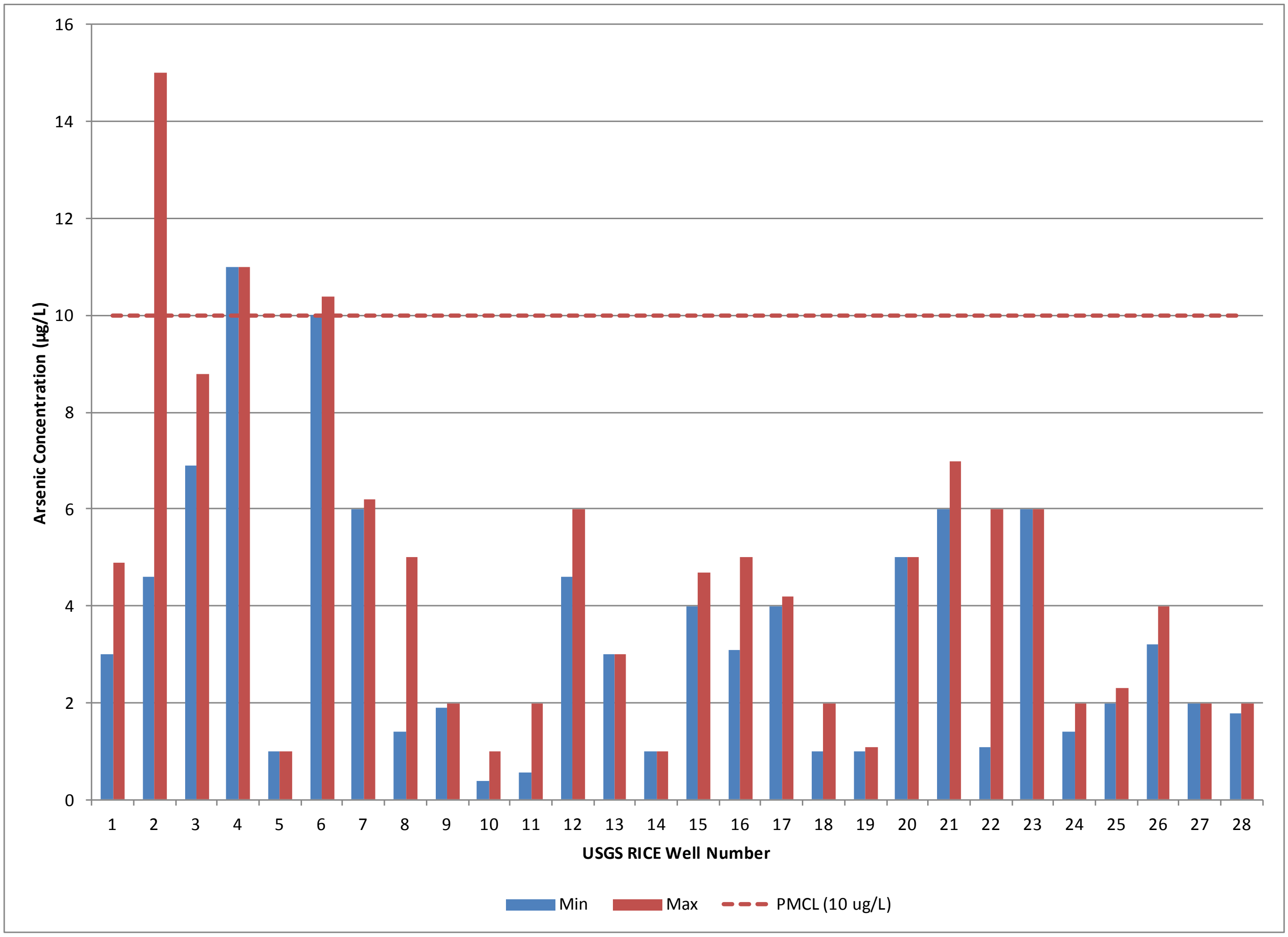
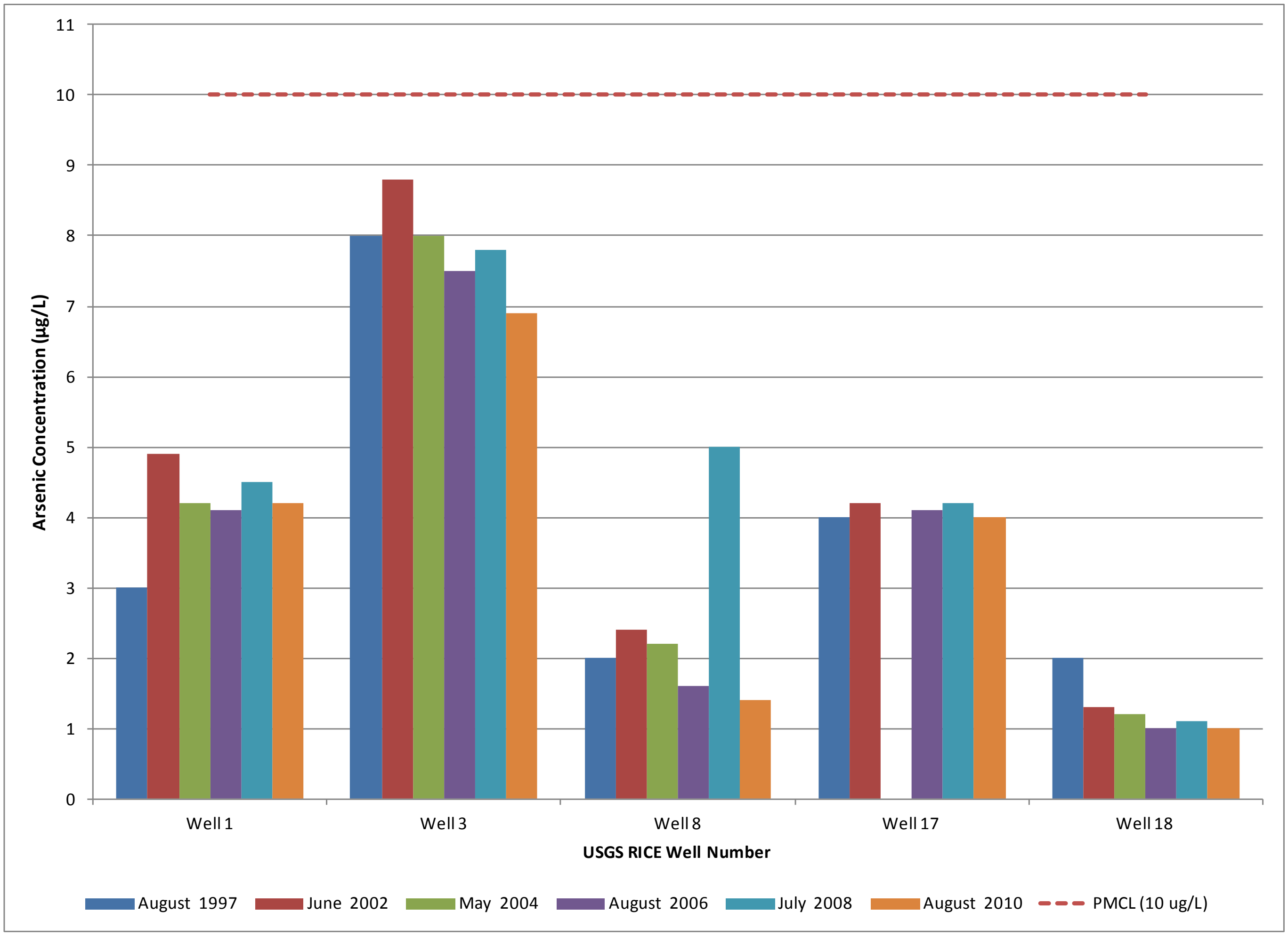


FIGURE 5-16
Arsenic Trends in USGS Rice Wells



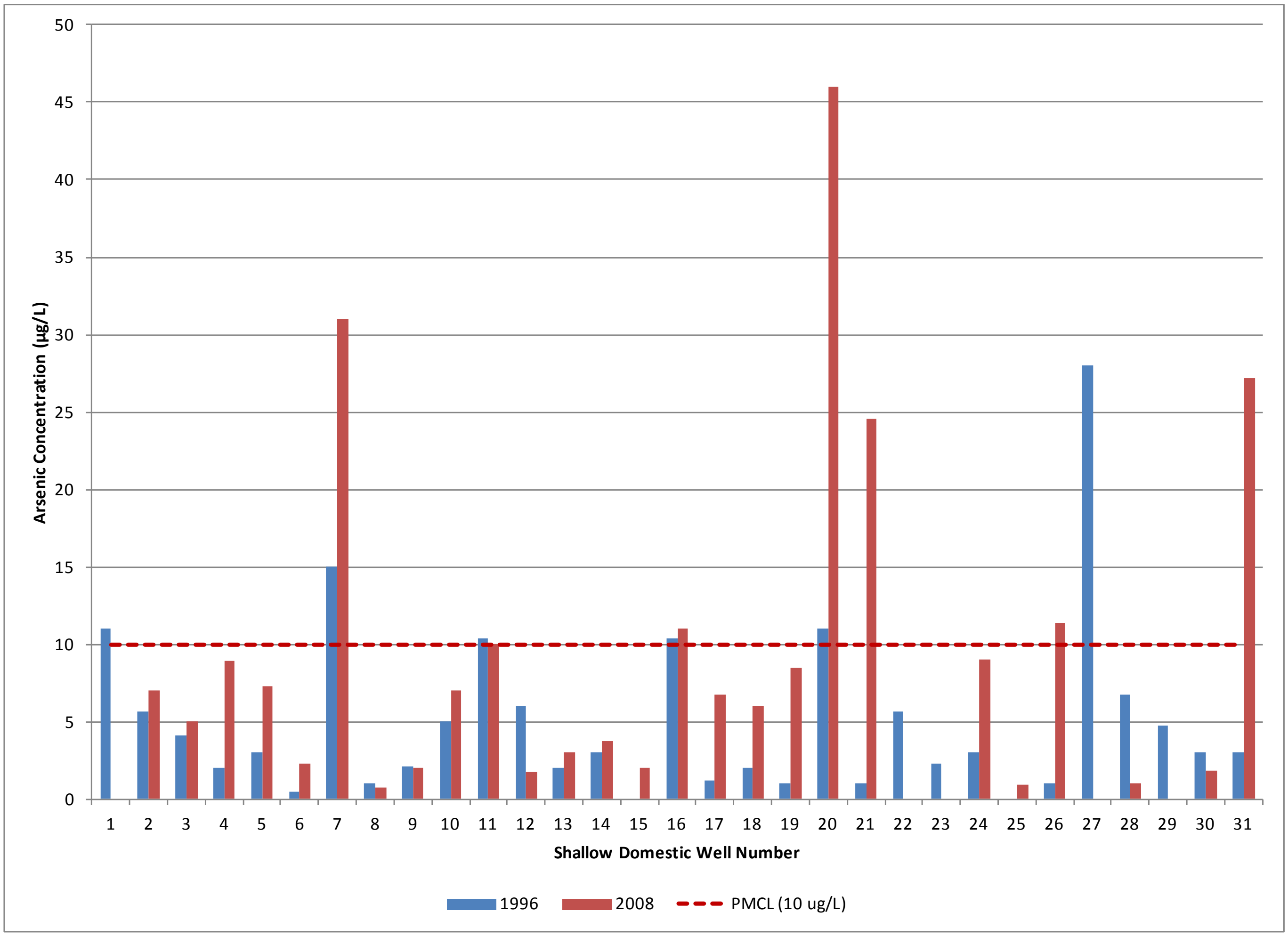
The following summarizes the arsenic results from the USGS Rice Wells:

- In 25 of 28 USGS Rice Wells, maximum observed arsenic concentrations were less than 10 µg/L.
- The maximum arsenic detection of 15 µg/L occurred at Well 2 in 1997. A subsequent 2006 measurement at Well 2 showed a concentration of 4.9 µg/L. Well 2 is located in the Sutter groundwater basin, south of the Sutter Buttes. Wells 4 and 6 had maximum concentrations of 11 µg/L and 10.4 µg/L, respectively.
- An analysis of the results of the five wells that have been sampled six times shows relatively stable concentrations in each well, with some fluctuations in the 2 to 3 µg/L range.

Arsenic in Shallow Domestic Wells

Figure 5-17 shows the arsenic concentrations detected in 1996 and 2008 sampling of the Shallow Domestic Wells.

FIGURE 5-17
Arsenic Concentrations in Shallow Domestic Wells



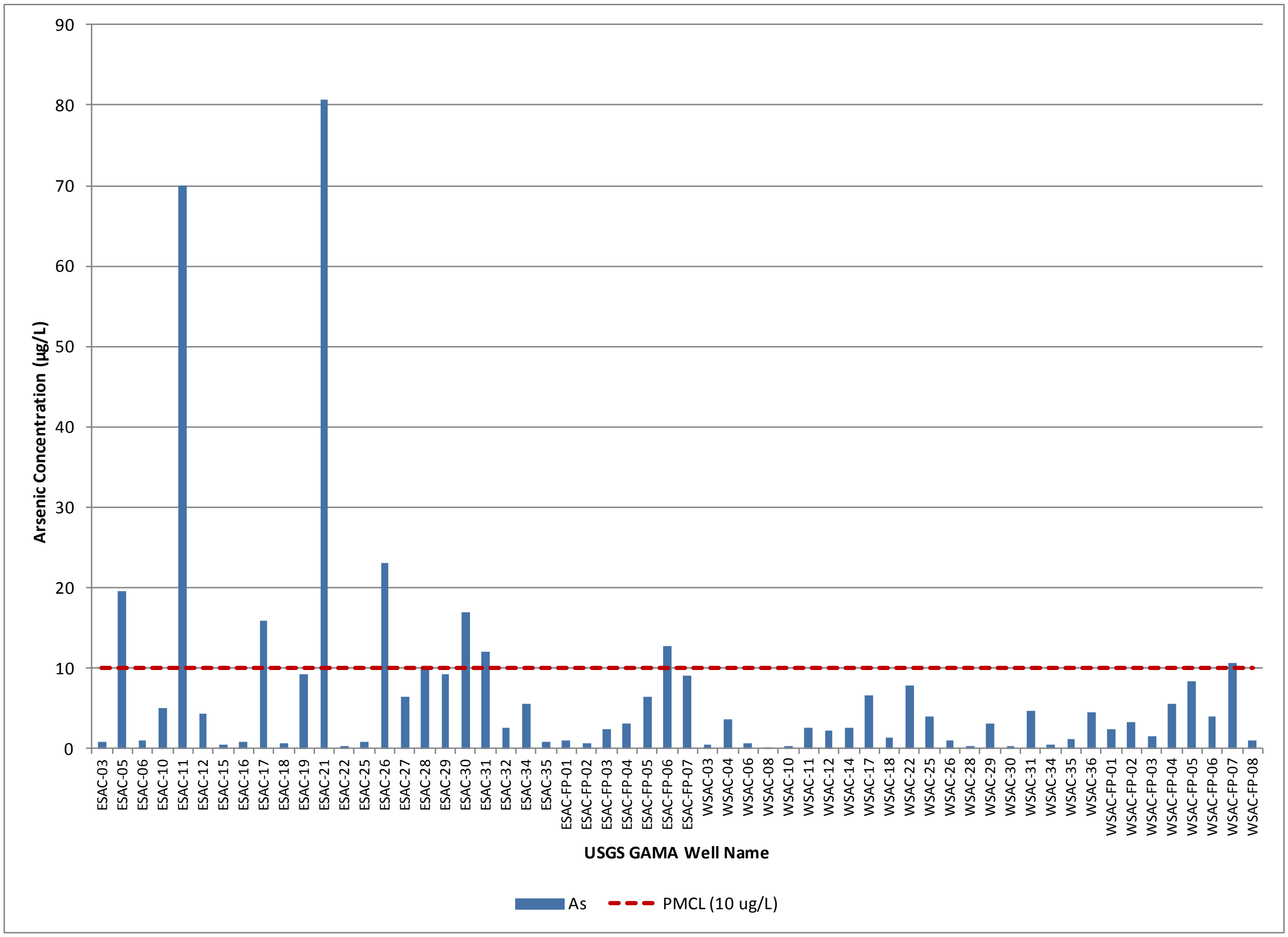
The following summarizes these results:

- In 22 of 31 Shallow Domestic Wells, the maximum arsenic concentration was less than 10 µg/L.
- A maximum observed arsenic concentration of 46 µg/L was detected in Well 20 in June 2008.
- The following additional wells had maximum arsenic observations above 10 µg/L: Wells 1, 7, 11, 16, 20, 21, 26, 27, and 31.
- In general, results from 2008 samples showed increased concentrations relative to 1996 samples.
- Concentrations observed in Shallow Domestic Wells generally exceeded those found in USGS Rice Wells.
- It is noted that this dataset included two duplicate samples in the 1996 sampling. Well 4 duplicates had results of 2 µg/L and 1 µg/L, and the Well 5 duplicates had results of 3 and 0.46 µg/L. These highly variable duplicate results indicate potential variability in test methods and/or within-well samples. The maximum value from the two duplicate samples was used in the graphing and summary.

Arsenic in USGS GAMA Wells

Figure 5-18 shows the results of the arsenic analysis for USGS GAMA Wells.

FIGURE 5-18
Arsenic Concentrations in USGS GAMA Wells



The following summarizes the arsenic results:

- Arsenic results are reported for 43 USGS GAMA grid wells and 15 USGS GAMA flow path wells.
- Observed arsenic was less than 10 µg/L in 35 of 43 grid wells and in 13 of 15 flow path wells.
- The maximum observed arsenic concentration was 80.6 µg/L, observed in Well ESAC-21.
- No WSAC grid wells had concentrations above 10 µg/L.

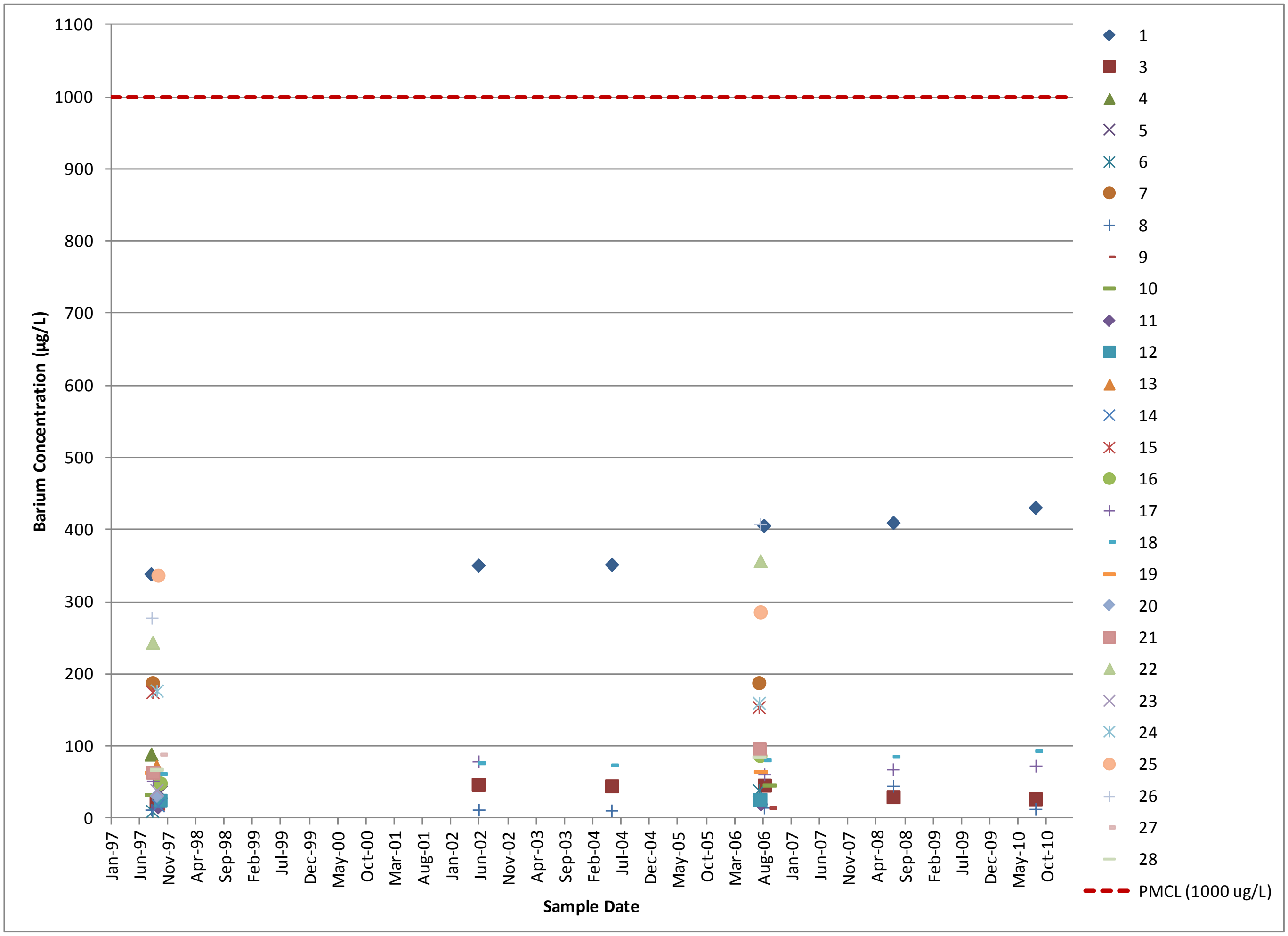
5.4.2.2 Barium

Barium is a naturally occurring element present in Sacramento Valley geology. Rice farmers do not add materials that contribute barium to the environment. The barium PMCL is 1,000 µg/L. Map 5-4 shows the mapped maximum observed barium results for the three USGS datasets.

Barium in USGS Rice Wells

Figure 5-19 shows barium results for USGS Rice Wells for the period 1997 through 2010.

FIGURE 5-19
Barium Concentrations in USGS Rice Wells
Note: Well 2 >5000 µg/L omitted for scale



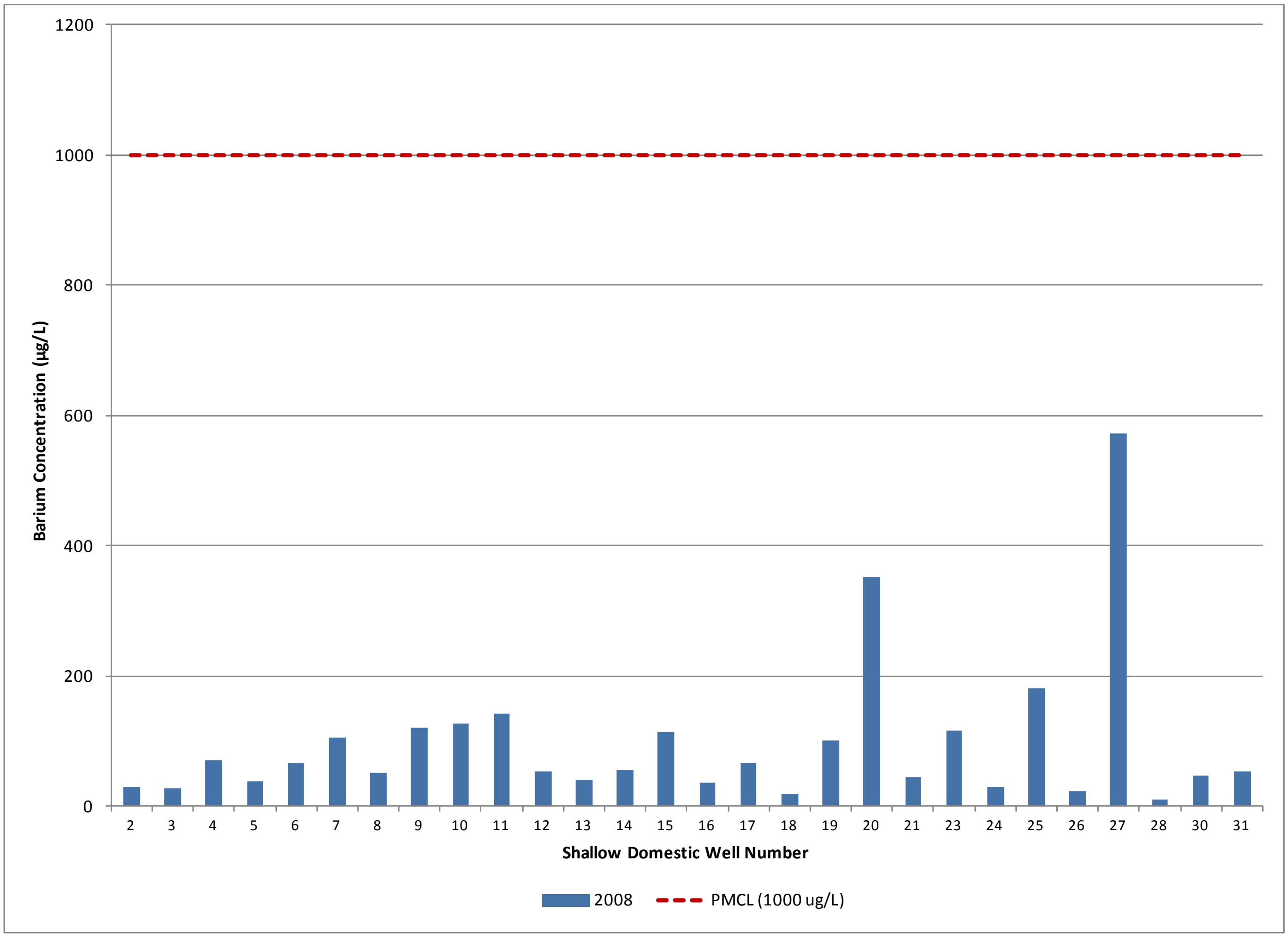
The following summarizes the results of barium sampling in USGS Rice Wells:

- In 27 of 28 USGS Rice Wells, the maximum observed concentration was less than 1,000 µg/L.
- The maximum observed barium concentration of 5,901 µg/L was from Well 2 in 2006.

Barium in Shallow Domestic Wells

Figure 5-20 shows barium results for Shallow Domestic Wells (2008 sampling event).

FIGURE 5-20
Barium Concentrations in Shallow Domestic Wells



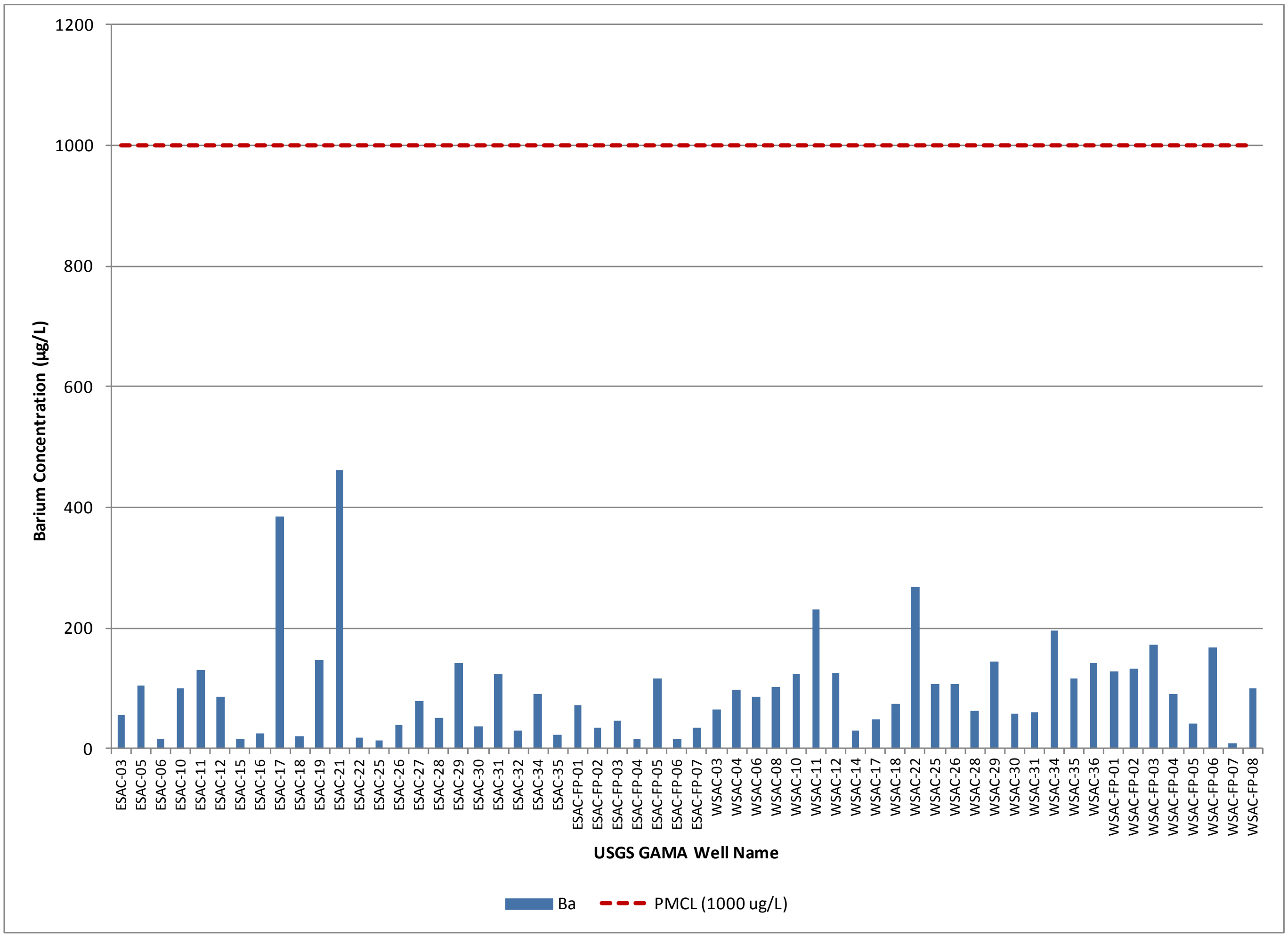
The following summarizes the results of the barium Shallow Domestic Well monitoring:

- 28 wells were sampled for barium once in 2008.
- No Shallow Domestic Well showed a concentration of barium above the PMCL.

Barium in USGS GAMA Wells

Figure 5-21 shows the results of barium sampling in USGS GAMA Wells.

FIGURE 5-21
Barium Concentrations in USGS GAMA Wells



The following summarizes the barium results for USGS GAMA wells:

- Barium results are reported for 43 GAMA USGS grid wells and 15 GAMA USGS flowpath wells.
- All sampled USGS GAMA wells had barium concentrations less than 1,000 µg/L.
- The maximum observed barium concentration was 461 µg/L.

5.4.2.3 Cadmium

Cadmium is a naturally occurring element present in Sacramento Valley geology. Rice farmers do not add materials that contribute cadmium to the environment. Map 5-5 shows the mapped maximum observed cadmium results for the three USGS datasets.

Cadmium in USGS Rice Wells

Figure 5-22 shows all of the cadmium results from the USGS Rice Wells for the period 1997 through 2010. Figure 5-23 shows the cadmium trends. The following summarizes the results for USGS Rice Wells:

- In 25 of 28 USGS Rice Wells, the maximum observed concentration was less than 5 µg/L.
- Wells 5, 11, and 25 had maximum observed cadmium concentrations of 6.08 µg/L, 7.43 µg/L, and 7.08 µg/L, respectively.

FIGURE 5-22
Cadmium Concentrations in USGS Rice Wells

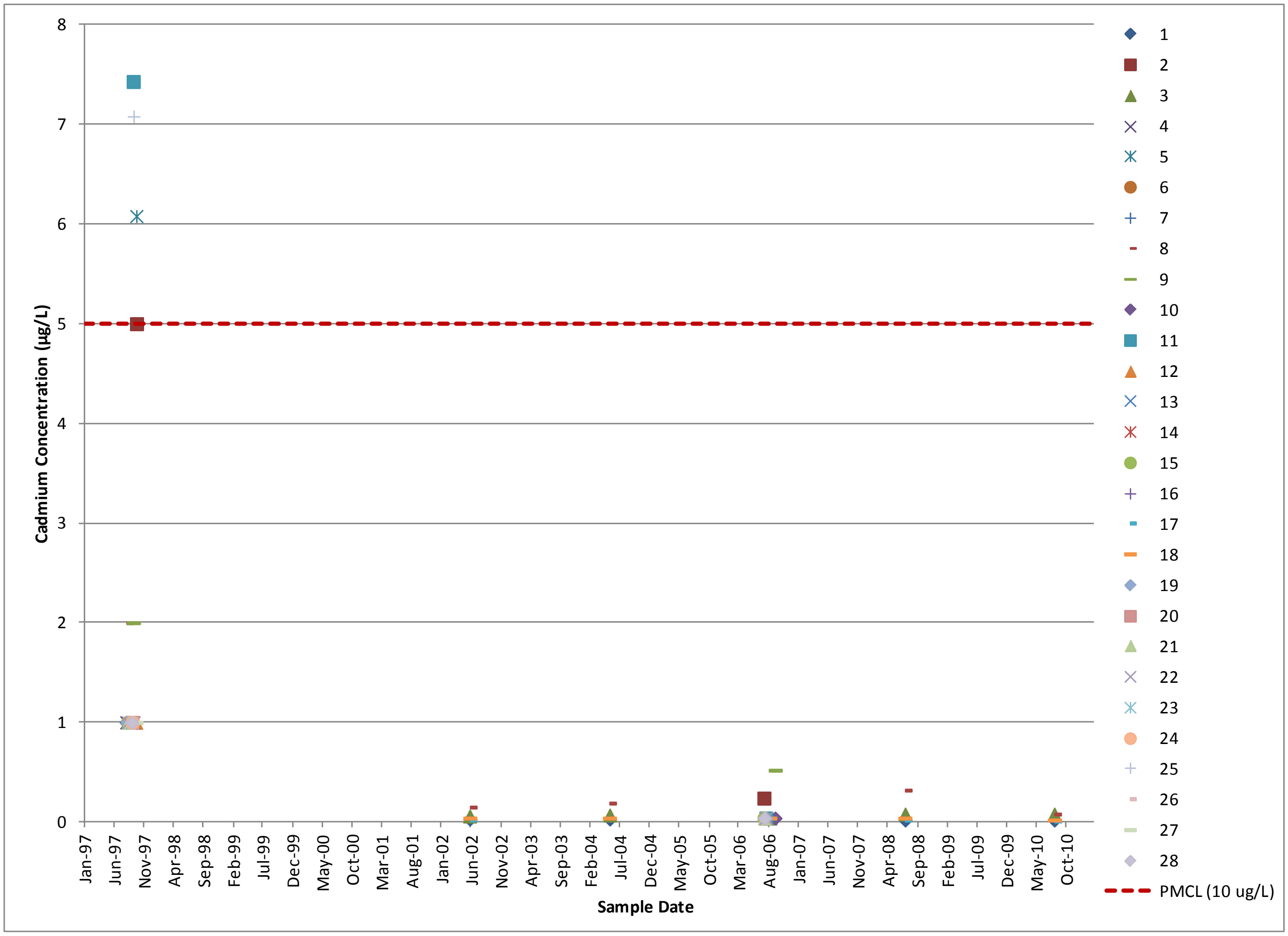
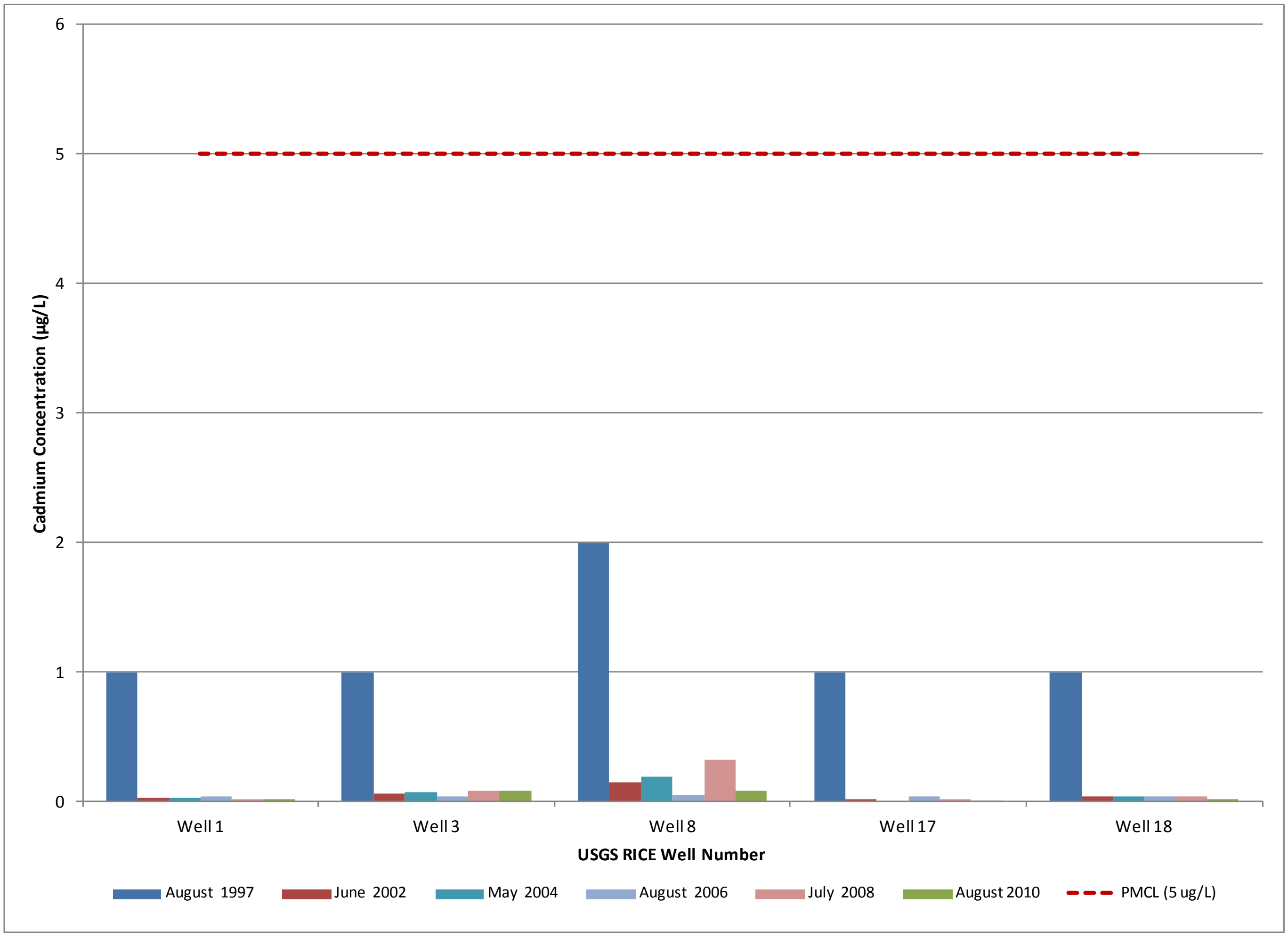


FIGURE 5-23
Cadmium Trends in USGS Rice Wells



Cadmium in Shallow Domestic Wells

The following summarizes the cadmium sampling of the Shallow Domestic Wells:

- Twenty-eight wells were sampled for barium once in 2008.
- No Shallow Domestic Wells showed concentrations of cadmium above the PMCL; all results were less than 0.05 µg/L.

Cadmium in USGS GAMA Wells

The following summarizes the barium results for USGS GAMA Wells:

- Cadmium results are reported for 43 USGS GAMA grid wells and 15 USGS GAMA flowpath wells.
- No USGS GAMA Wells had concentrations of cadmium above the MCL. Cadmium concentrations below the laboratory reporting limit in 55 of 58 wells ranged from 0.04 µg/L to 0.08 µg/L.
- The maximum observed cadmium concentration was 3.54 µg/L at Well WSAC-31.

5.4.2.4 Chloride

Chloride is a naturally occurring element. CDPH has established an upper limit taste and odor SMCL of 500 mg/L. Map 5-6 shows the maximum observed chloride results for the three USGS datasets.

Chloride in USGS Rice Wells

Figure 5-24 shows the chloride observations from the USGS Rice Wells for the period 1997 through 2010 (results from Well 2 are excluded in order to provide appropriate scale for the evaluation of the rest of the wells, as noted). Figure 5-25 shows chloride trends in USGS Rice Wells for 1997 through 2010.

FIGURE 5-24
Chloride Concentrations in USGS Rice Wells
Note: Well 2 results omitted for scale (4,770 µg/L in 1997 and 4,730 µg/L in 2006)

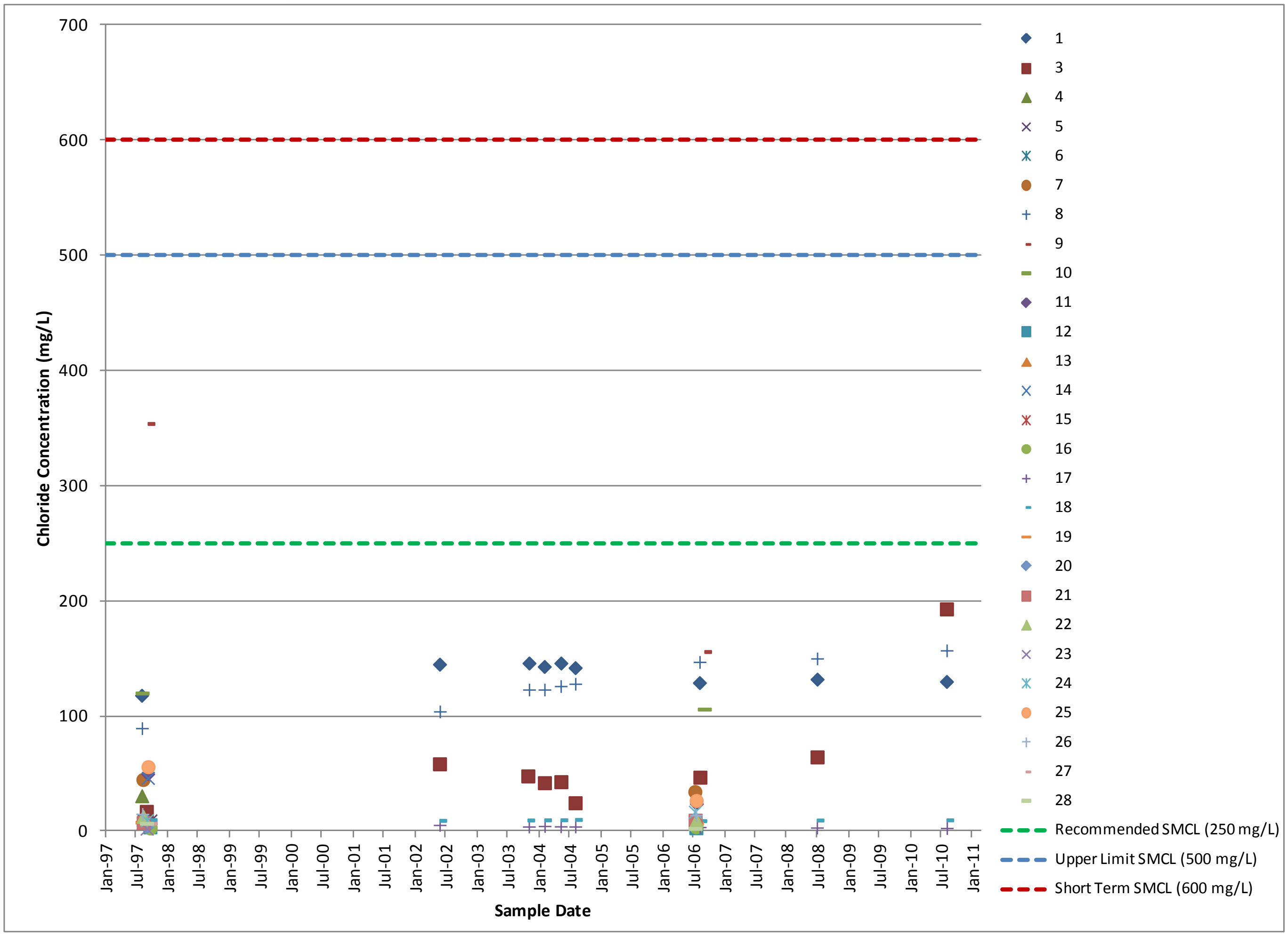
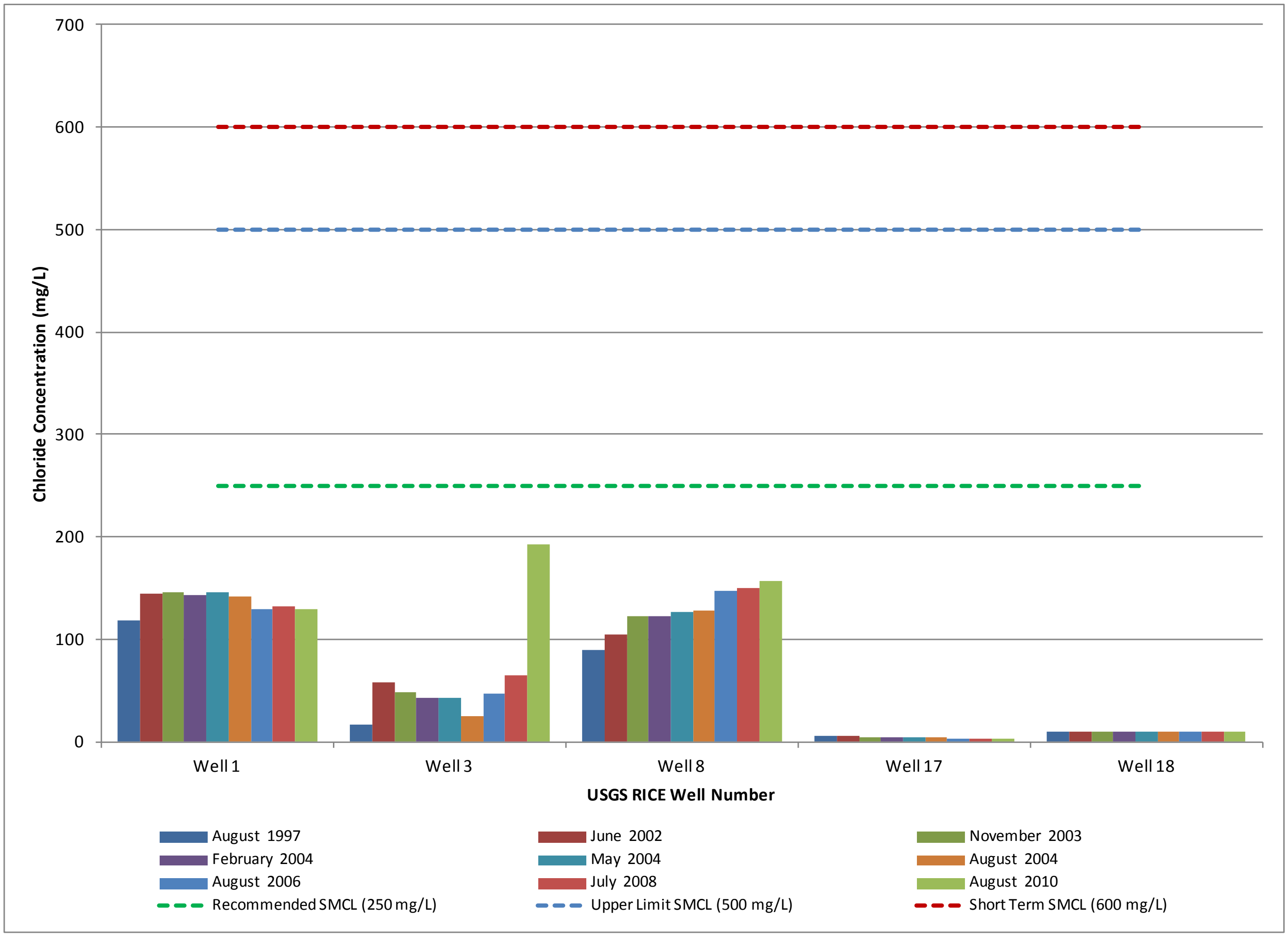


FIGURE 5-25
Chloride Trends in USGS Rice Wells



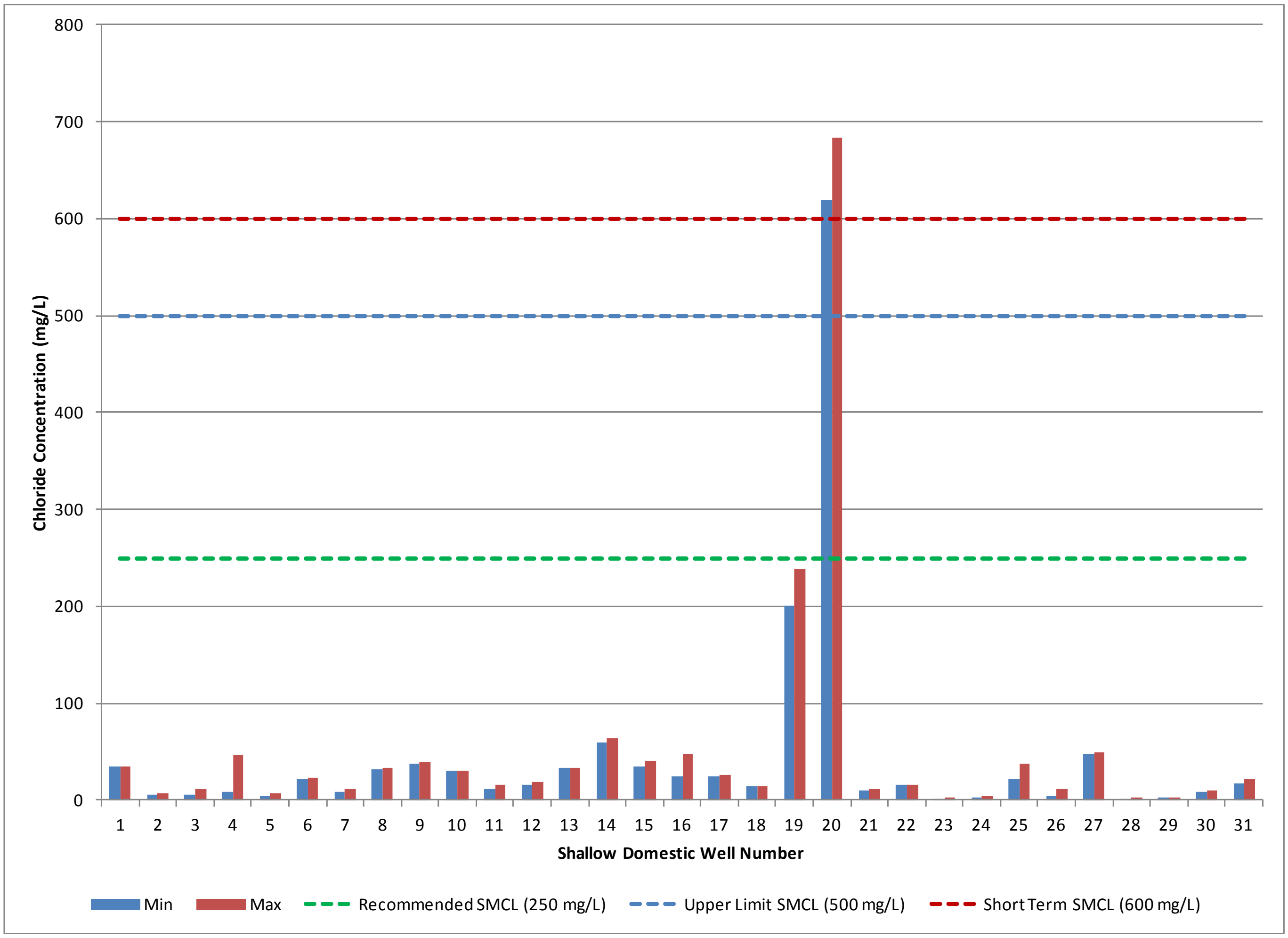
The following summarizes the results of chloride sampling in USGS Rice Wells:

- In 24 of 28 USGS Rice Wells, the maximum observed chloride concentration was less than 1,000 µg/L.
- The maximum observed chloride concentration of 4,770 µg/L was from Well 2 in 1997.

Chloride in Shallow Domestic Wells

Figure 5-26 shows the minimum and maximum observed chloride concentrations in the Shallow Domestic Wells.

FIGURE 5-26
Minimum and Maximum Observed Chloride Concentrations in Shallow Domestic Wells



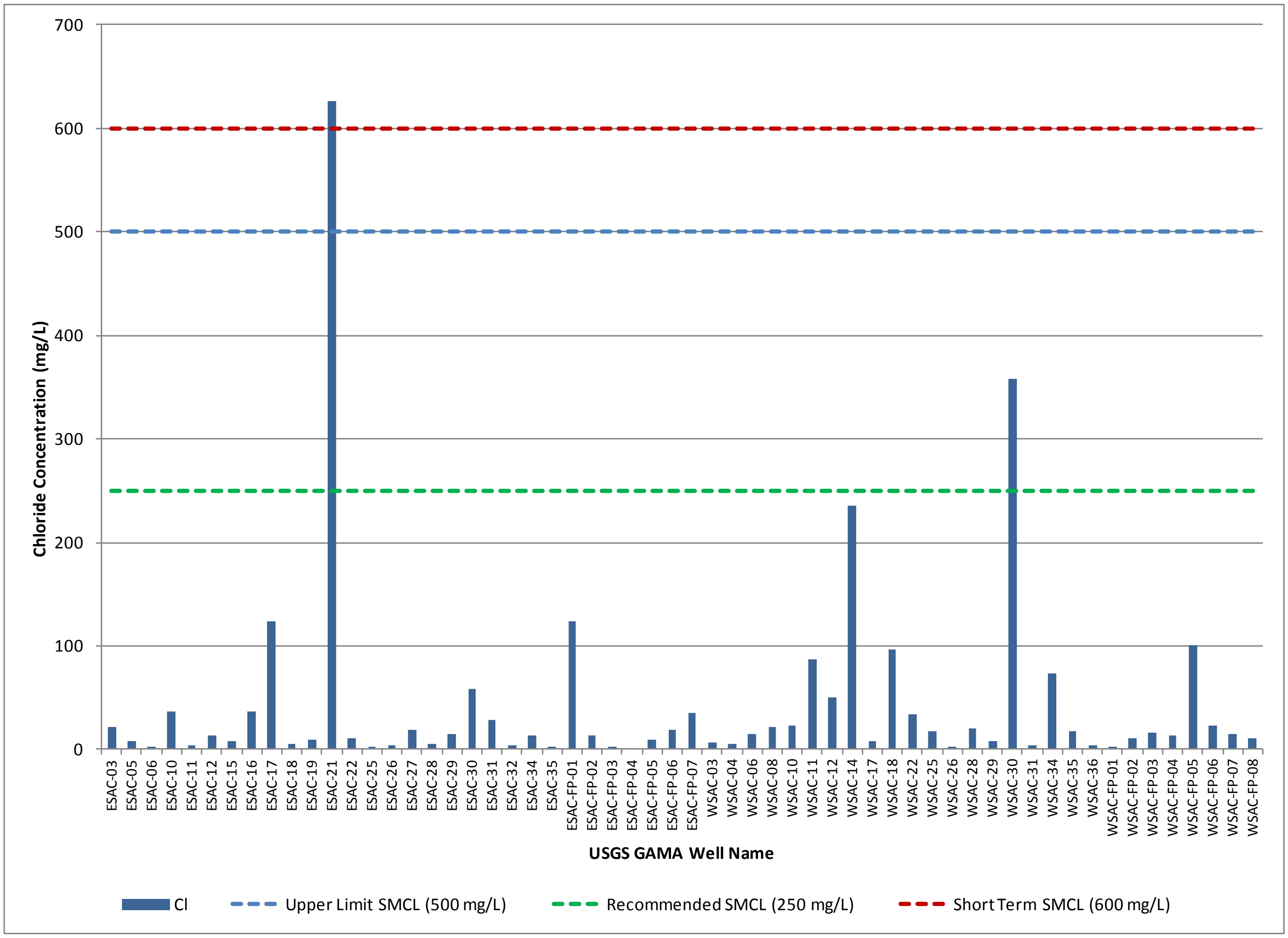
The following summarizes the results of chloride sampling in Shallow Domestic Wells:

- None of the 31 Shallow Domestic Wells had a maximum observed chloride concentration above 1,000 µg/L.
- The maximum observed chloride concentration of 683 µg/L was from Well 20 in 2008. Well 20 is the only well that has exceeded the Upper Limit SMCL for chloride (500 µg/L).

Chloride in USGS GAMA Wells

Figure 5-27 shows the results of chloride sampling in the USGS GAMA Wells.

FIGURE 5-27
Chloride Concentrations in USGS GAMA Wells



The following summarizes the results of chloride sampling in USGS GAMA Wells:

- Chloride results are reported for 43 USGS GAMA grid wells and 15 USGS GAMA flowpath wells.
- In 42 of 43 of USGS grid wells, observed chloride was less than the SMCL. Chloride was less than the SMCL in all flowpath wells.
- The maximum observed chloride concentration of 626 mg/L in Well ESAC-21.

5.4.2.5 Iron

Iron is a naturally occurring trace element; it is not applied to rice fields. Iron is sensitive to the redox state of the aquifer. Iron is oxidized from soluble and mobile Fe^{2+} to insoluble Fe^{+}. High concentrations of iron indicate reducing conditions that can mobilize iron present in aquifer sediments. CDPH has established a taste and odor SMCL of 300 µg/L for iron. Map 5-7 shows the mapped maximum observed iron results for the three USGS datasets.

Iron in USGS Rice Wells

Figure 5-28 shows the iron observations from the USGS Rice Wells for the period 1997 through 2010 (results from Well 2 are excluded in order to provide appropriate scale for the evaluation of the rest of the wells, as noted). Figure 5-29 shows the trends of the frequently sampled USGS Rice Wells.

FIGURE 5-28

Iron Concentrations in USGS Rice Wells

Note: Well 2 results omitted for scale (5,340 µg/L in 1997 and 4,610 µg/L in 2006)

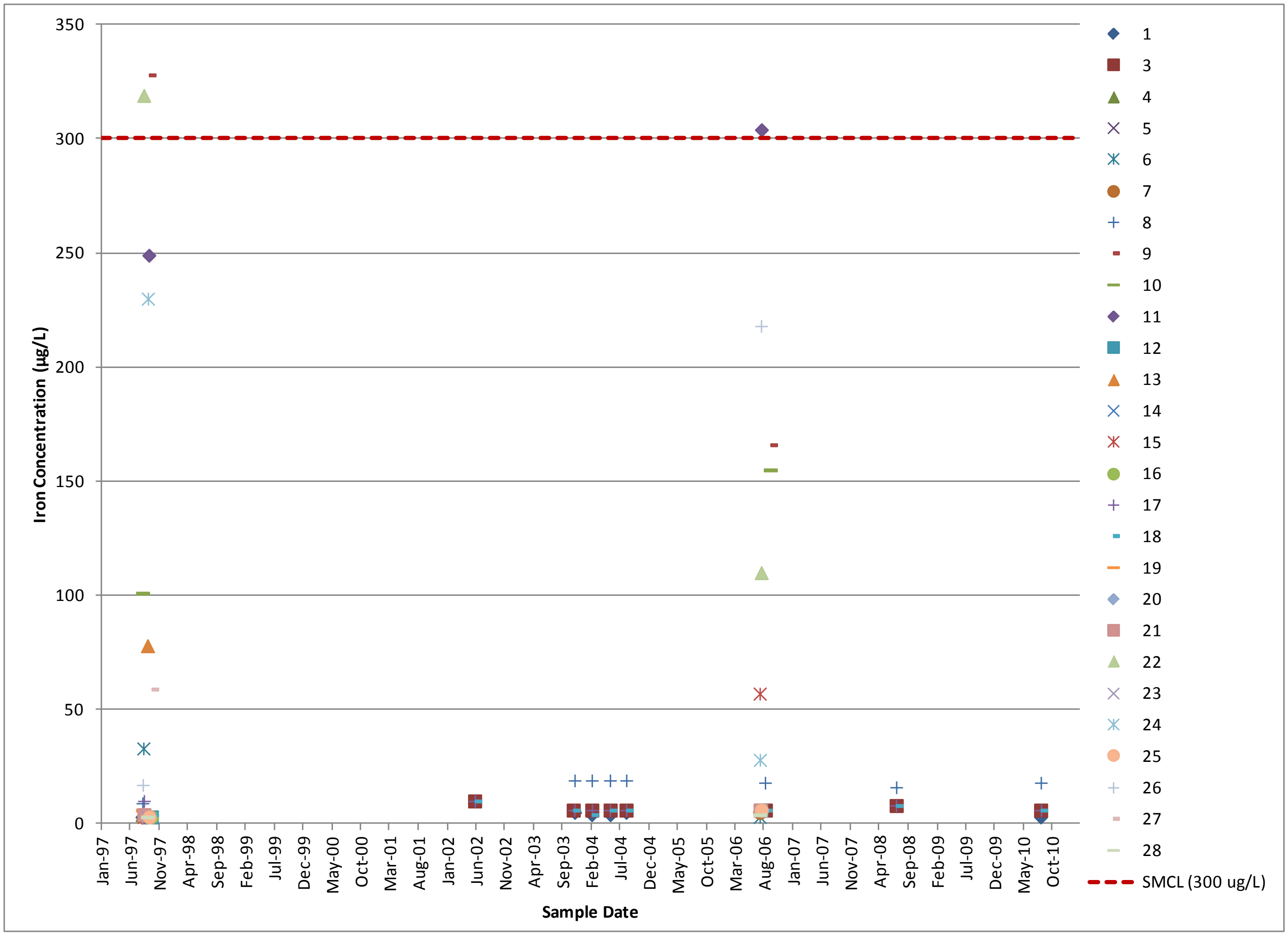
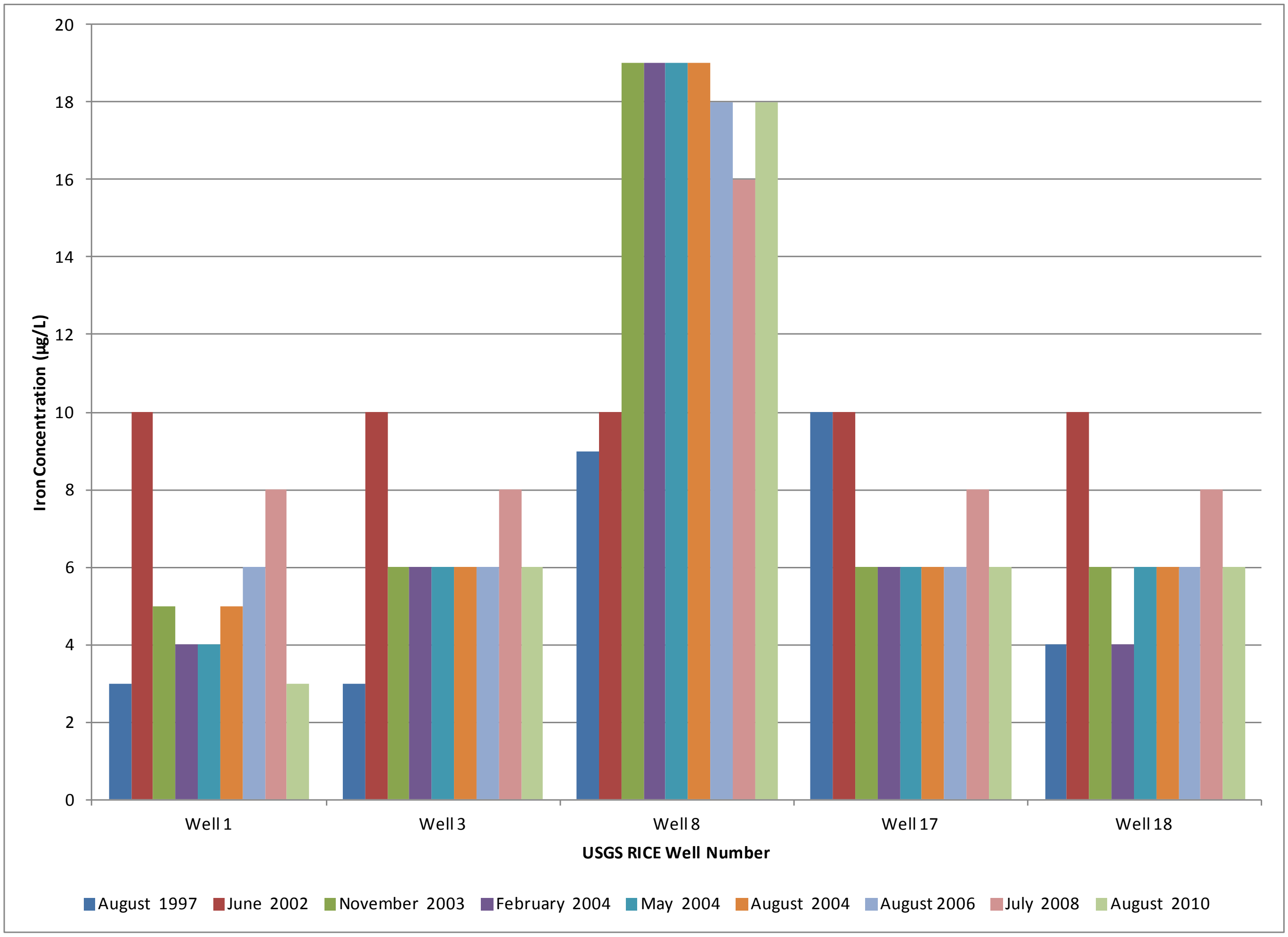


FIGURE 5-29
Iron Trends in USGS Rice Wells



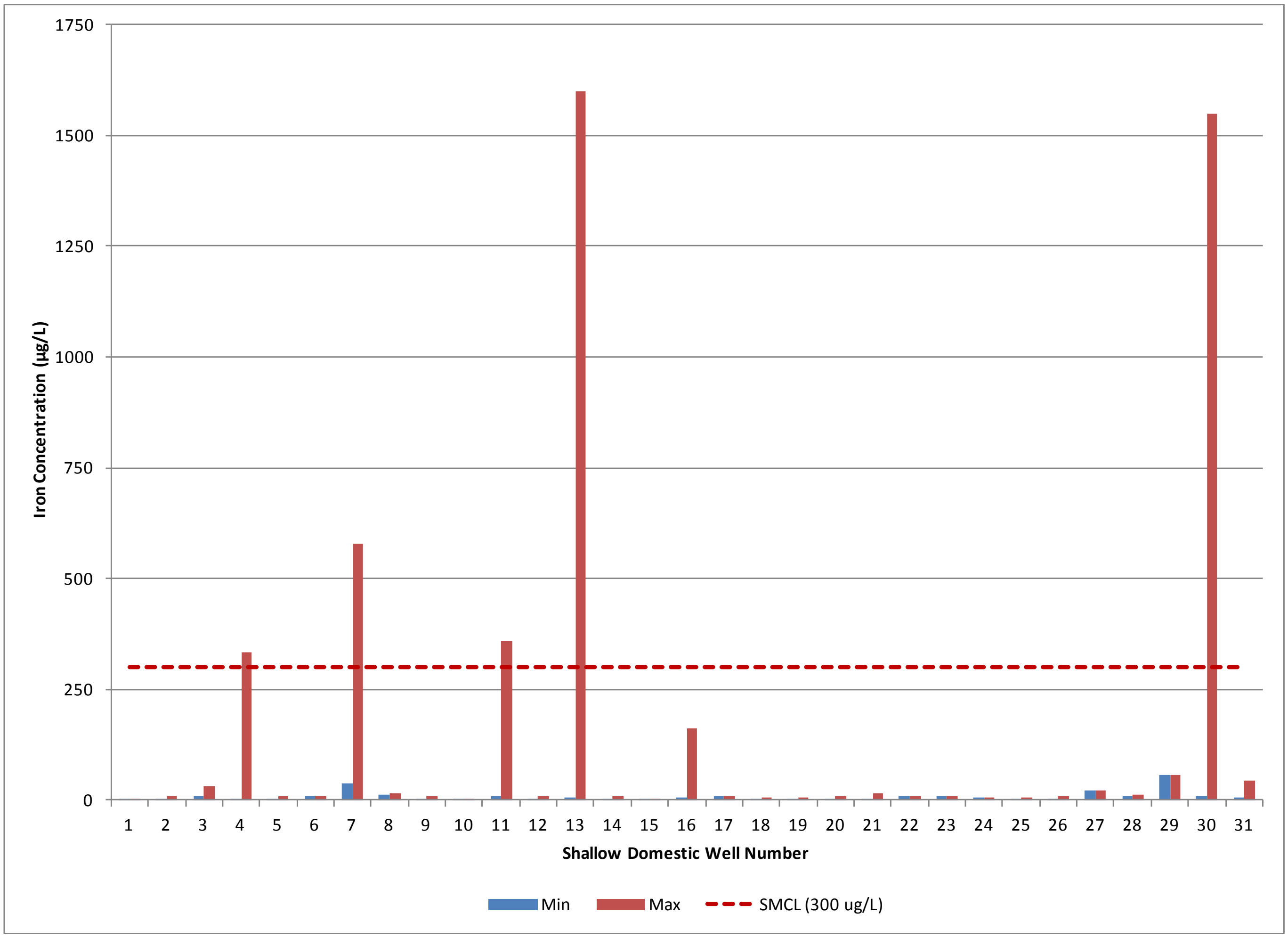
The following summarizes the USGS Rice Well iron observations:

- In 24 of 28 USGS Rice Wells, iron concentrations were less than the 300 µg/L PMCL.
- The maximum iron observation was 5,340 µg/L, observed in Well 2 in 1997.
- In 1997, the iron concentration in Well 9 was 328 µg/L. Subsequent 2006 samples resulted in an iron concentration of 166 µg/L. Likewise, the 1997 observation in Well 22 was 319 µg/L, followed by a 2006 result of 110 µg/L.
- Most USGS Rice Wells showed very low iron concentrations.

Iron in Shallow Domestic Wells

Figure 5-30 shows the minimum and maximum observed iron concentrations in the Shallow Domestic Wells.

FIGURE 5-30
Minimum and Maximum Observed Iron Concentrations in Shallow Domestic Wells



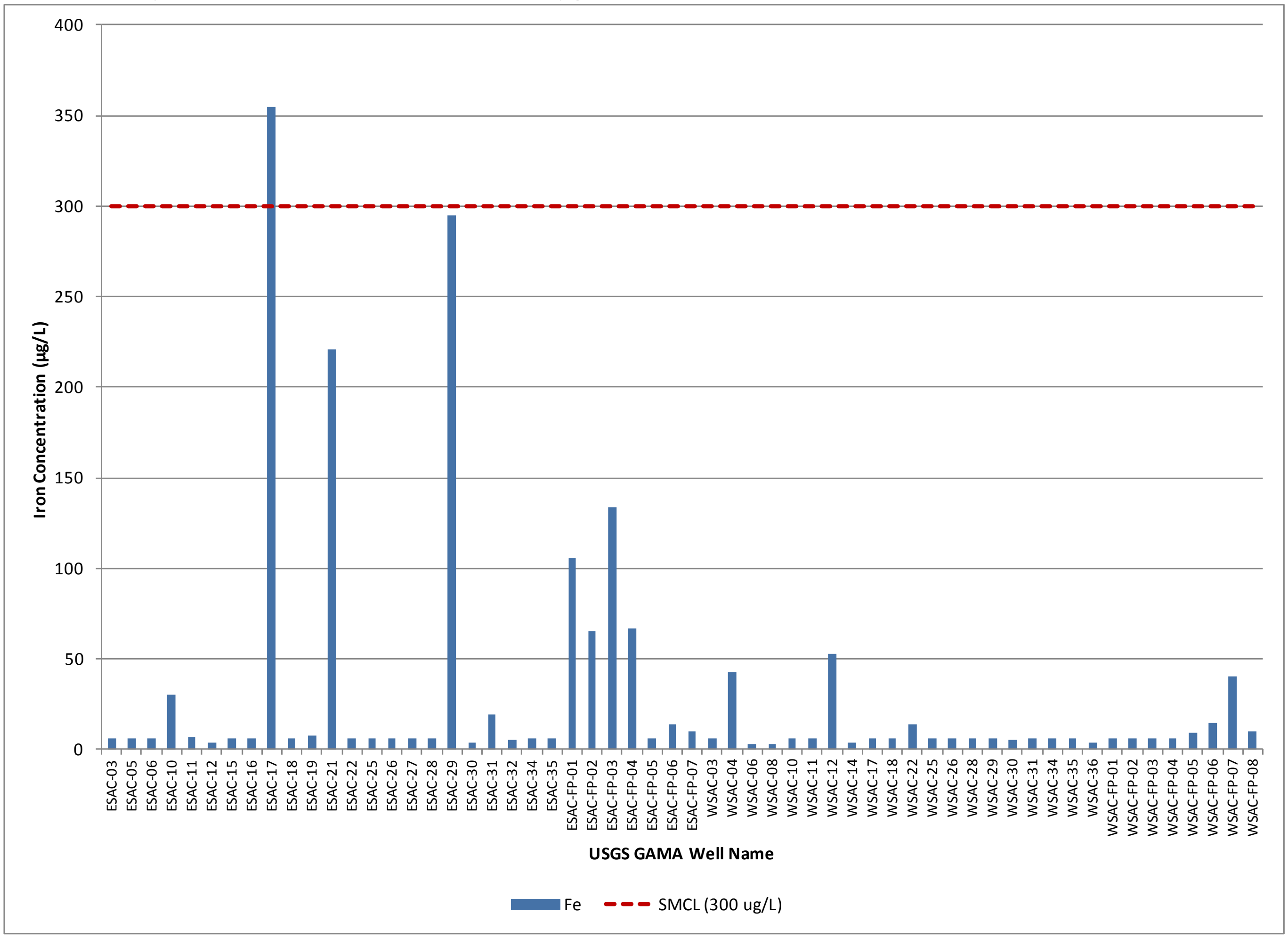
The following summarizes the Shallow Domestic Well iron results:

- In 26 of 31 Shallow Domestic Wells, the maximum observed iron concentration was less than 500 µg/L.
- A maximum iron concentration of 1,600 µg/L was observed in Well 13 in 1996. A subsequent 2008 sample showed a concentration of 7 µg/L in the same well. Wells 4, 7, 11, and 30 had maximum observed iron concentrations of 334 µg/L, 580 µg/L, 360 µg/L, and 1,550 µg/L, respectively.
- Most Shallow Domestic Wells have very low iron concentrations.
- It is noted that this dataset included two duplicate samples in the 1996 sampling. Well 4 duplicates both had results of 3 µg/L, and the Well 5 duplicates had results of 3 and 8 µg/L.

Iron in USGS GAMA Wells

Figure 5-31 shows the results of iron sampling in the USGS GAMA Wells.

FIGURE 5-31
Iron Concentrations in USGS GAMA Wells
Note: Values reported as <RL are shown as zero. RL = 6 µg/L.



The following summarizes the iron results for USGS GAMA Wells:

- Iron results are reported for 43 USGS GAMA grid wells and 15 USGS GAMA flowpath wells.
- Of the grid wells, 42 of 43 had iron concentrations less than 300 µg/L, and all 15 flowpath wells had concentrations less than 300 µg/L. Well ESAC-29 had an observed concentration of 295 µg/L.
- The maximum observed iron concentration was 355 µg/L at well ESAC-17.

5.4.2.6 Manganese

Manganese is a naturally occurring trace element; it is not applied in rice farming. Like iron, manganese is sensitive to the redox state of the groundwater. Manganese is oxidized from soluble Mn^{2+} to insoluble Mn^{+}. High concentrations of manganese indicate reducing conditions. CDPH has established a taste and odor SMCL of 50 µg/L for manganese; there is no human health PMCL for manganese.

A USGS analysis of the redox conditions of the shallow groundwater under the rice fields indicated that almost all of the wells reported anoxic or reducing conditions in the groundwater (USGS 2001a).

Map 5-8 shows the mapped maximum observed manganese results for the three USGS datasets.

Manganese in USGS Rice Wells

Figure 5-32 shows the manganese observations in the USGS Rice Wells. Figure 5-33 shows the trend results of the five USGS Rice Wells that were sampled nine times.

FIGURE 5-32
Manganese Concentrations in USGS Rice Wells
Note: Well 2 results were omitted for scale (3,010 µg/L in 1997 and 3,420 µg/L in 2006)

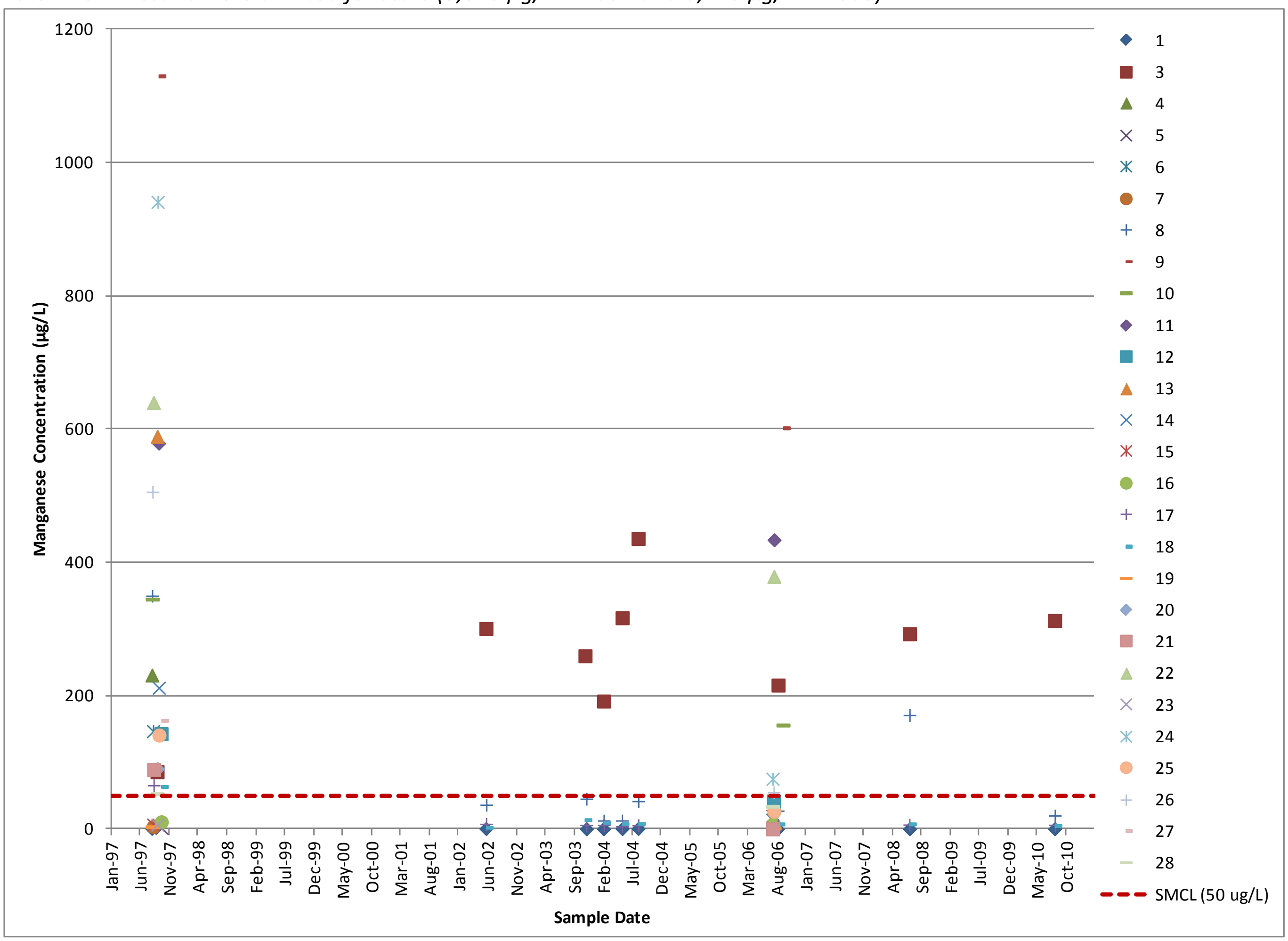
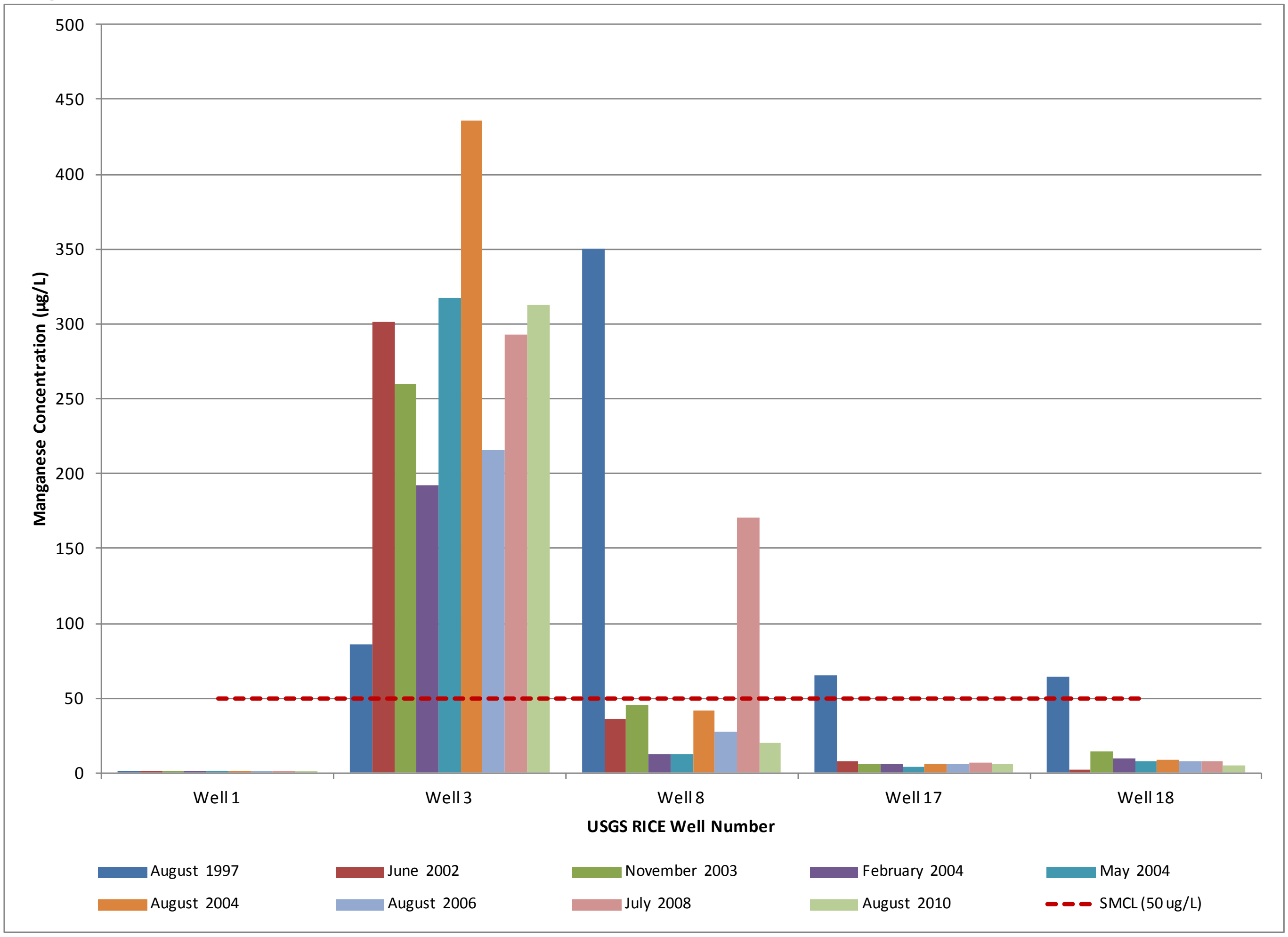


FIGURE 5-33
Manganese Trends in USGS Rice Wells



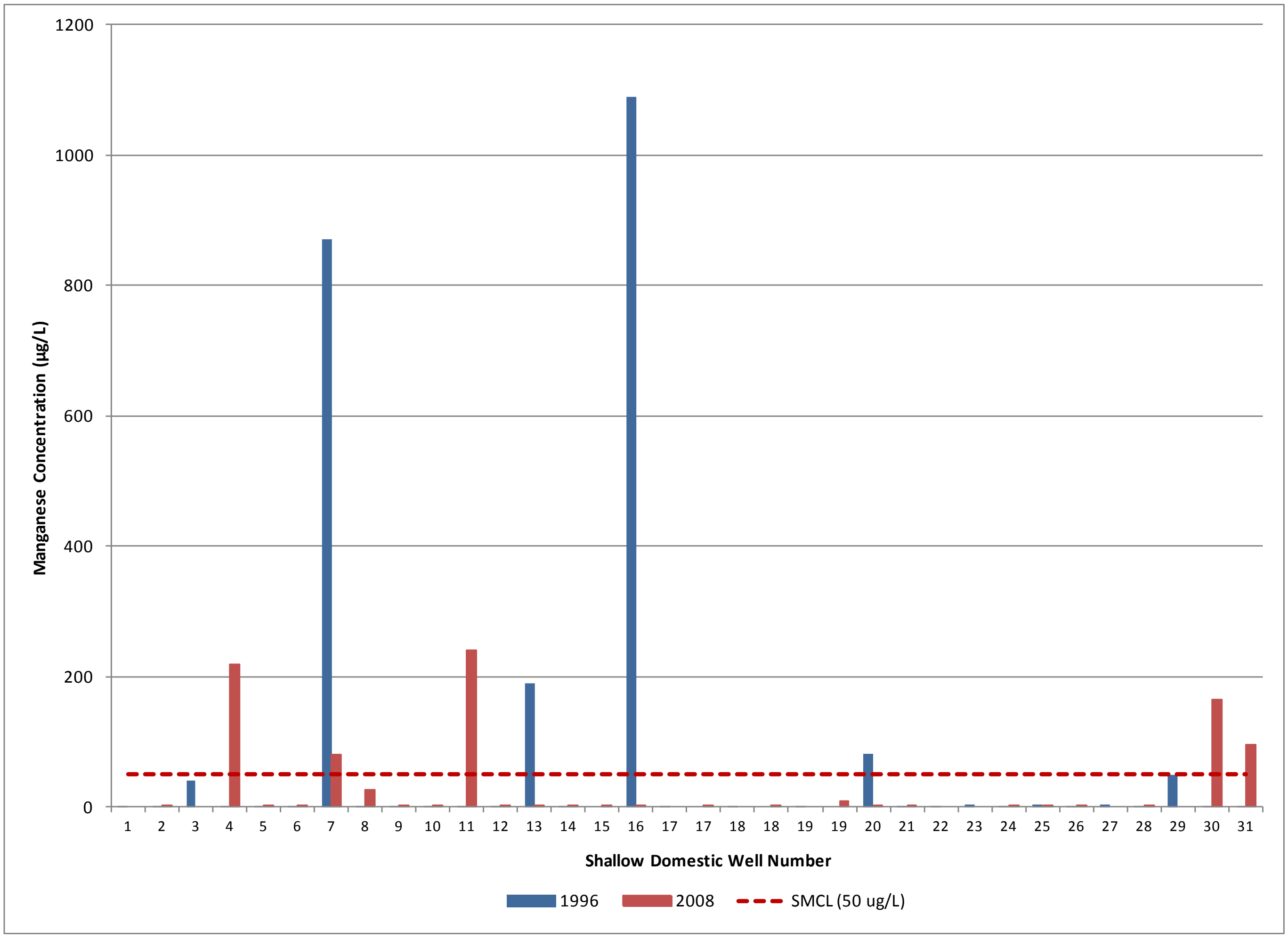
The following summarizes the results of manganese sampling in USGS Rice Wells:

- Maximum observed manganese exceeded the SMCL in 21 of 28 wells. As shown, the concentrations within individual wells can vary greatly. Some wells consistently show negligible concentrations (Wells 1, 17, and 18), but other wells can fluctuate by an order of magnitude. These highly variable results are consistent with the known mobile behavior of manganese. These results show the highly variable concentrations within a single well and indicate that a single high result is not indicative of a trend.

Manganese in Shallow Domestic Wells

Figure 5-34 shows the results of manganese sampling in Shallow Domestic Wells.

FIGURE 5-34
Manganese Concentrations in Shallow Domestic Wells



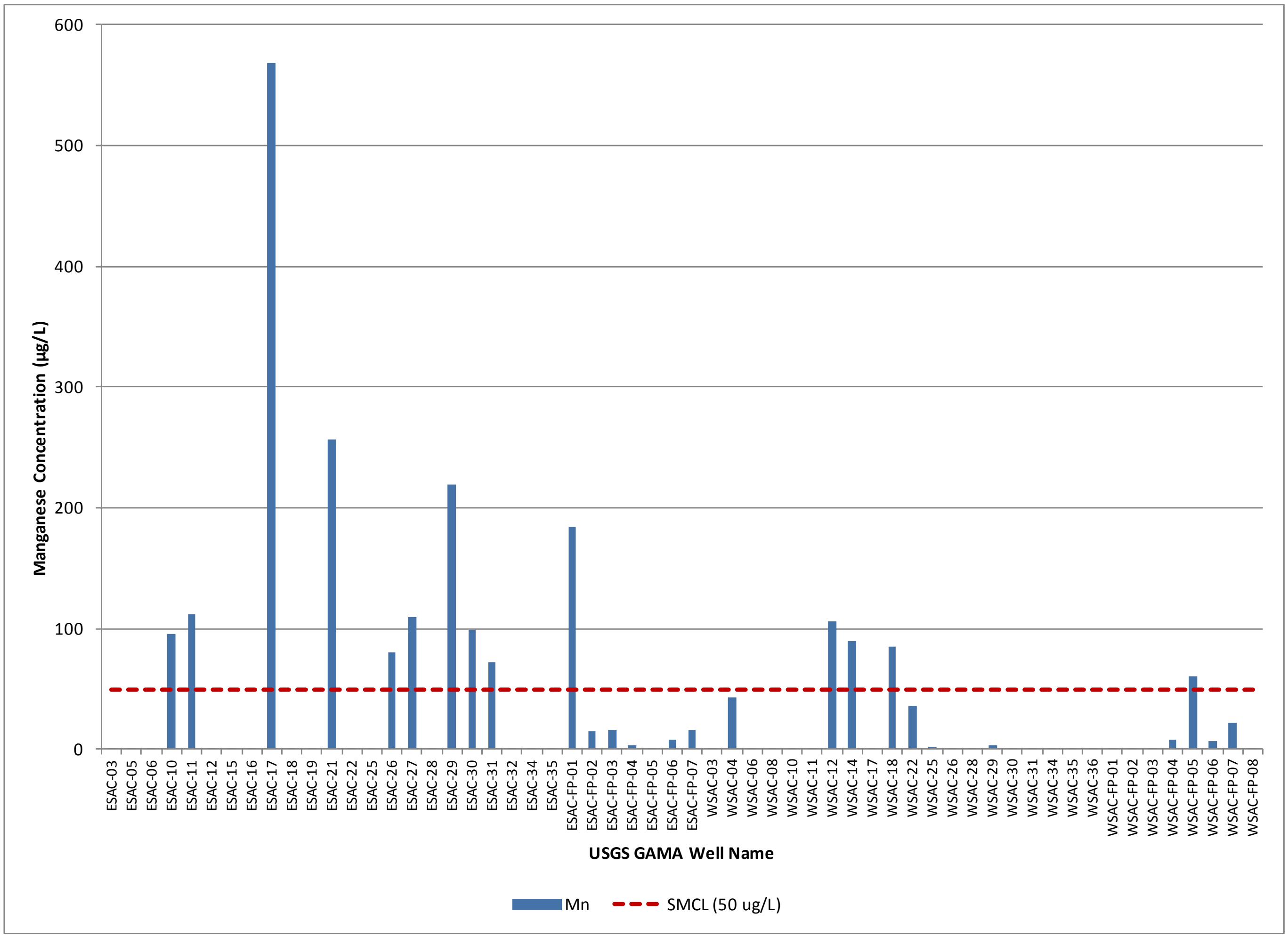
The following summarizes the results manganese sampling performed on Shallow Domestic Wells:

- In 23 of 31 Shallow Domestic Wells, maximum observed manganese concentrations were less than 50 µg/L.
- A maximum concentration of 1,090 µg/L was observed in Well 16 in 1996. A subsequent 2008 sample of the same well had a concentration of 1 µg/L. Well 7 had a maximum concentration of 870 µg/L in 1996 and a subsequent sample in 2008 with a concentration of 80 µg/L.
- Manganese concentrations are generally lower in Shallow Domestic Wells as compared to USGS Rice Wells, with most concentrations below 200 µg/L.

Manganese in USGS GAMA Wells

Figure 5-35 shows that samples from 12 wells contained manganese concentrations above the SMCL. One of these wells also had a concentration of iron above the MCL. In addition, samples from 6 of these wells contained concentrations of arsenic above the MCL. Manganese, Iron, and Arsenic often occur in similar subsurface environments as they are all highly mobile and sensitive to fluctuating redox conditions.

FIGURE 5-35
Manganese Concentrations in USGS GAMA Wells



The following summarizes the observations:

- Manganese was less than 50 µg/L in 31 of 43 flow path wells and 13 grid wells.
- Maximum observed manganese was 568 µg/L.

5.4.2.7 Sulfate

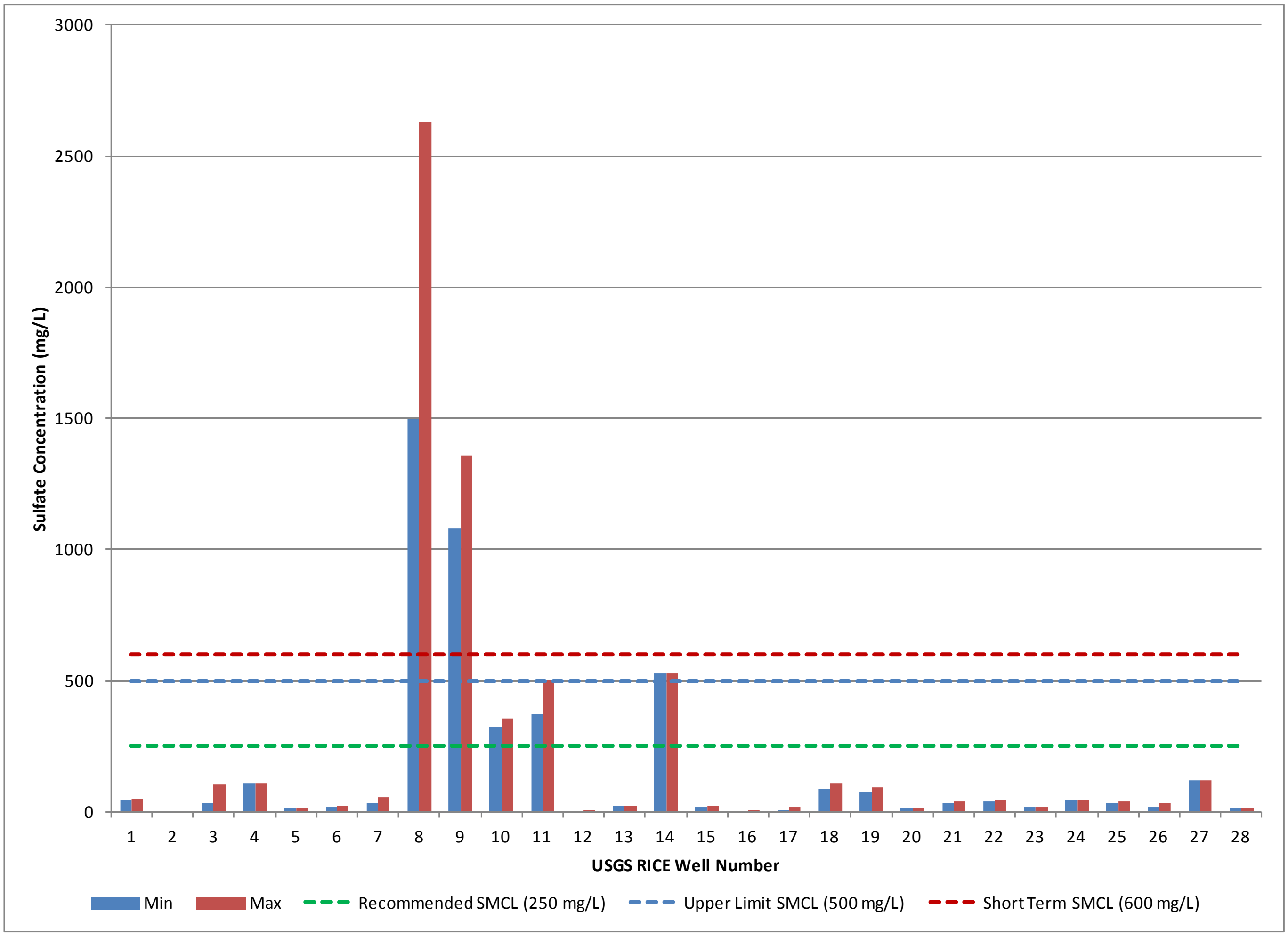
Sulfate is naturally occurring in Sacramento Valley geology. Sulfur is primarily applied to rice fields as part of certain nitrogen and phosphorus fertilizers. Fate of applied sulfur depends on soil conditions, but includes gaseous loss, microbial uptake and immobilization, uptake by plants, and sorption; the remainder may remain as dissolved sulfate. As an extreme example, were ammonium sulfate applied to supply 100 lbs/acre of N (although non-sulfur-bearing nitrogen forms are used far more frequently) and all of it were to become dissolved sulfate, this would boost dissolved sulfate in applied irrigation water by about 10 mg/L. However, the high end of the typical range of applied S (see Table 2-2) is about one-fifth of this example application rate. Although rice farmers use forms of sulfate in some fertilizers, the amount added is very small in comparison to the naturally occurring sulfate primarily present in volcanic formations (as described in Section 2.3.3).

Map 5-9 shows the mapped maximum observed sulfate results for the three USGS datasets.

Sulfate in USGS Rice Wells

Figure 5-36 shows the minimum and maximum observed sulfate concentrations in USGS Rice Wells.

FIGURE 5-36
Minimum and Maximum Sulfate Concentrations in USGS Rice Wells



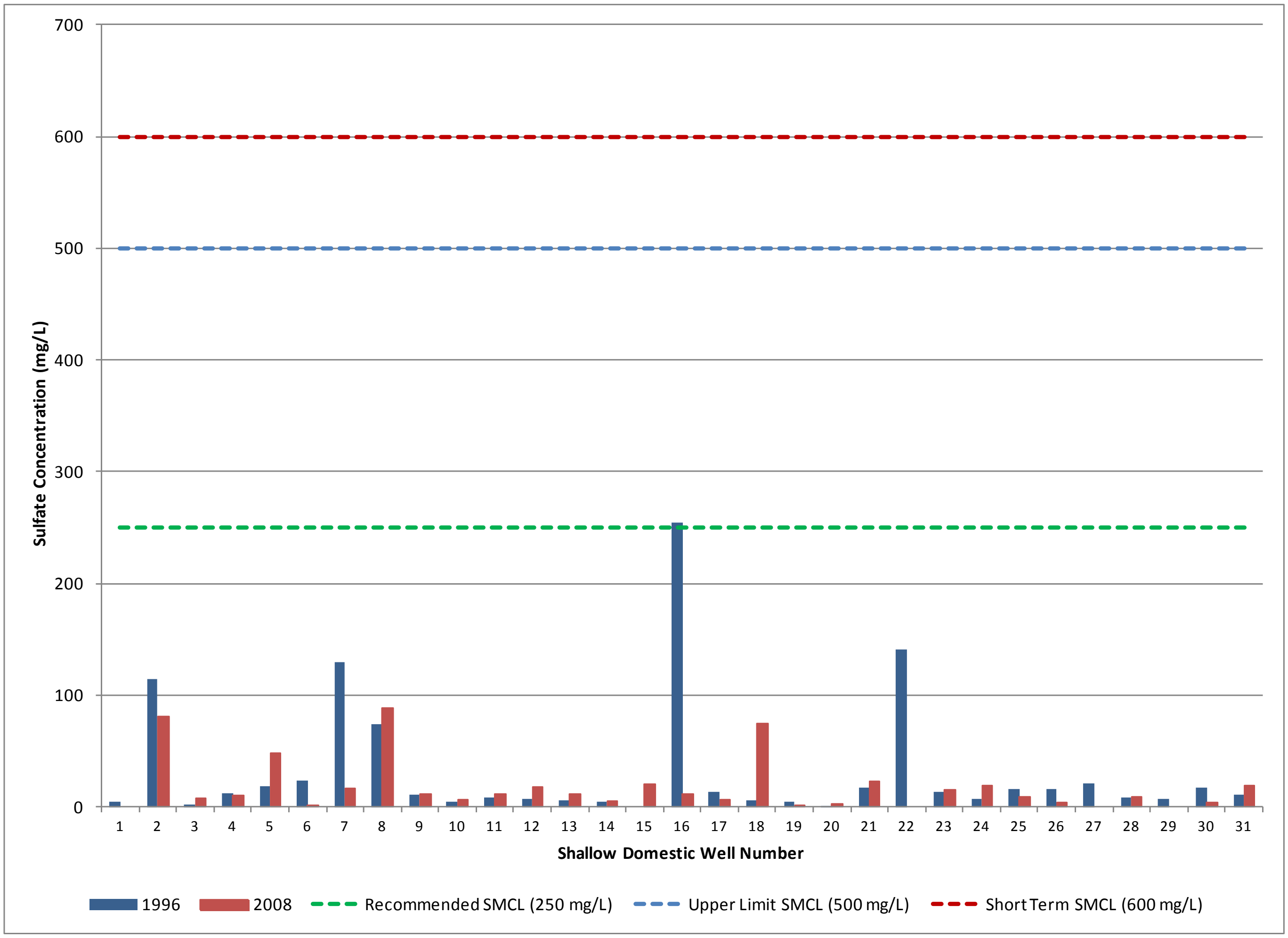
The following summarizes sulfate results for the USGS Rice Wells:

- In 24 of 28 USGS Rice Wells, sulfate concentrations were less than the 500 mg/L upper limit SMCL.
- Wells 8 and 9 showed the highest levels of sulfate. The other wells with high sulfate concentrations are wells 10 and 11, which are located in the same general area and overlie the Colusa Groundwater Subbasin. As described in Section 2.3.3 the areas where Wells 8 and 9 are located are known to have deep groundwater quality impairments because of high concentrations of chloride and sulfate. The concentrations seen in the USGS Rice Wells are most likely caused by upward migration of deeper groundwater into the shallow zone.

Sulfate in Shallow Domestic Wells

Figure 5-37 shows the results from the 1996 and 2006 Shallow Domestic Well sampling.

FIGURE 5-37
Sulfate Concentrations in Shallow Domestic Wells



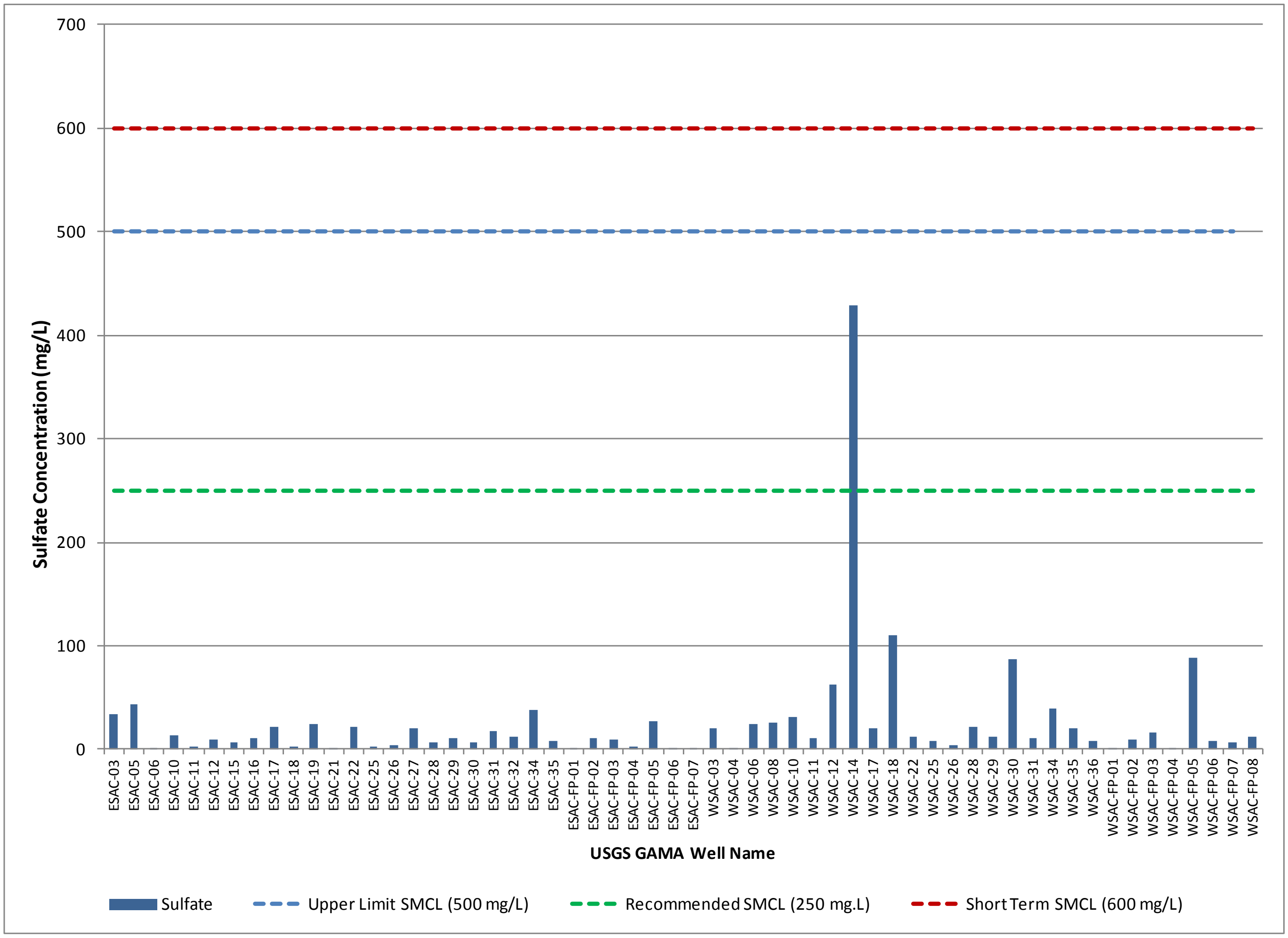
The following summarizes the sulfate observations in Shallow Domestic Wells:

- All Shallow Domestic Wells had observed sulfate concentrations below the upper limit SMCL of 500 mg/L.
- The maximum sulfate observation was 250 mg/L at Well 16 in 1998. The subsequent 2008 sample showed a greatly reduced concentration of 12 mg/L at the same well.
- Results from a few wells showed high variability from 1996 to 2008.

Sulfate in USGS GAMA Wells

Figure 5-38 shows the sulfate observations in USGS GAMA Wells. No USGS GAMA Well had a sulfate concentration in exceedance of the upper limit of the drinking water standard.

FIGURE 5-38
Sulfate Concentrations in USGS GAMA Wells



5.5 Pesticides

The four well network datasets were reviewed and pesticide detections were summarized. The list of pesticides included in past sampling was compared to the DPR GPL, and a summary of DPR's prioritization of monitoring of GPL pesticides is included. Finally, the DPR Groundwater Protection Program is summarized in an overall evaluation to provide an understanding of the comprehensive technical approach used by DPR.

5.5.1 Summary of Pesticide Sampling Results from Four Datasets

For each of the four monitoring datasets, Table 5-7 summarizes the detections of pesticides registered for use on rice. Table 5-8 is a detailed summary of the pesticide sampling performed at USGS Rice Wells. Table 5-9 compares the maximum detections to drinking water standards.

TABLE 5-7
Summary of Rice-Use Pesticides Detected in Each Monitoring Program

Dataset	Date Range	Pesticides Detected[a] (Number of Detections/Number of Samples)
USGS RICE Wells	1997–2010	Thiobencarb[b] (3/83)
Shallow Domestic Wells	1996, 2008	None
USGS GAMA Wells[c]	2006	Propanil (1/85)
DPR[d]	1986–2009	2,4-D (5/1490), Malathion (1/133), Paraquat Dichloride (5/76)

[a] Results reported as estimated concentration (E) or below the laboratory reporting limit (RL) are not included.
[b] A thiobencarb RL of 0.01 µg/L was reported in USGS 2008; however, the DPR database for the same dataset showed an RL of 0.003 µg/L. Using the USGS 2008 reported LRL, there would be 2/83 detections. Thiobencarb is regulated under the Basin Plan Rice Pesticides Program.
[c] Triclopyr is denoted as SEVIN in the GAMA Geotracker Database.
[d] The DPR detection counts exclude the USGS detections because the USGS detections are listed in the USGS detection counts.

TABLE 5-8
Summary of Rice Pesticides Sampled in the 28 USGS Rice Wells during 1997 through 2010

Material	Number of Samples							Total Number of Samples (1997–2010)	Number of Detections
	1997	2002	2003	2004	2006	2008	2010		
Bensulfuron-methyl	0	0	0	0	21	0	0	21	0
Lambda cyhalothrin	0	0	0	0	21	4	5	30	0
Propanil	28	5	5	15	21	4	5	83	0
propiconazole	0	0	0	0	21	0	0	21	0
S-cypermethrin	0	0	0	0	21	4	5	30	0
Thiobencarb*	28	5	5	15	21	4	5	83	3
Triclopyr	28	0	0	0	13	0	0	41	0
2,4-D	28	0	0	0	0	0	0	28	0
Pendimethalin	28	5	5	15	21	4	5	83	0
Carbaryl	28	5	5	15	21	4	5	83	0
Malathion	28	5	5	15	21	4	5	83	0

* Regulated under the Basin Plan Rice Pesticides Program

TABLE 5-9
Summary of Pesticides Registered for Use on Rice Versus Drinking Water Standards

	Maximum Detection (µg/L)				Number of Wells with Pesticide Detections Exceeding Drinking Water Standard				
Pesticide	USGS Rice Wells	Shallow Domestic Wells	USGS GAMA Wells	DPR Well Inventory Database	USGS Rice Wells	Shallow Domestic Wells	USGS GAMA Wells	Drinking Water Standard (µg/L)	Type of Standard
Propanil	—	—	0.097	—	—	—	—	—	—
Thiobencarb[a]	0.0254[b]	—	—	—	0	0	0	70 1	PMCL SMCL
2,4-D	—	—	—	3.60	0	0	0	70	PMCL
Malathion	—	—	—	0.32	—	—	—	160 1600	NL RL
Paraquat Dichloride	—	—	—	16.00	0	0	0	—	—

[a] Regulated under the Basin Plan Rice Pesticides Program.
[b] Detections by USGS are unconfirmed by DPR. The RLs used by USGS are more than 80% less than the approved detection limits available to DPR.

The following summarizes the results of pesticides sampling in groundwater:

- Of the pesticides sampled, none has been detected at levels within the order of magnitude of drinking water standards. Further, none of the detections have been confirmed in follow-up sampling by DPR.
- Propanil was detected in USGS GAMA Well ESAC-09, according to the USGS report on its GAMA Program sampling (USGS 2008); however, this result was not included in the results reported to DPR.
- Thiobencarb was detected in 1997 USGS Rice Well sampling. The highest detection was 0.0254 µg/L (Well 10), and the most recent detection was 0.006 µg/L (Well 12). These detections were reported in DPR's 2003 Cumulative Report (DPR 2003). The detections are considered unconfirmed because the detection limit was less than 80 percent of DPR's approved detection limit.
- 2,4-D was detected in five wells. These samples were taken in 1985, 1989, and 2006. Subsequent sampling in all five wells showed non-detections of 2,4-D. The most recent malathion sampling included in the DPR Well Inventory Database was conducted in 2008. Use of 2,4-D on rice has been almost eliminated.
- Malathion was detected in one well in 1984. A subsequent sample, taken 2 months later, resulted in non-detection of malathion. The most recent malathion sampling included in the DPR Well Inventory Database was conducted in 2002. Use of malathion on rice has been almost eliminated and is restricted to crack and crevice control in storage silos.
- Paraquat dichloride was detected in five wells. These samples were taken in 1990, 1993, and 1997. Subsequent sampling in all five wells showed non-detections of paraquat. DPR reports that follow-up sampling was performed, and the pesticide was not detected (DPR 1994). Paraquat is a very minor use material on rice.

5.5.2 Evaluation of Pesticides Sampled

The list of pesticides registered for use on rice was compared to the sampling results from the four datasets. Table 5-10 shows all of the pesticides registered for use on rice and indicates if the pesticide was included in the USGS sampling or in the DPR Well Inventory Database.

TABLE 5-10
Summary of Pesticide Sampling Under Each Dataset

Pesticide	Section 6800 List	USGS Shallow Rice Wells	USGS Shallow Domestic Wells	USGS GAMA Wells	DPR Wells
California rice pesticides					
2,4-D	●	●	●	●	●
Bensulfuron-methyl[a]	●	●	X	●	X
Bispyribac-sodium	●	X	X	X	X
Clomazone[a]	●	X	X	X	X
Halosulfuron	●	X	X	X	X
Penoxsulam	●	X	X	X	X
Thiobencarb[a]	●	●	●	●	●
Carfentrazone-ethyl	○	X	X	X	X
Cyhalofop-butyl[a]	○	X	X	X	X
Glyphosate[b]	○	X	X	X	●
Orthosulfamuron[a]	○	X	X	X	X
Paraquat dichloride	○	X	X	X	●
Pendimethalin	○	●	●	●	●
California rice insecticides					
Carbaryl	●	●	●	●	●
Malathion	●	●	X	●	●
Methyl Parathion	●	●	●	●	●
Cypermethrin	○	●	●	●	●
Diflubenzuron	○	X	X	X	X
Lambda cyhalothrin	○	●	●	●	X
California rice fungicides					
Azoxystrobin	●	X	X	X	X
Propiconazole	○	●	X	●	X
Trifloxystrobin	○	X	X	X	X
Copper sulfate (pentahydrate)	○	X	X	X	X
Sodium Carbonate Peroxyhydrate	○	X	X	X	X

● Pesticide is on the DPR Section 6800 list and/or was sampled.
○ Pesticide is not on the DPR Section 6800 list.
X Pesticide was not sampled.
[a] Pesticide is rice-use only
[b] Glyphosate = diammonium salt, isopropylamine salt, potassium salt

As shown, the following pesticides that are included on the GPL have been included in sampling:

- 2,4-D
- Bensulfuron-methyl
- Carbaryl
- Malathion
- Methyl parathion
- Thiobencarb

The following GPL pesticides have not been included in the groundwater sampling:

- Bispyribac-sodium
- Clomazone
- Halosulfuron
- Penoxsulam
- Thiamethoxam
- Azoxystrobin[7]

Of the GPL 6800(b) pesticides that have not been included in past sampling, bispyribac-sodium was identified as a low priority for DPR monitoring, and thiamethoxam was identified as medium priority (DPR 2011b). The remaining pesticides (clomazone, halosulfuron, penoxsulam, and azoxystrobin) were demoted to the lowest rankings because they have physical-chemical properties, such as extreme volatility, that would displace the effect of the use data on their rankings making their movement to groundwater highly improbable. Thiobencarb was listed as high priority, although DPR notes that its modeling and prioritization method may overestimate the risk, due to the lower hydraulic permeability of rice soils as compared to the modeled permeability. DPR indicated that a rice-specific sampling program that incorporates sampling of prioritized rice pesticides may be reasonable to address the uncertainty inherent in its modeling approach.

5.5.3 Evaluation of DPR Technical Approach

The DPR Groundwater Protection Program is a comprehensive regulatory program that evaluates risk to groundwater posed by the range of registered agricultural pesticides. The following characteristics demonstrate the robustness of the DPR Groundwater Protection Program:

- DPR's Well Inventory Database includes pesticide sampling of groundwater performed by municipal water supplies and other entities. The database is publically available and includes sufficient information for independent review and follow-up.
- DPR performs its own sampling based on a prioritization that accounts for the physical-chemical properties and usage of pesticides. This approach prioritizes sampling of pesticides with characteristics that could contribute to pesticide leaching to groundwater, and it defers sampling of pesticides with properties that would prevent migration into groundwater.
- The derivation of the Special Numeric Values used to assign leaching or non-leaching designations to pesticides is published.
- The program includes documented follow-up of detections, confirmatory sampling, and annual reporting of detections and activities.
- DPR's technical approach to evaluate pesticide risk to groundwater is documented in publically available technical reports.
- DPR has demonstrated use of its regulatory authority to address pesticides posing a risk to groundwater.
- DPR actively coordinates with other agencies evaluating groundwater, including USGS and SWRCB.

[7] Note that this pesticide and its degradates were sampled by DPR in 2011. In 2012, DPR reported three detections of the degradate azoxystrobin acid, all in wells in Glenn County. Azoxystrobin acid is a degradation product of azoxystrobin. DPR did not enter this degradation product into the Pesticide Detection Response Process because DPR determined that the detected concentrations did not pose a threat to public health (DPR 2013).

SECTION 6

Summary and Hydrogeologic Vulnerability Analysis

Data presented in preceding sections are reviewed comprehensively here to identify areas where groundwater quality may be vulnerable due to rice farming. The results of this analysis are presented with refined mapping of the initial HVAs and an assessment of constituents identified for long-term monitoring. The following analysis is framed by these questions:

- Are the monitoring networks sufficiently representative to draw regional conclusions? Are sampled areas representative of non-sampled areas?
- Based on the CSM and environmental data, what constituents are of concern?
- Can initial HVAs be refined in light of more detailed review of soils, water quality, and/or rice root-zone data? That is, are some of the initial HVA areas in fact not hydrogeologically vulnerable?

6.1 Application of the CSM

The large, contiguous acreage in the Sacramento Valley farmed continuously in rice, combined with the uniqueness and consistency of rice-farming practices, support the use of a rice-specific approach to groundwater quality management. The rice-specific CSM provides a comprehensive picture of potential pathways and transformations for water and applied materials in the subsurface under rice-farming conditions.

The CSM helped define the following conditional scenarios, which were expanded upon from the original goals described in Section 2.5:

- Where risk of transport from the root zone to the shallow groundwater is low, for a given set of characteristic conditions (constituent of concern, soil conditions, and management practices), it can be concluded that the low risk applies to all similar conditions in rice-farming areas.
- Where a preponderance of the groundwater observed in shallow monitoring wells typical of rice-farming conditions is of high quality, it can be concluded that rice is not causing degradation of groundwater quality, and it can be assumed that rice farmed under similar conditions in unmonitored areas is likewise not causing degradation.
- Where exceedances of drinking water standards are observed in areas confirmed to be a weak source condition, these may be caused by site-specific conditions or other sources nearby. Additional evaluation in these and similar areas may be warranted if there is reason to believe that rice farming might be a significant source.
- Where exceedances of drinking water standards are observed and either rice farming has been proven not to contribute to a groundwater quality problem, or a clear source has been identified (for example, septic systems or land use other than rice farming), no additional monitoring or source identification by the CRC in these areas is warranted.
- Where exceedances of drinking water standards are observed and a clear naturally occurring source has been identified, no additional monitoring by the CRC in these areas is warranted.
- Where groundwater quality monitoring has not been conducted for a given set of conditions (for example, relatively coarser soils than where monitoring has been conducted) or for a certain geographical area, such monitoring may be indicated to confirm the weak source condition for these areas and to fill a data gap.

6.2 Monitoring Network Assessment

The USGS monitoring networks were assessed to determine whether the monitored locations are representative of the larger area and can therefore be considered characteristic of regional conditions. The following assessments were performed to draw conclusions on the applicability of the datasets:

- **Rice land use representativeness:** Do the reviewed well networks adequately represent groundwater within the rice-growing region?
- **Geographic representativeness:** Are wells within the GAR's geographic extent, and do they adequately represent the area? Are the initial HVAs adequately monitored to draw conclusions on the hydrogeologic vulnerability of rice growing areas?
- **Soils representativeness:** Are wells representative of the range of soil conditions within the within the rice-growing areas analyzed in this GAR, and are there wells sited in or near the full range of soil types found on significant rice land acreage?

6.2.1 Rice Land Use Representativeness

The following datasets were reviewed: Linquist et al. 2011 research results, USGS Rice Wells, Shallow Domestic Wells, USGS GAMA Wells, DPR Well Inventory Database (pesticides only), and NRCS soil survey data for the area. The Linquist et al. (2011) data were used to evaluate nitrate in the root zone, and the three types of well data from the USGS were chosen to evaluate groundwater quality at various depths. Table 6-1 summarizes the four water quality datasets.

Of the reviewed groundwater datasets, the USGS Rice Wells network is well suited for the characterization of the impacts of rice farming on groundwater quality. The other groundwater datasets provide additional lines of evidence to assess regional groundwater quality.

TABLE 6-1
Summary of Water Quality Datasets

Dataset	Subsurface Zone	Summary
Linquist et al.	Root Zone	The Linquist et al. (2011) research provides a good understanding of root-zone characteristics and the fate of applied N in rice fields, and characterizes a range of soil physical properties.
USGS Rice Wells	Shallow groundwater (30 to 50 feet deep) located near rice fields	The USGS Rice Well network provides a sufficient spatial and temporal dataset on which to base conclusions about the influence of rice farming on groundwater quality. The USGS Rice Wells provide a substantial network of shallow wells considered to be representative of lands on which rice is farmed (rice lands). This well network was constructed in 1997 by USGS, which continues to monitor it. The network initially included 28 wells distributed throughout the Sacramento Valley rice lands. This dataset provides the best water quality data for shallow groundwater quality potentially affected by rice farming, and is therefore well suited to representative shallow monitoring as well as trend monitoring for a wide range of constituents since 1997. See Appendix E-3 for detailed aerial maps showing land use surrounding each well.
Shallow Domestic Wells	Shallow groundwater used for domestic supply in the eastern portion of the Study Area (average top perforation is 112 feet and average bottom perforation is 149 feet below land surface)	The Shallow Domestic Wells provide additional shallow groundwater quality data to complement data from the USGS Rice Wells. Shallow Domestic Wells are not all located near rice fields and may have mixed land uses around them, but nevertheless can provide an understanding of groundwater quality upgradient and downgradient of rice lands (all sampled in 1996, and a subset in 2008).
USGS GAMA Middle Sacramento Valley Study Unit	Deep public groundwater supply wells (average top perforation is 197 feet and average bottom perforation is 340 feet below land surface)	The USGS GAMA Wells include deeper water supply wells and represent groundwater quality near rice fields and under the influence of prolonged rice farming on land in the region (sampled in 2006).

6.2.2 Initial HVAs and Geographic Representativeness

The SWRCB initial HVAs form the basis of the initial vulnerability assessment described in this section. An evaluation was performed to assess if the initial HVAs within each county were represented by the USGS Rice Wells network.

Map 6-1 shows the USGS well networks and location of rice lands that intersect with the initial HVAs (SWRCB initial HVAs and DPR GPAs). A GIS analysis was performed to calculate the number of acres of rice lands within initial HVAs. This analysis showed approximately 48,000 acres overlying initial HVAs and more than 537,000 acres overlying non-HVA lands. Table 6-2 shows the GIS calculation results for each county and includes the number of USGS Rice Wells in each county. This analysis led to the following observations:

- Just 9 percent of total potential rice acreage overlies initial HVAs; 91 percent of rice is grown on areas that do not overlie initial HVAs.
- Over half of the rice acreage in Yuba County (~21,000 acres) overlies initial HVAs, thus representing 43 percent of all rice lands overlying initial HVAs. No USGS Rice Wells are located in Yuba County.
- Other than Yuba County, the highest percent of rice overlying an initial HVA is in Colusa County. About 8 percent of rice lands (~11,000 acres) in Colusa County overlie initial HVAs.
- The remaining ~16,000 acres are spread over Sutter (~8,000 acres), Butte (~3,000 acres), Glenn (~2,400 acres), and Yolo (~2,000 acres) counties.
- Very minor acreages overlie initial HVAs in Placer (~400 acres) and Sacramento (~160 acres) counties.
- Tehama County rice acreage is negligible and, likewise, so is its potential impact to groundwater quality. Therefore, Tehama County was excluded from the analysis.

TABLE 6-2
Geographic Breakdown of USGS Rice Wells and Initial HVA Acreages by County

County	Number of USGS Rice Wells per County	Acres of Rice not within an Initial HVA*	Acres of Rice within an Initial HVA*	Percent of Rice Overlying Initial HVA
Butte County	5	102,300	3,300	3%
Colusa County	4	136,100	11,300	8%
Glenn County	13	88,200	2,400	3%
Placer County	0	21,000	400	2%
Sacramento County	1	11,300	200	1%
Sutter County	4	132,000	7,900	6%
Yolo County	1	28,500	1,900	6%
Yuba County	0	18,100	20,800	53%
Total	**28**	**516,500**	**48,200**	**8%**

* Values are rounded to the nearest 100 acres.

On the basis of the above calculations and the water quality data presented in Section 5, the following observations can be made:

- The 26 USGS Rice Wells located in Butte, Colusa, Glenn, and Sutter counties provide an adequate characterization of shallow groundwater quality for rice areas in these counties.
- Placer and Sacramento counties have poor characterization of shallow groundwater by USGS Rice Wells, but they have very small acreages overlying initial HVAs.
- Yuba County has no USGS Rice Wells for characterization of shallow groundwater and has a relatively large acreage overlying initial HVAs.

6.2.3 Soils Representativeness

A GIS evaluation was performed to assess whether the well networks were characteristic of rice soil conditions in the Study Area. This included evaluation of the following characteristics:

- NRCS drainage classes as compared to the locations of monitoring wells
- NRCS drainage classes by county
- Soil texture class evaluations for the higher drainage class areas

Rice is farmed on five NRCS soil drainage classes that range from "very poorly drained" to "well drained," but they are predominantly farmed on "poorly drained" soils (NRCS 2012).

In general, for rice areas, poorly drained soils occur in the center of the valley, and better-drained soils occur in limited acreages on the valley margin: northern Glenn County, Yuba County, eastern Sutter County, and Placer County (see Map 2-7). Information about the distribution of shrink-swell clays in rice-farming areas is provided on Map 2-12, and the locations of wells relative to those clays is shown in Appendix H on Map H-1.

6.2.3.1 Well Locations and Drainage Classes

The NRCS soil drainage classification and the locations of each well relative to the soil drainage classes were determined. A GIS analysis was performed to identify the NRCS drainage class of soil around each well from the three USGS datasets. It was also determined whether other drainage classes were located within 1 mile of a well. The detailed results of this analysis are included in Appendix H. Table 6-3 is a summary of the wells associated with each of the NRCS soil drainage classes. Map H-2 illustrates the location of these wells relative to soil drainage classes.

Analysis and an evaluation of the well locations resulted in following conclusions concerning soil drainage characteristics:

- The majority of USGS Rice Wells are sited on poorly drained or somewhat poorly drained soils that comprise over 390,000 acres (67 percent) of rice lands. Among the USGS Rice Wells, 15 are sited on poorly drained soils, and 7 wells are sited on somewhat poorly drained soils. Data from these wells have shown that the shallow groundwater in these areas is of good quality. Since rice is farmed continuously and almost homogeneously throughout the area, these wells provide an adequate characterization of shallow groundwater underlying these soil types.
- Shallow groundwater beneath the remaining 6 USGS Rice Wells represents more than 190,000 acres. The wells are situated on moderately well- and well-drained soils. Groundwater had no observable impairment by rice cultivation even thought rice has been cultivated in these areas for a long time. These observations are consistent with the interpretation of the CSM of the Sacramento Valley rice cropping system.
- The majority of the shallow domestic wells are located on well-drained and moderately well-drained soils.
- The GAMA wells are distributed among the well-drained to poorly drained soils.
- The USGS Rice Wells network does not cover the valley margin areas well, so this area may not be represented by this network and could be considered a data gap.
- An initial gap in groundwater monitoring associated with "moderately well drained" and "well drained" rice lands was identified. These soils constitute 105,300 acres (18 percent) and 86,700 acres (15 percent), respectively, and are mostly located on the upgradient valley fringes (closer to the Coast Range and Sierra Nevada mountain ranges). This potential data gap is further evaluated below.
- Somewhat excessively drained soils, excessively drained soils, and unclassified soils constitute only 1,000 acres of rice lands (0.17 percent).

TABLE 6-3
Summary of Soil Drainage Classes Associated with Wells Monitored by the USGS

		Number of Wells		
NRCS Soil Drainage Class	**Rice Acres[a]**	**USGS Rice**	**Shallow Domestic**	**USGS GAMA**
Excessively drained	400	0	0	1
Somewhat excessively drained	300	0	1	5
Well drained	86,700	3	15	32
Moderately well drained	105,300	3	8	13
Somewhat poorly drained	87,600	7	4	14
Poorly drained	303,800	15	1	12
Very poorly drained	—	0	0	0
Outside Study Area	—	0	2	9
Unclassified drainage class	300	0	0	0
Totals	**584,400**	**28[b]**	**31**	**86**

[a] Values are rounded to the nearest 100 acres.
[b] The USGS Rice Wells network initially included 28 wells, but now only 23 functional wells remain.

6.2.3.2 Drainage Classes by County

A second analysis was performed to evaluate geographic extent of the monitoring networks and soils characteristics on rice lands. The acres of each drainage class in each county were tabulated, and detailed maps of the drainage classes of rice lands were prepared for each county (Appendix H). Table 6-4 shows the acres of each drainage class in each county. About 70 percent of rice is grown on land classified as poorly or somewhat poorly drained, and the rest on better drained land. When interpreting these data, the following considerations should be borne in mind:

- Drainage classes are mapped on natural pedons (profiles) and do not reflect changes in actual drainage induced by management.
- Drainage classes may also reflect relatively well-drained topsoil under a non-flooded irrigation regime, and may ignore the potential influence of restrictive layers in a flooded rice setting.
- Repeated plowing and flooding without subsoil tillage (as practiced in rice) tends to induce development of a plowpan where natural restrictive layers are lacking.
- Some restrictive layer is present and functional in nearly all rice fields because it is needed to help retain a constant flood, which is necessary in turn to control weeds and maintain fertility (i.e., avoid loss of N).

Appendix H includes figures that show the proportions of rice land acres in each NRCS drainage class for each county. A total of 67 percent of rice lands (391,400 acres) are located on poorly drained and somewhat poorly drained soils. A total of 23 USGS Rice Wells were sited on these drainage classifications. The results from these wells were all below the MCL; 22 wells showed an NO2+NO3-N concentration less than 3 mg/L, indicating an unimpacted condition (Well 3 had a spike in NO2+NO3-N concentration in 2009 and a subsequent sample in 2010 had a level of 1 mg/L). This consistent finding demonstrates that rice farming is not impacting shallow groundwater within these drainage classifications, and it supports the application of the findings to non-sampled areas.

Within the following counties, the great majority of rice lands are located on poorly drained and somewhat poorly drained soils: Butte (97 percent), Colusa (82 percent), Glenn (76 percent), Sacramento (83 percent), and Yolo (86 percent). Within the other counties, a lesser proportion of rice lands are on poorly drained and somewhat poorly drained soils: Placer (11 percent), Sutter (43 percent), and Yuba (3 percent). These lands are considered to be well represented by the historical sampling conducted at the 23 USGS Rice Wells sited on these drainage classifications.

TABLE 6-4
Geographic Breakdown of Soil Drainage Class Acreages by County

County	Poorly Drained	Somewhat Poorly Drained	Moderately Well Drained	Well Drained	Somewhat Excessively Drained	Excessively Drained	Undefined	Total*
Butte	89,500	12,700	1,600	1,300			2	105,100
Colusa	106,400	15,800	14,700	12,000	3		43	149,000
Glenn	32,400	37,300	2,000	19,000	300	400	16	91,400
Placer	1,800	400	800	16,500		5	2	19,500
Sacramento	3	8,600	1,600	80			24	10,300
Sutter	49,800	9,500	53,500	27,200	50		76	140,100
Yolo	23,900	2,000	3,400	800			39	30,100
Yuba		1,300	27,600	9,700			56	38,600
Total	**303,800**	**87,600**	**105,200**	**86,600**	**400**	**400**	**300**	**584,300**

* Values are rounded to the nearest 100 acres.

Appendix H includes figures that show the proportions of rice land acres in each NRCS drainage class for each county. A total of 67 percent of rice lands (391,400 acres) are located on poorly drained and somewhat poorly drained soils. A total of 23 USGS Rice Wells were sited on these drainage classifications. The results from these wells were all below the MCL; 22 wells showed an NO2+NO3-N concentration less than 3 mg/L, indicating an unimpacted condition (Well 3 had a spike in NO2+NO3-N concentration in 2009 and a subsequent sample in 2010 had a level of 1 mg/L). This consistent finding demonstrates that rice farming is not impacting shallow groundwater within these drainage classifications, and it supports the application of the findings to non-sampled areas.

Within the following counties, the great majority of rice lands are located on poorly drained and somewhat poorly drained soils: Butte (97 percent), Colusa (82 percent), Glenn (76 percent), Sacramento (83 percent), and Yolo (86 percent). Within the other counties, a lesser proportion of rice lands are on poorly drained and somewhat poorly drained soils: Placer (11 percent), Sutter (43 percent), and Yuba (3 percent). These lands are considered to be well represented by the historical sampling conducted at the 23 USGS Rice Wells sited on these drainage classifications.

A total of 33 percent of rice lands (192,000 acres) are located on moderately well-drained and well-drained soils. A total of 10 USGS Rice Wells were sited on these drainage classifications. The results from these wells were all below the MCL; eight wells showed a NO2+NO3-N concentration less than 3 mg/L, indicating an unimpacted condition, while one well showed a NO2+NO3-N concentration only slightly elevated above 3 mg/L, and the other well shows potential influence from non-rice sources. This consistent finding demonstrates that rice is not impacting shallow groundwater within these drainage classifications, and supports the application of the findings to non-sampled areas.

The following counties have a majority of rice lands in moderately well-drained and well-drained soils: Placer (89 percent), Sutter (58 percent), and Yuba (97 percent). Within the other counties, lesser proportions of rice lands are located on moderately well-drained and well-drained soils: Butte (3 percent), Colusa (18 percent), Glenn (23 percent), Sacramento (16 percent), and Yolo (14 percent). These lands are well represented by the historical sampling conducted at the 10 USGS Rice Wells sited on these drainage classifications. However, due to the large proportion of rice lands farmed on the lesser represented moderately well-drained and well-drained soils, and the fact that no USGS Rice Wells are sited within Yuba County, this county is carried forward for additional vulnerability analysis. Placer County has only minimal acreage of initial HVAs (402 acres) and was therefore not further evaluated. Sutter County, which has just 6 percent of its rice land overlying an initial HVA, is further evaluated in Section 6.3. Tehama County rice acreage is negligible and, likewise, so is its potential impact to groundwater quality. Therefore, Tehama County was excluded from the analysis.

6.3 Water Quality Vulnerability Assessment

As demonstrated in Section 5, the reviewed monitoring networks provide sampling data that include a broad range of chemical parameters tested in groundwater samples. The main groups of constituents evaluated include nutrients and salts, general parameters, and pesticides. As demonstrated with the CSM and shown in past research, leaching of contaminants from rice fields to groundwater is extremely slow because of poor drainage, soil conditions, and the presence of restrictive layers in the rice soils. These drainage characteristics coupled with flood irrigation methods practically eliminate nitrate from soils within the root zone. Limited water movement, the absence of nitrate in soil pore water, and low to very low nitrate concentrations in shallow groundwater together suggest that applied nitrogen does not pose a significant risk to groundwater in this cropping system throughout its geographic extent. Minor exceptions may exist, but where they do, they would have a highly localized influence on groundwater quality.

Reducing conditions also exist within shallow aquifers, where certain constituents (arsenic, iron, manganese) can become mobilized. The volume of these aquifer materials dwarfs the volume of the thin veneer of sediments comprising overlying rice root zones. Thus, the mass of these elements mobilized from rice root zones cannot contribute a significant proportion of these naturally occurring solutes. Where elevated concentrations of these constituent are detected in deeper groundwater, they are caused by sources in naturally occurring sediments and geologic formations in aquifers. More details are presented in the sections below.

6.3.1 Nitrate and Salinity

The primary constituents being addressed by the LTILRP are nitrate and salinity. A summary of nitrate and salinity results for the USGS Rice Wells is provided in Table 6-5.

TABLE 6-5
USGS Rice Wells Nitrate and Salinity Results

Rice Well #	Number of Samples	Range of NO2+NO3-N Detections (mg/L)	Range of TDS Detections (ppm)*	Geographic Area
1	10	2.49–6.22	843–950	North of the City of Sacramento
2	3	0.05–0.06	**7390–7510**	South Sutter Basin
3	11	0.65–5.97	471–774	South Sutter Basin
4	1	0.05	671	Proximity to Dunnigan, west of Sacramento River
5	1	1.13	310	Southwest of Wheatland
6	3	0.88–0.92	362–402	North Sutter Basin
7	3	1.72–2.35	566–570	North Sutter Basin
8	10	0.53–0.99	**2740–4300**	West of Sutter Buttes, between Colusa and WIlliams
9	3	0.05–0.06	**2240–2940**	West of Sutter Buttes, between Colusa and Williams
10	3	0.17–0.28	**1010–1050**	Proximity to Maxwell
11	3	0.08–0.33	**1200–1410**	Proximity to Maxwell
12	3	0.04–0.05	174–199	Proximity to Princeton
13	1	0.56	419	North of Sutter Buttes

TABLE 6-5
USGS Rice Wells Nitrate and Salinity Results

Rice Well #	Number of Samples	Range of NO2+NO3-N Detections (mg/L)	Range of TDS Detections (ppm)*	Geographic Area
14	1	1.22	**1110**	Proximity of Willows and wildlife refuge
15	3	0.47–0.8	404–474	North of Sutter Buttes
16	3	0.28–0.36	155–212	Proximity to Glenn
17	10	0.02–0.08	222–425	Between Glenn and Princeton
18	10	0.52–0.85	518–540	Proximity of Willows and wildlife refuge
19	3	0.3–0.97	566–586	Proximity of Willows and wildlife refuge
20	1	0.38	433	Between Glenn and Princeton
21	3	1.64–1.83	487–494	Proximity to Richvale
22	3	0.05–0.06	478–505	Proximity to Glenn, west of Sacramento River
23	1	0.21	404	West of Butte Creek
24	3	0.06–0.21	569–570	West of Sierra Nevada Foothills
25	3	3.12–3.82	539–569	Proximity of Willows and wildlife refuge
26	3	0.4–2.25	444–468	Proximity to Glenn, west of Sacramento River
27	1	2.34	741	Between Willows and Glenn
28	2	0.27–1.84	435–456	West of Sierra Nevada foothills, proximity to Durham

* Boldface results show the wells that have TDS concentrations above the SMCL.

6.3.1.1 Nitrate

Nitrate was not detected in any USGS Rice Well at a level exceeding the MCL, and the large majority showed concentrations below the level indicative of anthropogenic impacts.

The quality of this shallow groundwater suggests that despite the short distance from the root zone to shallow groundwater observed beneath rice fields, there is no evidence of nitrate contamination from rice lands monitored by these wells. This further suggests that rice cultivation is not a source of nitrate contamination throughout areas of rice land use. These results are consistent with geochemical understanding of rice root zone properties and are validated by the other USGS datasets reviewed. These results are also consistent with USGS's conclusions after analyzing results from sampling of the USGS Rice Wells (USGS 2001a). Similar results were also obtained in a USGS rice land use study in Louisiana (USGS 2004).

It was hypothesized that rice is a weak source of N to groundwater. Low permeability soils combined with saturated conditions contribute to a redox and transport environment that favors the conversion of nitrate to nitrite and volatile gases (denitrification), and that could only very slowly transport nitrogen present in any form to groundwater. This root zone analysis is substantiated by Sacramento Valley field work conducted on a range of soil types representative of virtually all rice farm lands (Linquist et al. 2011). As would be expected based on the known behavior of N in the rice root-zone environment, shallow groundwater in USGS Rice Wells representative of rice land use has low levels of N relative to drinking water quality standards. Further, deep groundwater near rice fields (monitored by USGS GAMA Wells) also contains low N concentrations. These three lines of evidence substantially confirm the hypothesis that rice farming is a weak source of N to groundwater.

As a result of these features of the Sacramento Valley rice-farming system, monitoring results show that rice field root zones are as dilute as underlying groundwater, with low rates of downward percolation. The observed quality of underlying groundwater is consistently high (nitrate concentrations are very low). The lines of evidence reviewed demonstrate that Sacramento Valley groundwater is not vulnerable to nitrate contamination by rice farming.

6.3.1.2 Salinity

The TDS results for the 28 USGS Rice Wells were varied, ranging from 155 mg/L to over 7,500 mg/L. Groundwater samples collected from most of the USGS Rice Wells had TDS concentrations below 1,000 mg/L (the upper limit SMCL—taste and odor—for TDS). A total of 7 of the 28 USGS Rice wells had TDS concentrations in excess of the 1,000 mg/L taste-and-odor MCL. This finding is consistent with the historical information regarding the natural occurrence of salinity in these areas (DWR 1978). Three wells had maximum observed TDS concentrations above 2,000 mg/L, which is generally considered the lower limit of saline water, with the maximum concentration measured at 7,510 mg/L in Well 2.

Rice agriculture in the Sacramento Valley generally utilizes high-quality surface water to maintain a standing flood in the rice fields and a productive cropping system. This use of high-quality irrigation water, combined with the generation of a relatively dilute surface and subsurface drainage, ensure that salts do not build up in the soil profile beneath rice fields. Rice has a very low salinity tolerance (approximately 430 mg/L of TDS in irrigation water, or an effective soil EC of about 1 dS/m) and could not tolerate the accumulation of additional salinity in the root zone without substantial yield reduction. These observations are consistent with the low levels of TDS observed in the USGS Rice Wells and with other studies showing that TDS is generally at concentrations below 500 mg/L in the SVGB.

Well 2 is located south of the Sutter Buttes near the confluence of the Feather and Sacramento rivers, which is an area where high TDS levels in deeper wells are commonly observed. Water quality measured in DWR nested wells between 2001 and 2012 showed that high EC in the vicinity of USGS Rice Well 2 was not only found in the shallow aquifer, but also in the deeper zones; at approximately 695 feet, EC was found to be 1,004 µS/cm (Sutter County 2012). These observations suggest that the elevated salinity values in this area are due to regional geochemical conditions that exist throughout the aquifer and are not related to near-surface irrigation practices.

The other two wells that showed high TDS and EC levels are USGS Rice Wells 8 and 9, located near Colusa and Williams, west of the Sutter Buttes. Some DWR wells that are 200 to 500 feet deep in this general area show EC levels above 2,650 µS/cm (Colusa County 2008). A source of recharge to groundwater in this area is subsurface inflow from the Coast Ranges, which is known to have lower quality water due to the presence of marine sediments and mineral springs located upgradient. In addition, high salinity in groundwater around the Sutter Buttes is believed to be caused by upwelling of saline water from underlying marine sediments (USGS 1984). These data also suggest that elevated salinity levels in groundwater are due to regional influences rather than shallow irrigation practices.

Historical observations documented in DWR Bulletin 118-78 further support the hypothesis discussed above. It states that there are two major areas of high salinity in the Sacramento Valley, both of which correspond to the areas where high salinity values have been observed in the USGS Rice Wells. The report states that saline water occurs at a shallow depth west of the Sutter Buttes near Colusa, and also in south Sutter County (near the Sacramento and Feather River confluence). The source is believed to be marine sediments surrounding the Sutter Buttes, as saline water is believed to have been flushed from the uplifted Cretaceous sediments. In south Sutter County, saline water is believed to be rising along a permeable zone associated with a fault.

The presence of high TDS in shallow groundwater is not reasonably attributable to rice. The lines of evidence reviewed demonstrate that Sacramento Valley groundwater is not vulnerable to salinity contamination due to rice agriculture.

6.3.2 General Parameters

A few constituents known to be present in natural geologic aquifer formations of the Sacramento Valley, including arsenic, barium, cadmium, iron, manganese, and sulfate, were found to be above their respective MCL in localized areas. Known historical issues related to naturally occurring manganese and iron were documented by DWR in 1978. This GAR evaluation identified arsenic, barium, cadmium, iron, manganese, sulfate, and salinity indicators as constituents present in USGS Rice Wells at levels above MCLs. Table 6-6 provides a short summary of the water quality vulnerability assessment for general parameters.

Some of these naturally occurring constituents might be periodically mobilized through human practices, such as rice farming, as well as through natural seasonal drying/wetting cycles; however, in cases where soils were flooded under native hydrologic regimes (such as the wetland conditions present prior to land reclamation), historical flooded conditions would have had similar effects on these constituents so that they would have been similarly mobilized (and thus leached and depleted) under pre-development conditions. Depletion of common salts, Fe, and Mn is a diagnostic feature of natural wetland soils, including many soils that are now used to grow rice. Due to this type of natural history and the low downward hydraulic conductivity of rice soils, rice lands are not plausible strong sources of any of these elements, especially when compared to voluminous reduced aquifer materials. The volume of aquifer sediment bearing these constituents far exceeds the total volume of rice soils, which are by comparison a thin veneer coating the land surface; therefore, the aquifer sediments are the likely source of these constituents in groundwater.

TABLE 6-6
Summary of General Parameter Data and Vulnerability Analysis

Parameter	Summary
Arsenic	Rice farming does not directly contribute to arsenic in the soil or groundwater. Arsenic detected in shallow groundwater at the foot of the Sutter Buttes is likely the result of volcanic deposition. Arsenic is not applied to rice fields (except in trace amounts in irrigation water) and is not a groundwater quality constituent of concern with respect to rice farming.
Barium and cadmium	Barium was detected in USGS Rice Well Number 2 (a high-salinity, high-mineral well) at a level above the MCL. There were no other exceedances of barium MCLs, and barium was not detected in Shallow Domestic Wells or USGS GAMA Wells above the MCL. Barium is not applied to rice fields (except in trace amounts in irrigation water) and is not a groundwater quality constituent of concern with respect to rice farming.
Iron and manganese	It is recognized that the naturally occurring elements iron and manganese may be mobilized by the saturated conditions maintained on rice fields. These elements are highly mobile and are sensitive to the fluctuating redox conditions that occur seasonally. This is evident from the widely varying results observed at single wells over time. It is reasonable to assume that the wide variation in iron and manganese concentrations would have occurred under the historical wetland conditions of lands converted to rice farm uses. Fe and Mn are not applied to rice fields (except in trace amounts in irrigation water) and are not groundwater quality constituents of concern with respect to rice farming.
Sulfate	The two limited areas showing higher levels of sulfate were identified in an area known to have deep groundwater quality impairments caused by high concentrations of chloride and sulfate. The concentrations in these shallow wells are most likely caused by upward migration of deeper groundwater into the shallow zone. Sulfate is not a groundwater quality constituent of concern with respect to rice farming.

6.3.3 Pesticides

There have been no confirmed detections of pesticides currently registered for use on rice. DPR has a robust program in place to prioritize pesticides and monitor for their presence in groundwater. However, the suite of sampled pesticides may represent a data gap. Some pesticides are included on DPR's GPL and have not yet been monitored. DPR's inclusion on the GPL was recognized to be based in part on a technical methodology that likely overestimated the leaching potential of the pesticides. DPR used a coarse San Joaquin soil for their modeled risk assessment rather than the finer textured or duripan soils on which rice is farmed in the Sacramento Valley. Also, these pesticides were previously lower ranked than others and were therefore not included in previous DPR sampling. DPR intends to monitor for high-priority GPL pesticides under its Groundwater Protection Program. DPR indicated that additional (non-GPL) pesticides used in rice farming may be included to take advantage of sampling efficiencies.

6.4 Temporal Representation

Rice has been farmed in California for more than 100 years, and on large acreages in the Sacramento Valley since the 1920s. Readily available statistical records of California (mostly Sacramento Valley) rice acreage showed a steady climb from over 100,000 acres in the 1930s to over 500,000 acres by 1980. Since 1980, rice acreage has fluctuated between 350,000 and 580,000 acres in the Sacramento Valley. Farming practices and cropping systems have been fairly constant since the advent of short-stature, high-yielding rice varieties over 30 years ago.

The USGS Rice Wells network provides an excellent record of groundwater quality that is representative of modern rice-farming practices since it was determined that the groundwater sampled by these wells was recharged approximately in the 1950s (Section 4.2). In addition, these wells provide a good temporal period of record (since 1997) to provide an initial assessment of groundwater quality trends.

Groundwater quality problems related to nitrate are not observed near rice farms. This demonstrates that rice, as it was farmed historically and as it is farmed today, has been a weak (dilute) source of N to groundwater. Because all of the USGS Rice Wells data indicates NO2+NO3-N below the MCL, it can be concluded that historical rice land use did not contribute to nitrate problems in shallow groundwater.

6.5 Refined Vulnerability and Data Gap Determination

The vulnerability of groundwater to contamination is determined based on analysis of physical and chemical conditions (soil, drainage, moisture regime, and geologic/hydrogeologic properties), historical groundwater quality sampling results, and land use practices (rice management practices). The analysis presented in this GAR supports a rice-specific refinement of the initial SWRCB vulnerability designations.

Because Yuba, Colusa, Sutter, and Butte counties had the largest number of acres overlying initial HVAs, an additional evaluation was conducted for these counties; soil drainage classes and restrictive layers overlying the initial HVAs were identified and analyzed.

Yuba County was determined to be an initial data gap because of three interrelated factors:

- The high proportion of Yuba County rice acreage farmed on moderately well-drained and well-drained soils, as classified by NRCS
- The lack of substantial numbers of USGS Rice Wells located throughout the Study Area in these moderately well-drained and well-drained soil classes
- The lack of USGS Rice Wells in Yuba County

The NRCS drainage classes represent just one means of characterizing soil and provided a valid screening analysis. More detailed map unit description information, available as part of the NRCS SSURGO dataset, provides additional information for vulnerability analysis.[8] The map units were queried for the Yuba County rice lands. Appendix H shows the predominant map units in Yuba County, the acres of rice grown on each map unit, and the acres of rice overlying the approximate 21,000 acres of initial HVAs on the map unit.

One component of these data is the depth to duripan. A duripan is a soil horizon cemented by silica into a subsurface hardpan. A duripan constitutes a restrictive layer to vertical movement of water and constituents and has very low hydraulic conductivity. The detailed data are included in Appendix H. Rice acres overlying initial HVAs characterized as having a duripan less than 60 inches bgs constitute approximately 16,000 acres, or 78 percent of all initial HVA rice lands. About 1,700 acres (8 percent) are characterized as having a duripan greater than 60 inches bgs, and 2,800 acres (13 percent) had unreported depths to duripan.

[8] A map unit is a collection of areas defined and named the same in terms of their soil components. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map (NRCS 2007).

This analysis found the following:

- About 5,000 acres of rice lands overlying HVAs in Yuba County represent a data gap, for the reasons described above, and have soil properties that are not characterized as low risk.
- The approximately 16,000 acres of rice overlying initial HVAs have properties that are restrictive to vertical migration of applied materials to groundwater. However, these loamy soil types with a restrictive duripan are not well characterized by the reviewed datasets, and although the presence of the duripan indicates that rice farming in these areas poses a low risk to water quality, the area does represent a data gap.

Colusa County includes about 12,000 acres of rice overlying initial HVAs. These acres were evaluated against NRCS drainage classes, and it was determined that nearly 10,000 acres are poorly drained and somewhat poorly drained, with the remaining 2,000 acres moderately well drained and well drained. Poorly drained and somewhat-poorly drained soils are not well characterized by USGS Rice Wells in the initial HVA areas. However, USGS Rice Wells 9, 10, and 11 are representative of poorly drained soils in non-HVA areas, and these results can be used to assess the impacts on groundwater underlying these types of soils. Moderately well-drained and well-drained soils are not well characterized by USGS Rice Wells. About 27,000 acres in Colusa County are designated as moderately well-drained and well-drained soils, including 25,000 acres that were not designated as initial HVAs. These areas were further evaluated on the basis of map unit descriptions. Approximately 11,000 acres are of the Capay loam soil classification, including a large area of contiguous Capay loam. USGS Rice Well 8 is located in the center of this area and provides characterization of the rice-specific vulnerability to these soils.

Sutter County included about 7,900 acres of rice overlying initial HVAs. These acres were evaluated against NRCS drainage classes, and it was determined that nearly 4,900 acres are poorly drained and somewhat poorly drained, with the remaining 3,000 acres moderately well drained and well drained. Approximately 80,700 acres are designated as moderately well-drained and well-drained soils, including 75,800 acres that were not designated as initial HVAs. USGS Rice Well 5 is located in a contiguous area of the well-drained classes and provides characterization of the rice-specific vulnerability. Additionally, two Shallow Domestic Wells are located in this contiguous area and were found to have NO3-N concentrations less than half the MCL. However, no wells were found to be representative of the moderately well-drained soils that are predominantly in the eastern part of the county in non-initial HVAs. This area will be further assessed during the data gap evaluation.

Butte County included about 3,700 acres of rice overlying initial HVAs. These acres were evaluated against NRCS drainage classes, and it was determined that nearly 3,000 acres are poorly drained and somewhat poorly drained, with the remaining 700 acres moderately well drained and well drained. This small acreage is near a USGS GAMA Well located in well-drained soil, thus providing characterization of this area for deeper groundwater. Results from USGS Rice Wells located in these soils in adjacent Glenn County can also be used for characterization of shallow groundwater, since it is anticipated that rice is farmed in a similar manner in fields with the same types of soils.

Map 6-2 shows the refined HVAs and data gap areas. In summary, the additional analysis indicates that none of the initial HVA areas outside of Yuba County have rice-specific vulnerability. The Yuba County area represents a data gap and will be further evaluated as described in Section 7.2.3. However, additional smaller data gaps were identified in the valley fringe areas in which well-drained and moderately well-drained soils occur. These areas will be analyzed as part of the Yuba data gap analysis.

In summary, the monitoring network assessment and the water quality vulnerability analysis presented in Section 6 evaluated potential monitoring needs and data gaps. A detailed soils analysis showed that most of the soils in rice farmland are poorly drained or have a shallow duripan that restricts vertical flow. These characteristics are likely what made, and continue to make, these lands suitable for farming rice. Areas with well-drained or moderately well-drained soils are sparse, disconnected, and located near surface water bodies. Only one area, in Yuba County, has a large area of moderately well-drained and well-drained soils. In addition, relatively small acreages of the valley fringes in northern Glenn, eastern Sutter, and Placer counties also have well-drained or moderately well-drained soils coupled with minimal monitoring representation by USGS Rice Wells.

SECTION 7

Recommendations

The purpose of the groundwater component of the LTILRP is to protect the designated beneficial uses of groundwater from farming impacts. The GAR is required by the Central Valley RWQCB as part of the LTILRP, and the GAR's monitoring and reporting requirements will be incorporated into a rice-specific Monitoring and Reporting Plan (MRP) for implementation by the CRC. The purpose of the GAR is to review and evaluate physical characteristics pertaining to rice-growing soils, rice root-zone properties, and well monitoring results from shallow and deep groundwater quality underlying the rice fields, identify rice-specific vulnerability, and then develop monitoring recommendations based on the findings. A *Summary of Groundwater Assessment Report Requirements and Compliance* is provided in Appendix I and shows how this GAR addressed the technical items and analysis requested by the RWQCB.

The previous sections provided a comprehensive and detailed review of rice-farming practices, site conditions, and groundwater quality data. Three robust USGS well datasets were evaluated for near-surface, shallow, and deep groundwater quality beneath rice growing areas.

The following recommendations were developed in consideration of the findings and conclusions and to inform a rice-specific LTILRP.

7.1 Principles for Rice-specific Groundwater Quality Monitoring

Before initiating LTILRP monitoring, it is important to establish the objectives of groundwater quality monitoring and the requirements that would trigger its implementation. The following principles should be incorporated into the program:

- If a water quality problem is identified and the problem is caused by or may be caused by rice-farming practices, Representative Monitoring is warranted. Water quality monitoring may also be appropriate to track the effectiveness of management practice implementation as part of a Groundwater Management Plan.
- Literature review and root zone studies are a primary tool for assessing the risk that rice farming poses to groundwater quality. In a well-understood cropping system such as rice, data from the literature and root-zone studies can be used to assess risk to groundwater quality.
- Direct measures of first-encountered groundwater are needed to confirm the results of root-zone studies if Representative Monitoring is required.
- Although concentrated zones of naturally occurring constituents may exist, these are not a result of rice farming. Monitoring should not be required to confirm the known mobile behavior of these minerals or trace elements.
- Most counties in the Sacramento Valley have monitoring in place for field parameters and salinity indicators. Where such networks already exist, data should be reviewed and fully interpreted. New wells should be installed only to answer important questions that cannot otherwise be addressed.
- Advantageous coordination with agencies that operate and maintain existing monitoring networks (DWR, USGS, counties, and other districts) to assess the applicability of adding monitoring events to benefit the rice MRP will be considered. For example, the USGS NAWQA program is willing to share all data it will collect in the future with the CRC.
- Where monitoring networks are maintained by other agencies (DWR and USGS) and are used for water levels or field measurements only, and such wells are deemed to be located in areas representative of rice farming, arrangements with these agencies shall be sought to add water quality monitoring to the other monitoring activities. This focuses costs on the most needful network, and favors data sharing among agencies.
- Monitoring requirements should be clearly tied to addressing relevant, rice-farming-related data gaps or tied to monitoring the effects of management practice implementation.

7.2 Monitoring and Reporting Program Recommendations

The LTILRP will include an MRP that will specify special studies, interim reports and milestones, and monitoring requirements necessary to achieve program objectives. The following are recommended for inclusion in the MRP:

- Trend monitoring
- Supplemental root zone studies
- Analysis to address data gap
- Coordination with DPR
- Periodic land use reporting
- Grower nutrient management plan program
- Annual reporting and review

7.2.1 Trend Monitoring Program

Two types of groundwater monitoring are called for under the LTILRP (as described by Thomas Harter in his comments on the Eastern San Joaquin River Watershed Tentative WDRs and MRP in July 2012 [Harter 2012]):

1. A Representative Groundwater Monitoring Program (Representative Monitoring) is to be developed where known groundwater quality impacts exist for which irrigated agricultural operations are a potential contributor or where conditions make groundwater more vulnerable to impacts from irrigated agricultural activities (high vulnerability areas).
2. The purpose of the Regional and Temporal Trend Groundwater Monitoring Program (Trend Monitoring) is to provide an adequate record of actual regional groundwater quality distribution (spatial, regional trends) and of actual long-term groundwater quality changes (temporal trends) in irrigated lands regions.

On the basis of the information reviewed for this GAR, no rice-specific groundwater quality impacts were identified, and there are no confirmed high vulnerability areas; therefore, a rice-specific Representative Groundwater Monitoring Program is not triggered.

Consistent with LTILRP requirements, Trend Monitoring is to be conducted for low-vulnerability areas. It is recommended that the RWQCB's MRP include a requirement for submittal of a Monitoring Workplan, which will confirm the viability of specific sites (landowner access, USGS agreement), include a Quality Assurance Project Plan, and define a specific schedule of sampling. Upon approval of the Monitoring Workplan, the CRC would be required to implement specific monitoring and reporting actions.

The following describes the recommended rice-specific Trend Monitoring Program, including approximate site selection, coordination considerations, parameters, and sampling frequency.

The USGS Rice Well network has proven to be an excellent network for the purpose of assessing shallow groundwater quality underneath rice fields, and the USGS uses five wells from this network for Trend Monitoring as part of the NAWQA Cycle II groundwater monitoring activities. Therefore, it would be appropriate to use a subsample of the USGS Rice Well network for rice-specific LTILRP MRP Trend Monitoring. The USGS has informally confirmed that the CRC may collaborate with the USGS to obtain any sampling results and gain access to these wells for further sampling.

It is recommended that seven USGS Rice Wells be included in rice-specific Trend Monitoring: Wells 3, 8, 10, 15, 17, 18, and 21 (numbered according to the USGS 2001a report). These wells are chosen because they possess the following characteristics:

- They are geographically (regionally) disperse and are located in the counties that have the most rice acreage. Colusa, Butte, Sutter, and Glenn counties together represent approximately 82 percent of the total rice lands in the Sacramento Valley and approximately 52 percent of the initial HVAs.
- Each is adequately representative of rice land use, as demonstrated in Appendix E-3.

- They are located on the four soil drainage classes on which 99 percent of the rice is grown, thus providing representation of groundwater quality under the primary types of soils on which rice is grown in the Sacramento Valley. Appendix H provides detailed county maps showing the soil drainage classes and well networks analyzed in this report.
- USGS Rice Wells 3, 8, 17, and 18 include a record of trend monitoring since 1997.

Table 7-1 provides a detailed summary of characteristics and representativeness of each proposed Trend Monitoring well.

TABLE 7-1
Proposed Trend Monitoring Wells Description

Well ID/Location*	County	Land Use Representativeness	Soil Drainage Class	Soil Texture
USGS Rice Well 3	Sutter	Completely surrounded by rice	Poorly drained	Clay
USGS Rice Well 8	Colusa	Completely surrounded by rice	Moderately well drained	Clay loam
USGS Rice Well 10	Colusa	Completely surrounded by rice; east side of the valley	Poorly drained and close to moderately well drained	Silty clay
USGS Rice Well 15	Butte	Completely surrounded by rice; west side of the valley	Poorly drained	Clay
USGS Rice Well 17	Glenn	Located on relatively small patch of rice, but downgradient of large extents of rice	Somewhat poorly drained	Clay
USGS Rice Well 18	Glenn	Completely surrounded by rice	Well drained	Clay
USGS Rice Well 21	Butte	Completely surrounded by rice	Poorly drained	Clay loam

*Numbered according to the USGS 2001a report

Summary statistics for the Trend Monitoring network:

- Collectively, the selected wells represent approximately 30 percent of all the USGS Rice Wells.
- Distribution on well-drained soils is one well per 86,700 acres (135 square miles).
- Distribution on moderately well-drained soils is one well per 105,300 acres (164 square miles).
- Distribution on somewhat poorly drained soils is one well per 87,600 acres (137 square miles).
- Distribution on poorly drained soils is one well per 75,950 acres (119 square miles).
- Wells 3, 10, 15, and 21 located in Sutter, Colusa, and Butte counties, respectively, represent groundwater conditions underlying poorly drained soils, which account for 52 percent of all the soils on which rice is farmed and generally found in all the rice-growing counties, except for Yuba and Placer counties.
- Well 17, located in Glenn County, represents groundwater conditions underlying somewhat poorly drained soils, which account for 15 percent of all soils on which rice is farmed and generally found in Glenn and Butte counties, with a few smaller areas in Colusa, Sutter, and Sacramento counties.
- Well 8, located in Colusa County, represents groundwater conditions underlying somewhat moderately well drained soils, which account for 18 percent of all soils on which rice is farmed and are generally found in western Colusa County (on the edges of rice fields), in the Sutter Basin, and in the eastern side of the valley (Yuba and Placer counties). This well is located in an area with high background salinity, but nonetheless provides representation of the vulnerability of these types of soils to nitrate impacts.
- Well 18, located in Glenn County, represents groundwater conditions underlying well drained soils, which account for 15 percent of all soils on which rice is farmed and generally found in northern Glenn County and interspersed in Glenn county rice areas, at the edges of western Colusa County rice fields, and predominantly in eastern Sutter and western Placer counties.

In conclusion, this proposed Trend Monitoring network provides a good representation of all the soil drainage classes on which rice is grown and supports the continued monitoring of potential impacts of rice agriculture on shallow groundwater. Map 7-1 shows the location of these wells compared to soil drainage classes in rice fields, and Map 7-2 shows the trend monitoring network compared to soil textures. Table 7-2 presents the proposed sampling frequency and parameters to be sampled as part of the Trend Monitoring.

TABLE 7-2
Trend Monitoring Locations, Parameters, and Frequency

Locations	Frequency	Parameters
USGS Rice Wells 3, 8, 10, 15, 17, 18, and 21	Annual	Electrical conductivity, total dissolved solids, pH, dissolved oxygen, temperature, nitrate as nitrogen
USGS Rice Wells 3, 8, 10, 15, 17, 18, and 21	Every 5 years	Carbonate, bicarbonate, chloride, sulfate, boron, calcium, sodium, magnesium, potassium, and total kjeldahl nitrogen (TKN)

Note: Based in part on Harter 2012.

It is recommended that the Sacramento Valley Rice Coalition coordinate with the USGS NAWQA team in Sacramento to obtain the latest well locations and well construction details for each of the wells proposed to be used for rice-specific Trend Monitoring and include this information in the MRP Workplan. The MRP workplan, as required by the rice-specific WDR, will include details regarding the trend monitoring network design, well construction details, sampling protocols, and reporting requirements.

As discussed previously, some rice is also grown on the fringe areas of the valley in northern Glenn County, Yuba County, eastern Sutter County, and Placer County, where soils tend to be coarser and oxic and are classified as well drained to somewhat excessively drained. These areas are not well represented by the USGS Rice Wells network. The Yuba County area is the largest contiguous rice area farmed in better-drained soils. As described in Section 7.2.3, it is recommended that the Yuba County data gap analysis be used to identify potential vulnerability of other data gap areas and assess the need for additional monitoring wells to be added to this preliminary proposed network.

7.2.2 Supplemental Root-Zone Studies

To improve the geographic distribution and representation of the Trend Monitoring network consisting of 7 shallow wells, it is recommended that two, root-zone soil pore-water sampling sites be added in the following unrepresented geographic areas and areas of underrepresented soil drainage classes and soil textures:

- Area identified as an initial HVA northwest of the Sutter Buttes in well-drained soils (with loam soil texture)
- Area within rice lands in eastern Yolo County in very poorly drained soils (with clay loam soil texture)

The specific, confirmed locations are to be identified and described in the MRP Workplan. General locations are shown on Maps 7-1 and 7-2.

Soil pore water sampling is typically through a porous cup or plate installed in the soil with a tube extending to an accessible collection point. Soil water is extracted by applying suction to the tube (for example, with a hand-operated, portable vacuum pump). The exact equipment (type, manufacturer) that is used will be described in the MRP Workplan which will be developed in consultation with the CVRWQCB staff and UCCE experts. Sampling equipment is generally installed during each sampling event, and removed between sampling events. Sampling locations are established and re-located with the aid of a GPS device.

Sampling depth is based on the depth to first encountered saturated soil at the sampling time (water levels fluctuate throughout the year). Note that in rice fields, root zones are often saturated, even though hydraulic connectivity to groundwater may be limited by permeability of soil layers.

Sampling will occur twice a year: once during field preparation in March (the driest period), and once after fields are drained in September. To the extent feasible, the second sampling event will be timed to coincide with the Trend Monitoring event in monitoring wells.

7.2.3 Analysis to Address Data Gap

To address the spatial and soils representation data gap identified in Section 6, it is recommended that a further analysis be performed to address the identified data gap. As described, the portion in Yuba County farmed in rice is the only identified large data gap. In addition, the fringe areas of northern Glenn, eastern Sutter, and Placer counties are considered a small data gap.

It is recommended that the data gaps analysis be performed to provide characterization of the rice-groundwater conditions within the North Yuba and South Yuba groundwater subbasins. The analysis should include a review of additional, existing monitoring networks, such as those implemented by Yuba County or DWR. The analysis should also include a detailed review of soils data in this region to assess the similarity of the subbasin soil characteristics to similar drainage classes in the other counties, including northern Glenn County, eastern Sutter County, and Placer County. This effort would address the spatial, hydrogeologic vulnerability, and soils data gaps that exist for this area.

To address both the Yuba County data gap and the fringe area data gap, it is recommended that a data gap analysis be focused on Yuba County. This recommendation is based on Yuba County rice lands having the largest contiguous area farmed in rice that overlies initial HVAs. If rice farming posed a risk to groundwater in “atypical” soil conditions, this area would be the most prone to impact. If impacts are not detected in this area, it is reasonably deducted that poorer drained soils are likewise protective of groundwater quality. The following objectives and approaches are recommended:

- Perform additional groundwater quality data collection and analysis to provide characterization of groundwater quality in Yuba County:
  - Determine if additional groundwater quality data (such as Yuba County or DWR) are available to characterize rice-specific vulnerability.
  - Provide an overview of current and historical non-USGS groundwater quality data in the area, if available.
  - Perform an inventory of existing groundwater wells such as those maintained by Yuba County or DWR to assess if there are dedicated shallow monitoring wells present in Yuba County that could be used for a monitoring effort as part of the LTILRP.
  - Review Yuba County groundwater quality reports and GWMPs.
  - Coordinate with Yuba County Water Agency and DWR to obtain additional groundwater quality data.
  - Identify appropriate water quality information and perform additional water quality analysis, with mapping and graphing of results, similar to those presented in Section 5.
- Assess the applicability of the additional data to the rice-specific evaluation:
  - Determine if existing groundwater wells are located in or directly downgradient of rice fields, and whether sufficient background (upgradient) water quality data are available for comparison with downgradient groundwater quality.
  - Determine if there are other land uses in Yuba County adjacent to rice fields that might influence the quality of groundwater underlying rice fields.
- Perform additional GIS soils mapping and evaluation to assess the similarity of the subbasin soil characteristics to similar drainage classes in the other counties, including northern Glenn County and eastern Sutter and Placer counties, and confirm the applicability of the Yuba County analysis to the fringe areas. Evaluate duripan and other soil characteristics.
- Make determinations with regard to vulnerability:
  - Are there impacted groundwater quality areas that are reasonably attributed to rice?

- Make recommendations, if indicated, for additional root zone studies or implementation of groundwater quality monitoring, such as:
  - Perform additional nitrate studies in the coarser soils.
  - Determine if Representative or Trend Monitoring is indicated, and identify appropriate shallow monitoring wells to be used for monitoring, as needed.
  - Identify constituents and frequency of recommended monitoring.

It is recommended that interim milestones be specified for the Data Gaps Analysis, including an annotated outline, an administrative draft report, and a final report. It is anticipated that the MRP requirements would be amended to incorporate monitoring or studies recommended as a result of this additional Data Gaps Analysis.

7.2.4 Coordination with DPR

The Pesticide Contamination Prevention Act (PCPA) (Food and Agricultural Code Sections 13141–13152) specifies the regulatory framework for pesticides in groundwater, including coordination between the SWRCB and DPR. Consistent with the PCPA, it is recommended that the DPR Groundwater Protection Program form the basis of pesticides regulation under the LTILRP, and that DPR and the SWRCB and RWQCB closely coordinate regarding pesticide risks to groundwater and necessary monitoring. It is recommended that a rice-specific working group comprising DPR, Central Valley RWQCB, and CRC representatives be convened to understand the detailed analysis that led to the GPL designation; DPR risk modeling assumptions, methodologies, and results; planned DPR monitoring; and approaches to addressing outstanding data gaps where needed. Pesticides that are on the DPR 6800 list but not included in the DPR Groundwater database may be candidates for further evaluation in collaboration with DPR.

7.2.5 Periodic Land Use Reporting

Rice land use is well represented with the currently reviewed monitoring networks. The CRC has committed to providing routinely (every 3 years) provide updated management practice (mainly rice-specific nutrient management planning) inventories and an updated GIS layer of rice lands. This will indicate whether rice management practices or geographic distribution change in the future. Significant changes might warrant alteration of monitoring spatial distribution.

7.2.6 Grower Nutrient Management Plan Program

The CRC Coalition is currently discussing inclusion of a rice-specific nutrient management planning program. Although the risk of nutrient pollution from rice fields has been shown to be low, this is the single most protective measure (to further reduce risk) that could be implemented, and therefore the most worthwhile. However, the inclusion of this element in the MRP is contingent upon finalizing discussions of the WDRs and associated documents with Central Valley RWQCB staff, and approval by their Board.

7.2.7 Annual Reporting and Review

Elements above would be subject to reporting, which would be annual and capture monitoring results from the preceding year. Such reporting might include the following, depending on the year:

- Land use reporting: triennial submittal of a GIS layer of rice lands
- Management practice reporting: triennial review of management practice (mainly rice-specific nutrient management planning) adoption and related grower outreach
- Update regarding special study plans and results
- Sampling and analysis results

Data would be reviewed relative to historical observations (much of which has been presented in this GAR) and interpreted relative to the goals of the program, and to confirm that rice lands are not causing degradation of groundwater. If there are indications to the contrary, then the WDR will provide for appropriate processes to perform focused investigations and to address problem sources as necessary.

SECTION 8

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SECTION 9

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Pesticides – Roberta Firoved

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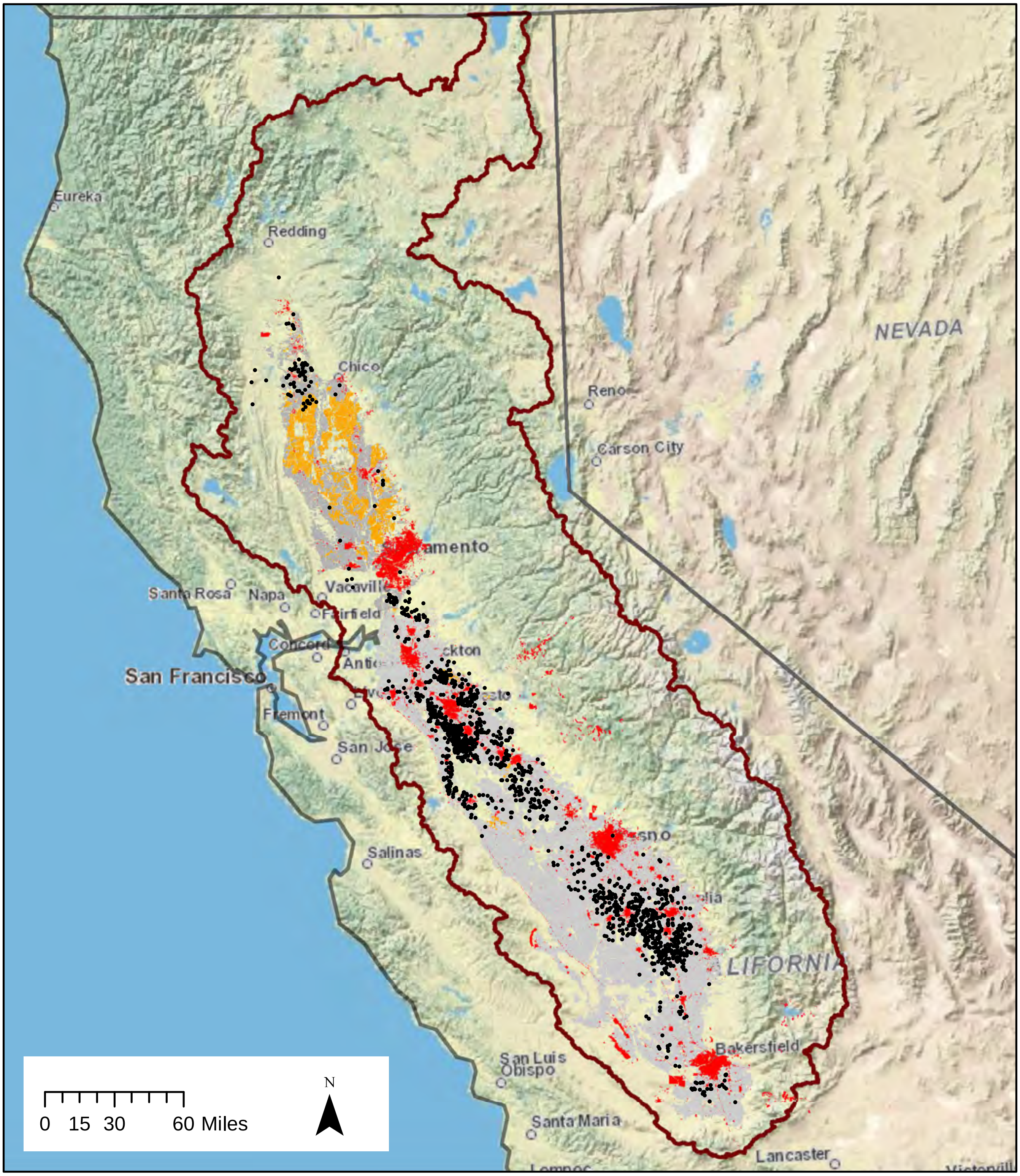


Data Sources: Land Use (California DWR 2010); Dairy Farms (LSCE 2009); Basemap (ESRI 2011). Datum is NAD83.

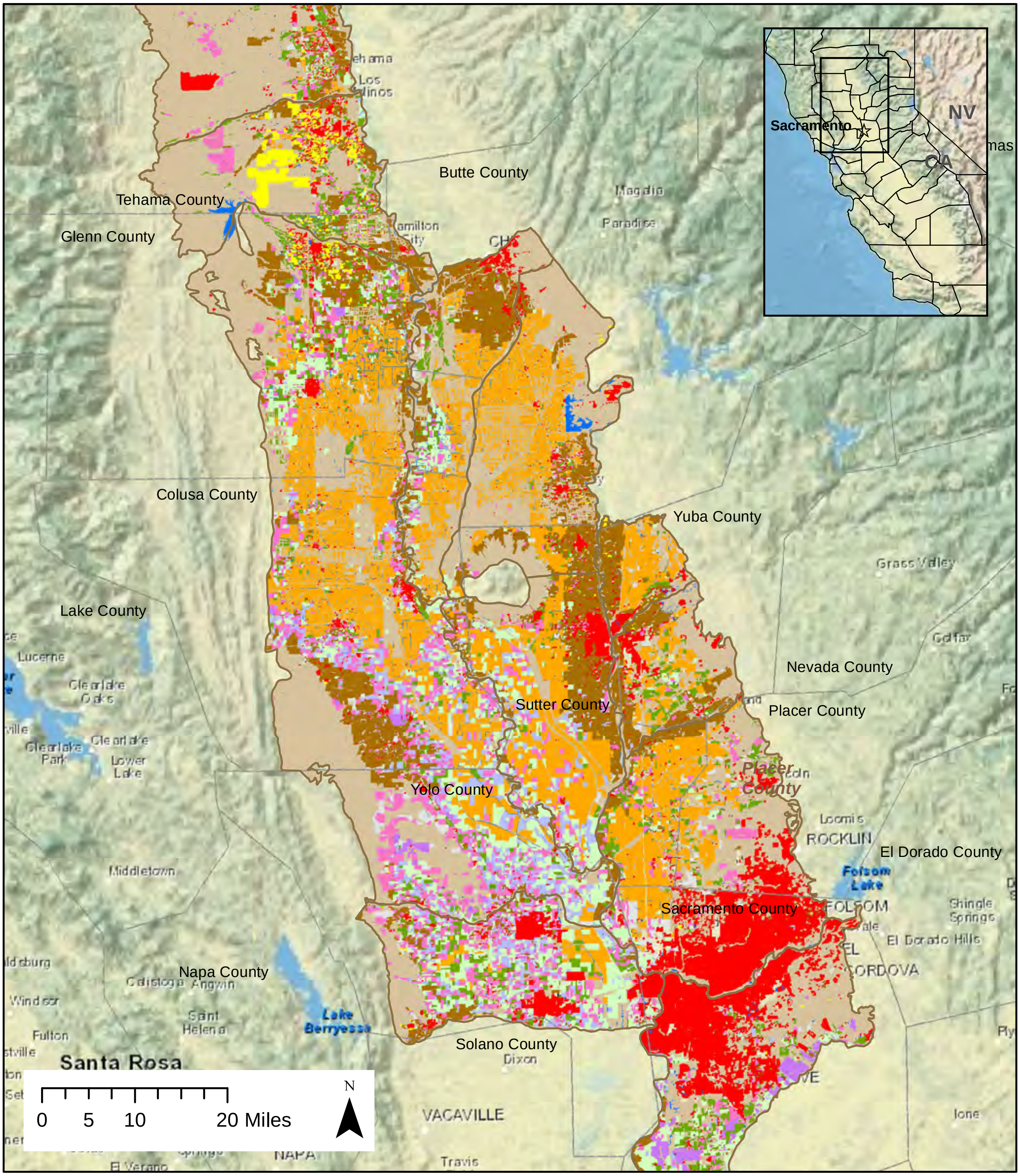
Land Use

- Agriculture (other)
- Rice Crop
- Urban Areas
- Dairy Farms (2009)
- Central Valley RWQCB (Region 5) Boundary

MAP 2-1

Land Use in the Central Valley

Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

DWR Land Use

- Citrus
- Deciduous Fruits & Nuts
- Field Crops
- Grass & Hay
- Idle
- Native Classes
- Pasture
- Rice Crop
- Semi-Agriculture
- Truck Crops
- Urban Areas
- Vineyards
- Water
- County Boundary
- Groundwater Basins

MAP 2-2
Land Use in the Sacramento Valley
Rice-Specific Groundwater Assessment Report

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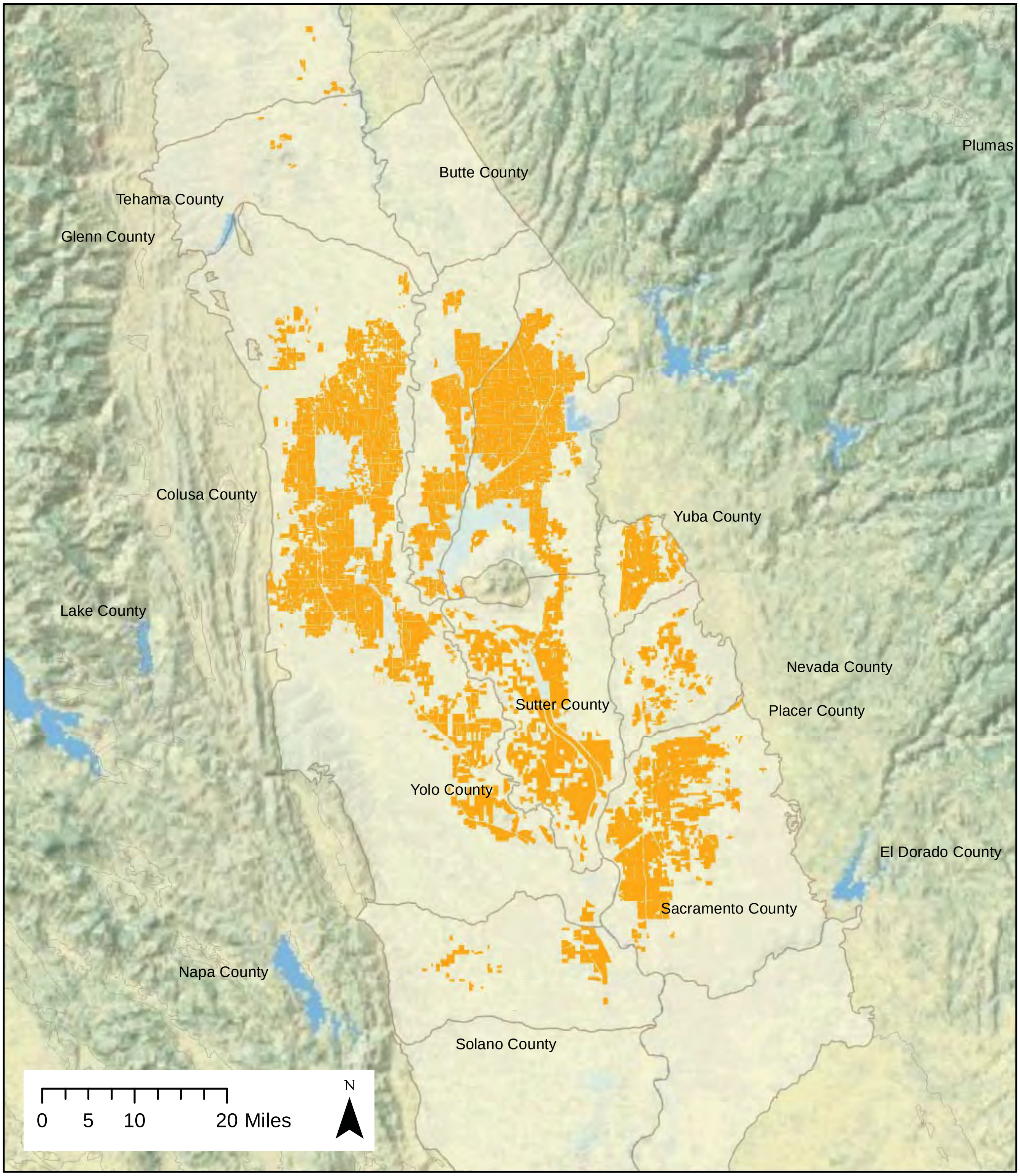


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

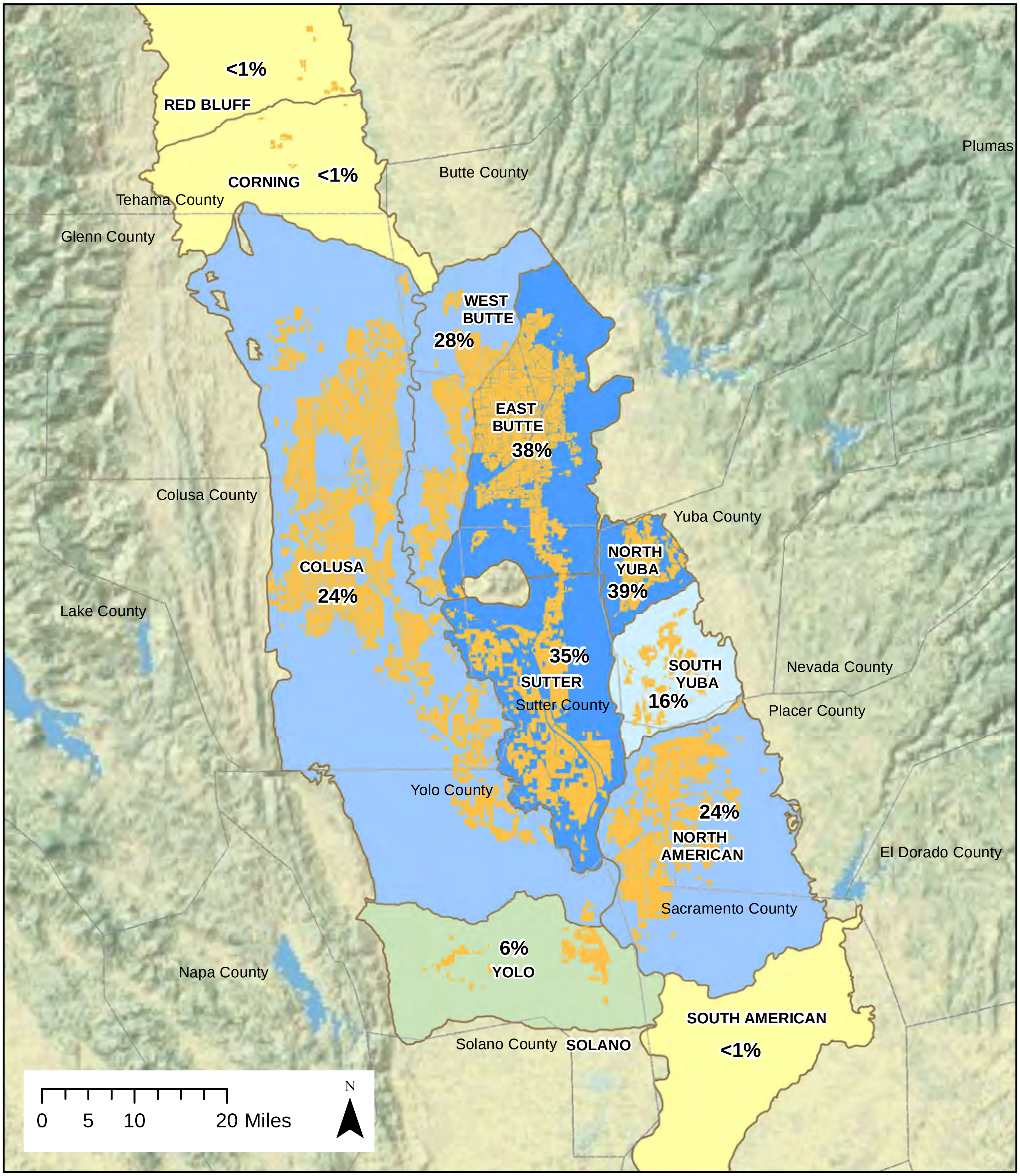
Legend

County Boundary
Groundwater Basins
Rice Lands (DWR)

MAP 2-3

Geographic Extent of Assessment

Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

Rice Land Use as Percent of GW Basin

- 0 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- 30 - 40

- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 2-4

Percent Rice Land per Groundwater Basin

Rice-Specific Groundwater Assessment Report

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MAP 2-5
Landforms of the Sacramento Valley between Sacramento and the Sutter Buttes
Rice-Specific Groundwater Assessment Report

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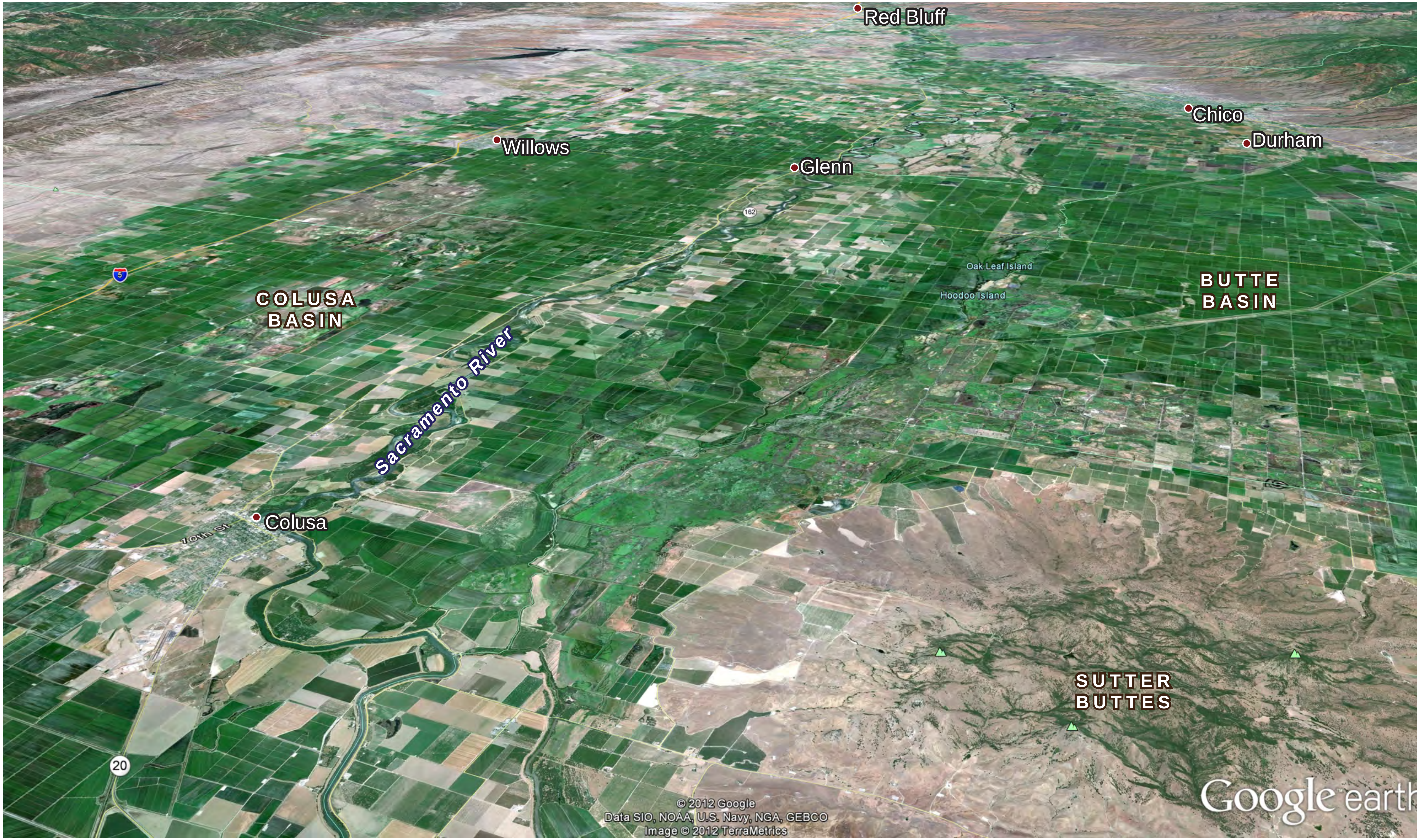
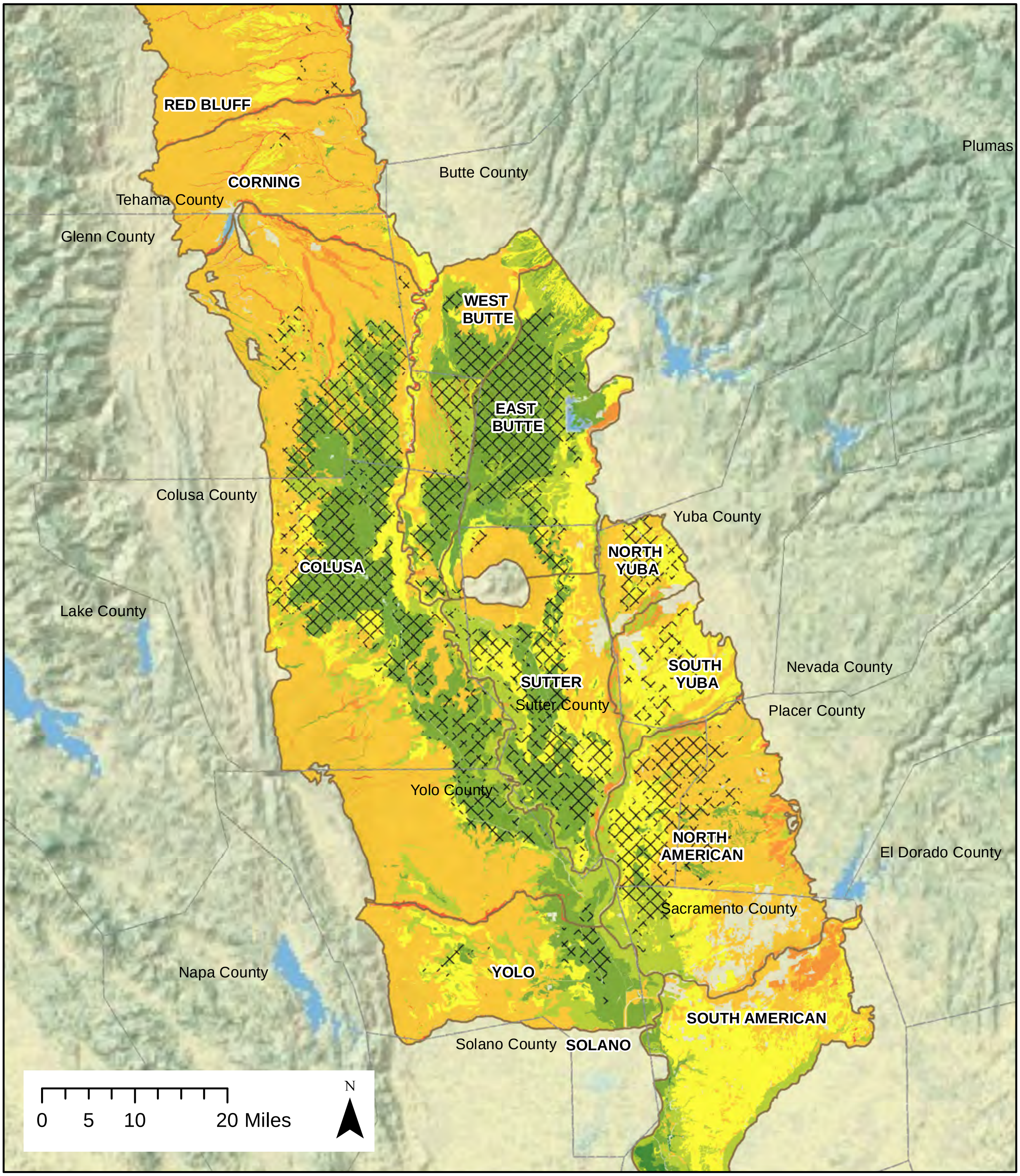
WBG122011013027SAC Map_2-5.ai tdaus 06.27.2013



North

NOT TO SCALE

MAP 2-6
Landforms of the Sacramento Valley between the Sutter Buttes and Red Bluff
Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Drainage Class (NRCS 2012); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

NRCS Soil Drainage Class

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 2-7
NRCS Soil Drainage Classes in the SVGB
Rice-Specific Groundwater Assessment Report

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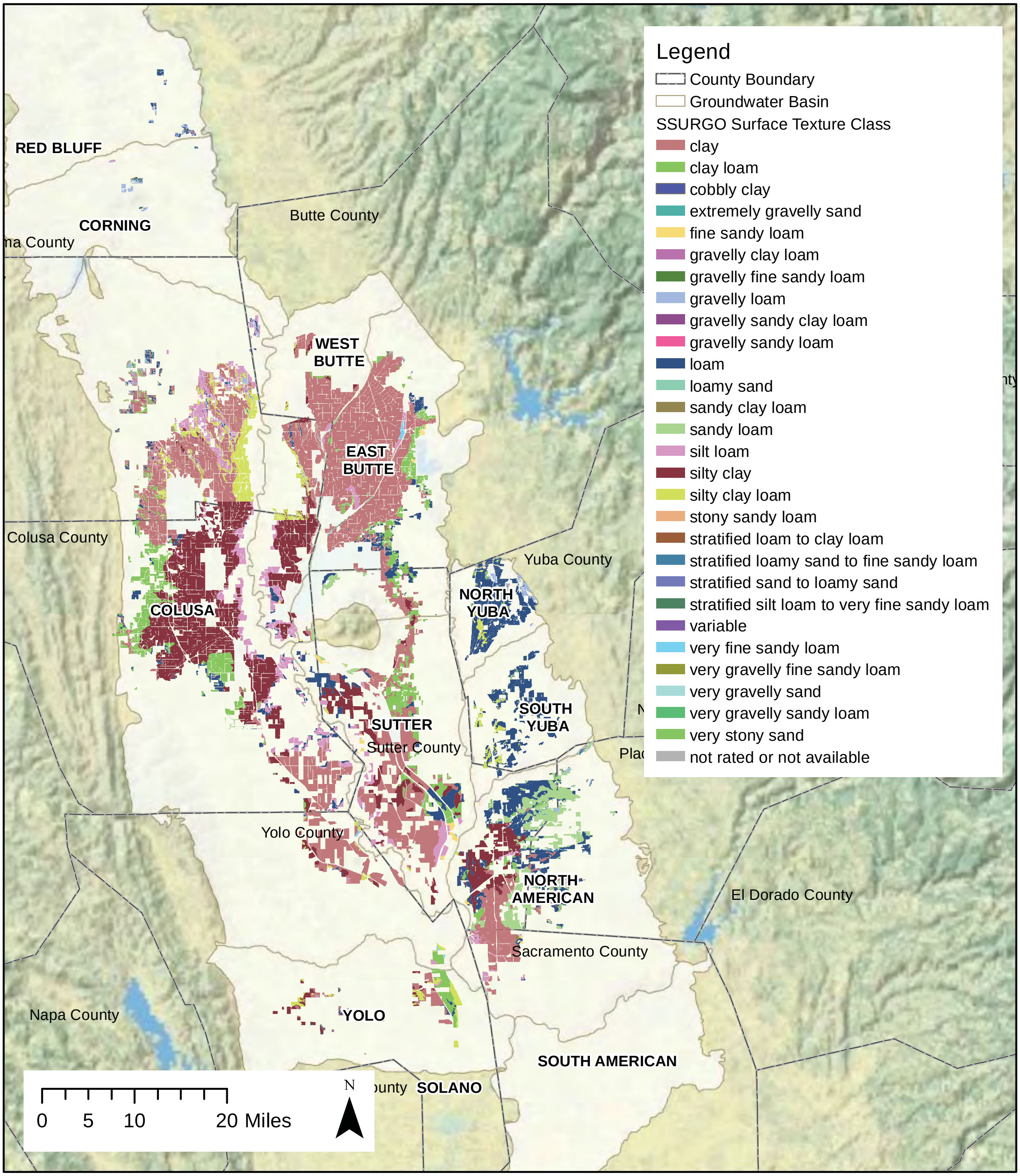
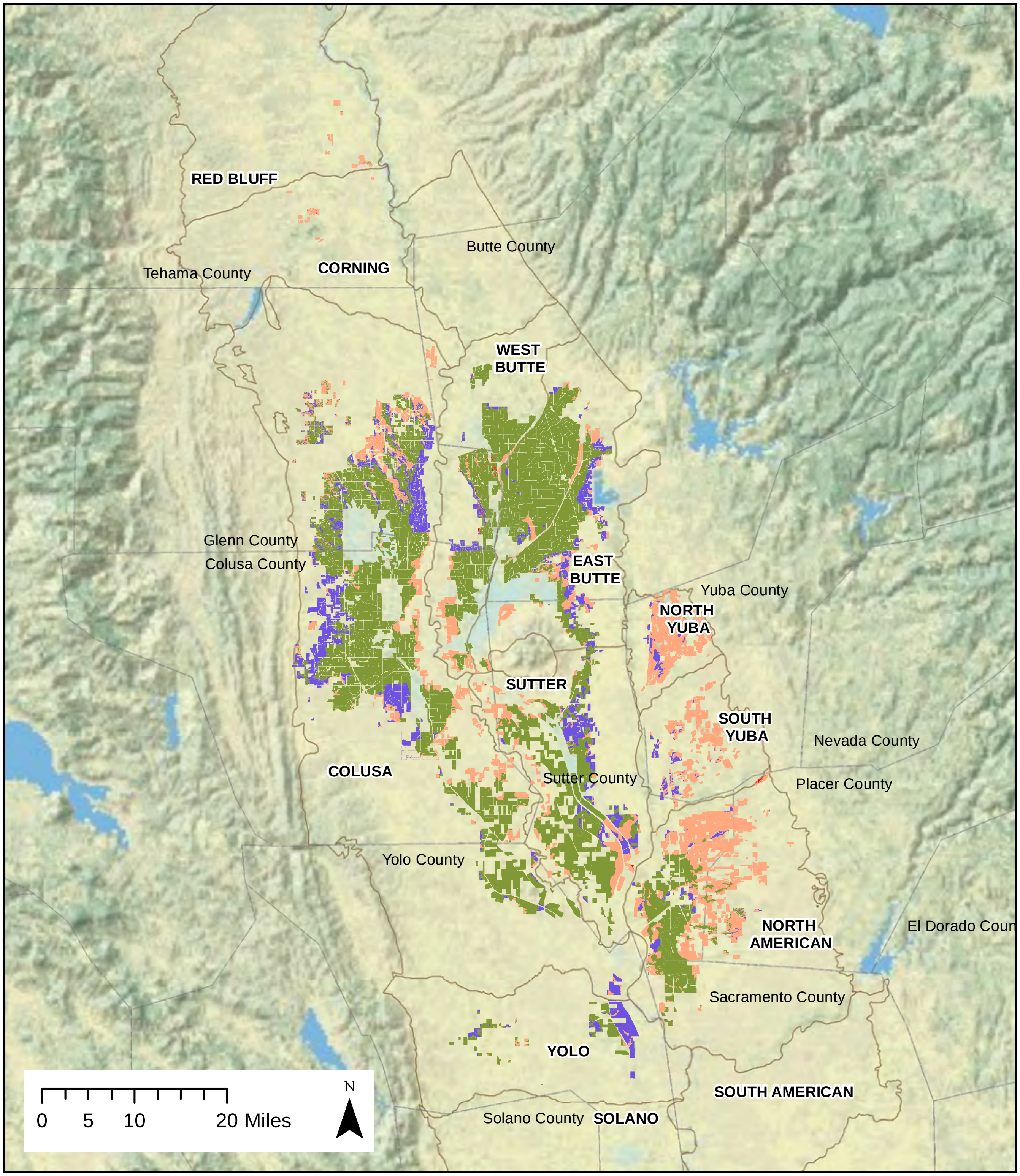


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011); Soil Texture (NRCS 2012). Datum is NAD83.

MAP 2-8
SSURGO Soil Textures of Rice Lands
Rice-Specific Groundwater Assessment Report



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

Hydraulic Conductivity

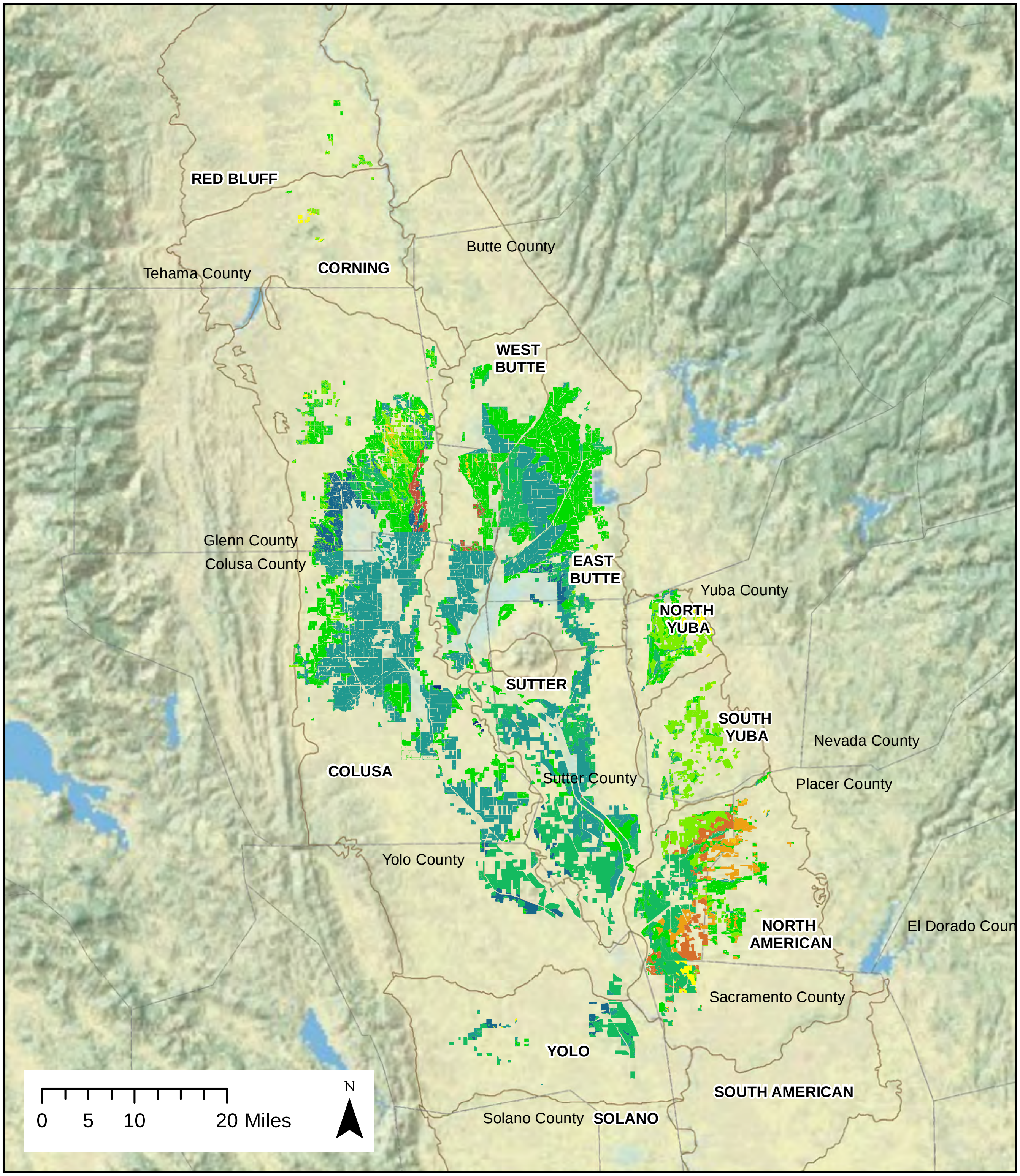
- Low
- Moderately Low
- Moderately High
- High

- Groundwater Basins
- County Boundary

MAP 2-9
Hydraulic Conductivity of Rice Land Soils

Rice-Specific Groundwater Assessment Report

CH2MHILL.



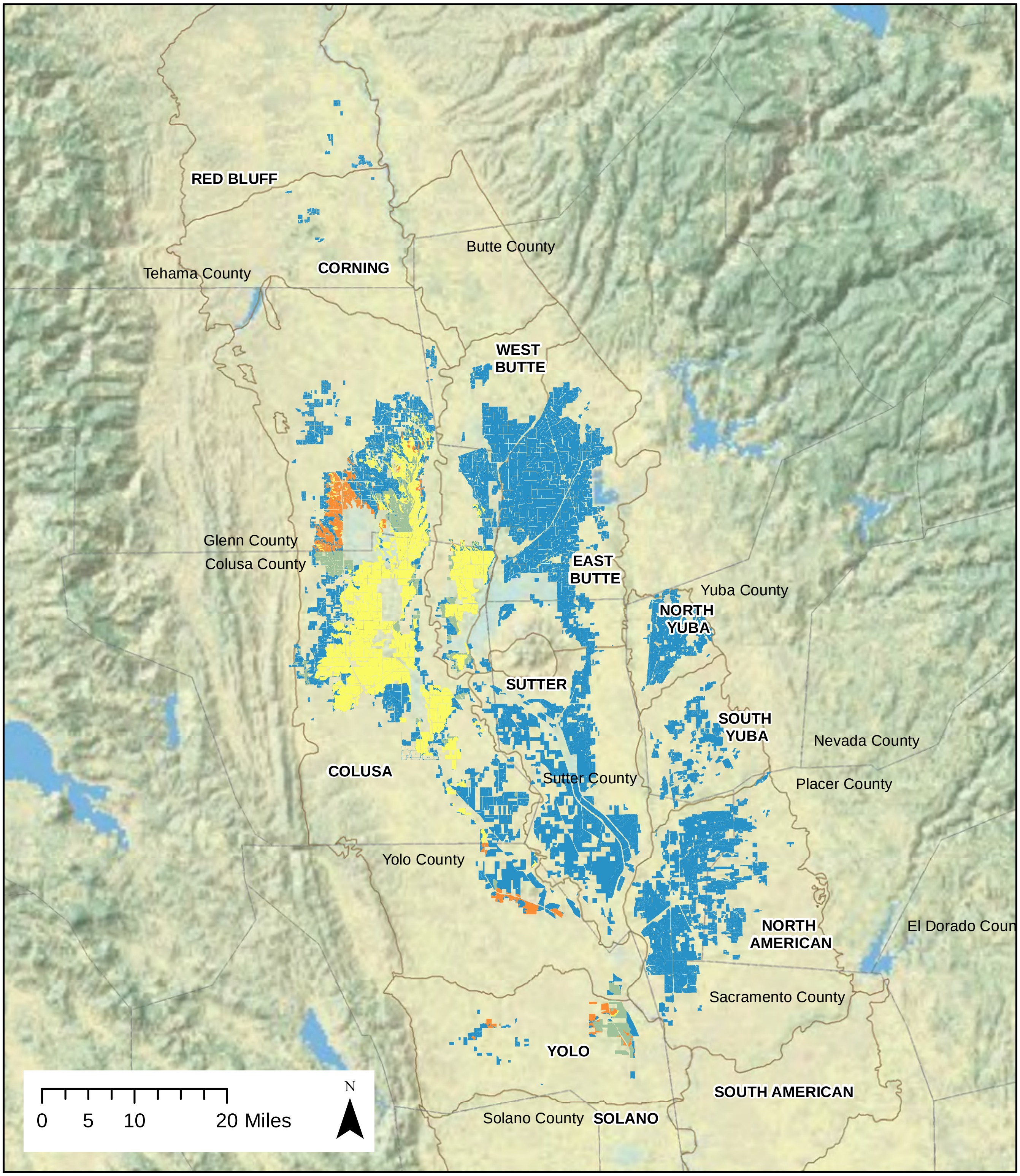
Data Sources: SSURGO (NRCS 2012), Groundwater Basins (DWR 2010), Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

Soil pH

- Ultra acid (pH < 3.5)
- Extremely acid (pH 3.5 - 4.4)
- Very Strongly Acid (pH 4.5 - 5.0)
- Strongly Acid (pH 5.1 - 5.5)
- Moderately Acid (pH 5.6 - 6.0)
- Slightly Acid (pH 6.1 - 6.5)
- Neutral (pH 6.6 - 7.3)
- Slightly alkaline (pH 7.4 - 7.8)
- Moderately alkaline (pH 7.9 - 8.4)
- Strongly alkaline (pH 8.5 - 9.0)
- Very strongly alkaline (pH > 9.0)
- County Boundary
- Groundwater Basins

MAP 2-10
pH of Rice Land Soils
Rice-Specific Groundwater Assessment Report



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Legend

Soil Electrical Conductivity

- 0 to 2 dS/m .....nonsaline
- 2 to 4 dS/m ..... very slightly saline
- 4 to 8 dS/m ..... slightly saline
- 8 to 16 dS/m ..... moderately saline
- more than 16 dS/m ..... strongly saline

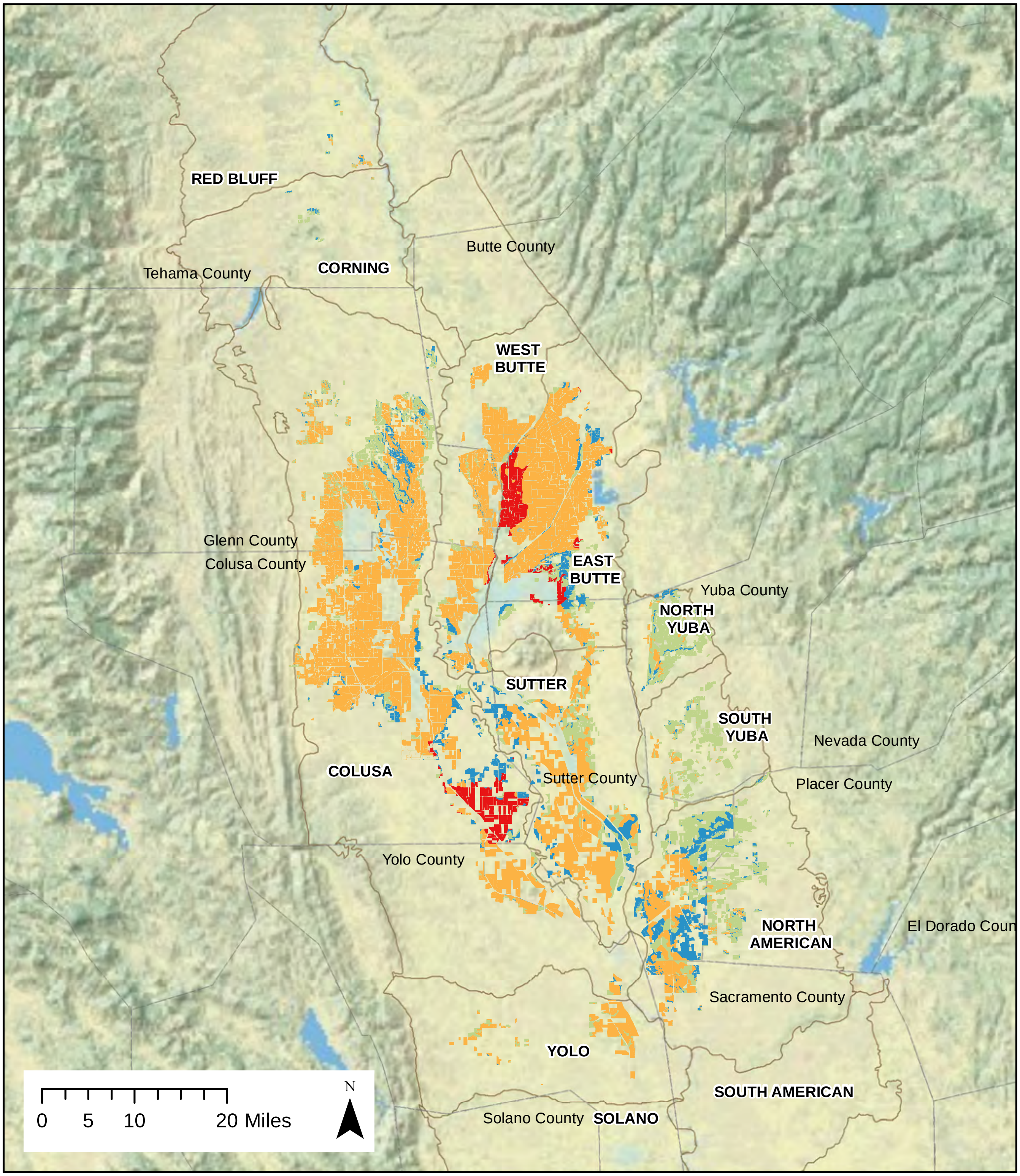
- County Boundary
- Groundwater Basins

MAP 2-11

Electrical Conductivity of Rice Land Soils

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

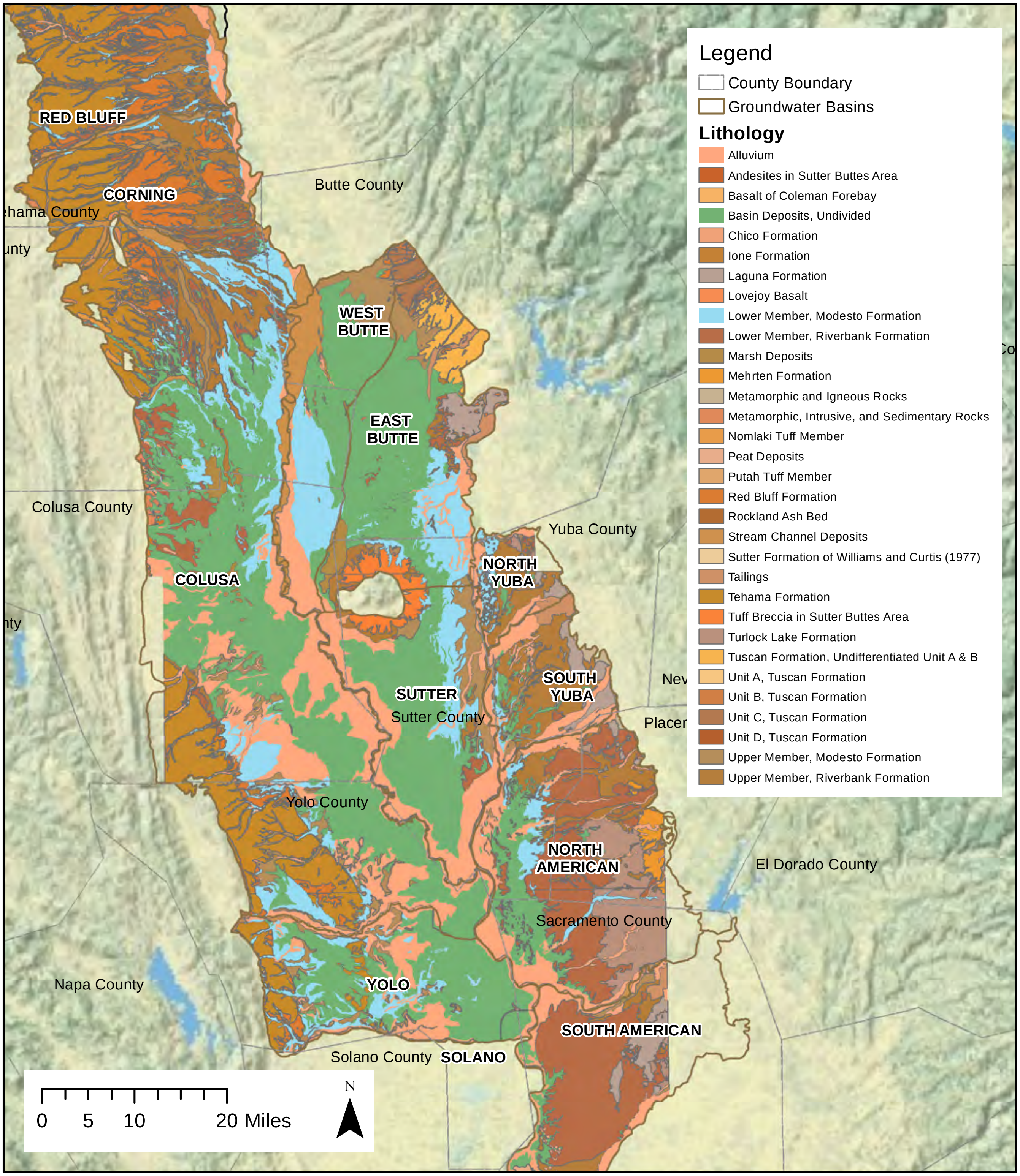
Legend

Linear Extensibility (Shrink-Swell)
- Low (0 - 3)
- Moderate (3 - 6)
- High (6 - 9)
- Very High (9 - 30, max is 12.4)

- County Boundary
- Groundwater Basins

MAP 2-12
Linear Extensibility (Shrink-Swell) of Rice Land Soils
Rice-Specific Groundwater Assessment Report

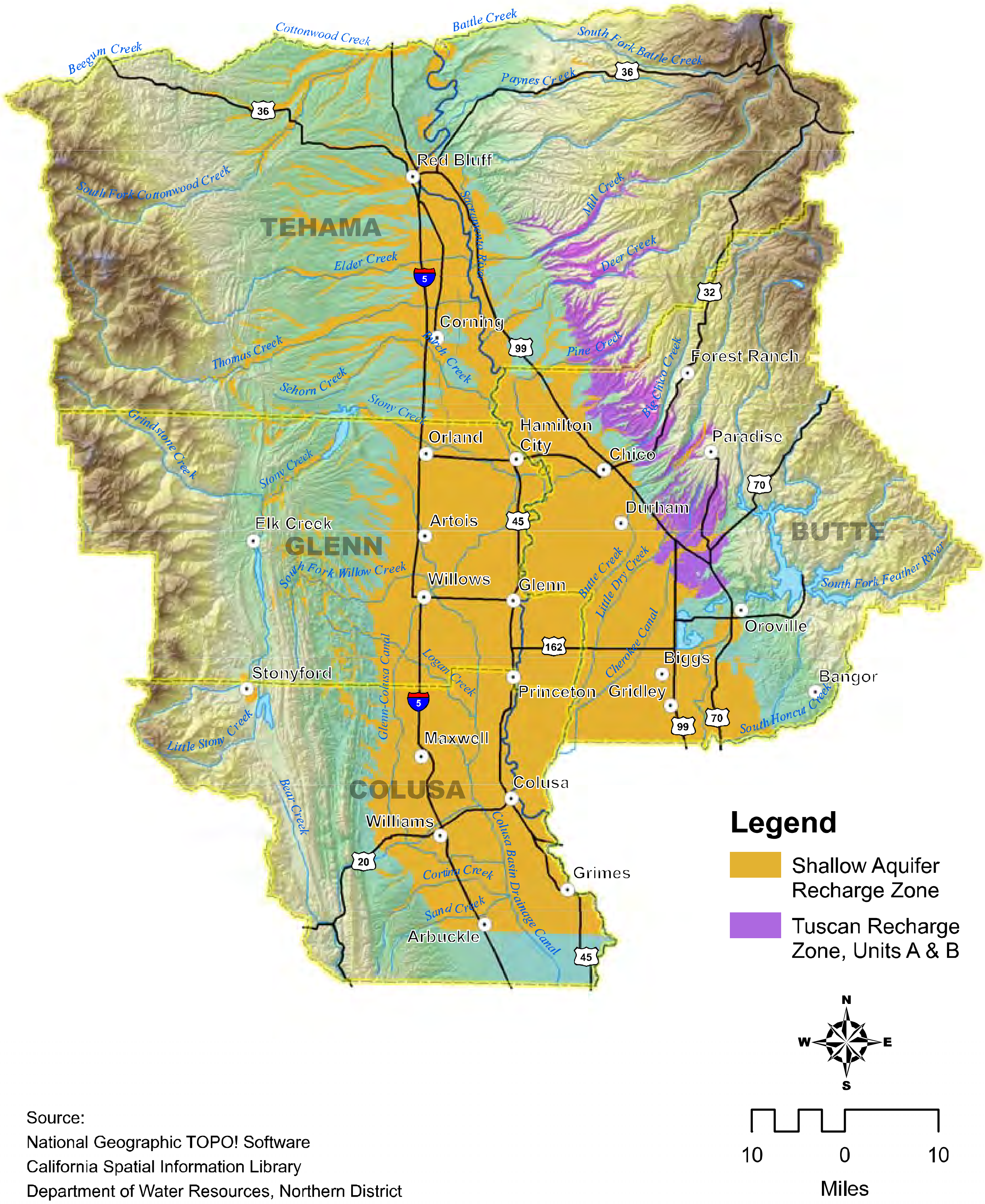
CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

MAP 2-13
Lithology in the SVGB
Rice-Specific Groundwater Assessment Report

CH2MHILL

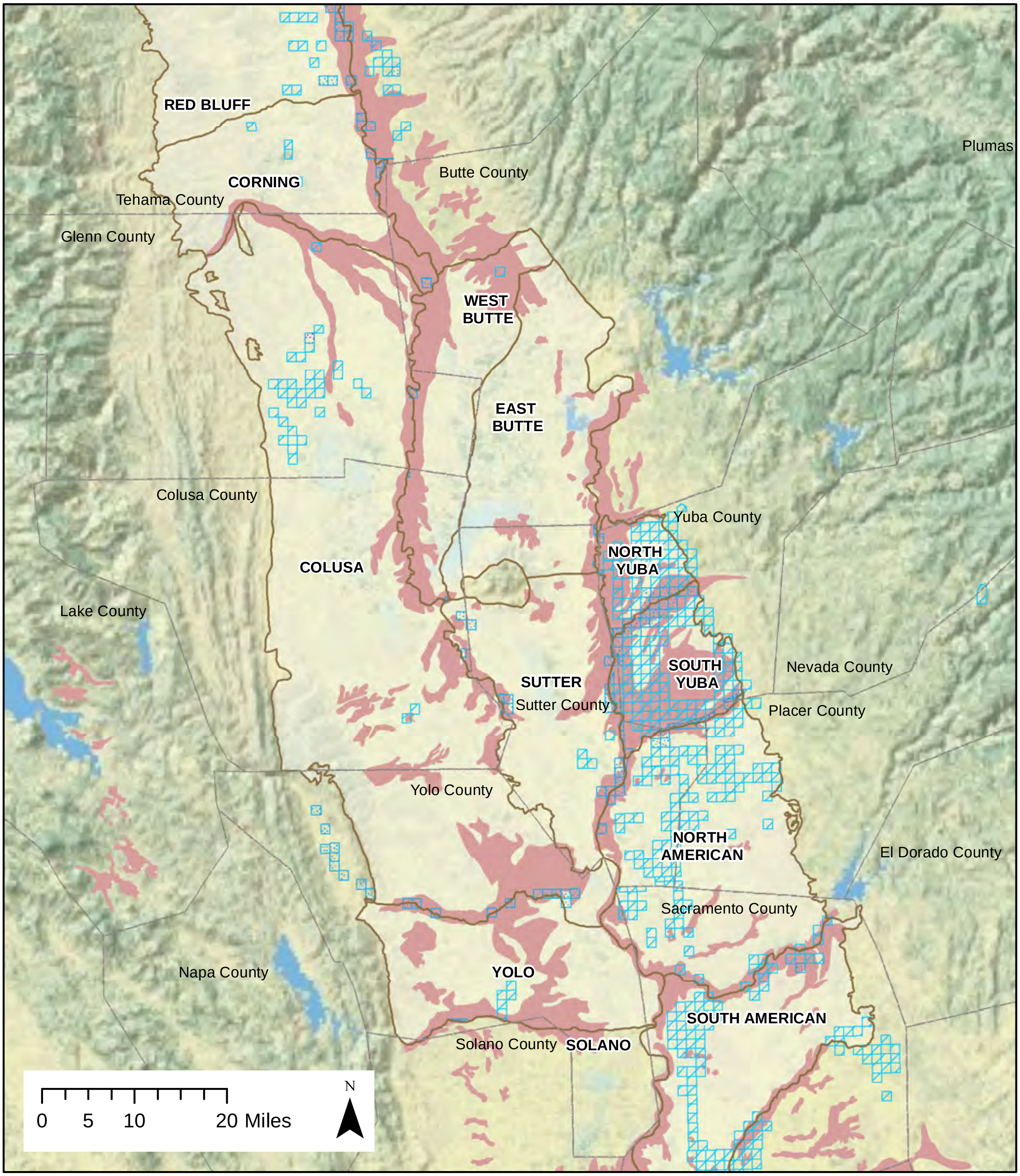


Source:
National Geographic TOPO! Software
California Spatial Information Library
Department of Water Resources, Northern District

MAP 2-14
Groundwater Recharge Areas in the Northern Sacramento Valley

Rice-Specific Groundwater Assessment Report

Note: Reproduced from Glenn County Department of Agriculture 2005.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011); SWRCB (2000); DPR (2004). Datum is NAD83.

Legend

SWRCB Initial HVA

DPR GPAs

Leaching

Runoff

Runoff or Leaching

County Boundary

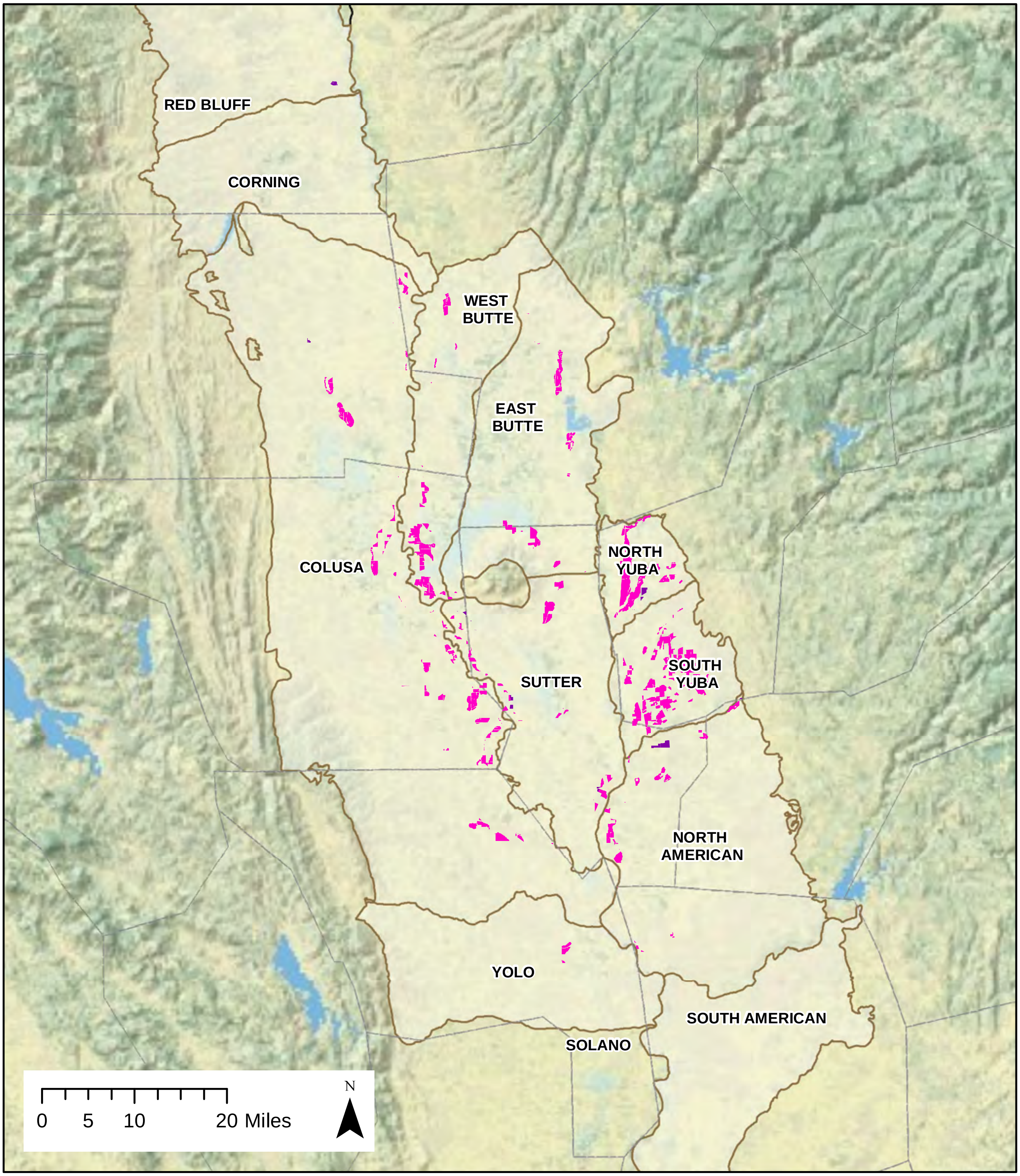
Groundwater Basins

MAP 2-15

SWRCB Initial HVAs and DPR GPAs

Rice-Specific Groundwater Assessment Report

CH2MHILL.

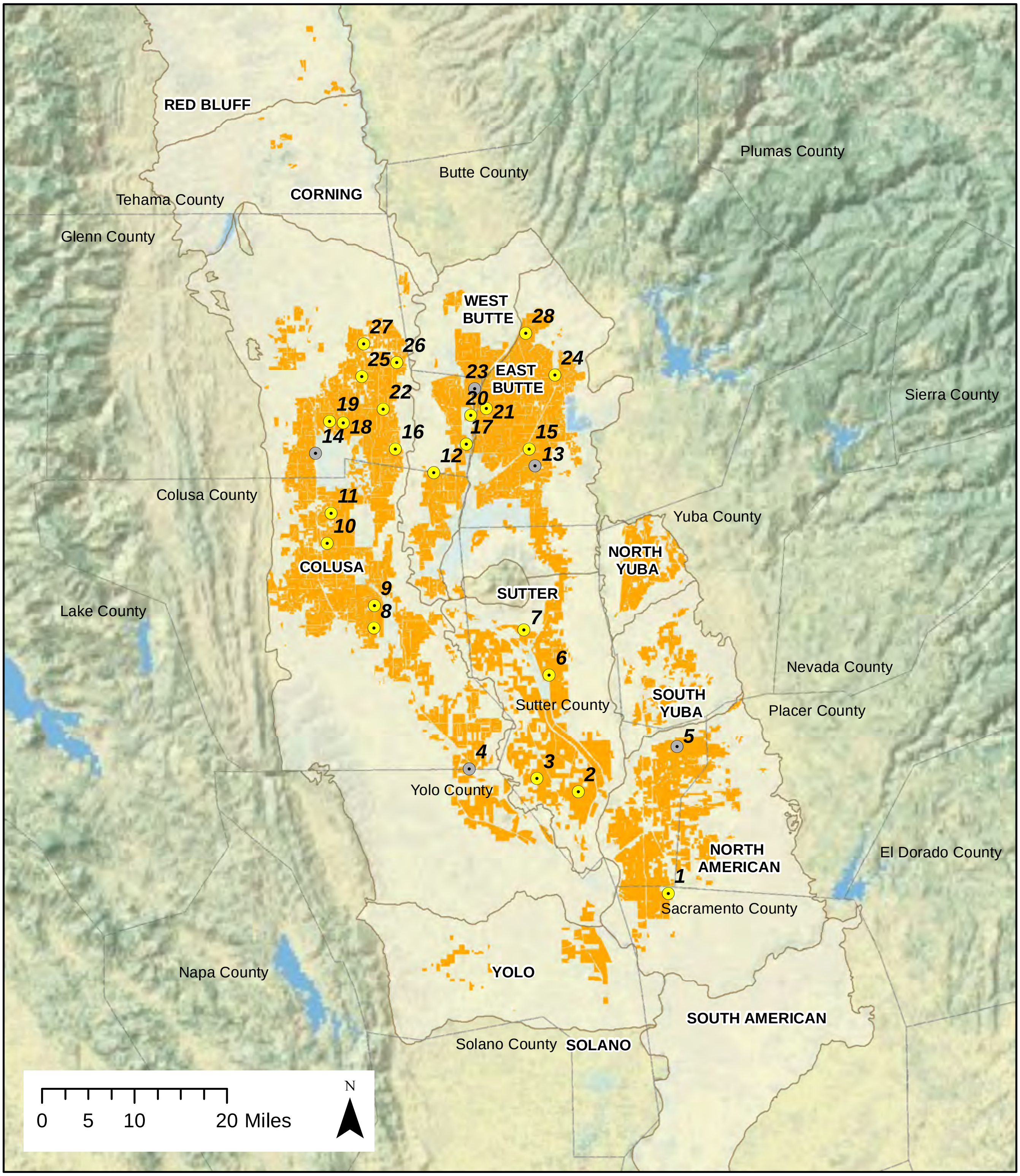


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011); SWRCB (2000); DPR (2004). Datum is NAD83.

Legend

- Rice within Initial SWRCB HVA
- Rice within DPR Leaching and Leaching or Runoff GPA
- County Boundary
- Groundwater Basins

MAP 2-16
Rice Lands in
SWRCB Initial HVAs and DPR GPAs
Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a). Datum is NAD83.

Legend

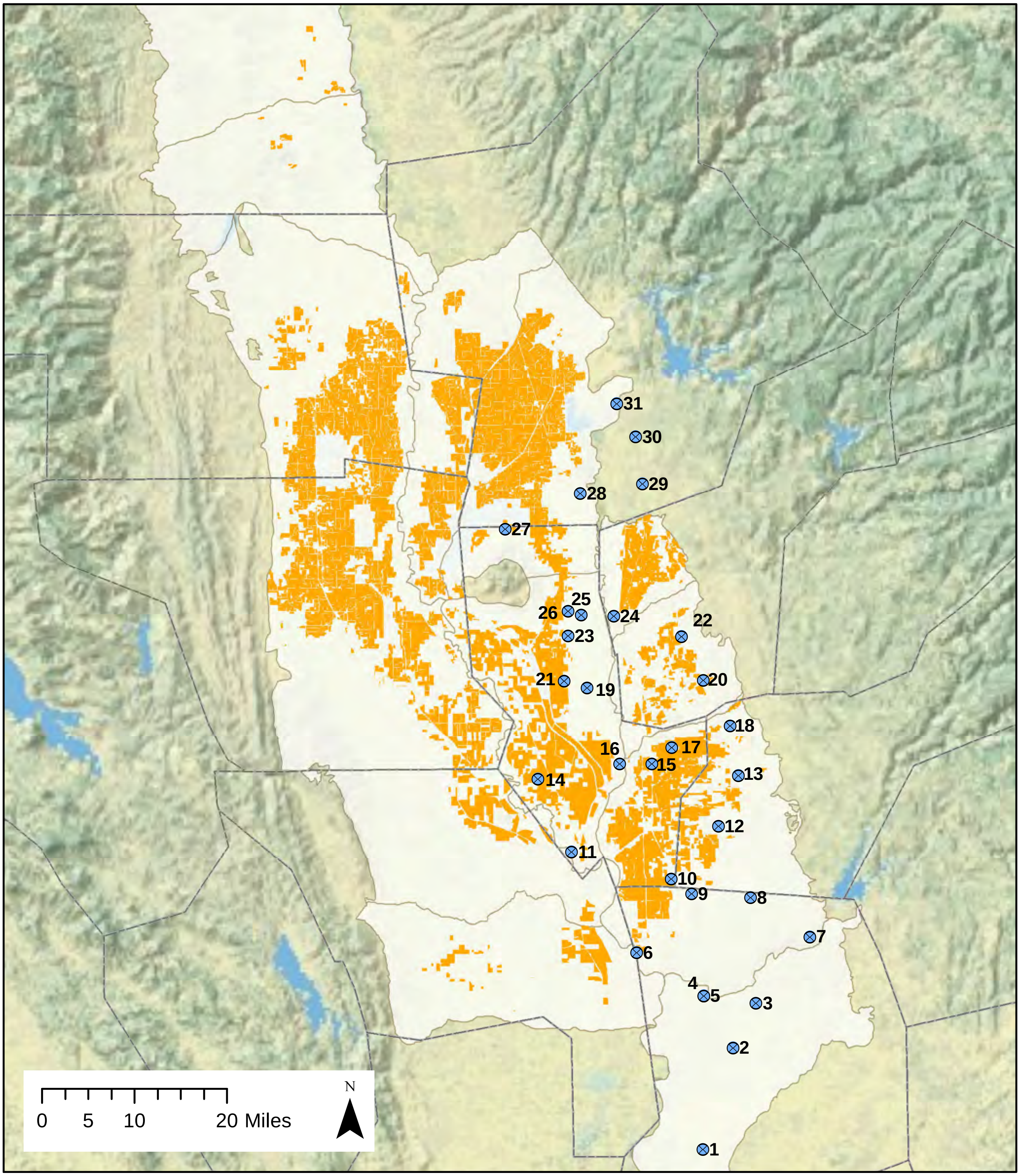
USGS Rice Wells
- Active Monitoring Well
- Abandoned Monitoring Well
- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 3-1

USGS Rice Wells Network

Rice-Specific Groundwater Assessment Report

CH2MHILL



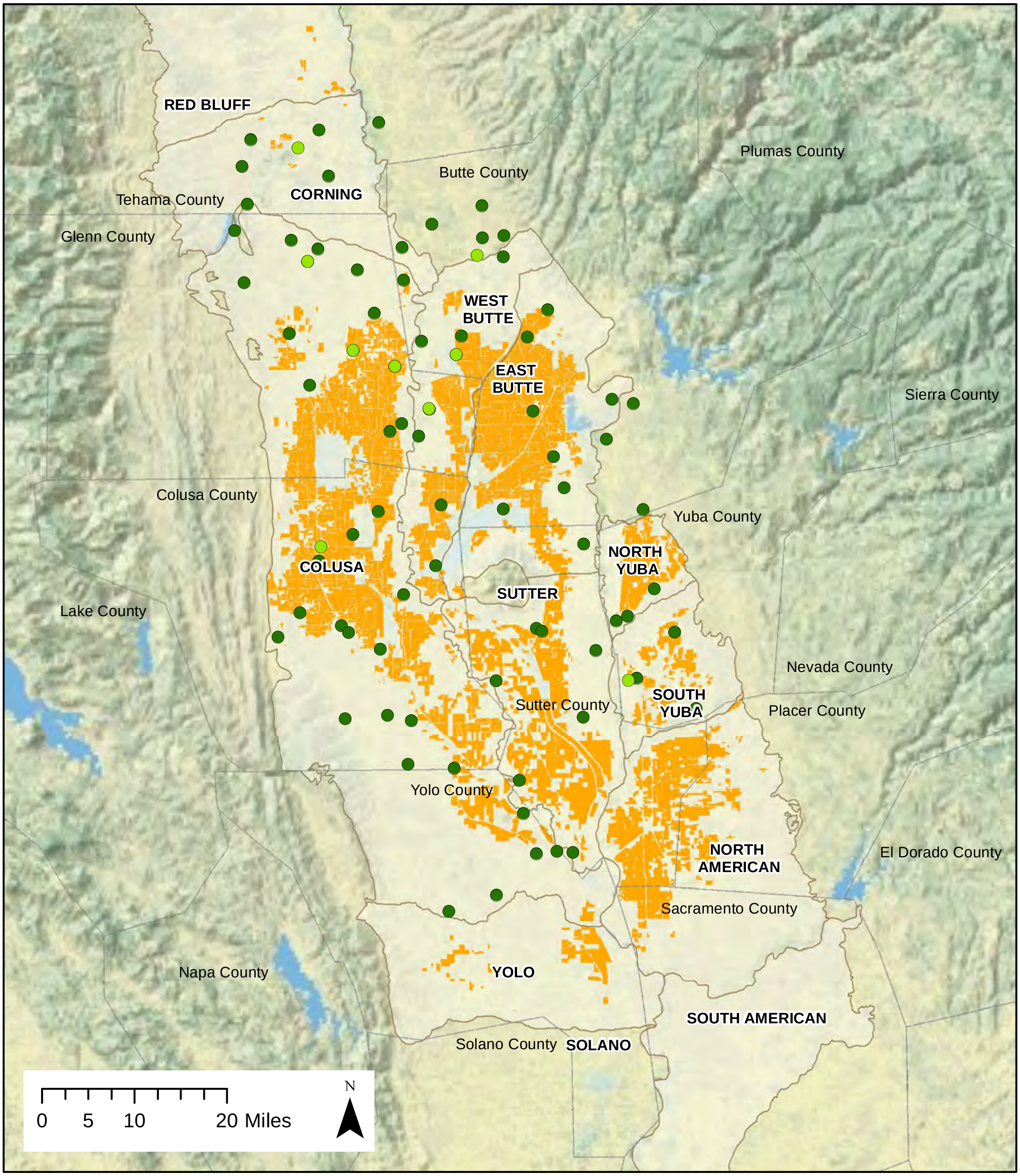
Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001b). Datum is NAD83.

Legend
- USGS Shallow Domestic Wells
- County Boundary
- Rice Lands (DWR)
- Groundwater Basin

MAP 3-2
USGS Shallow Domestic Wells Network

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2008). Datum is NAD83.

Legend

USGS GAMA Wells
- Grid Well
- Flow Path Well

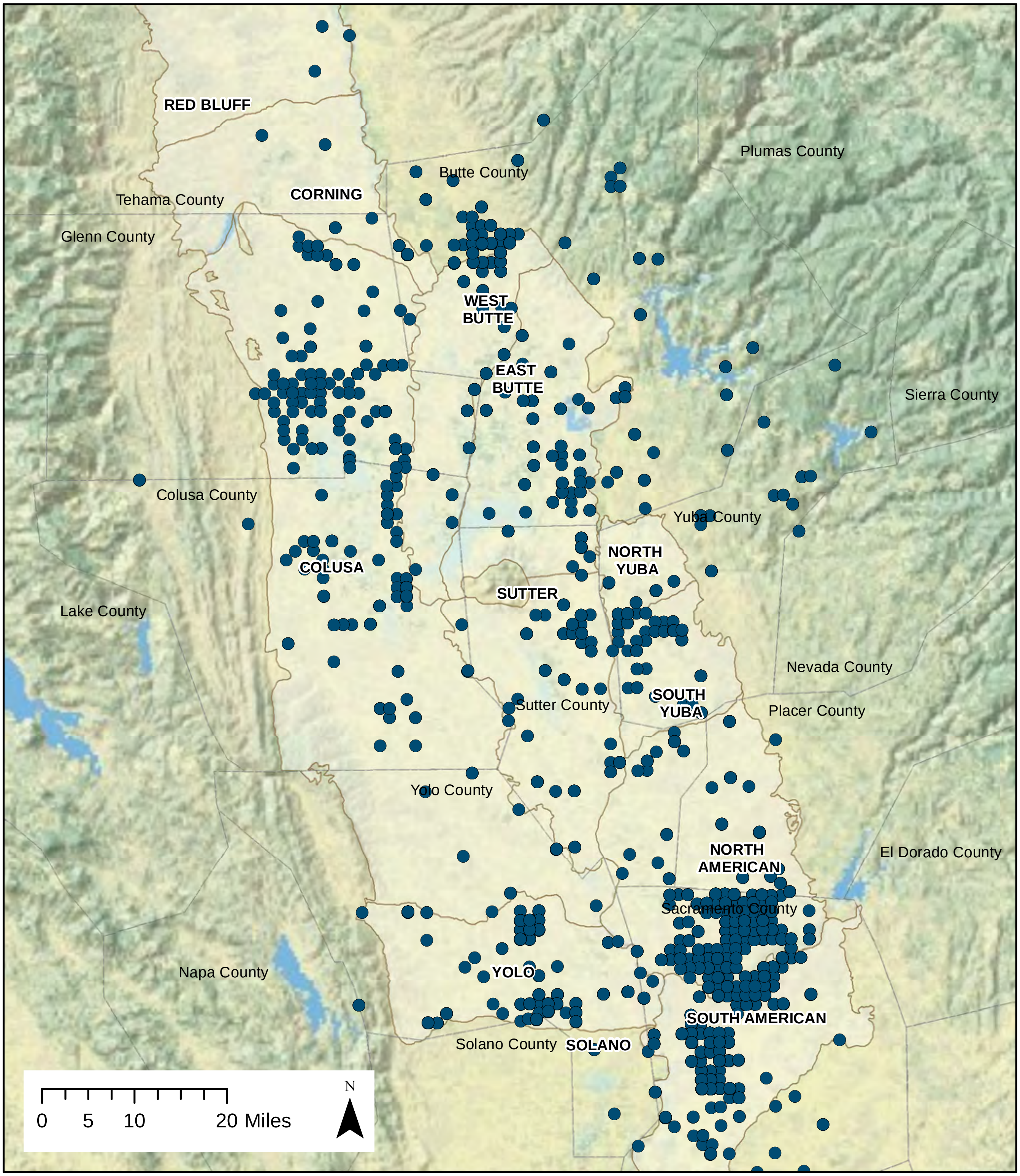
- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 3-3

USGS GAMA Middle Sacramento Valley Study Unit Wells

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), DPR (2011). Datum is NAD83.

Legend

Groundwater Basins

County Boundary

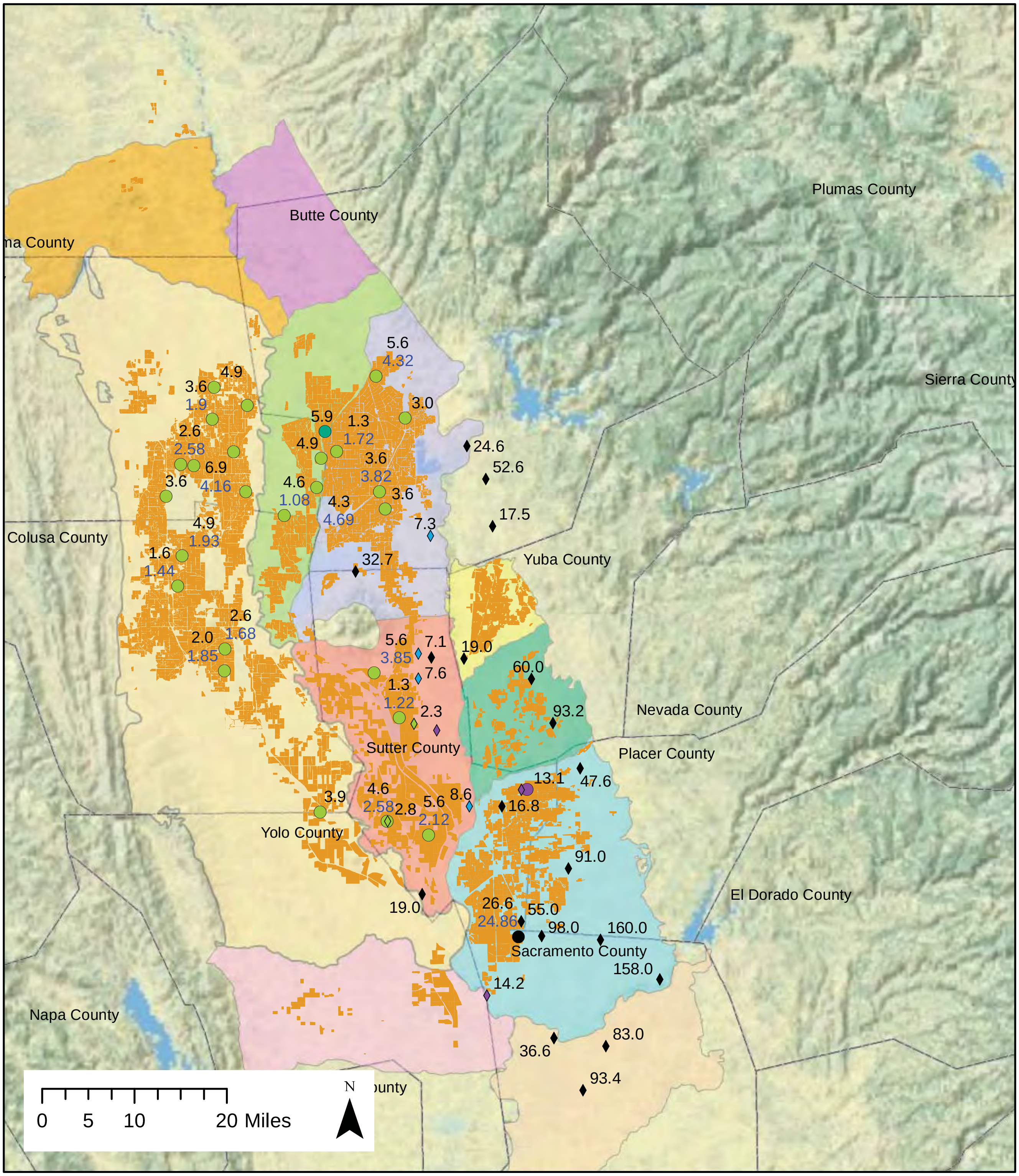
DPR Well Inventory Database

Well Sampled for Pesticides Registered for Use on Rice

MAP 3-4
Location of DPR Well Inventory Database Wells Sampled for Pesticides Registered for use on Rice

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: USGS Rice Wells, Shallow Domestic Wells (USGS 2001a, 2001b; CH2M HILL), Groundwater Basins and Rice Crop (California DWR 2010); Basemap, County (ESRI 2011). Datum is NAD83.

Groundwater Basins
- Colusa
- Corning
- East Butte
- North American
- North Yuba
- South American
- South Yuba
- Sutter
- Vina
- West Butte
- Yolo

Rice Crop

County Boundary

USGS Rice Well
- 0-5 fbls
- 5-10 fbls
- 10-15 fbls
- 15 fbls and deeper

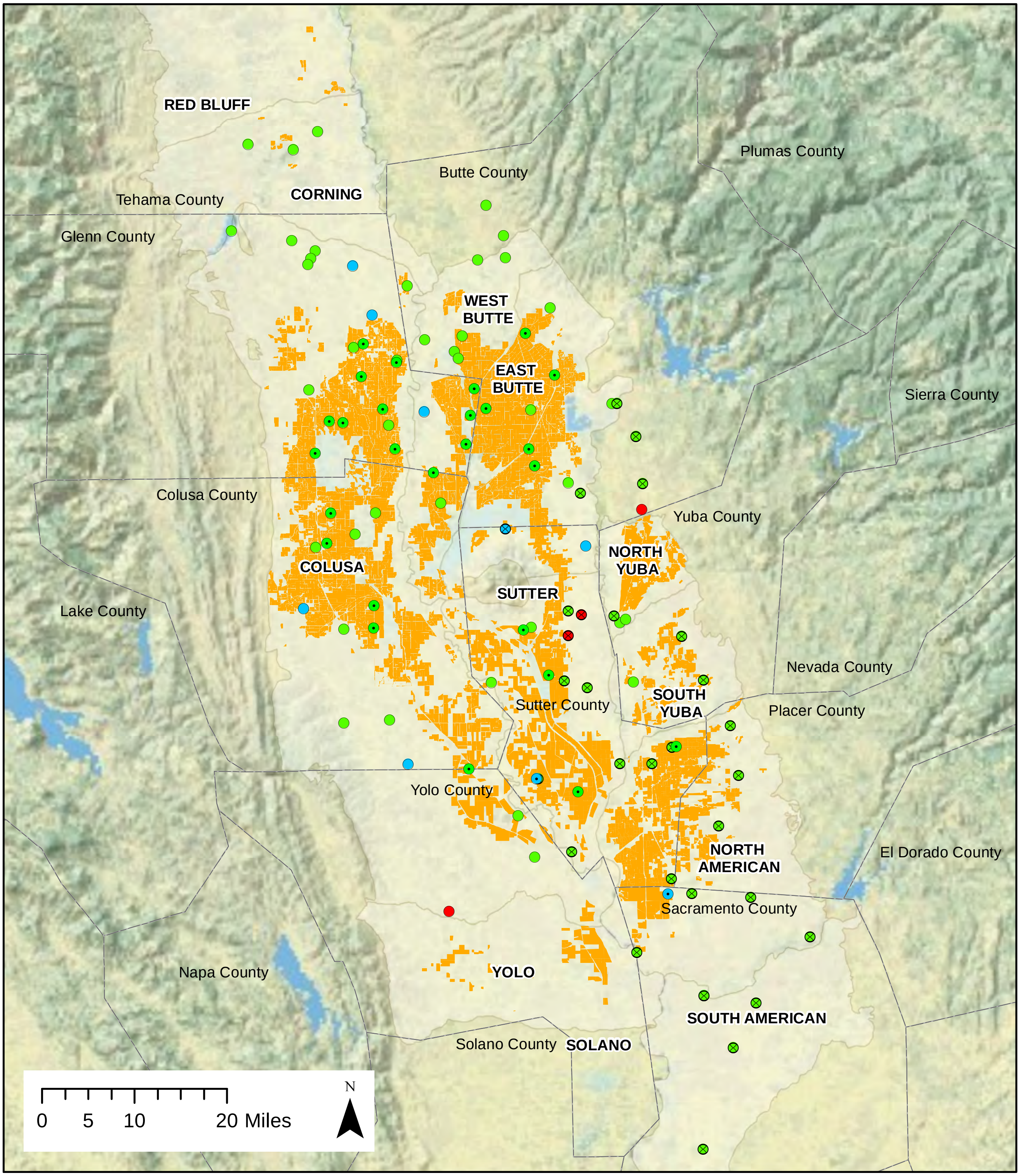
USGS Rice Wells:
1997 Water Level
2010 Water Level

Shallow Domestic Well
- 0-5 fbls
- 5-10 fbls
- 10-15 fbls
- 15 fbls and deeper

MAP 4-1
Depth to Groundwater for USGS Rice Wells and Domestic Wells

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- <5 mg/L NO2+ NO3-N
- 5 mg/L - 10 mg/L NO2+ NO3-N

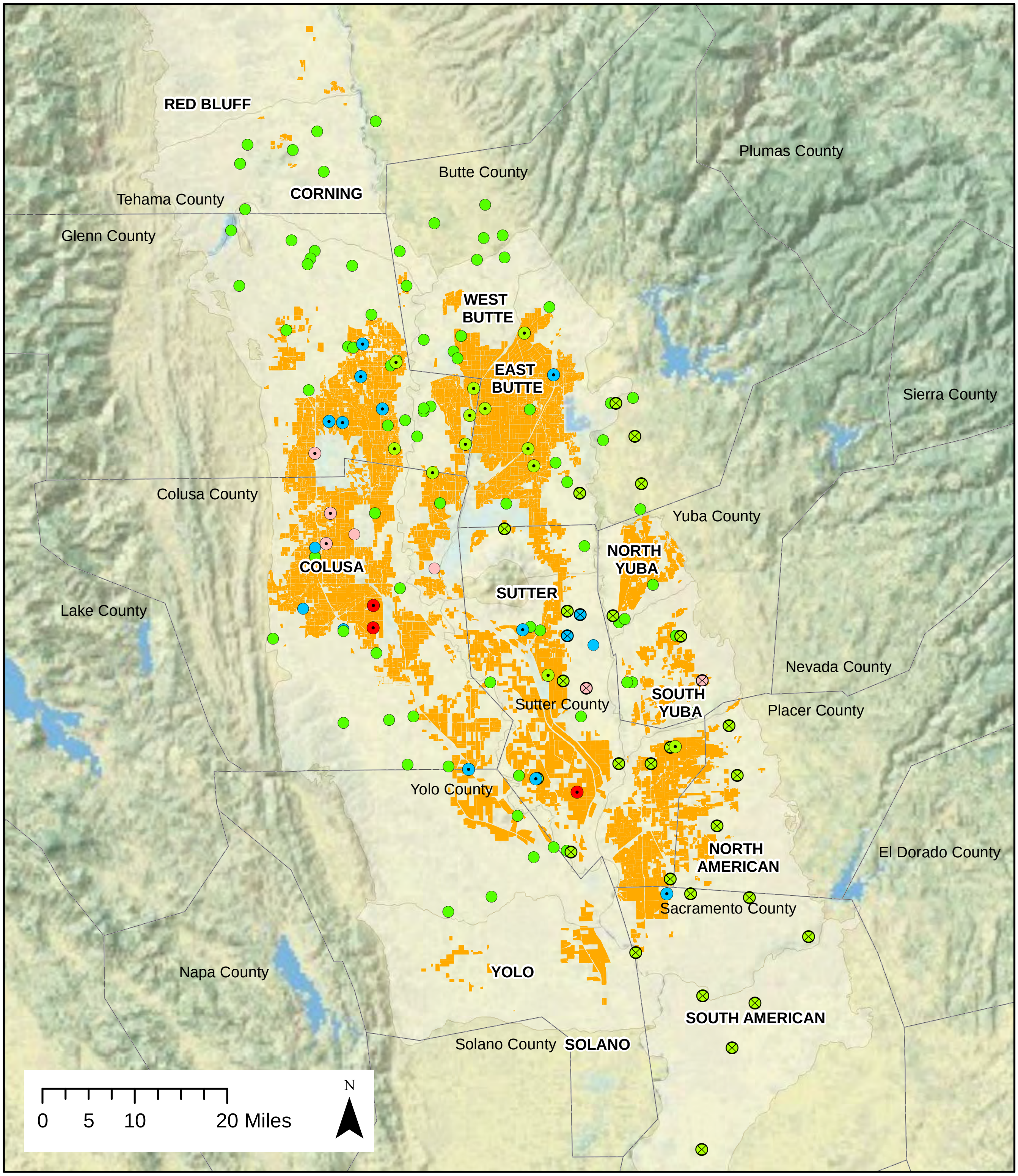
Shallow Domestic Wells
- < 5 mg/L NO2+NO3-N
- 5 mg/L - 10 mg/L NO2+NO3-N
- > 10 mg/L NO2+NO3-N

GAMA Wells
- <5 mg/L NO2+ NO3-N
- 5 mg/L - 10 mg/L NO2+ NO3-N
- >10 mg/L NO2+ NO3-N

County Boundary
Rice Lands (DWR)
Groundwater Basins

MAP 5-1
Maximum Observed NO2+NO3-N Concentrations
Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice WellsT
- <500 mg/L TDS
- 500 - 1000 mg/L TDS
- 1000 - 1500 mg/L TDS
- >1500 mg/L TDS

Shallow Domestic Wells
- <500 mg/L TDS
- 500 - 1000 mg/L TDS
- 1000 - 1500 mg/L TDS

GAMA Wells
- < 500 mg/L TDS
- 500 - 1,000 mg/L TDS
- 1,000 - 1,500 mg/L TDS

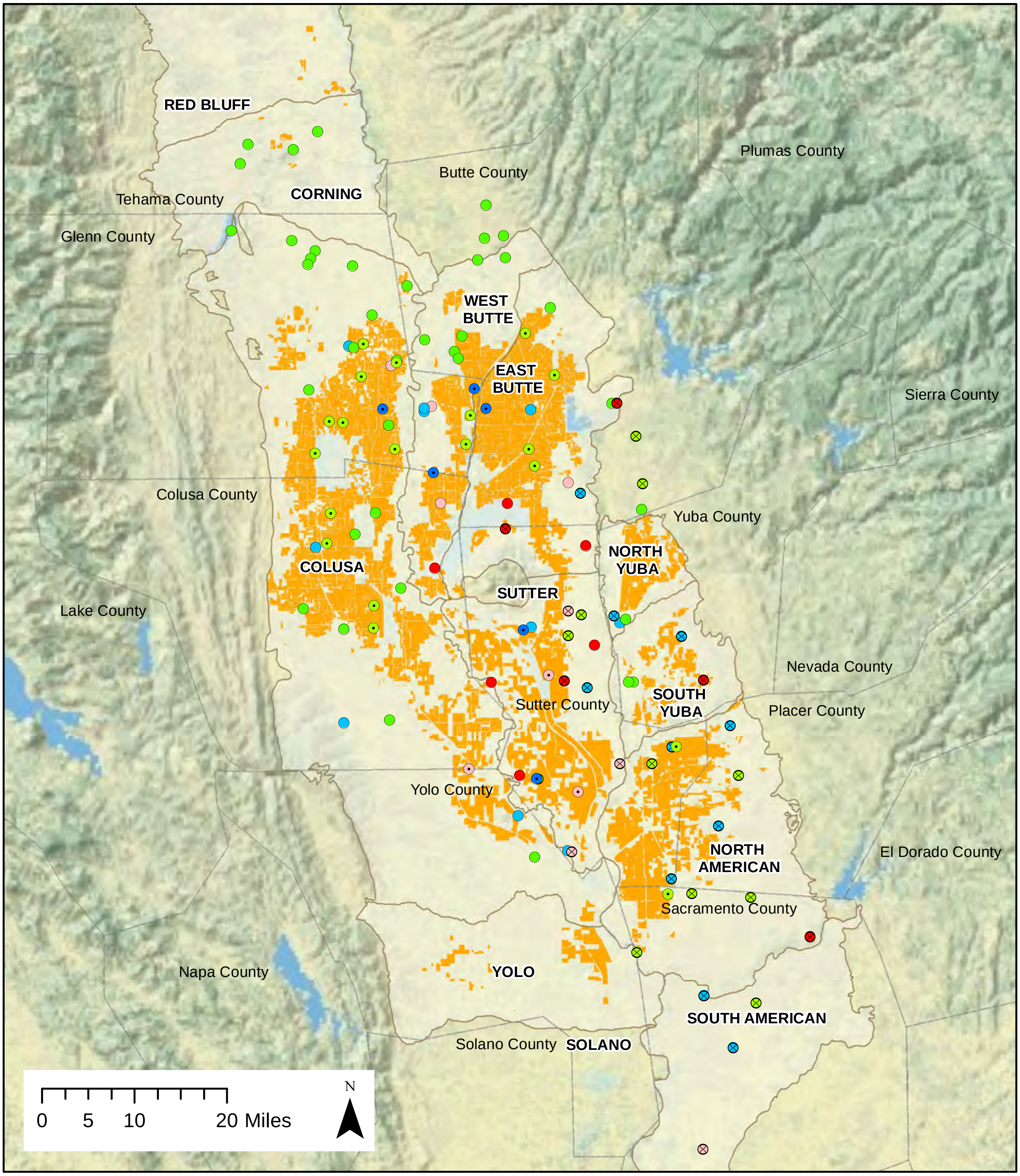
- County Boundary
- Rice Lands (DWR)
- Groundwater Basins

MAP 5-2
Maximum Observed TDS Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL

CRC_GAR_MAP5-2_TDS_V2 alabelle 7/26/2013



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- < 5 µg/L As
- 5 µg/L - 10 µg/L As
- 10 µg/L - 15 µg/L As (Max 15.25 µg/L)

Shallow Domestic Wells
- < 5 µg/L As
- 5 - 10 µg/L As
- 10 - 15 µg/L As
- > 15 µg/L As (Max 46 µg/L)

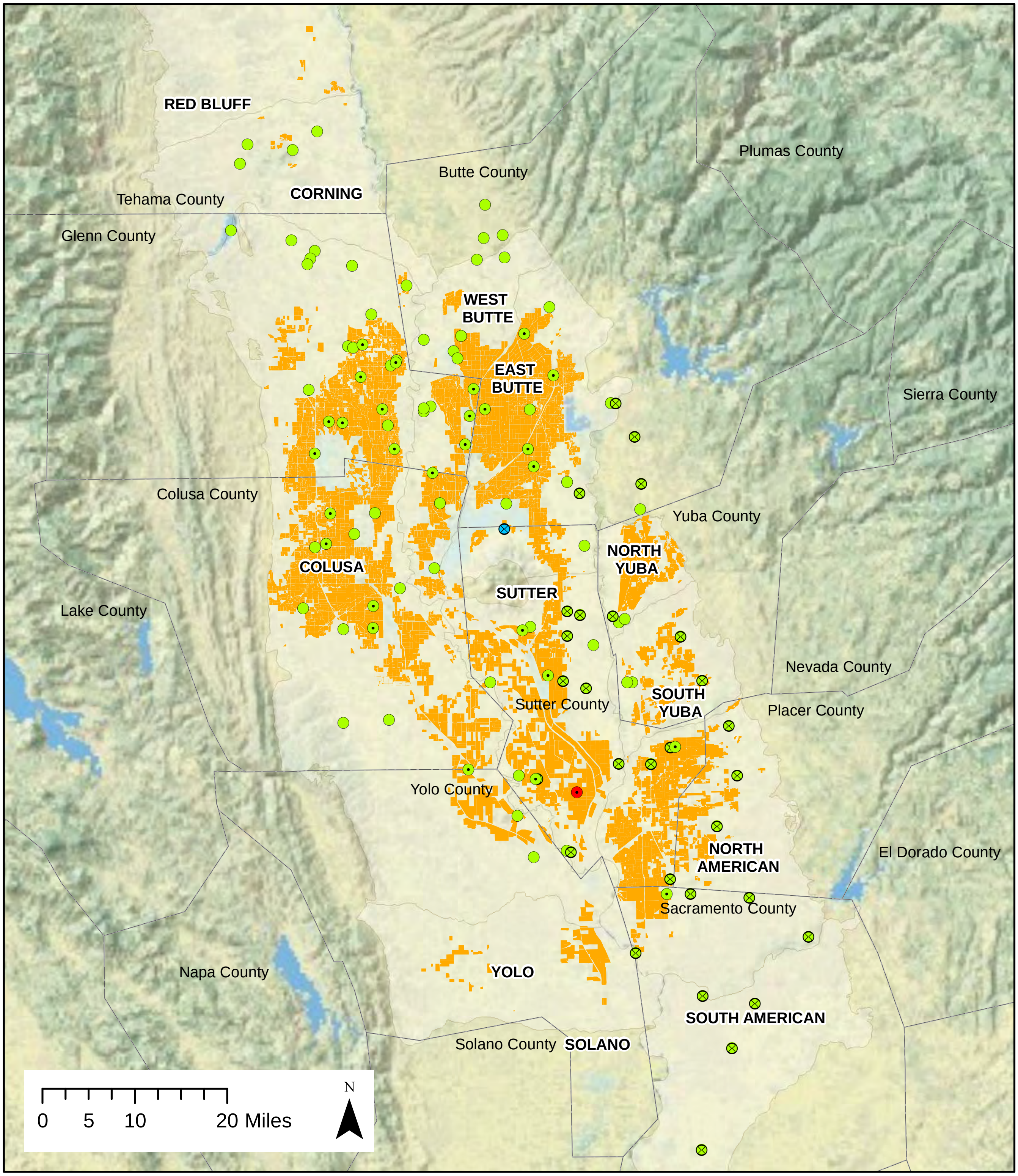
GAMA Wells
- < 5 µg/L As
- 5 - 10 µg/L As
- 10 - 15 µg/L As
- > 15 µg/L As (Max 80.6 µg/L)

- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 5-3
Maximum Observed Arsenic Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- <500 µg/L Ba
- 500 - 1000 µg/L Ba
- >1000 µg/L Ba

Shallow Domestic Wells
- <500 µg/L Ba
- 500 - 572 µg/L Ba

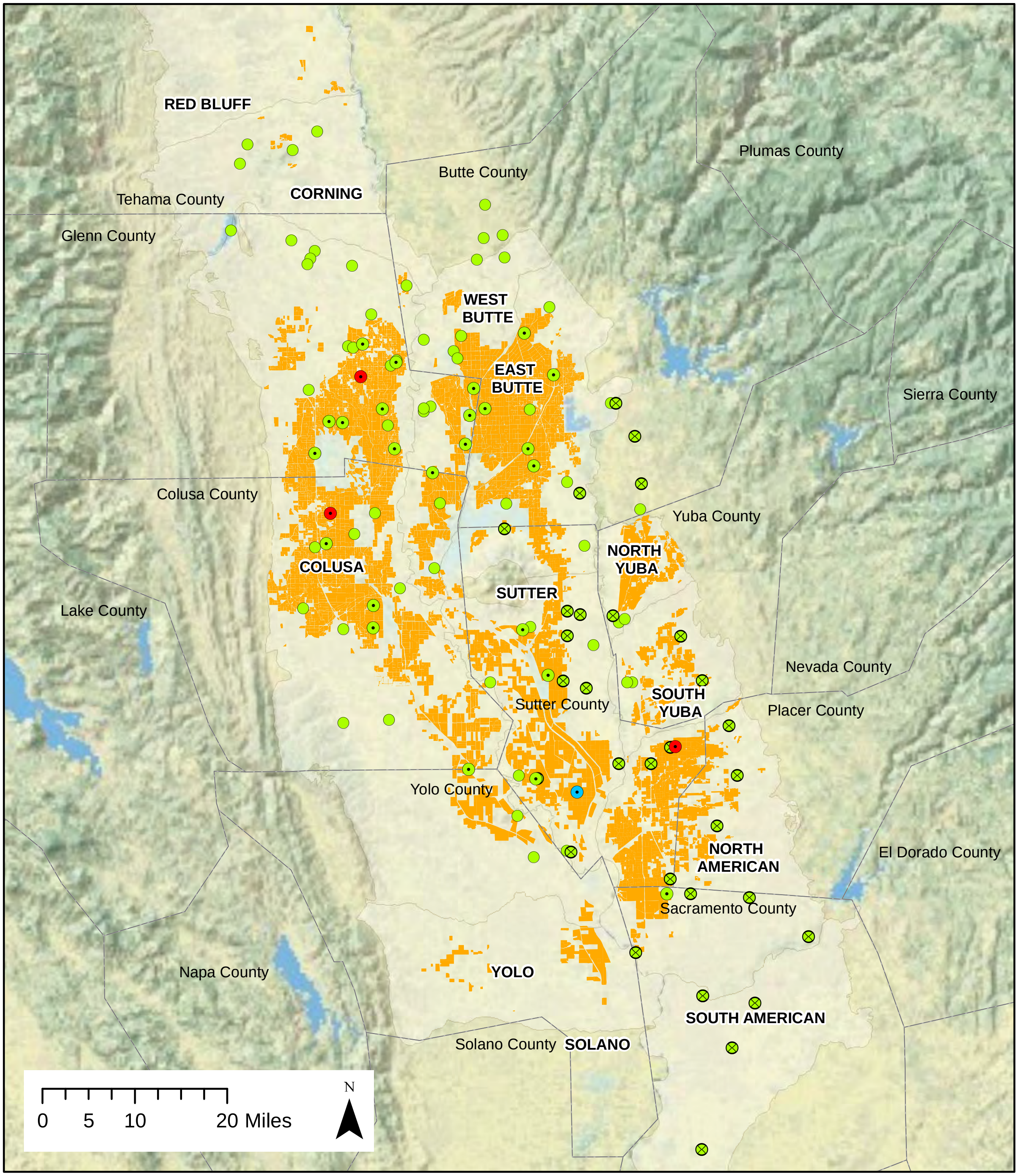
GAMA Wells
- < 500 µg/L Ba

County Boundary
Groundwater Basins
Rice Lands (DWR)

MAP 5-4
Maximum Observed Barium Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- < 2.5 µg/L Cd
- 2.5 - 5.0 µg/L Cd
- >5 µg/L Cd

Shallow Domestic Wells
- < 0.05 µg/L Cd

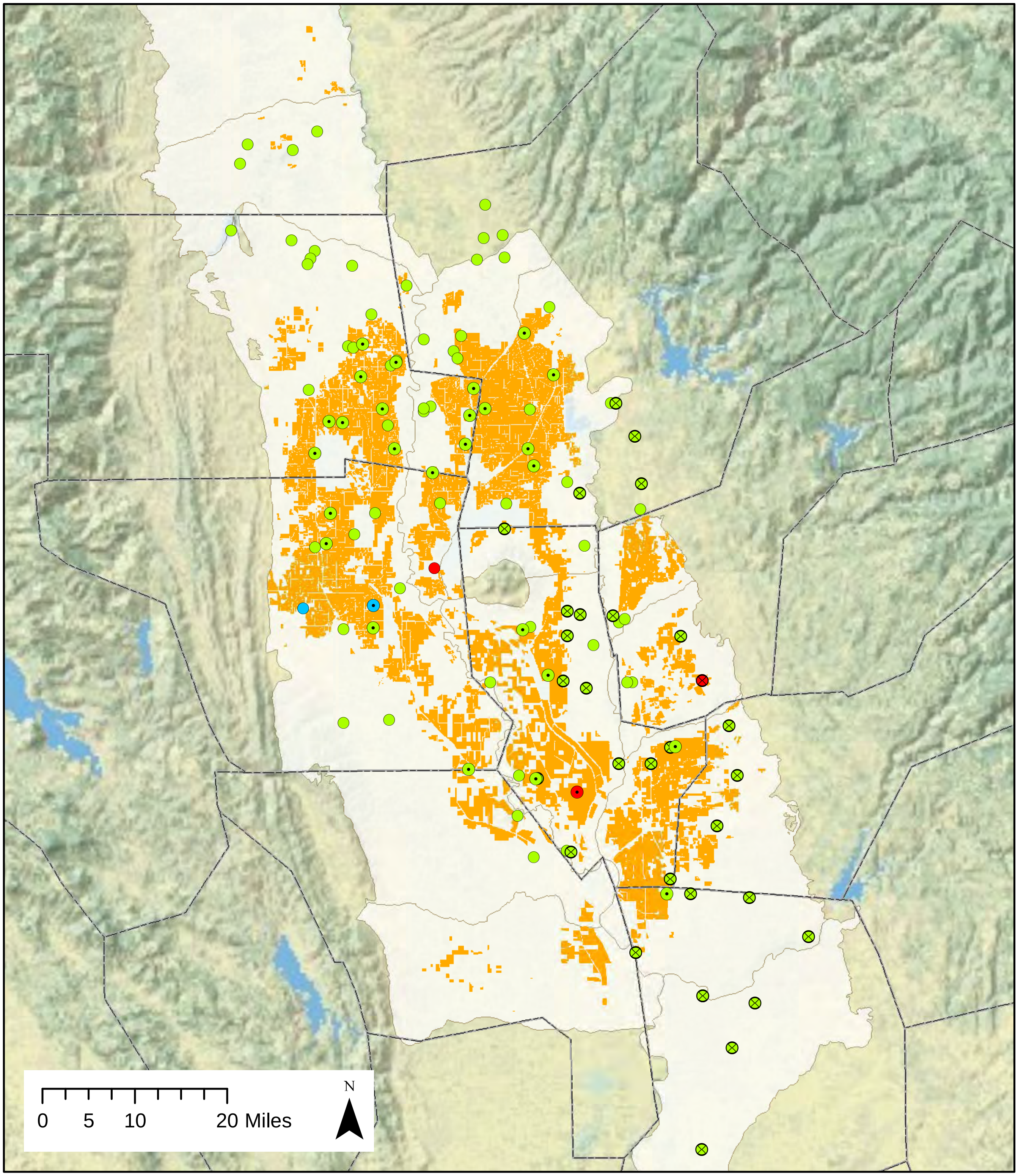
GAMA Wells
- <5 µg/L Cd

County Boundary
Rice Lands (DWR)
Groundwater Basins

MAP 5-5
Maximum Observed Cadmium Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- <250 mg/L Cl-
- 250 mg/L - 500 mg/L Cl-
- >500 mg/L Cl-

Shallow Domestic Wellsc
- <250 mg/L Cl-
- 250 mg/L - 500 mg/L Cl-
- > 500 mg/L Cl-

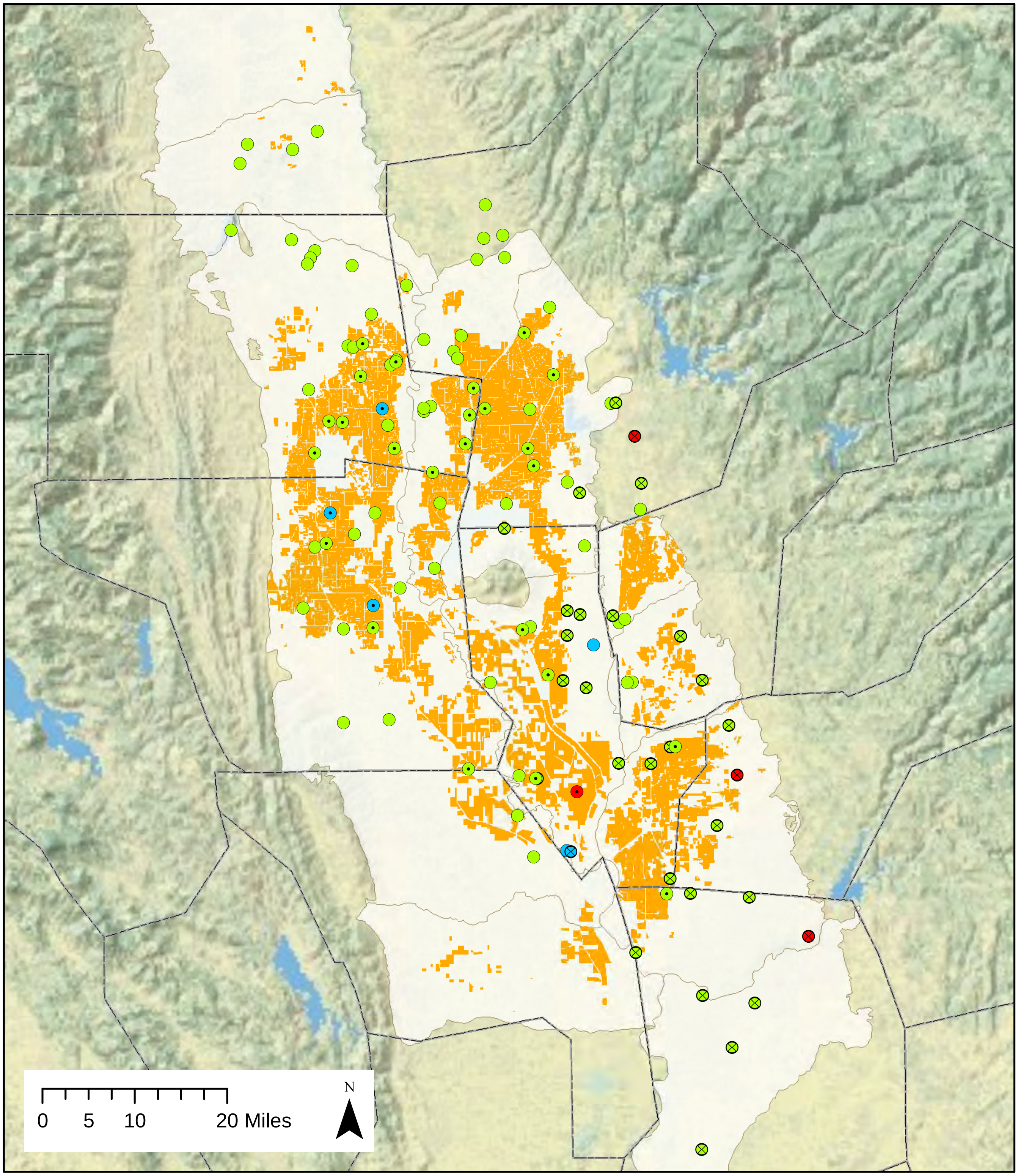
GAMA Wellsc
- <250 mg/L Cl-
- 250 mg/L - 500 mg/L Cl-
- >500 mg/L Cl-

- County Boundary
- Rice Lands (DWR)
- Groundwater Basin

MAP 5-6
Maximum Observed Chloride Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wellss
- <250 µg/L Fe
- 250 - 500 µg/L Fe
- > 500 µg/L Fe

Shallow Domestic Wells
- < 250 µg/L Fe
- 250 - 500 µg/L Fe
- > 500 µg/L Fe

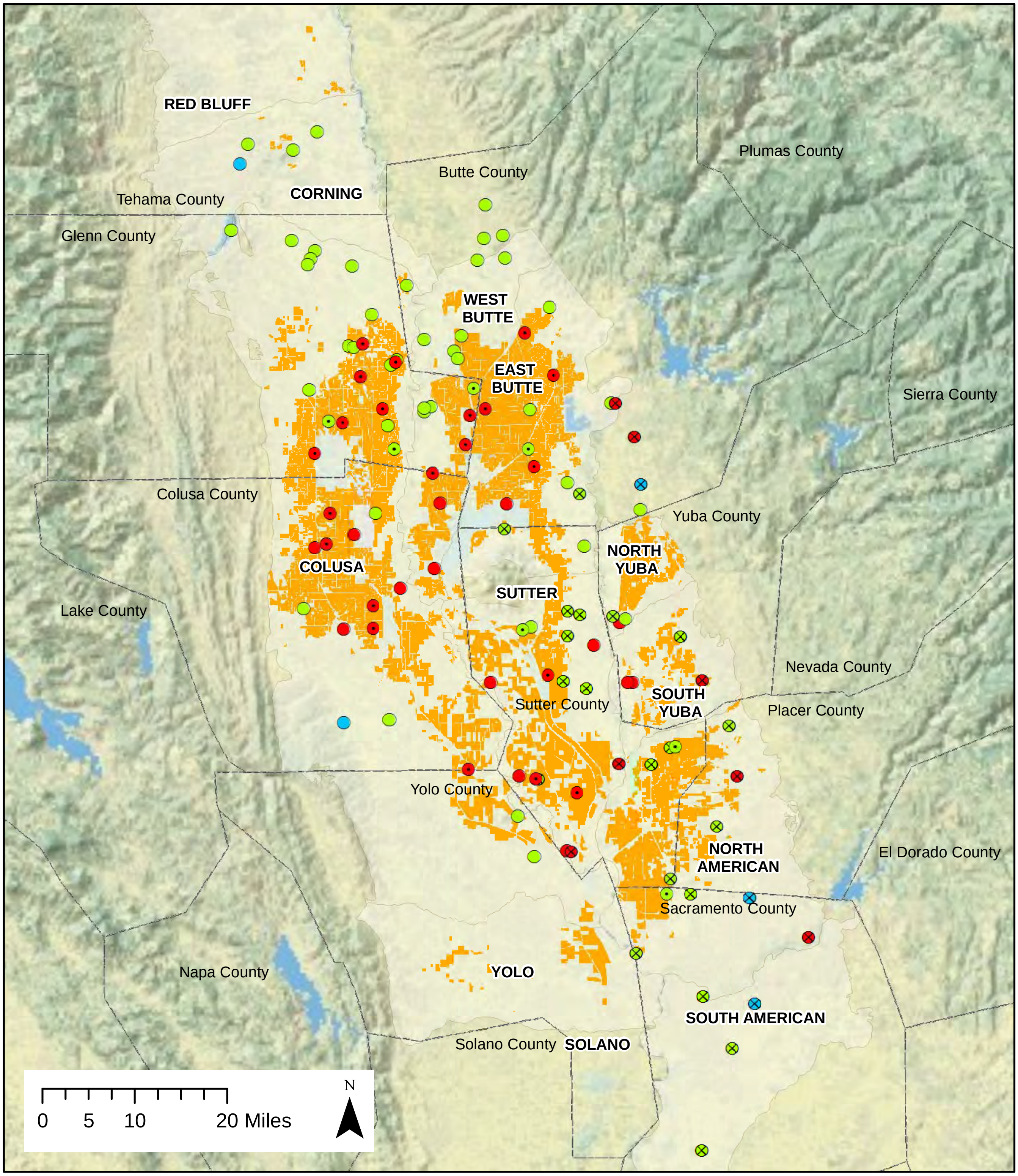
GAMA Wells
- < 250 µg/L Fe
- 250 - 500 µg/L Fe

County Boundary
Rice Lands (DWR)
Groundwater Basins

MAP 5-7
Maximum Observed Iron Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- <25 µg/L Mn
- 25 - 50 µg/L Mn
- > 50 µg/L Mn

Shallow Domestic Wells
- <25 µg/L Mn
- 25 - 50 µg/L Mn
- > 50 µg/L Mn

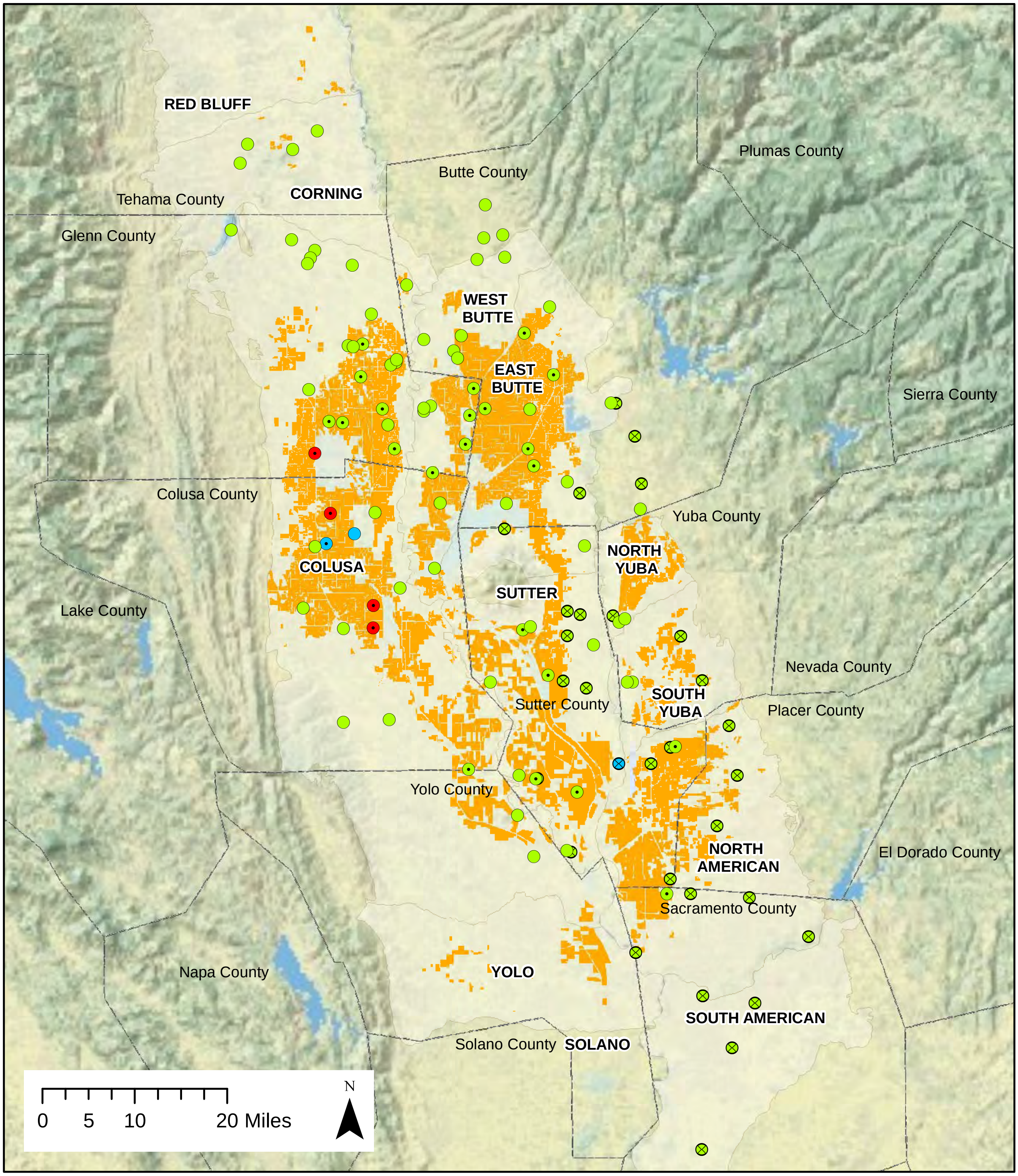
GAMA Wells
- < 25 µg/L Mn
- 25 - 50 µg/L Mn
- > 50 µg/L Mn

County Boundary
Rice Lands (DWR)
Groundwater Basins

MAP 5-8
Maximum Observed Manganese Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a, 2001b, 2008). Datum is NAD83.

Legend

USGS Rice Wells
- <250 µg/L SO4
- 250 - 500 µg/L SO4
- >500 µg/L SO4

Shallow Domestic Wells
- < 250 µg/L SO4
- 250 - 255 µg/L SO4

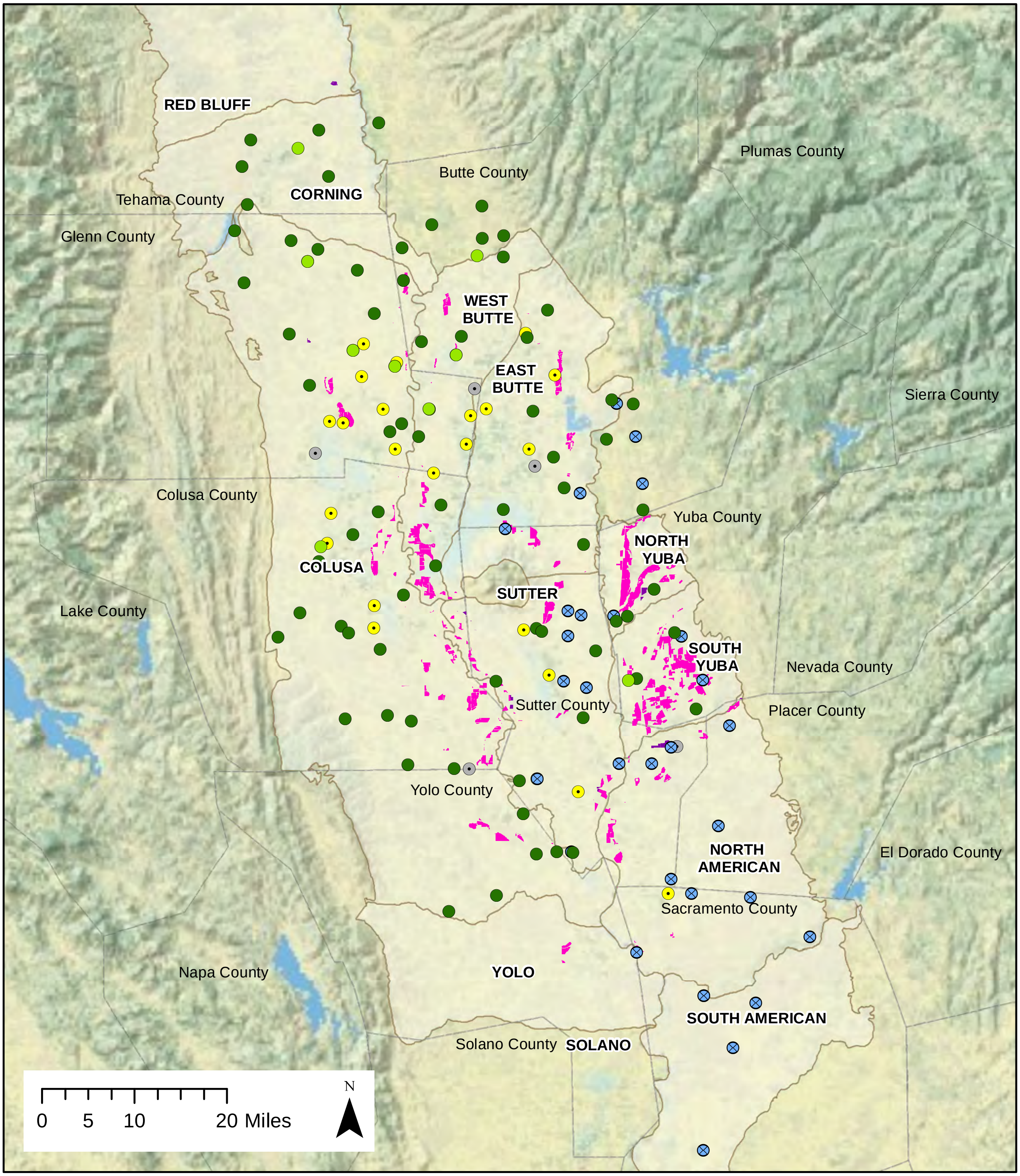
GAMA Wells
- < 250 µg/L SO4
- 250 - 500 µg/L SO4

- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

MAP 5-9
Maximum Observed Sulfate Concentrations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2008). Datum is NAD83.

Legend

- USGS Shallow Domestic Wells

USGS Rice Wells

- Active Monitoring Well
- Abandoned Monitoring Well

USGS GAMA Wells

- Grid Well
- Flow Path Well

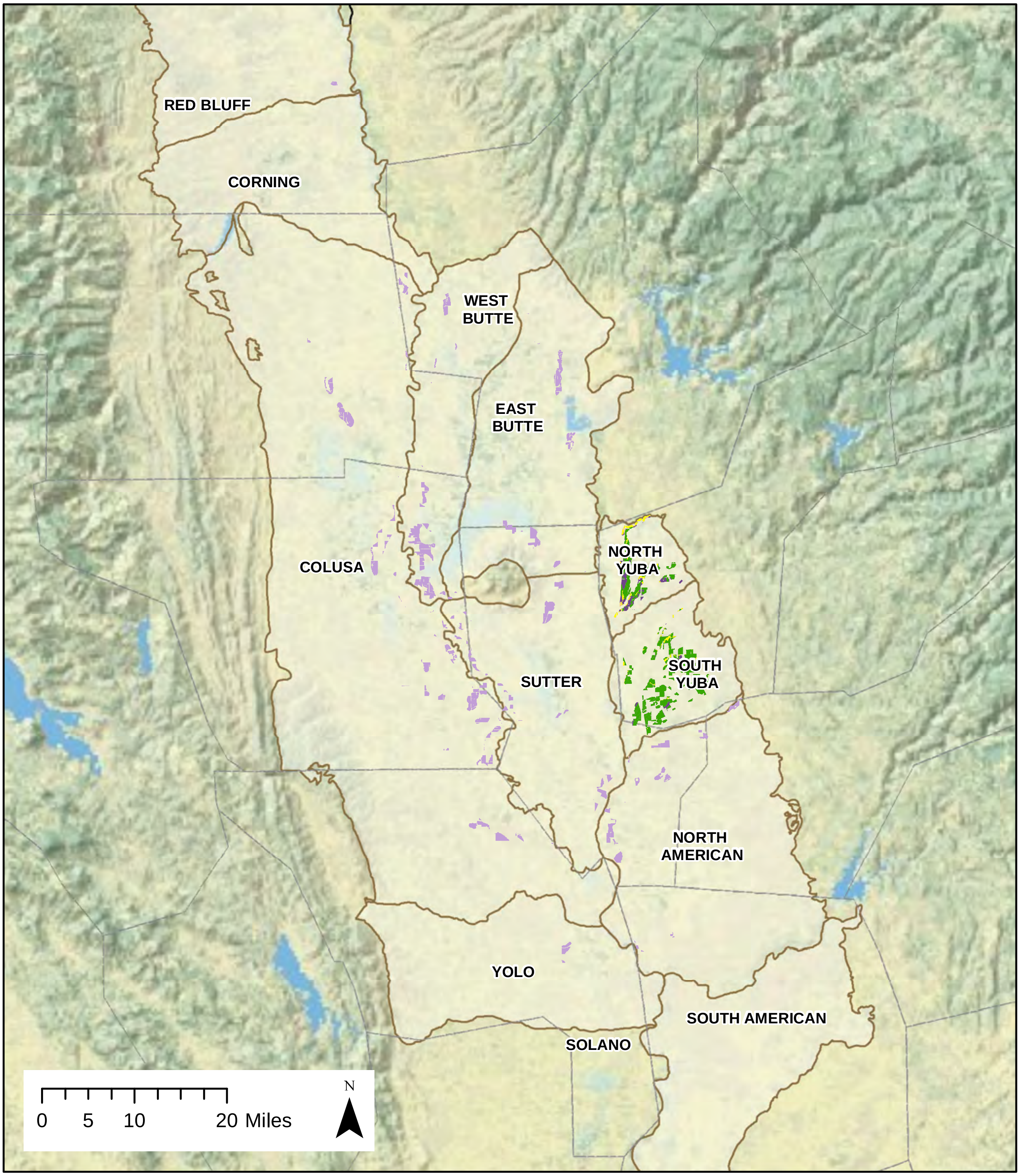
- Rice within Initial SWRCB HVA
- Rice within DPR Leaching and Leaching or Runoff GPA
- County Boundary
- Groundwater Basins

MAP 6-1

USGS Monitoring Networks and Rice within Initial HVAs and DPR Leaching Areas

Rice-Specific Groundwater Assessment Report

CH2MHILL



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011); SWRCB (2000); NRCS SSURGO (2012). Datum is NAD83.

Legend

Yuba County Data Gap (Initial HVA Area)

Depth to Duripan

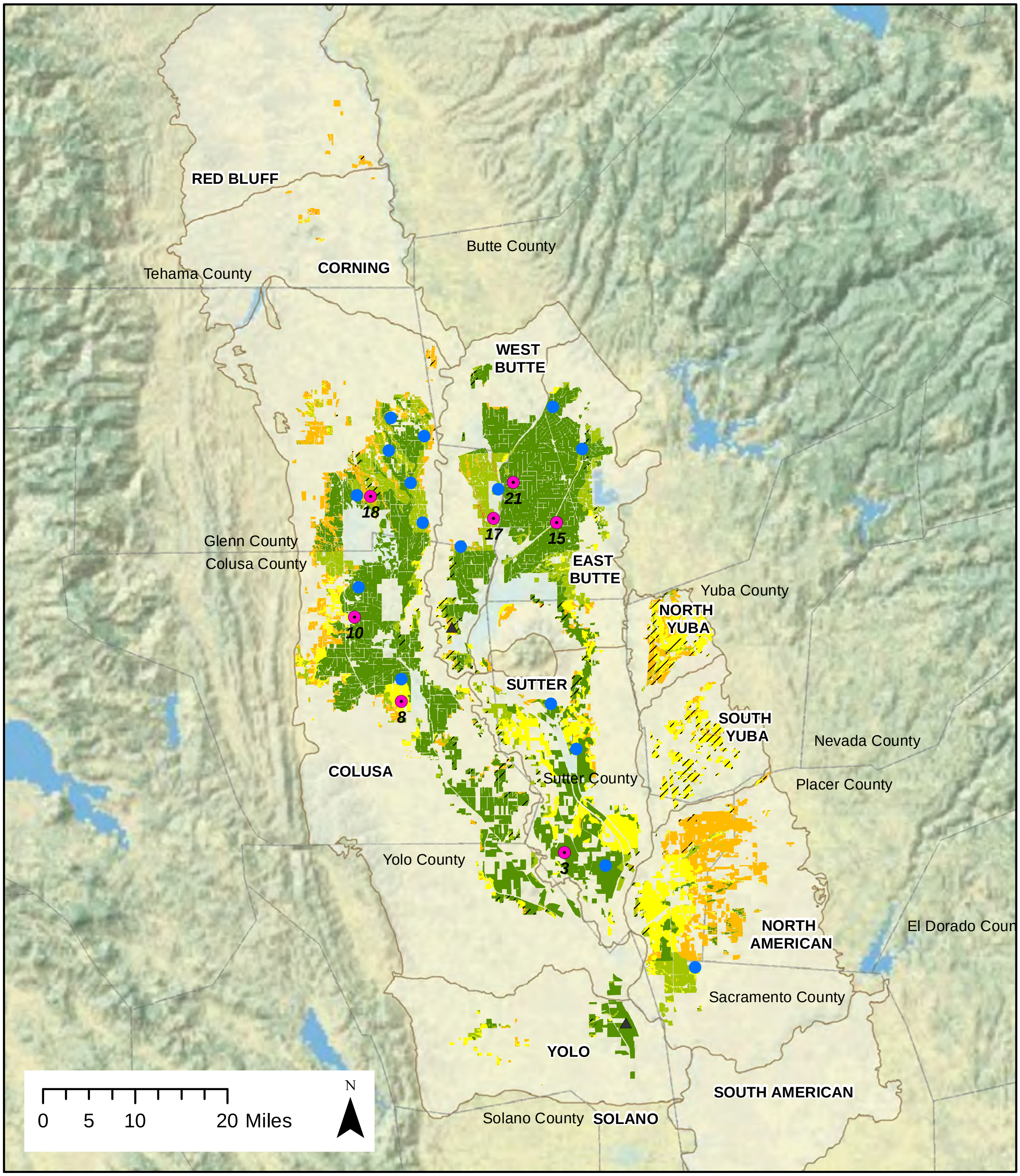
- >60" depth to duripan
- <60" to duripan
- unreported depth to duripan
- minimal acreage (map units less than 60 acres)

- Groundwater Basins
- County Boundary
- Initial HVA; Low Rice-Specific Vulnerability

MAP 6-2
Refined Rice-Specific Data Gaps and Vulnerability Determinations

Rice-Specific Groundwater Assessment Report

CH2MHILL.



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a). Datum is NAD83.

Legend

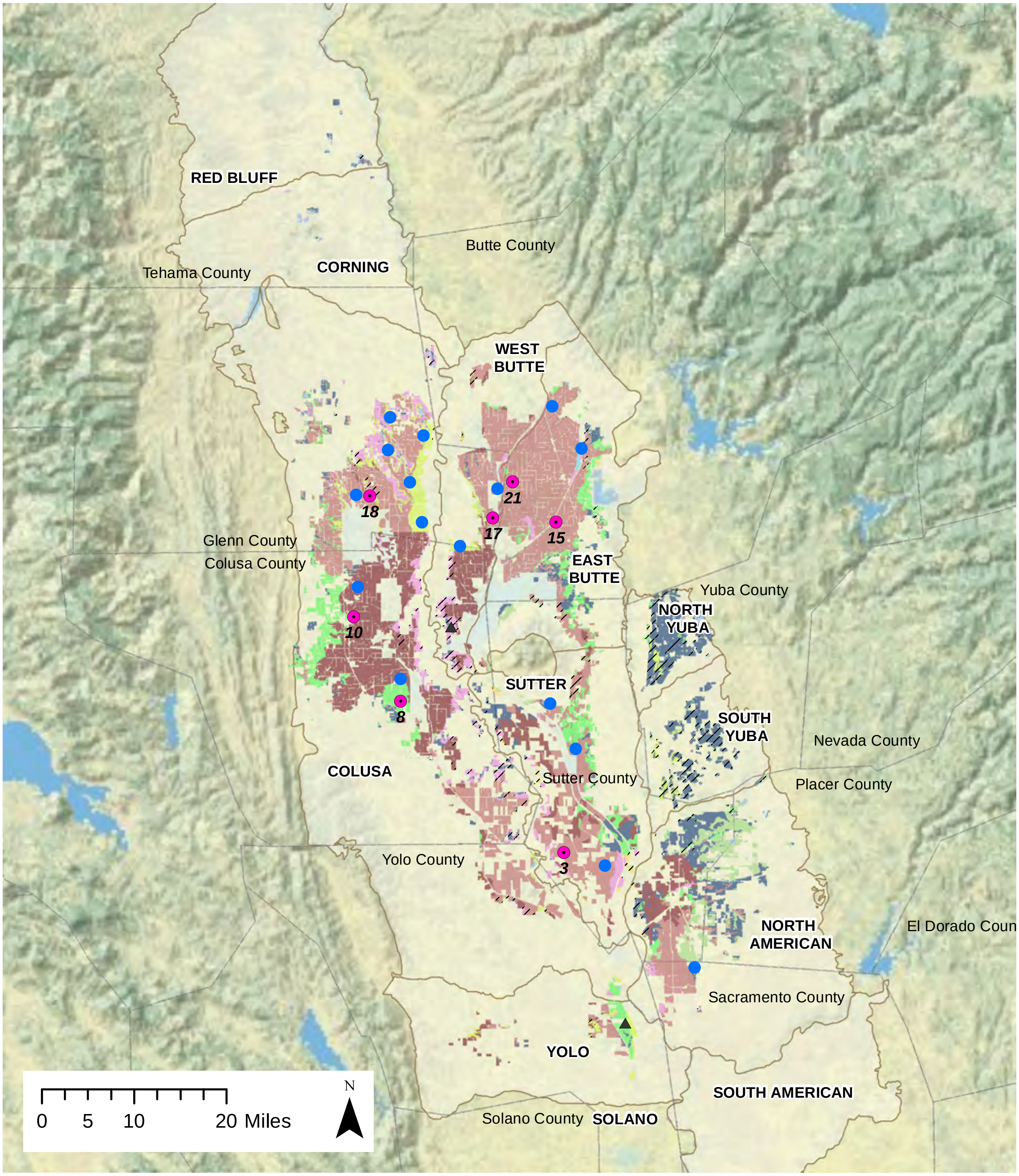
NRCS Drainage Class
- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

▲ Recommended Root Zone Study Site
// Rice within Initial SWRCB HVA or DPR GPA

USGS Rice Wells
- Proposed LTILRP Trend Monitoring Well
- Other Active USGS Rice Well

MAP 7-1
Recommended Rice-Specific Trend Monitoring Network and Root Zone Study Sites with Soil Drainage Classes

Rice-Specific Groundwater Assessment Report



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011), USGS (2001a). Datum is NAD83.

Legend

SSURGO Soil Texture

- clay
- clay loam
- cobbly clay
- extremely gravelly sand
- fine sandy loam
- gravelly clay loam
- gravelly fine sandy loam
- gravelly loam
- gravelly sandy clay loam
- gravelly sandy loam
- loam
- loamy sand
- sandy clay loam
- sandy loam
- silt loam
- silty clay
- silty clay loam
- stony sandy loam
- stratified loam to clay loam
- stratified loamy sand to fine sandy loam
- stratified sand to loamy sand
- stratified silt loam to very fine sandy loam
- variable
- very fine sandy loam
- very gravelly fine sandy loam
- very gravelly sand
- very gravelly sandy loam
- very stony sand
- not rated or not available

- Recommended Root Zone Study Site
- Rice within Initial SWRCB HVA or DPR GPA

USGS Rice Wells

- Proposed LTILRP Trend Monitoring Well
- Other Active USGS Rice Well

MAP 7-1
Recommended Rice-Specific Trend Monitoring Network and Root Zone Study Sites with Soil Texture

Rice-Specific Groundwater Assessment Report

CH2MHILL.

Appendix A
Pesticides Registered for Use on Rice and 2010 Usage Data

APPENDIX A

Pesticides Registered for Use on Rice

Chemical	Trade Name	Pounds Applied	Agricultural Applications	Acres* Treated	Percentage of Acres Treated	2010 PUR/553,000 Acres Treated (acres/percent)
California Rice Herbicides						
Bensulfuron-methyl (CAS No. 83055-99-6) Rice Specific	DuPont™ Londax® Herbicide	1,479.76	369	30,925.44	5.5%	52,052 / 9.4%
Bispyribac-sodium (CAS No. 125401-92-5)	Regiment® CA Herbicide	2,376.09	1,393	81,752.99	14.6%	93,783/ 17%
Carfentrazone-ethyl (CAS No. 128639-02-1)	Shark® Herbicide	1,303.56	163	13,225.06	2.3%	10,967/ 2%
Clomazone (CAS No. 81777-89-1) Rice Specific	Cerano® 5 MEG	74,192.61	2,174	154,099.73	27.5%	205,176/ 37%
Cyhalofop-butyl (CAS No. 122008-85-9) Rice Specific	Clincher® CA	24,402.11	1,072	76,145.06	13.6%	90,180/ 16.3%
2,4-D (CAS No. 20940-37-8)	Various names	4,224.11	235	22,584,49	4.0%	13,571/ 2.5%
Glyphosate: Diammonium salt (CAS No. 69254-40-6) Isopropylamine salt (CAS No. 38641-94-0) Potassium salt (CAS No. 70901-12-1)	Roundup®, Touchdown®	2,963.82	51	3,708.05	0.66%	6,090/ 1.1%
Halosulfuron (CAS No. 100784-20-1)	Sempra® CA Herbicide	193.39	78	4,303.59	0.80%	4,340/ 0.78%
Orthosulfamuron (CAS No. 213464-77-8)	Strada® CA	373.61	99	6,276.40	1.1%	5,305/ 0,96%
Paraquat dichloride (CAS No. 1901-42-5)	Gramoxone® Max	62.29	5	60	0.01%	772/ 0.14%

Chemical	Trade Name	Pounds Applied	Agricultural Applications	Acres* Treated	Percentage of Acres Treated	2010 PUR/553,000 Acres Treated (acres/percent)
Pendimethalin (CAS No. 40487-42-1)	Prowl® 3.3 EC Herbicide, Harbinger™ Herbicide	9,862.52	133	10,400.01	1.9%	12,894/ 2.3%
Penoxsulam (CAS No. 219714-96-2)	Granite™ GR, Granite® SC	22,552.84	1,130	75,624.70	13.5%	128,850/ 23.3%
Propanil (CAS No. 709-98-8) Rice Specific	Riceshot 48 SF, Stam® 80 EDF, Super Wham!® CA, Ultra Stam 4SC ® DF, WHAM® EZ CA	1,899,632.27	5,075	366,413.58	65.3%	392,929/ 71%
Thiobencarb (CAS No. 28249-77-6) Rice Specific	Bolero® Ultra Max Herbicide, Abolish™ 8 EC	278,768.47	855	72,659.91	13.0%	75,172/ 14%
Triclopyr TEA (CAS No. 57213-69-1)	Grandstand® CA Herbicide	53,111.86	3,857	287,450.85	51.2%	322,605/ 58.3%
California Rice Insecticides						
Carbaryl (CAS No. 63-25-2)	Sevin® 4F	36,474.84	2,716	221,331,18	0.09%	248/ 0.04%
(s) or zeta-cypermethrin (CAS No. 52315-07-8)	Mustang® Max Insecticide, Mustang® Insecticide	1067.23	876	35,656.05	6.4%	25,963/ 4.7%
Diflubenzuron (CAS No. 35367-38-5)	Dimilin® 2L Insect Growth Regulator	157.89	33	870.96	0.2%	1,463/ 0.3%
Lambda cyhalothrin (CAS No. 91465-08-6)	Warrior® Insecticide, Silencer®, Lamdastar®, Lambda-cy®	2,081.51	1,861	71,996.90	12.8%	97,877/ 17.7%
Malathion (CAS No. 121-75-5)	Gowan Malathion 8 Flowable, Clean Crop Malathion 8 Aquamul	86.42	1	60	0.01%	0/ 0%
California Rice Fungicides						
Azoxystrobin (CAS No. 131860-33-8)	Quadris® Flowable Fungicide	36,474.84	2,716	221,331,18	39.5%	196,265/ 35.5%

Chemical	Trade Name	Pounds Applied	Agricultural Applications	Acres* Treated	Percentage of Acres Treated	2010 PUR/553,000 Acres Treated (acres/percent)
Propiconazole (CAS No. 60207-90-1);	Stratego® Fungicide	2,278.04	189	14,927.76	2.7%	13,101/ 2.4%
Trifloxystrobin (CAS No. 141517-21-7)		2,278.04	189	14,927.76	2.7%	13,101/ 2.4%
Copper sulfate (pentahydrate) (CAS No. 7758-99-8)	Known as "Bluestone"	1,381,948.79	1,442	97,757.53	17.4%	70,126/ 12.7%
Sodium Carbonate Peroxyhydrate (CAS No. 15630-89-4)	GreenClean Pro Granular Algaecide	16,650.58	31	1,177.00	0.3%	3,599/ 0.65%

CAS: Chemical Abstract Services
PUR: Pesticide Use Report

Appendix B
NRCS Definitions

APPENDIX B

NRCS Definitions

The information presented below is available in the National Soil Survey Handbook (NSSH) (USDA 2012).

Part 618 – Soil Properties and Qualities

From http://soils.usda.gov/technical/handbook/contents/part618.html

Subpart A – General Information

618.16 Drainage Class

A. Definition.—“Drainage class” identifies the natural drainage condition of the soil. It refers to the frequency and duration of wet periods.

B. Classes.—The eight natural drainage classes are listed below. Chapter 3 of the *Soil Survey Manual* provides a description of each natural drainage class.

1. Excessively drained
2. Somewhat excessively drained
3. Well drained
4. Moderately well drained
5. Somewhat poorly drained
6. Poorly drained
7. Very poorly drained
8. Subaqueous

C. Significance.—Drainage classes provide a guide to the limitations and potentials of the soil for field crops, forestry, range, wildlife, and recreational uses. The class roughly indicates the degree, frequency, and duration of wetness, which are factors in rating soils for various uses.

D. Estimates.—Infer drainage classes from observations of landscape position and soil morphology. In many soils the depth and duration of wetness relate to the quantity, nature, and pattern of redoximorphic features. Correlate drainage classes and redoximorphic features through field observations of water tables, soil wetness, and landscape position. Record the drainage classes assigned to the series.

E. Entries.—Enter the drainage class name for each map unit component. Use separate map unit components for different drainage class phases or for drained versus undrained phases where needed.

618.35 Hydrologic Group

A. Definition

1. The complete definition and official criteria for hydrologic soil groups are available online at (Title 210, National Engineering Handbook, Part 630, Chapter 7, “Hydrologic Soil Groups”). Table 7-1 of this document is reproduced below.

2. “Hydrologic group” is a group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonal high water table, saturated hydraulic conductivity after prolonged wetting, and depth to a layer with a very slow water transmission rate. Changes in soil properties caused by land management or climate changes also cause the hydrologic soil group to change. The influence of ground cover is treated independently.

B. Classes.—The soils in the United States are placed into four groups, A, B, C, and D, and three dual classes, A/D, B/D, and C/D.

C. Significance.—Hydrologic groups are used in equations that estimate runoff from rainfall. These estimates are needed for solving hydrologic problems that arise in planning watershed-protection and flood-prevention projects and for planning or designing structures for the use, control, and disposal of water.

D. Measurements.—The original classifications assigned to soils were based on the use of rainfall-runoff data from small watersheds and infiltrometer plots. From these data, relationships between soil properties and hydrologic groups were established.

E. Estimates.— Assignment of soils to hydrologic groups is based on the relationship between soil properties and hydrologic groups. Wetness characteristics, water transmission after prolonged wetting, and depth to very slowly permeable layers are properties used in estimating hydrologic groups.

F. Entries.—Enter the soil hydrologic group, such as A, B, C, D, A/D, B/D, or C/D.

Table 7–1 Criteria for assignment of hydrologic soil group (HSG)

Depth to water impermeable layer [1/]	Depth to high water table [2/]	K_{sat} of least transmissive layer in depth range	K_{sat} depth range	HSG [3/]
<50 cm [<20 in]	—	—	—	D
50 to 100 cm [20 to 40 in]	<60 cm [<24 in]	>40.0 μm/s (>5.67 in/h)	0 to 60 cm [0 to 24 in]	A/D
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 60 cm [0 to 24 in]	B/D
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 60 cm [0 to 24 in]	C/D
		≤1.0 μm/s (≤0.14 in/h)	0 to 60 cm [0 to 24 in]	D
	≥60 cm [≥24 in]	>40.0 μm/s (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		≤1.0 μm/s (≤0.14 in/h)	0 to 50 cm [0 to 20 in]	D
>100 cm [>40 in]	<60 cm [<24 in]	>10.0 μm/s (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A/D
		>4.0 to ≤10.0 μm/s (>0.57 to ≤1.42 in/h)	0 to 100 cm [0 to 40 in]	B/D
		>0.40 to ≤4.0 μm/s (>0.06 to ≤0.57 in/h)	0 to 100 cm [0 to 40 in]	C/D
		≤0.40 μm/s (≤0.06 in/h)	0 to 100 cm [0 to 40 in]	D
	60 to 100 cm [24 to 40 in]	>40.0 μm/s (>5.67 in/h)	0 to 50 cm [0 to 20 in]	A
		>10.0 to ≤40.0 μm/s (>1.42 to ≤5.67 in/h)	0 to 50 cm [0 to 20 in]	B
		>1.0 to ≤10.0 μm/s (>0.14 to ≤1.42 in/h)	0 to 50 cm [0 to 20 in]	C
		≤1.0 μm/s (≤0.14 in/h)	0 to 50 cm [0 to 20 in]	D
	>100 cm [>40 in]	>10.0 μm/s (>1.42 in/h)	0 to 100 cm [0 to 40 in]	A
		>4.0 to ≤ 10.0 μm/s (>0.57 to ≤1.42 in/h)	0 to 100 cm [0 to 40 in]	B
		>0.40 to ≤4.0 μm/s (>0.06 to ≤0.57 in/h)	0 to 100 cm [0 to 40 in]	C
		≤0.40 μm/s (≤0.06 in/h)	0 to 100 cm [0 to 40 in]	D

1/ An impermeable layer has a K_{sat} less than 0.01 μm/s [0.0014 in/h] or a component restriction of fragipan; duripan; petrocalcic; orstein; petrogypsic; cemented horizon; densic material; placic; bedrock, paralithic; bedrock, lithic; bedrock, densic; or permafrost.

2/ High water table during any month during the year.

3/ Dual HSG classes are applied only for wet soils (water table less than 60 cm [24 in]). If these soils can be drained, a less restrictive HSG can be assigned, depending on the K_{sat}.

Source: National Engineering Handbook, 2009
.http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba:

618.67 Texture Class, Texture Modifier, and Terms Used in Lieu of Texture

A. Definition.—“Texture class” refers to the soil texture classification used by the U.S. Department of Agriculture as defined in the Soil Survey Manual. Soil texture is the relative proportion, by weight, of the particle separate classes finer than 2 mm in equivalent diameter. The material finer than 2 mm is the fine-earth fraction. Material 2 mm or larger is rock or pararock fragments.

   Click Interactive Online Soil Texture Calculator to enter the percent sand and clay, and let the calculator do the rest.

B. Significance.—Soil texture influences engineering works and plant growth and indicates how soils formed. Soil texture has a strong influence on soil mechanics and the behavior of soil when it is used as construction or foundation material. It influences such engineering properties as bearing strength, compressibility, saturated hydraulic conductivity, shrink-swell potential, and compaction. Engineers are also particularly interested in rock and pararock fragments. Soil texture influences plant growth by its affect on aeration, the water intake rate, the available water capacity, the cation-exchange capacity, saturated hydraulic conductivity, erodibility, and workability. Changes in texture as related to depth are indicators of how soils formed. When texture is plotted with depth, smooth curves indicate translocation and accumulation. Irregular changes in particle-size distribution, especially in the sand fraction, may indicate lithologic discontinuities, specifically differences in parent material.

C. Measurement.— USDA texture can be measured in the laboratory by determining the proportion of the various size particles in a soil sample. The analytical procedure is called particle-size analysis or mechanical analysis. Stone, gravel, and other material 2 mm or larger are sieved out of the sample and thus are not considered in the analysis of the sample. Their amounts are measured separately. Of the remaining material smaller than 2 mm, the amount of the various sizes of sand is determined by sieving. The amount of silt and clay is determined by a differential rate of settling in water. Either the pipette or hydrometer method is used for the silt and clay analysis. Organic matter and dissolved mineral matter are removed in the pipette procedure but not in the hydrometer procedure. The two procedures are generally very similar, but a few samples, especially those with high organic matter or high soluble salts, exhibit wide discrepancies. The detailed procedures are outlined in Soil Survey Investigations Report No. 42, *Soil Survey Laboratory Methods Manual*, Version 4.0, November 2004, USDA, NRCS.

D. Estimates

   1. The determination of soil texture for the less than 2 mm material is made in the field mainly by feeling the soil with the fingers. The soil must be well moistened and rubbed vigorously between the fingers for a proper determination of texture class by feel. This method requires skill and experience but good accuracy can be obtained if the field soil scientist frequently checks his or her estimates against laboratory results. Many NRCS offices collect reference samples for this purpose.

The content of particles larger than 2 mm cannot be evaluated by feel. The content of the fragments is determined by estimating the proportion of the soil volume that they occupy. Fragments in the soil are discussed in Section 618.27.

2. Each soil scientist must develop the ability to determine soil texture by feel for each genetic soil group according to the standards established by particle-size analysis. Soil scientists must remember that soil horizons that are in the same texture class but are in different subgroups or families may have a different feel. For example, natric horizons generally feel higher in clay than “non-natric” horizons. Laboratory analysis generally shows that the clay in natric horizons is less than the amount estimated from the field method. The scientist needs to adjust judgment and not the size distribution standards.

E. Entries.—Texture is displayed by the use of five data elements in NASIS: texture class, texture modifier, texture modifier and class, stratified texture flag, and terms used in lieu of texture. As many as four entries can be made for each horizon for each of these data elements. However, only one texture for a surface horizon should be entered for each component. Only use multiple textures if they interpret the same for the horizon. Only textures that represent complete horizons should be entered. A representative value is also identified for each horizon. This choice should match the representative values of the various soil particle-size separates posted elsewhere in the database.

F. Texture Class

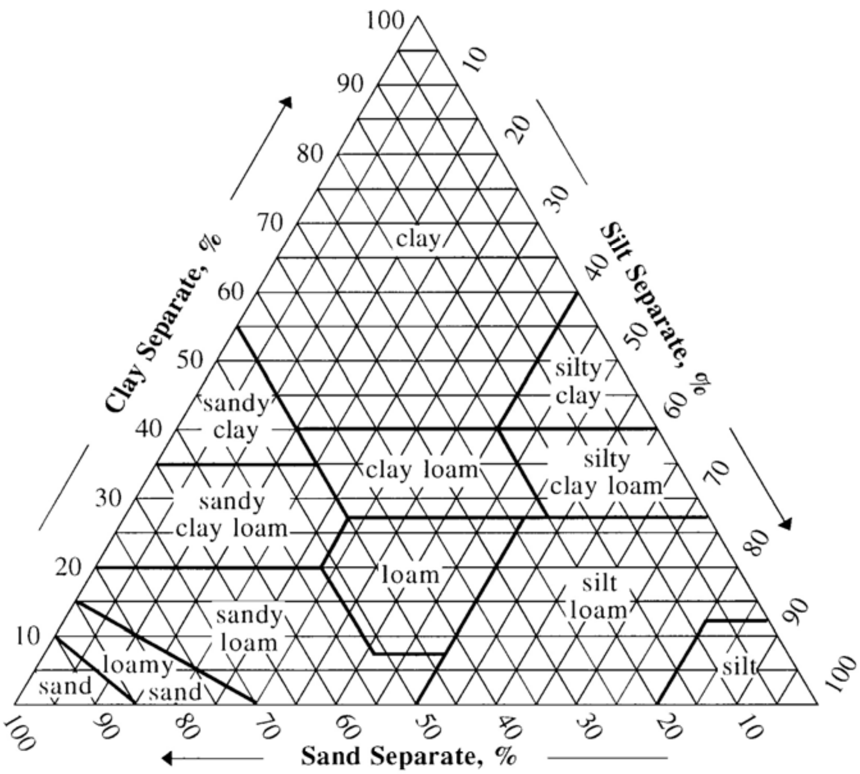
1. Definition

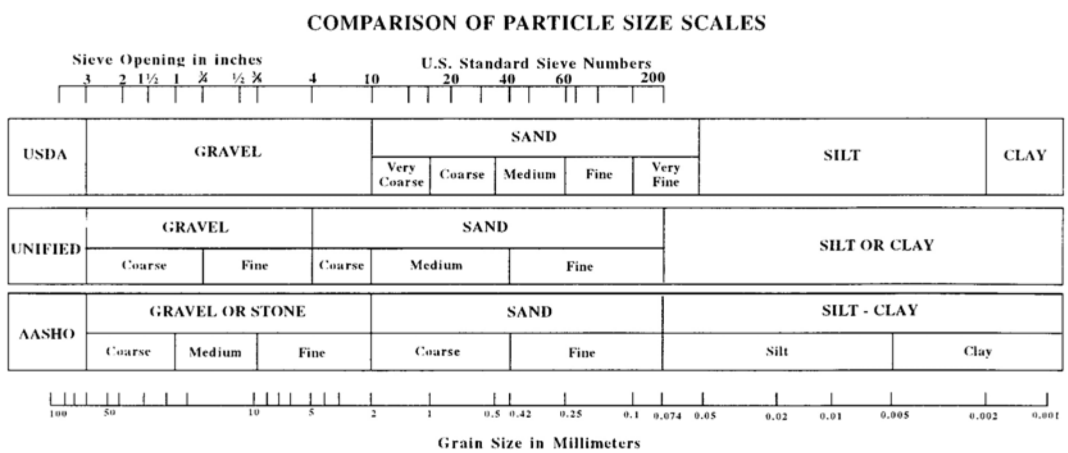
   i. “Texture class” is an expression, based on the USDA system of particle sizes, for the relative portions of the various size groups of individual mineral soil grains less than 2 mm equivalent diameter in a mass of soil.

   ii. Each texture class has defined limits for each particle separate class of mineral particles less than 2 mm in effective diameter. The basic texture classes, in the approximate order of increasing proportions of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The sand, loamy sand, and sandy loam classes may be further subdivided into coarse, fine, or very fine. The basic USDA texture classes are given graphically in Part 618, Subpart B, Exhibits, Section 618.87 as a percentage of sand, silt, and clay. The chart at the bottom of the figure shows the relationship between the particle size and texture classes among the AASHTO, USDA, and Unified soil classification systems.

2. Entries.—Enter the texture class for each horizon using the list in Part 618, Subpart B, Exhibits, Section 618.94.

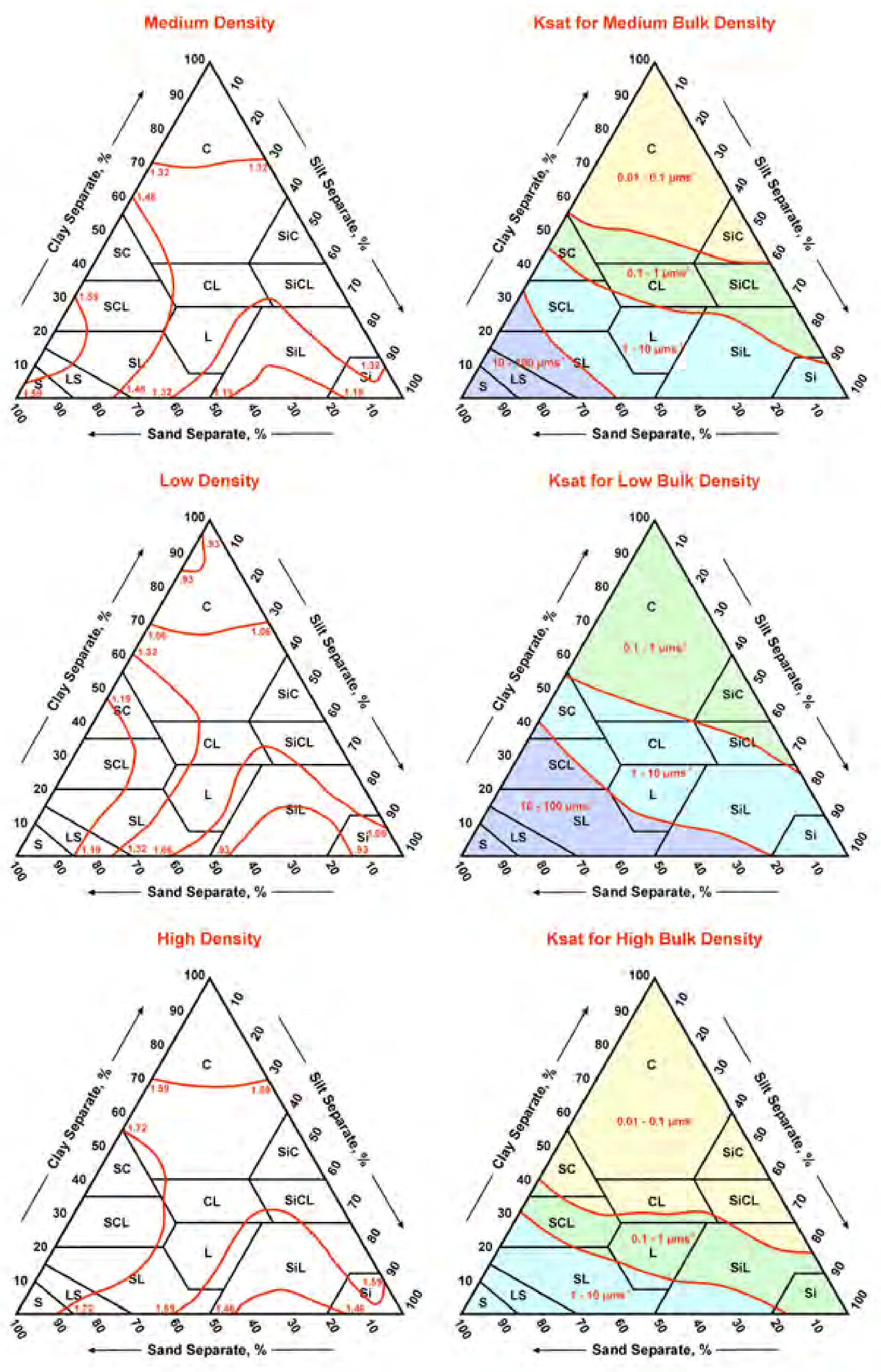
618.87 Texture Triangle and Particle-Size Limits of AASHTO, USDA, and Unified Classification Systems





618.88 Guide for Estimating K_{sat} from Soil Properties

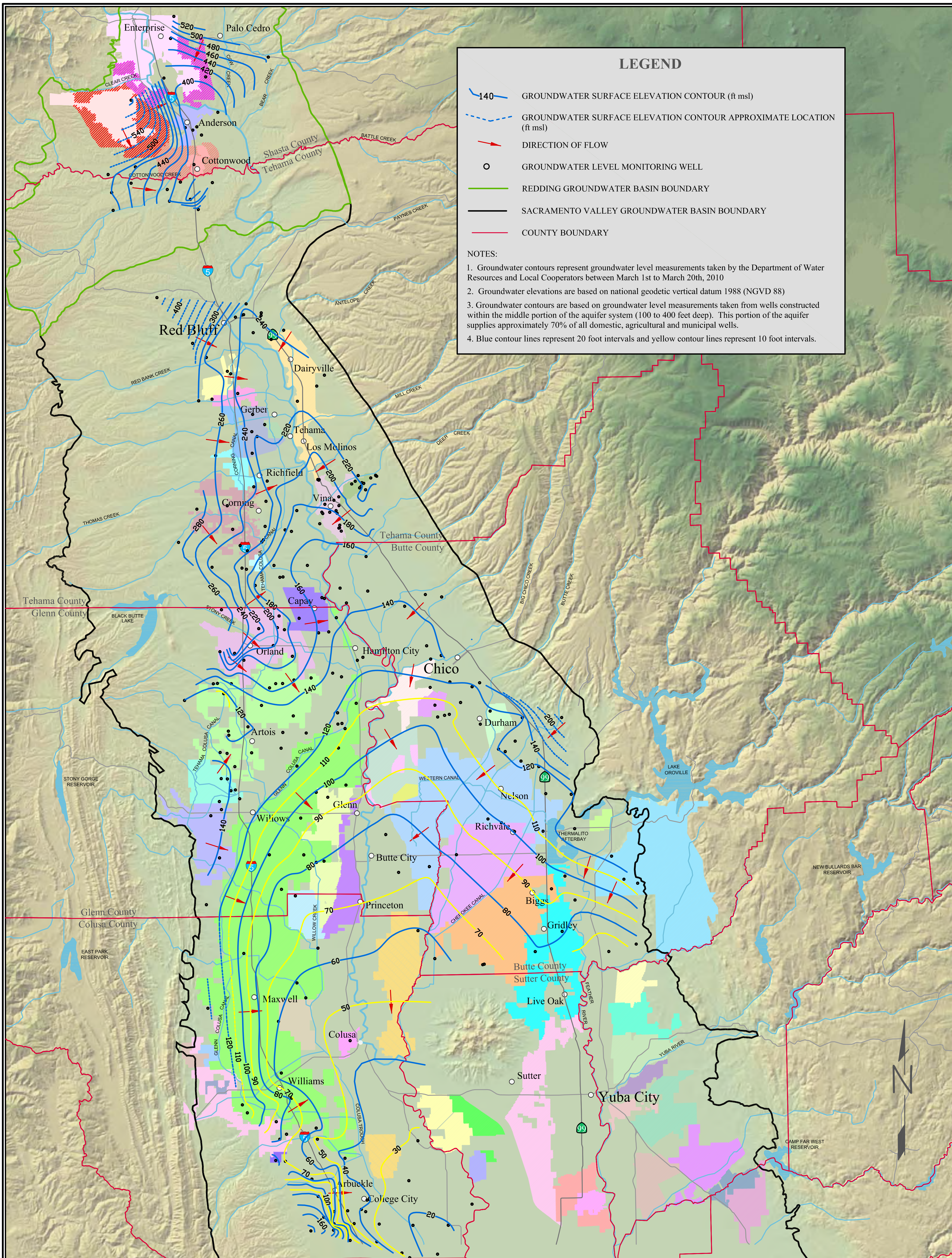
Estimate saturated hydraulic conductivity (K_{sat}) from soil texture by first selecting the bulk density class of medium, low, or high. Then use the corresponding textural triangle to select the range of saturated hydraulic conductivity in μms^{-1}. Overrides follow the textural triangles.



References

U.S. Department of Agriculture (USDA). 2012. Natural Resources Conservation Service. National soil survey handbook, title 430-VI. Available online at http://soils.usda.gov/technical/handbook/. Accessed September 5, 2012.

Appendix C
DWR Groundwater Elevation Contour Maps



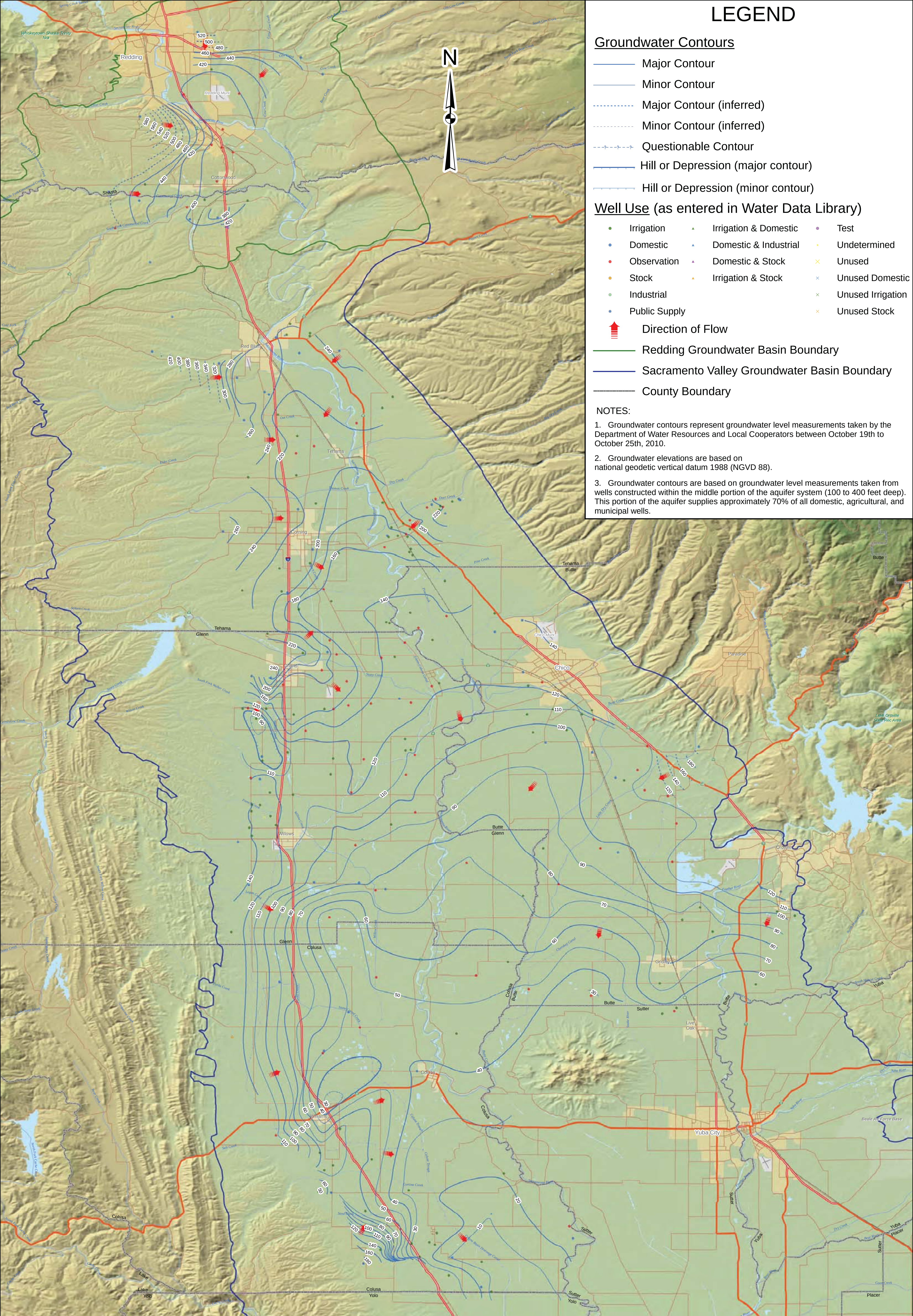
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN REGION OFFICE

SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP SPRING 2010

Northern Region Department of Water Resouces
2440 Main Street
Red Bluff, CA 96080
(530) 529-7300
http://www.nd.water.ca.gov/index.cfm

DEPARTMENT OF WATER RESOURCES · STATE OF CALIFORNIA

DATE:	SCALE:	By:	LOCATION:
August 23, 2010	5 0 5 MILES	S Lawrence P.E.	N:\Groundwater\ACTIVE PROJECTS\REGIONAL\Sacramento Valley\Contours\Work\2010_contours\Spring 2010\Spring2010_lines_draft.dwg



STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

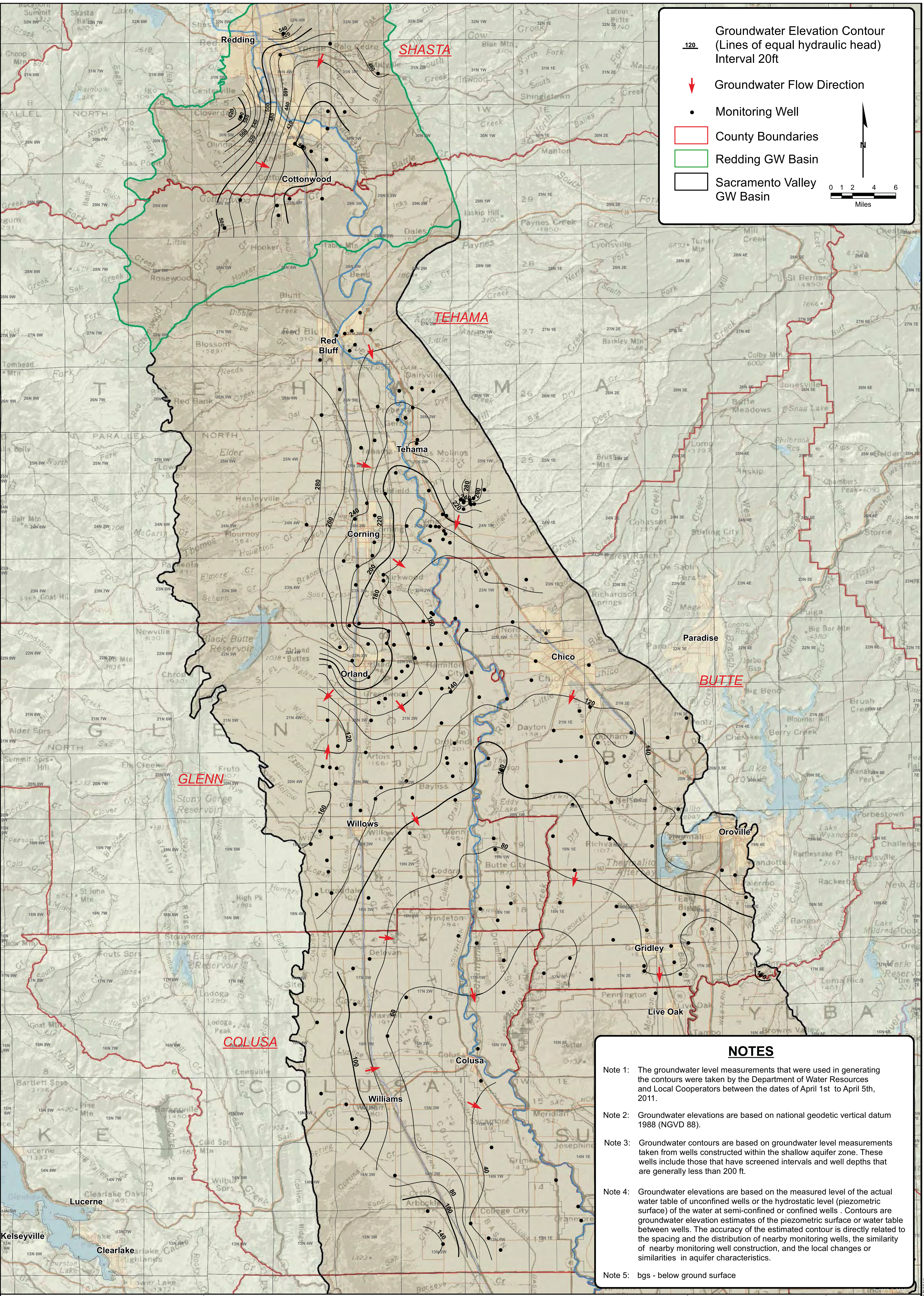
SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP FALL 2010

Northern Region Office
Department of Water Resources
2440 Main Street
Red Bluff, CA 96080
(530) 529-7300
http://www.water.ca.gov/index.cfm

File: N:\RAID2\Geo\BaseMapsAndMore\GeologicMaps\SacramentoValley\ArcMapProject\2010FallContours--2010-12-30.mxd
Date & Time: Dec 30, 2010 2:19:19 PM
Created by Jonathan Mulder, Department of Water Resources, Northern Region Office, Groundwater Unit

0 4 8 12 16
Miles

Basemap Data Sources: ESRI Street Maps Plus



NOTES

Note 1: The groundwater level measurements that were used in generating the contours were taken by the Department of Water Resources and Local Cooperators between the dates of April 1st to April 5th, 2011.

Note 2: Groundwater elevations are based on national geodetic vertical datum 1988 (NGVD 88).

Note 3: Groundwater contours are based on groundwater level measurements taken from wells constructed within the shallow aquifer zone. These wells include those that have screened intervals and well depths that are generally less than 200 ft.

Note 4: Groundwater elevations are based on the measured level of the actual water table of unconfined wells or the hydrostatic level (piezometric surface) of the water at semi-confined or confined wells . Contours are groundwater elevation estimates of the piezometric surface or water table between wells. The accuracy of the estimated contour is directly related to the spacing and the distribution of nearby monitoring wells, the similarity of nearby monitoring well construction, and the local changes or similarities in aquifer characteristics.

Note 5: bgs - below ground surface

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NORTHERN SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP SPRING 2011

SHALLOW AQUIFER ZONE

(Wells generally less than 200 ft bgs)

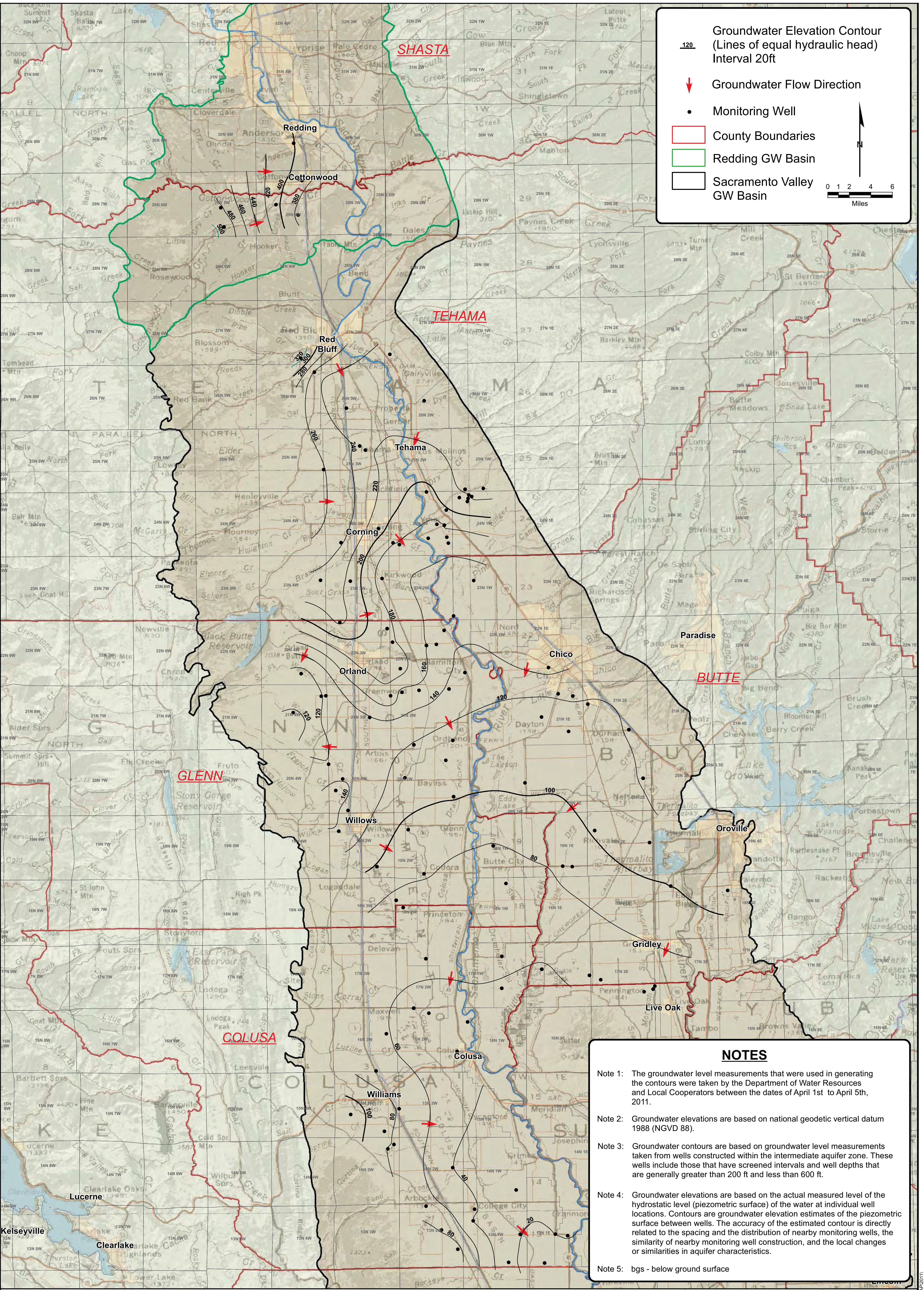
PLATE 1S

Date: February 2012

BY: G. Gordon

Location: R:\Sections\OCM\CONTOUR_MAP\2011\

http://www.water.ca.gov/groundwater/data_and_monitoring/northern_region/GroundwaterLevel/gw_level_monitoring.cfm



NOTES

Note 1: The groundwater level measurements that were used in generating the contours were taken by the Department of Water Resources and Local Cooperators between the dates of April 1st to April 5th, 2011.

Note 2: Groundwater elevations are based on national geodetic vertical datum 1988 (NGVD 88).

Note 3: Groundwater contours are based on groundwater level measurements taken from wells constructed within the intermediate aquifer zone. These wells include those that have screened intervals and well depths that are generally greater than 200 ft and less than 600 ft.

Note 4: Groundwater elevations are based on the actual measured level of the hydrostatic level (piezometric surface) of the water at individual well locations. Contours are groundwater elevation estimates of the piezometric surface between wells. The accuracy of the estimated contour is directly related to the spacing and the distribution of nearby monitoring wells, the similarity of nearby monitoring well construction, and the local changes or similarities in aquifer characteristics.

Note 5: bgs - below ground surface

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NORTHERN SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP SPRING 2011

INTERMEDIATE AQUIFER ZONE

(Wells generally greater than 200 ft and less than 600 ft bgs)

PLATE 1I

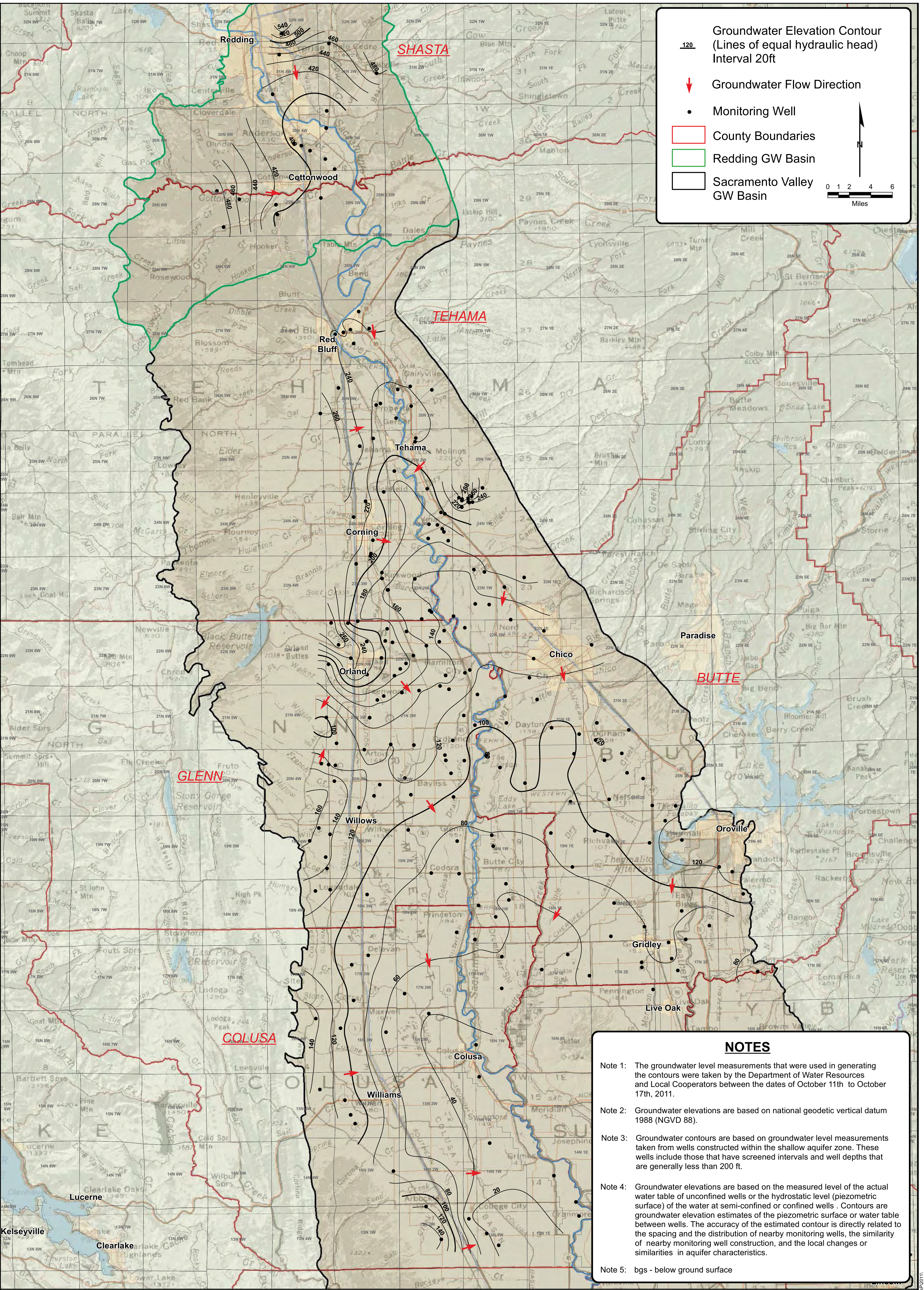
Date: February 2012

BY: G. Gordon

DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA

Location: R:\Sections\DC\CONTOUR_MAP\2011

http://www.water.ca.gov/groundwater/data_and_monitoring/northern_region/GroundwaterLevel/gw_level_monitoring.cfm



NOTES

Note 1: The groundwater level measurements that were used in generating the contours were taken by the Department of Water Resources and Local Cooperators between the dates of October 11th to October 17th, 2011.

Note 2: Groundwater elevations are based on national geodetic vertical datum 1988 (NGVD 88).

Note 3: Groundwater contours are based on groundwater level measurements taken from wells constructed within the shallow aquifer zone. These wells include those that have screened intervals and well depths that are generally less than 200 ft.

Note 4: Groundwater elevations are based on the measured level of the actual water table of unconfined wells or the hydrostatic level (piezometric surface) of the water at semi-confined or confined wells. Contours are groundwater elevation estimates of the piezometric surface or water table between wells. The accuracy of the estimated contour is directly related to the spacing and the distribution of nearby monitoring wells, the similarity of nearby monitoring well construction, and the local changes or similarities in aquifer characteristics.

Note 5: bgs - below ground surface

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NORTHERN SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP FALL 2011

SHALLOW AQUIFER ZONE

(Wells generally less than 200 ft bgs)

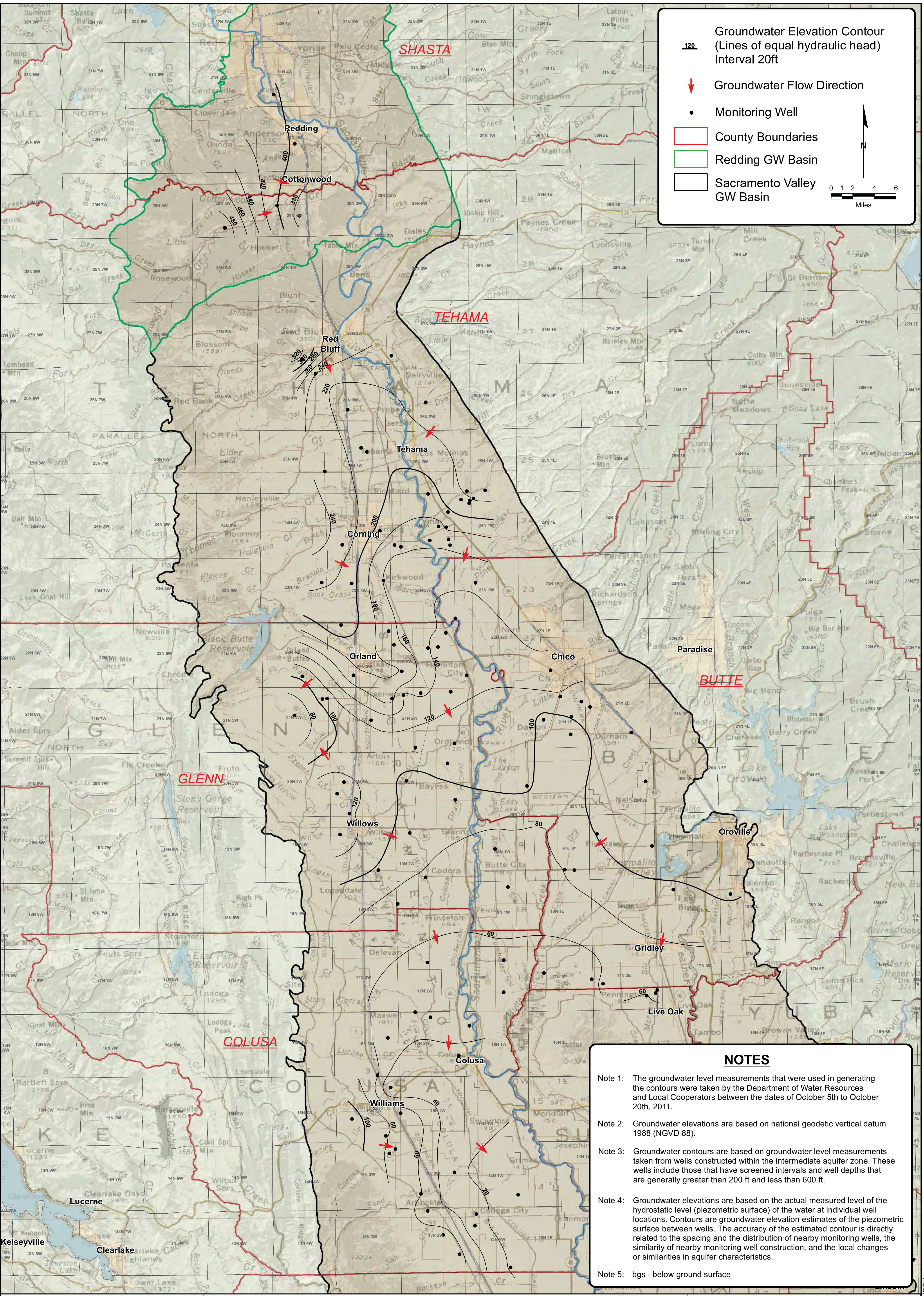
PLATE 3S

Date: February 2012

BY: G. Gordon

Location: R:\Sections\DCM\CONTOUR_MAP\2011\

http://www.water.ca.gov/groundwater/data_and_monitoring/northern_region/GroundwaterLevel/gw_level_monitoring.cfm



NOTES

Note 1: The groundwater level measurements that were used in generating the contours were taken by the Department of Water Resources and Local Cooperators between the dates of October 5th to October 20th, 2011.

Note 2: Groundwater elevations are based on national geodetic vertical datum 1988 (NGVD 88).

Note 3: Groundwater contours are based on groundwater level measurements taken from wells constructed within the intermediate aquifer zone. These wells include those that have screened intervals and well depths that are generally greater than 200 ft and less than 600 ft.

Note 4: Groundwater elevations are based on the actual measured level of the hydrostatic level (piezometric surface) of the water at individual well locations. Contours are groundwater elevation estimates of the piezometric surface between wells. The accuracy of the estimated contour is directly related to the spacing and the distribution of nearby monitoring wells, the similarity of nearby monitoring well construction, and the local changes or similarities in aquifer characteristics.

Note 5: bgs - below ground surface

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Red Bluff, California 96080
(530) 529-7300

NORTHERN SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP FALL 2011

INTERMEDIATE AQUIFER ZONE

(Wells generally greater than 200 ft and less than 600 ft bgs)

PLATE 3I

Date: February 2012

BY: G. Gordon

http://www.water.ca.gov/groundwater/data_and_monitoring/northern_region/GroundwaterLevel/gw_level_monitoring.cfm

Appendix D
Fate of Nitrogen in California Rice Soils: A More Detailed Discussion

MEMO

From: *John Dickey (PlanTierra)*

To: *Tim Johnson, Roberta Firoved (California Rice Commission)*

Date: April 30, 2012

Subject: GAR Appendix D: Fate of Nitrogen in California Rice Soils: A More Detailed Discussion

This memo was prepared to serve as an appendix to the Groundwater Assessment Report (GAR), which was prepared by several authors for the California Rice Commission (CRC). Sections are as follows:

- Soils in Rice Growing Areas and Their Properties
- Nitrogen Forms and Fate in Soils

Soils in Rice Growing Areas and Their Properties

Soils in the Sacramento Valley vary widely in texture and ease of drainage (the removal of excess water from the soil by natural means). However, rice lands tend to be located on heavy (fine) textured soils with relatively slow drainage (Figures 1 and 2; Tables 1 and 2; Dickey and Nuss, 2002) and high cation exchange capacity (CEC, or the capacity of a soil to interact chemically and retard the movement of positively charged ions, like ammonium).

In Linquist et al. (2011), soils at a broad range of Sacramento Valley rice land locations and clay content were systematically selected and sampled. Soil samples were analyzed for physical properties. Nitrate-N profiles were also measured at these sites, and are discussed in a later section. Figure 1 shows the range of textures (clay and sand content), and in hydraulic conductivity results, for these sites. Conductivity at seven of the eight sites was in the impermeable range, and site 7 (with 77% sand) had slow conductivity (NCSS, 2003).

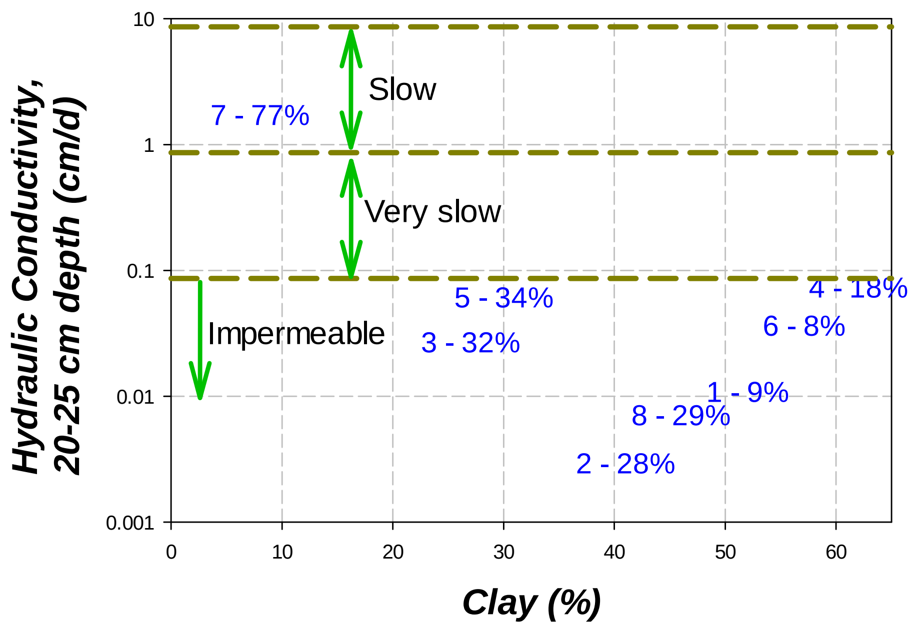

Figure 1. Average hydraulic conductivity (measured on four to six, 2-inch long, undisturbed soil cores from about a foot depth each site) for soils representing a wide range of Sacramento Valley geographic locations, landscape positions, and soil textural conditions. Points are plotted as "# - x%", where "#" is the site number, and "x%" is the % sand.

While fine-textured (high-clay-content) soils are widespread among rice lands, and are helpful to a rice farmer, they are not essential. Rice can also be farmed in soils of lower clay content (as may occur, for example, in flood bypass locations like site 7) when they are flooded and planted with rice. This is so because:

- Flooding itself (a cultural practice and farmer choice) changes nitrogen chemistry (please see later section on "Nitrogen Forms and Fate in Soil"), so that nitrate-N is virtually absent. This restricts nitrogen mobility in all but the deepest, coarsest sands.
- Even the coarser-textured soils among rice lands tend to be poorly drained due to naturally restrictive or artificially compacted layers. These conditions lengthen water and solute residence time in the root zone in a similar manner to the presence of fine textured soil horizons.

Of the seven sites evaluated in Linquist et al. (2011), five (including Site 7, containing 77% sand) had high bulk density[1] (> 1.4 g/cm^3) at about 1 foot depth, just below the depth of most tillage. See Figure 2.

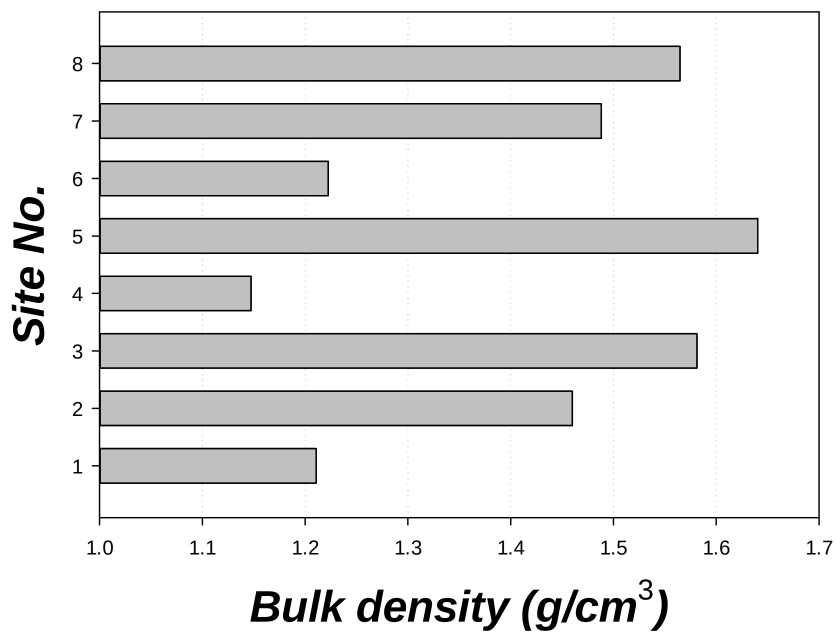

Figure 2. Bulk density for soils at sites shown in Figure 1.

This combination of properties (fine textures, poor drainage, and high bulk density), occurring in varying combinations on rice lands, facilitates the following:

- establishment and maintenance of the flooded regime favored by rice
- retention of water and dissolved constituents in the root zone for long periods of time after they infiltrate
- minimization of the period of the year and soil depth in which nitrate-N is present (discussed later)
- protection of groundwater quality
- use of rice to reclaim and maintain lands that are otherwise less viable farmland
- enhancement of the land's habitat value by flooding beyond the cropping season

[1] Soils with high bulk density have relatively less pore space as a proportion of their total volume, slowing the rate at which fluids flow through them.

Nitrogen Forms and Fate in Soils

In this section, the following will be discussed:

- General principles of N forms and fate
- The special case of flooded soils
- Previous studies and a planned, upcoming study

General Principles of N Forms and Fate

Nitrogen cycles are frequently illustrated to summarize the multiple forms and transformations of N in soil systems. Flooded soils are no exception. Figure 2-12 in the GAR (similar to Figure 4.2 from Williams, 2010) illustrates the role of the oxidized layer (upper inch or so) of a flooded soil, and the underlying reduced layer, on N fate. Figure 2-12 may serve as a helpful reference as these processes are referred to throughout this Appendix.

Organic and ammonium N are far less mobile than nitrate (see later sections). The basic reason for this is that nitrate is more water soluble than organic N, and unlike ammonium, is negatively charged. In temperate soils with substantial net negative charge (or CEC, as predominates in the Sacramento Valley), nitrate interacts little with the solid phase, being of like charge to it. Positively charged ammonium, on the other hand, interacts vigorously with the solid phase, both electrostatically and sometimes through stronger chemical affinity with interlayer sites in clay silicate minerals.

Although non-nitrate forms of N are less mobile in soils, their use may confer only a temporary limitation to N mobility. This is because ammonium and organic N can be converted to nitrate, at which time the applied form no longer influences mobility.

When organic N is “mineralized”, or converted to inorganic forms, it is first converted to the ammonium-N form. Conditions favoring conversion of organic-N to ammonium-N are aeration (high redox potential), higher temperature, and a robust microbial population. Organic N is not a widely used source of N in rice fields.

Conditions favoring conversion of ammonium-N to nitrate-N are aeration (high redox potential) and higher temperatures. These conditions are generally less frequent in rice fields than in fields where other crops are grown, due to universal flooding (which eliminates aeration) during the growing season, widespread fall and winter flooding, and soils whose properties make them slow to dry and aerate. Oxidation of ammonium- to nitrate-N may occur to a limited extent in the rhizosphere (soil immediately adjacent to roots), but this nitrate is rapidly absorbed by roots, or if it moves toward the bulk soil, it is denitrified.

The Special Case of Flooded Soils

Flooded and saturated soil thus maintains N in less mobile forms, which in turn greatly increases N residence time in a root zone, increasing the likelihood it will be absorbed by plants, and decreasing the chance that the same nutrients would leach below the root zone.

Rice is relatively sensitive to salinity (Dickey and Nuss, 2002) and irrigated with water of low salinity concentration, which is widely available in the Sacramento Valley. Due to the flooded irrigation regime and slow percolation, recharge through rice fields is slow, and has low salt and nitrate concentration.

Previous Studies

Drainage from rice dominated subwatersheds tend to average < 1 mg/L nitrate-N, <0.1 mg/L ammonium-N, and between 0.1 to 0.7 mg/L dissolved organic N (Krupa et al., 2011). This is flow-weighted surface outflow. This suggests that rice is a weak source of nitrate-N pollution of surface water.

Figure 3 illustrates that soil and N reduction ensues relatively rapidly after flooding. Within three days, nitrate-N concentrations in eight soils dropped from 10 mg/kg of nitrate-N (about 12 mg/L in soil solution) to < 0.1 mg/kg (< 0.12 mg/L in soil solution). This finding has been repeated by many experimenters, and illustrates why nitrate is so rarely present in flooded rice fields. Under these circumstances, nitrate-N is denitrified (converted to nitrogen and nitrous oxide gasses).

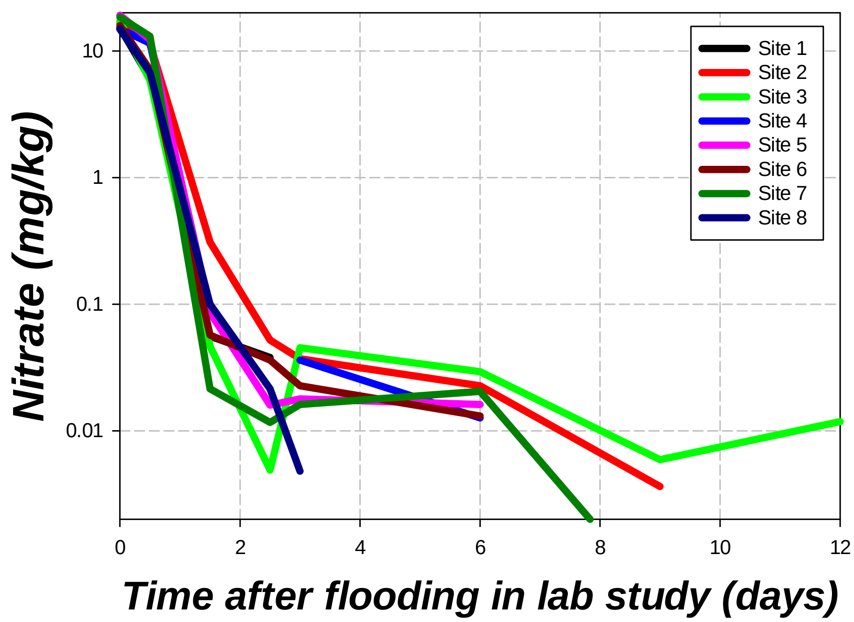

Figure 3 (from Linquist et al. 2011). Transformation of nitrate-N in flooded rice fields after the initiation of flooding.

Figure 4 shows that concentrations of nitrate-N at the base of the root zone in rice fields is < 0.2 mg/kg (approximately < 0.24 mg/L in the soil solution), and < 5 mg/kg (approximately < 6 mg/L in the soil solution) nearer to the soil surface, when sampled before spring flooding. This profile (with higher concentrations near the surface) reflects the greater drying and aeration of near-surface soils relative to those in deeper layers. This stratification is least pronounced at sites 6 and 7. Site 7 is an exceptionally (77%; see Figure 2) sandy soil for a rice field, which may have been one factor favoring greater aeration and nitrification. Although these nitrate-N concentrations are exceptionally low when compared to levels in most non-flooded croplands, they reflect the time of year when these soils had been drained for the longest period, so that conditions were most favorable for the accumulation of nitrate. As described in the previous paragraph and as shown in Figure 3, this nitrate is rapidly transformed as soon as the soil is flooded. For the duration of flooding, nitrate-N would be near zero at every soil depth.

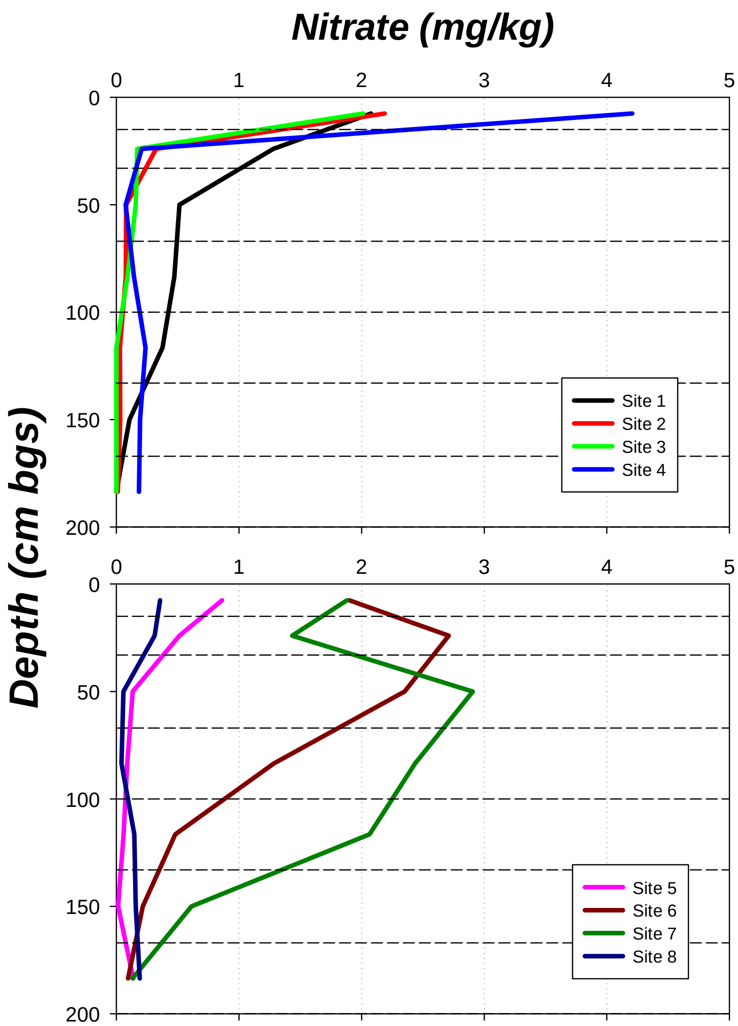

Figure 4 (from Linquist et al., 2011). Vertical distribution of nitrate-N on eight soil profiles sampled in the spring, pre-flooding.

Ammonia-based N fertilizer is applied at the surface or injected at a depth of about 4 inches (Williams, 2010). After application and field flooding, N mobility is relatively limited. This is illustrated by an agronomic problem that can arise when fertilizer is banded too deeply in N-deficient fields (see Figure 4.10 from Williams, 2010, below). In a non-flooded soil, nitrate-N moves to roots with water, so that fertilizer placement is less critical. However, in flooded soils, ammonium-N is sufficiently immobile so that plants must grow into close proximity to fertilizer bands before N concentrations are sufficient to supply their uptake needs.

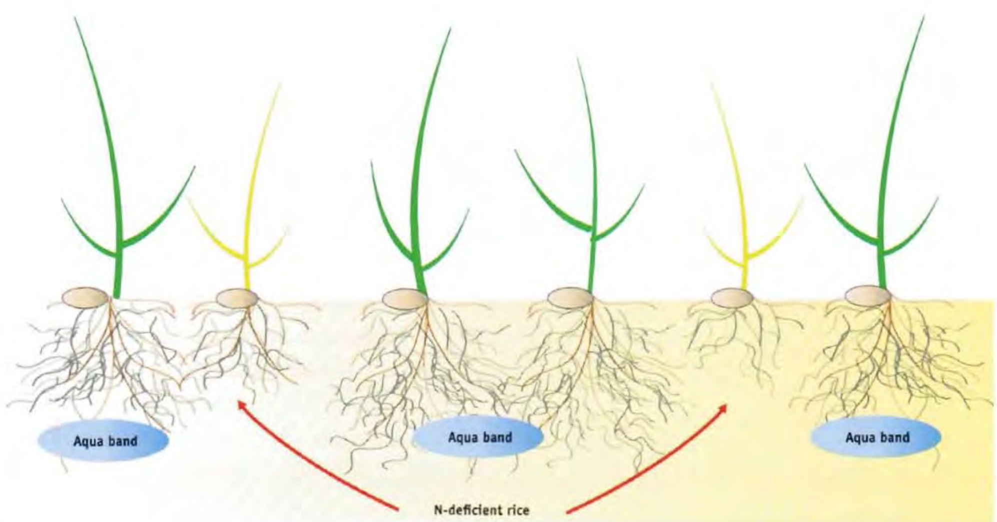

Figure 4.10. Diagramatic representation of streaking, showing how aqua placed too deeply in a nitrogen-deficient field may result in deficiency symptoms in seedlings that grow between the aqua bands and whose roots have not yet reached the aqua. These deficient plants will occur in fairly regular streaks consistent with the application pattern. The condition is temporary, and plants eventually recover as they absorb nitrogen.

The same phenomenon was demonstrated experimentally in research results presented by Linquist (2012; also Figure 5). In this work, isotope-labeled N fertilizer was applied to micro-plots, and movement studied. Nearly all applied N remained within 15 cm (6 inches) of the edge of the application area during a growing season, and practically none of it moved 30 cm (one foot) away from the micro-plot.

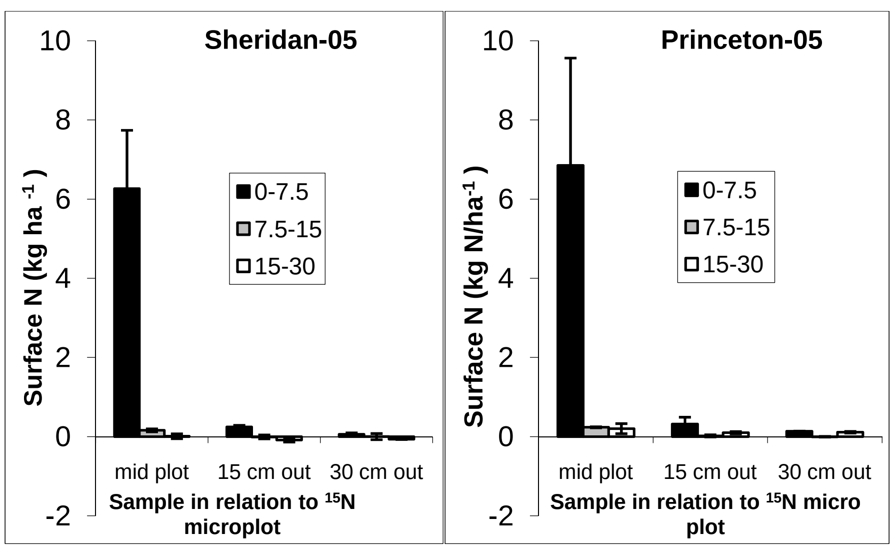

Figure 5. From Linquist (2012), showing the fate of fertilizer N in soil profile in two rice fields. ^{15}N was applied as a starter fertilizer, broadcast to the soil surface at the beginning of the growing season. At the end of the season soil samples were taken to a depth of 30 cm from the center of the micro-plot, and 15 and 30 cm from the edge of the micro-plot to determine if there was lateral movement of N.

Planned Study

To follow up on 2011 investigation of nitrate fate in California rice fields, a protocol has been developed for the same eight Sacramento Valley rice field sites (Linquist, 2012).

Characterization of rice soil physical properties that occurred in 2011 would not be repeated, as these properties do not vary significantly over time.

Soil core samples will again be taken, but to lesser depth (90 cm). This is justified since a) nitrate-N was less than 1 mg/kg (about 1.2 mg/L in soil solution) below 50 cm depth at 6 of 8 sites, and it was less than 3 mg/kg (about 3.6 mg/L in soil solution) in all samples; and b) sampling to two meters depth is costly in rice fields, where soils can be highly dense and compacted, and where moving heavy equipment can be difficult.

Micro-plots will be established in which ^{15}N will be applied. Soil solution samplers will be installed at 3 depths up to 50 cm (about 20 inches). This will allow investigators to trace the movement of applied fertilizer N within the rice soil system.

Rather than analyzing samples for nitrate-N alone, ammonium-N and dissolved organic N analyses will also be performed.

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SALINITY DISTRIBUTION AND IMPACT IN THE SACRAMENTO VALLEY

John Dickey
Gary Nuss[1]

ABSTRACT

In many irrigated regions of the Western United States, management of salinity poses a major challenge. The problem has received significant attention in areas such as the San Joaquin Valley and the Colorado River Basin. Salinity management is also a concern in the generally more dilute Sacramento River Valley watershed. The objective of this study was to combine existing and new data to characterize geographic and temporal patterns of salinity distribution in several irrigation districts along the Sacramento River. The analysis combines weather, water, soil, and crop data in an overview of regional salt distribution and impact. Patterns of salinity, drainage, and crop response were mapped at several points in time, then combined to characterize the problem. A data set relating crop performance to water and soil salinity in the study area was reviewed as a quantitative field indication of rice cropping system sensitivity to salinity. Monitoring results suggest that salinity is quickly elevated to levels that can reduce crop yields when extensive water recycling is practiced for conservation, and that a long-term salinization trend may exist. Field drainage and position within the complex of irrigation and drainage facilities combine to determine the severity of the problem at specific locations. Field data suggest rice is significantly less tolerant of salinity than the literature would suggest, effectively placing more stringent water quality constraints on irrigation in the area. The results suggest that salinity management planning will require refinement of our understanding of salinity distribution and trends, as well as their relationship to crop, soil, and water management, and to crop productivity.

INTRODUCTION

Much of the Sacramento Valley region is irrigated for field crop production. Nearly 60% of this area is flood irrigated rice. At a regional level, salinity generally increases with distance from the water sources (from north to south). At a local level, salinity depends on irrigation management and drainage. When water supplies suffice, salinity is adequately controlled in most of the region through dilution and removal with drainage. However, when water diversions are curtailed due to drought or other (e.g., economic, regulatory) causes, regional salinity begins to concentrate in areas receiving the most saline water supplies (including substitution of groundwater for surface supply) and/or with limited ability to remove salinity in drainage. Because elevated salinity impacts crop production, the principal economic activity throughout much of the region, this constraint to beneficial use of water is significant. This paper provides an overview of salinity patterns in 12 irrigation and reclamation districts within the region. Climatic, soil, water, and crop conditions are considered. A rice crop sensitivity study is reviewed, as this is a critical criterion for salt management in the region.

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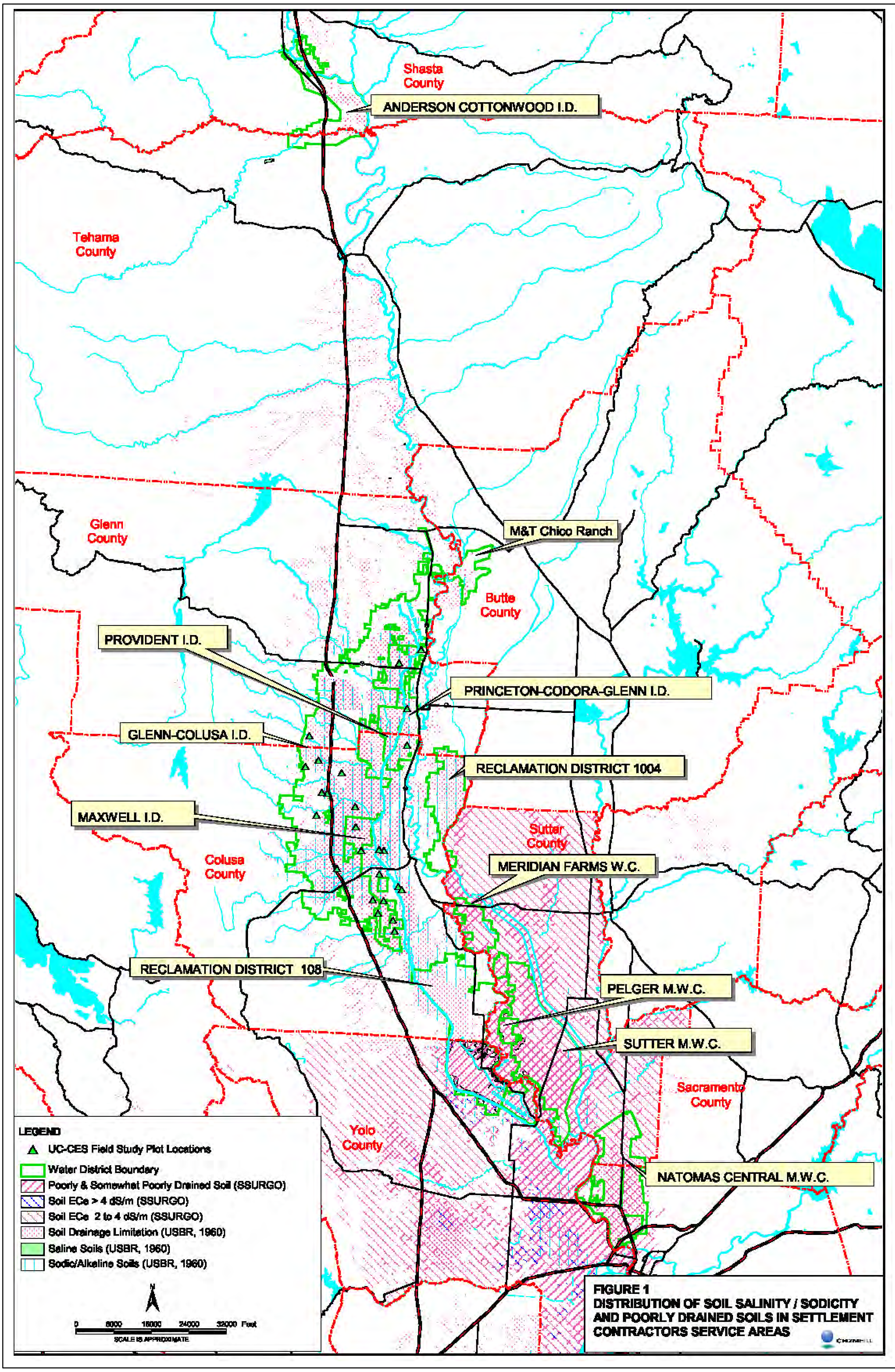
CLIMATE AND SOILS.

Figure 1 shows the extent saline, alkaline, and poorly drained soils in the study area. SSURGO data covers only the Yolo, Sutter, and Placer county portions of the districts. US Bureau of Reclamation (USBR, 1988; CH2M HILL, 1987) data cover the whole study area. Basin soils on both sides of the Sacramento River have widespread drainage limitations, long recognized and generally managed by extensive drainage canal networks in these areas. Many of these areas are historically alkaline, due to basin hydro-geochemical processes favoring sodium carbonate accumulation on basin margins (Whittig and Janitsky, 1963). Saline soils (Soil Survey Staff, 1993) are not observed in the region (USDA-SCS, 1967a, 1967b, 1974, 1988, 1993), but areas with intermediate salinity (mapped as EC_e from 2 to 4 dS/m in Yolo, Sutter, and Sacramento counties) are widespread within and beyond the areas with drainage limitations. US Bureau of Reclamation (1988) samples in Glenn-Colusa Irrigation District (GCID) from 1960 and before were EC_e < 2 dS/m. Figure 2 shows widespread salinity increase when the same area was sampled 38 years later (CH2M HILL, 1999), with average EC_e increasing by 0.6 dS/m, to an average level of 0.83 dS/m. While 2 sections exceeded 1 dS/m in 1960, 29 did in 1998, 3 of which also exceeded 2 dS/m. What led to this change? How could it affect crop production? What effects might it have on local and regional irrigation and drainage?

Water supply in this region depends on many factors, including local climate. Local precipitation trends are shown on Figure 3. Droughts in the 1930s, late 1970s, and early 1990s are evident in the 5-year moving averages. Precipitation provides winter flushing of soil salinity and is correlated with upper watershed precipitation, which in turn supplies upstream reservoirs. Water for salt management is thus periodically limited by drought.

Water districts in the northern (upstream) portion of the study area tend to divert relatively fresher water (< 0.3 dS/m) than downstream districts. Return flows from upstream users gradually increases salinity of irrigation water as one moves southward, with diversions up to 1.5 dS/m in the southern Colusa Basin (Scardaci et al., 1995, 1996, 1999). Figure 4 (data from Scardaci et al., 1999; Van Camp, 1999) illustrates lower-basin concentrations over time, measured in the Colusa Basin Drain, which is also a supply canal in this area. The highest concentrations were measured in June and July, when water is retained in fields to maximize herbicide decomposition. Salinity in these areas is highest during years when diversions are reduced, as they were during droughts in the late 1970s and early 1990s. Figure 5 (data from Scardaci et al., 1999) shows how water conservation affected water quality within a series of checks during the 1994 and 1995, increasing by up to 0.6 dS/m during June. The 27 field sites (2 measurement locations each) were in the northern end of the study area (see Figure 1 for locations).


Shasta County
ANDERSON COTTONWOOD I.D.
Tehama County
Glenn County
M&T Chico Ranch
Butte County
PROVIDENT I.D.
PRINCETON-CODORA-GLENN I.D.
GLENN-COLUSA I.D.
RECLAMATION DISTRICT 1004
MAXWELL I.D.
Sutter County
Colusa County
MERIDIAN FARMS W.C.
RECLAMATION DISTRICT 108
PELGER M.W.C.
SUTTER M.W.C.
Sacramento County
Yolo County
NATOMAS CENTRAL M.W.C.
LEGEND
UC-CES Field Study Plot Locations
Water District Boundary
Poorly & Somewhat Poorly Drained Soil (SSURGO)
Soil ECe > 4 dS/m (SSURGO)
Soil ECe 2 to 4 dS/m (SSURGO)
Soil Drainage Limitation (USBR, 1960)
Saline Soils (USBR, 1960)
Sodic/Alkaline Soils (USBR, 1960)
N
0 8000 16000 24000 32000 Feet
SCALE IS APPROXIMATE
FIGURE 1
DISTRIBUTION OF SOIL SALINITY / SODICITY AND POORLY DRAINED SOILS IN SETTLEMENT CONTRACTORS SERVICE AREAS

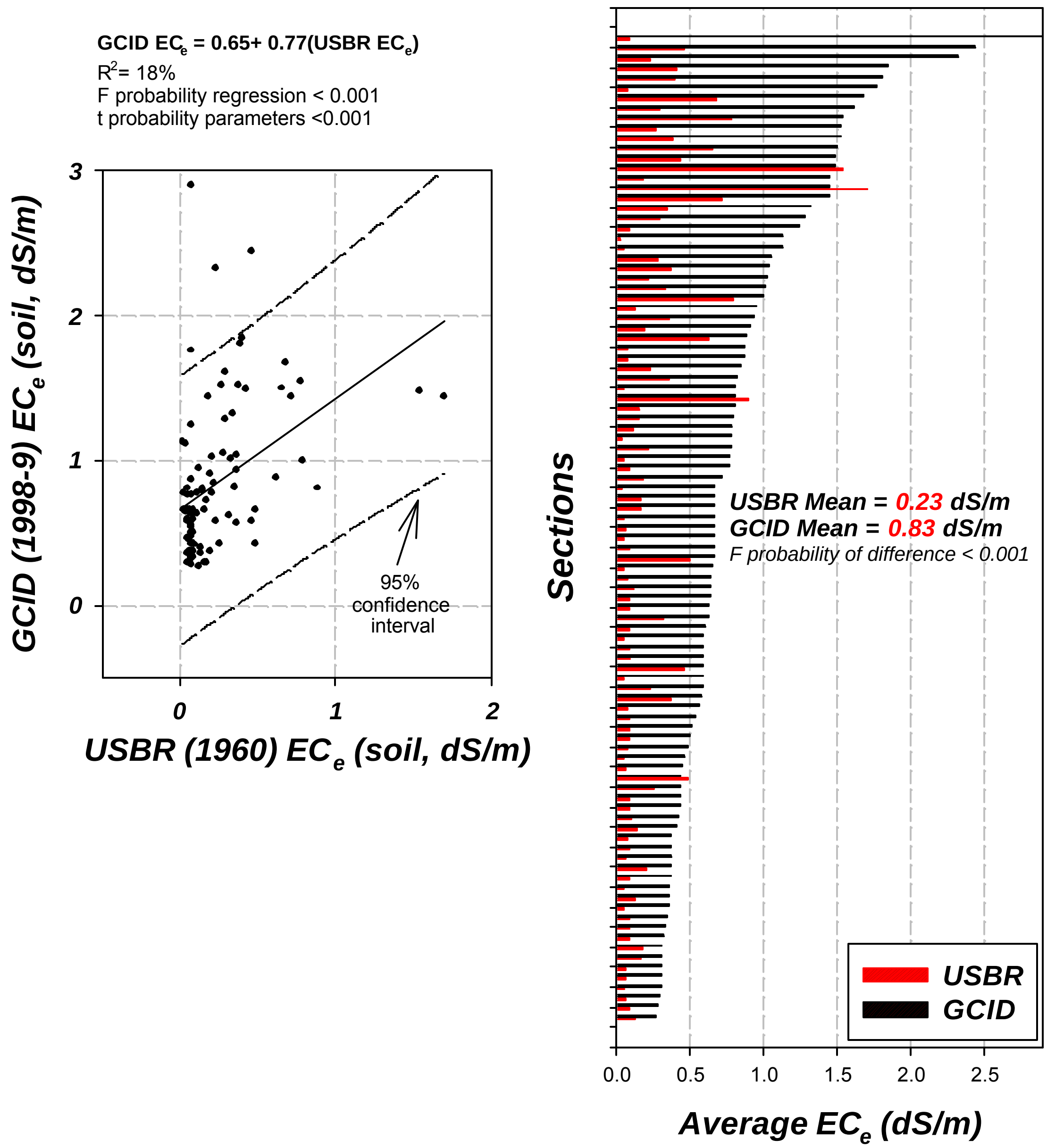


Figure 2. Change in soil salinity between 1960 and 1998 samplings. The shallow (0.77) slope suggests that areas with relatively less initial salinity were affected the most. This is apparent when you compare the length of red (USBR, 1960) and black (GCID, 1999) bars in each pair throughout the range of fields sampled. Sample depth for USBR range from 2 to 12 inches below ground surface. GCID sampled the interval from zero to 6 inches below ground surface.

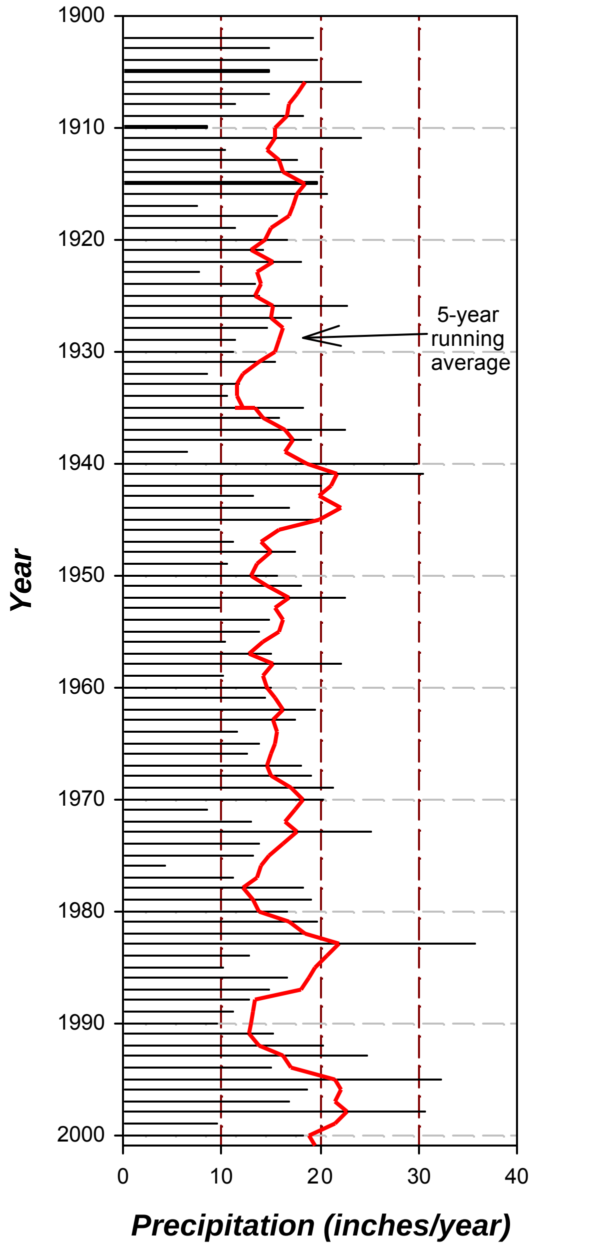


Figure 3. Annual and 5-year moving average precipitation at Colusa. Missing data were estimated from nearby stations.

WATER SUPPLY AND ITS AFFECT ON SOILS.

Exchange between surface and soil water during flood irrigation should cause soil and water salinity to track in parallel. Figure 6 shows the relationship between water and soil salinity within these same fields. With significant scatter, the fitted relationship for the two years of data is nearly 1:1, with a tendency for soils at less saline sites to be concentrated (about 1.5x) relative to irrigation water. Figure 5 shows that soil salinity levels are dynamic from month to month over a season, mirroring patterns in irrigation water salinity.

Recall that soil salinization (Figure 2) presented above was measured in 1998, in the northern (less saline) portion of the study area. This suggests several things.

First, either (1) the effects of water supply salinization on soil salinity, although apparently dynamic in the short term within a field, nevertheless may persist for several years after a period of water supply restriction, and/or (2) increases in soil salinity over time at GCID indicate a steadier, long-term process of general salinization. The widespread nature of salinization in GCID (see Figure 2) would suggest that (2) is true, although (1) may also be.

Second, since GCID's water supply is relatively fresher than water used by downstream irrigators, fields downstream with inadequate flushing flow could exhibit more severe salinization.

Third, curtailment of water supply, with corresponding reductions in flushing flow and increases in water supply salinity, should accelerate salinization trends.

CROP RESPONSE TO SALINITY

Early reports that rice was tolerant of alkali (Adams, 1914) were based on the crop's superior performance to upland small grains (wheat and barley) on alkaline land. How does this square with modern classification of rice as a salt-sensitive crop?

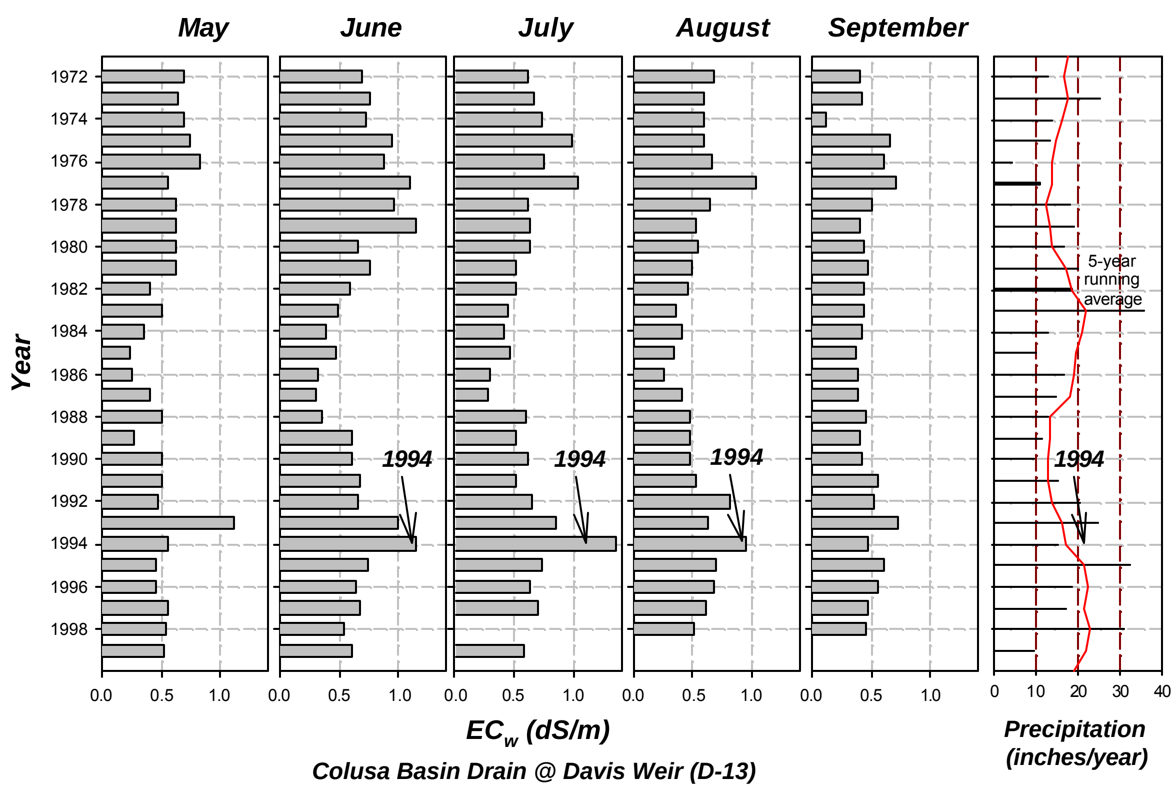


Figure 4. Salinity in the Colusa Basin Drain from 1972 to 1999. In a general sense, this represents the salinity concentrations entering drainage tributaries from surface flow out of lower checks and shallow groundwater seepage. GCID data from Scardaci et al. (1999) through 1997; 1998-9 data from Van Camp (1999).

The observations are reconciled as follows: (1) while alkalinity and salinity co-occur on much land in the region, they are not the same thing; (2) the pH effects of alkalinity, as well as concomitant salinity, can be moderated by tendency to neutral pH and flushing of salts upon flooding. Therefore, it is the flooded rice cropping system that mitigates native alkalinity and salinity, rather than the rice plant as such that is tolerant of alkalinity. Indeed, after some years in rice, historically alkaline land is more readily planted to upland crops that were marginally suitable to the land before reclamation.

Scardaci et al. (1999) summarizes the effects of salinity (EC_w) on rice crops as (1) seedling survival and growth were reduced above 1.85 dS/m in the greenhouse, and above about 2 dS/m in field studies, (2) yields were reduced when season-long salinity was above 1.9 dS/m, and (3) rice salinity response criteria warrant additional refinement.

Figure 7 shows the field-scale yields measured in these studies during 1994 and 1995, plotted together and separately against EC_e, which was a better predictor of yield than EC_w, and is an estimate of average EC_w (see Figure 6). EC_e and EC_w are effectively equated for this discussion. Also, because water recycling requirements and seedling sensitivity to salinity combine to make June the most sensitive period, June EC_e is considered as the independent salinity variable affecting yield..

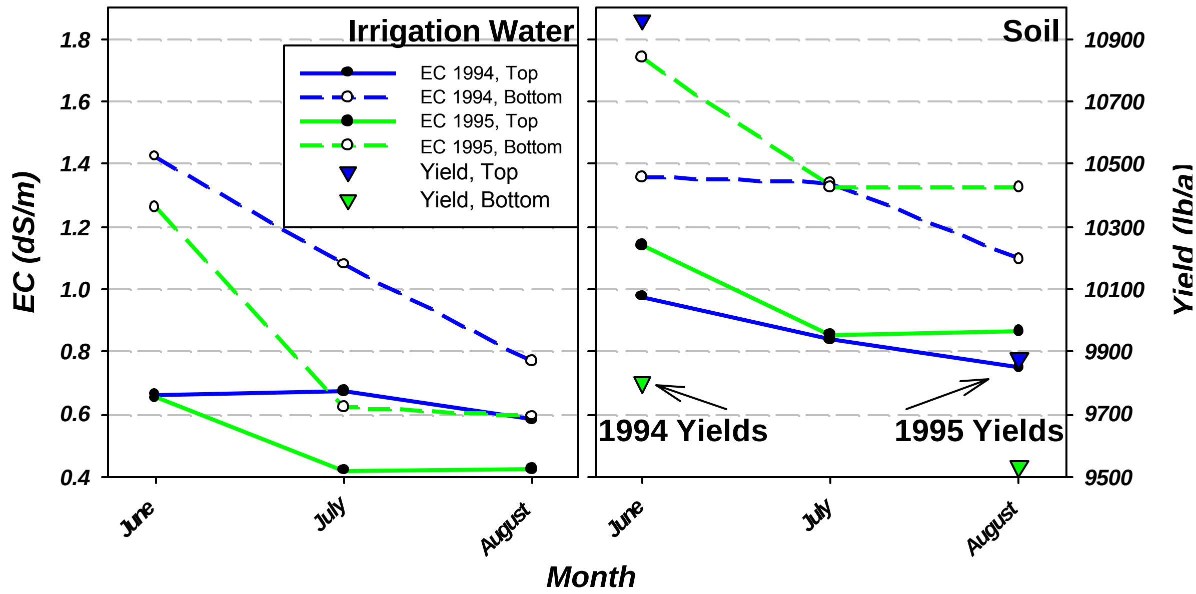


Figure 5. Water and soil electrical conductivity, and rice yield, response to distance from freshwater input to the field. Data from 1994 and 5 (Scardaci, et al., 1999).

Figure 7 shows (1) individual yield measurements in 54 plots located at the top and bottom of 27 fields, (2) average yields for measurements in 0.5 dS/m salinity groupings, (3) a regression line for 1994 yield response to salinity, (4) the yield reduction threshold and slope proposed for rice by Maas (1990; 3 dS/m and 12 (lb/a)/(dS/m)), (5) the yield reduction threshold and slope proposed by Scardaci et al. (1999; reduction from 3 to 1.85 dS/m). Maximum yield levels (before yield reduction by salinity) were defined as average rice yield for each year for locations with June EC_e<0.05. This is reasonable, since growing conditions in the absence of salinity stress for each year can be estimated by the performance of these plots.

It is apparent that the model revision proposed by Scardaci et al. is a substantial improvement for rice in these environments. However, an equivalent case could be made from these data for a threshold nearer to EC_e = 1 dS/m, and a slope around 8.5 (lb/a)/(dS/m). This line matches the regression shown on the 1994 plot. The significance of this would be to acknowledge a potentially valid, yet more stringent water quality criterion for rice irrigation water, and to retard the estimated rate of yield impact of exceeding the criterion.

CHAIN OF CAUSE AND EFFECT

Evidence in the data reviewed here suggest that, while it is theoretically possible to maintain reclamation and rice productivity, ongoing reclamation is constrained in some areas. In particular, the following “sequence” of causes and effects can be traced conceptually: (1) prolonged drought reduces water available for various beneficial uses, (2) physical, economic, and/or regulatory forces reduce supply of fresh, river water for irrigation, (3) irrigation water is detained within fields, especially during early-season holding periods for herbicide degradation, (4) salinity increases from top to bottom across fields, (5) salinization is further accelerated in drainage impaired areas due to less efficient salt removal, (6) head-gate salt concentrations increase substantially in the lower basin, (7) soil salinity more or less mirrors water salinity in rice fields, (8) rice stand density and growth rate are reduced in the areas where these conditions combine to elevate salinity beyond threshold concentrations, (9) the effects on young rice may translate into a yield reduction, roughly in proportion to the amount by which salinity thresholds are exceeded, (10) seasonal and long-term salinization trends combine to generally increase soil salinity over time, and (11) irrigation districts, farmers, and policy makers sort options to alleviate increasing salinity or its impacts.

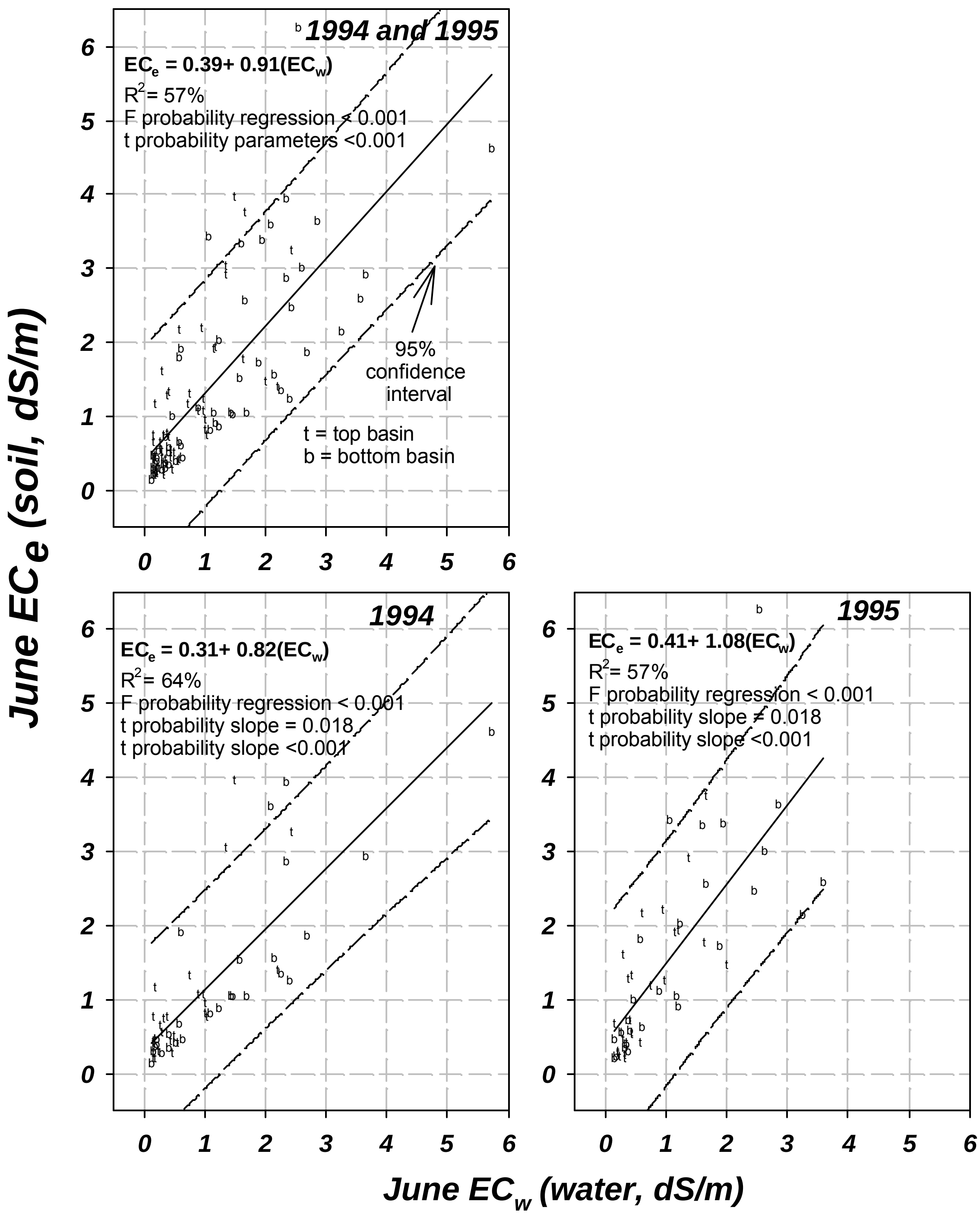


Figure 6. Relationship between water supply salinity and soil salinity in fields sampled in 1994 and 1995 (Scardaci et al., 1999).

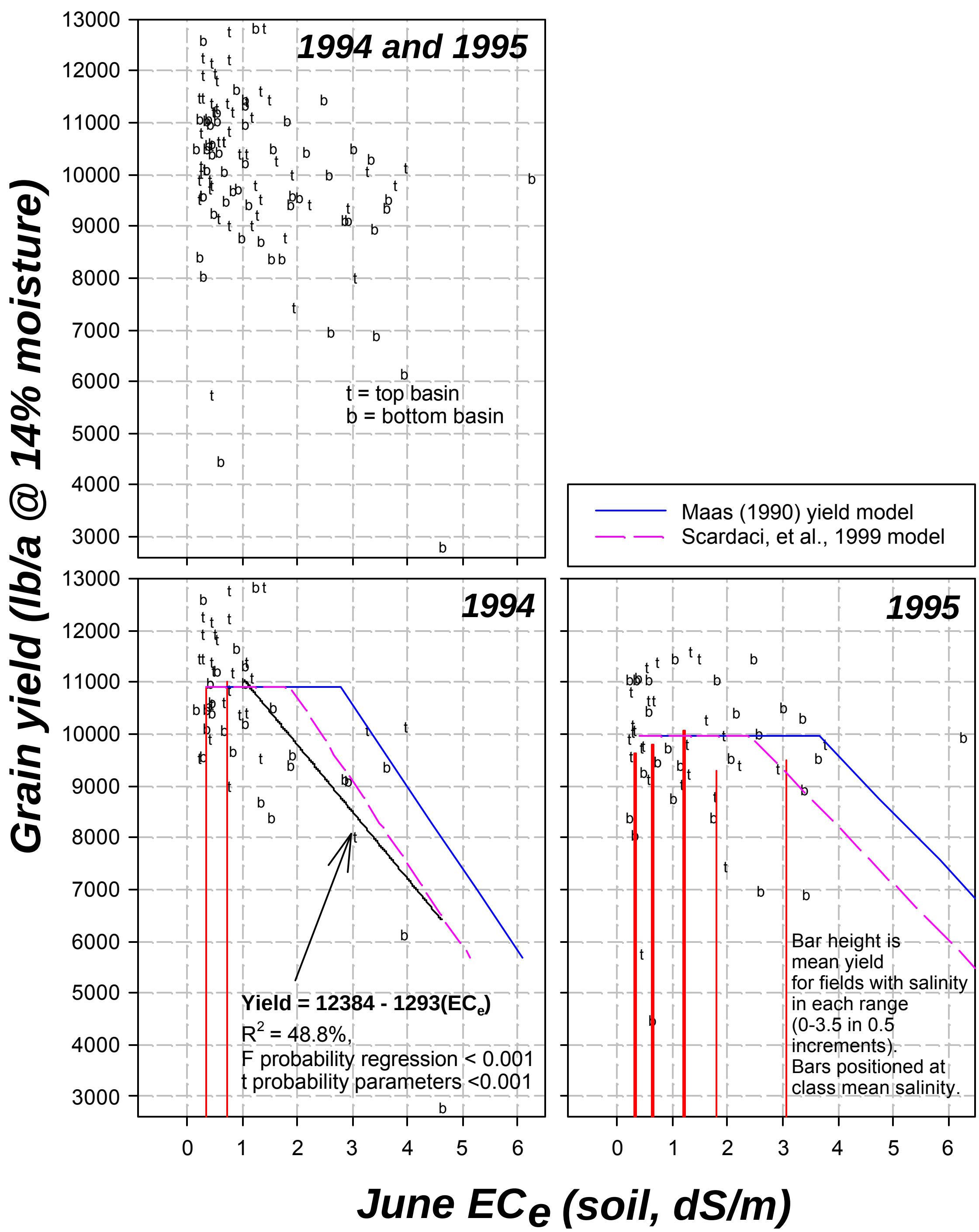


Figure 7. Rice grain yield response to salinity, 1994 and 1995 (data from Scardaci et al., 1999). Note that the EC_e levels shown for the vertical bars are the average EC_e of checks in each 0.5-dS / m increment along the x axis.

CRITICAL DATA NEEDS

The data in Figure 7 represent 54 field-scale plots monitored over 2 seasons. Scardaci et al. also used more controlled greenhouse and microplot studies to arrive at their conclusions. Water policy, farm economic, and water resources engineering decisions will likely be based on the best available crop salt tolerance criteria. Cost implications of these decisions far outweigh the relatively minor effort required to refine rice salt tolerance criteria, as recommended.

There are relatively few extensive surveys of soil salinity in the Sacramento Valley. Focused effort to improve and update salinity mapping, and to monitor trends over time, would refine our understanding of the problem and focus efforts at resolution. Recent advances in ground-based salinity sensing technology could greatly facilitate this work.

The response of soil salinity to various irrigation and drainage regimes over not months, but years and decades, needs to be measured. We must define operating criteria and practice that sustain salt concentrations within ranges favoring planned crop production levels and other beneficial uses. This is true at each level of management, from the individual field to the Sacramento River Basin, and extending across the domains of crop, soil, and water management. Current criteria and practice may be inadequate for this purpose, as significant salinization and associated crop impacts were observed.

Salinity is managed with water. The salt management system is therefore stressed when water supply is curtailed or degraded. Therefore, salt management strategies must explicitly consider the dynamics of water supply quantity and quality.

ACKNOWLEDGEMENTS

Work contributing to this review was executed by Albert Cox, Jim Thayer, Joel Kimmelshue, Tim Hill (all CH2M HILL), and Marc Van Camp (MBK Engineers). Steve Scardaci, formerly Farm Advisor with U.C. Cooperative Extension in Colusa County, freely shared published data in the hopes that it would be used productively to rationally plan regional water management. He, his co-authors and other associates in UC-CES are warmly acknowledged for their collaboration.

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ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2011-December 31, 2011

PROJECT TITLE: Improving fertilizer guidelines for California's changing rice climate.

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LEVEL OF 2011 FUNDING: $98,542

OBJECTIVES OF THE PROPOSED RESEARCH

Our overall objective of this project is to develop fertilizer guidelines for California rice growers which are economic viable and environmentally sound. Toward this objective, we proposed the following specific objectives for 2011:

1. Quantify N_2O and CH_4 emissions in California rice systems.
2. Quantify N losses due to NO_3 leaching in California rice systems.
3. Development of a web based decision tool to help growers determine how long they will need to keep their fields flooded for different weeds-based on P applications and temperature and weeds. Done in conjunction with Albert Fisher.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

1. Research on greenhouse gas (GHG) emissions highlight the importance between agronomic management and environmental quality in rice systems, where management practices appear to regulate GHG emissions more than N fertilizer rate. Nitrification appears to be the major process involved in N_2O emissions in flooded rice systems, although denitrification during the dry down periods may also contribute to overall emissions. Methane emissions were not directly affected by addition of fertilizer N but high fertilizer N application may lead to high crop residue inputs which eventually increase CH_4 emissions. Frequent flood-drain cycles resulted to high N_2O emission events. To mitigate emissions, continuous flooding practices and avoid flood-drain cycles during the growing season may reduce nitrogen losses from rice fields and consequently lower global warming potentials. Also, applying N deep into the soil as aqua ammonia may reduce N_2O losses compared to surface N applications. Application of high N fertilizer does not necessarily increase the Global Warming Potential (GWP) provided that rice is grown with best management practice resulting in high resource use efficiency.
2. Soil NO_3 beneath (to a depth of 7 ft) rice fields were low. The reasons that NO_3 levels are low are due to a combination of the following factors:
    a. Soil nitrate levels are low in the surface soil to begin with (0.4 to 4.2 ppm)
        i. Winter weeds take up
        ii. Straw immobilizes
    b. Growers do not (should not) apply NO_3 fertilizer
    c. Soils remain flooded for much of the season preventing nitrification (NH_4 to NO_3)
    d. Denitrification rates are very high (NO_3 to N gas)
    e. Hydraulic conductivity is very low - preventing downward movement of NO_3.
3. The overarching goal of this research is to develop a site-specific, web-based decision support tool that assists rice growers in planning for and implementing alternative stand establishment systems for weed control by predicting the minimum time to emergence for *Echinochloa spp*. and *Cyperus difformis* (smallflower umbrellasedge). In 2011 we: 1) quantified the spatial variability of species-specific physiological temperatures for for the period of rice establishment in the Sacramento Valley; 2) quantified the field-scale variability of weed emergence predictions (variability between years, between locations and within a single field) in stale-seedbed and drill-seeded fields; and 3) initiated construction of an online interface that will deliver the information from these particular emergence models to rice growers and serve as a platform for the delivery of information

from future rice-related models. This work is being done in cooperation with Albert Fischer and his students and serves as an initial step toward applying, in the field, the more elaborate germination, emergence and early growth models that have been/are being developed at the lab and greenhouse scales.

EXPERIMENTAL PROCEDURE TO ACCOMPLISH OBJECTIVES:

OBJECTIVE 1: QUANTIFY N_2O AND CH_4 EMISSIONS IN CALIFORNIA RICE SYSTEMS

California rice is produced by direct seeding into standing water with permanent flood for most of the season. Limited acreage is drill seeded and also uses permanent flood after crop establishment. Flooding the rice fields lead to conditions favorable for production of greenhouse gases (GHG) such as methane and nitrous oxide. Methane (CH_4) a greenhouse gas is about 20 times more potent than carbon dioxide, and accounts for a fifth of the global atmosphere's warming potential. Methane emission from rice fields is the net effect of CH_4 production (methanogenesis) and CH_4 oxidation (methanotrophy). Incorporation of organic matter in flooded fields stimulates CH_4 emissions. Nitrous oxide (N_2O) is about 296 times warming potential than CO_2 with atmospheric lifetime of 114 years. Main source of N_2O in rice systems is application of synthetic N fertilizers. In response to growing demand for rice in the US, the use of synthetic fertilizers is projected to increase, which in turn may accelerate the rate of increase of atmospheric N_2O content. Improved quantitative estimates of the amounts of CH_4 and N_2O coming from the rice fields are needed to prioritize effective mitigation rice practices.

Objectives

- Quantify GHG emissions for conventional and drill seeded rice production systems in the Sacramento Valley as affected by nitrogen (N) fertilizer rates, flooding, and rice seeding practices
- Determine environmental variables and management practices affecting GHG emissions
- Identify mitigation strategies for N fertilizer (e.g. rate, timing, source, placement) and crop management to reduce GHG emissions
- Link annual GHG emissions with grain yields and develop a new metric for assessing mitigation practices in rice cropping systems in California

Materials and Methods

Two on-farm experiments were implemented in 2011 at sites with contrasting rice establishment practices. The conventional field was aerially seeded (M-206), and a permanent flood was maintained for the duration of the growing season. In the drill seeded site rice seed (Koshihikari) was drilled into the soil. The field was flooded for several days and then drained to provide an aerobic environment for seedling emergence. Water management during crop establishment differed compared to the conventional system, as the field was flushed a couple of times before the permanent flood was applied approximately one month after seeding. At both sites the field was drained approximately one month prior to harvest.

At the conventional site, N rates ranging from 0 to 260 kg N ha^{-1} were applied in the form of aqua ammonia injected three to four inches below the soil surface (Table 1). As growers often apply the majority of their N as aqua ammonia and a smaller portion of their N to the soil surface, we included an additional split N treatment of 80 + 60 kg N ha^{-1} (N140sur = subsurface aqua ammonia plus surface applied urea, respectively) to assess the effects of N placement on emissions. Also, since growers often apply a topdress N application and that sulfate applications are known to reduce methane emissions an additional treatment (N140as) was added where 80 kg/ha was applied as aqua before flooding and 60 kg N/ha of ammonium sulfate (AS) was applied 35 days after seeding (DAS).

At the drill seeded site, N rates ranging from 0 to 200 kg N ha^{-1} were applied as urea to the soil surface immediately prior to the permanently flood, which occurred approximately thirty days after seeding (Table 1). As growers often apply a small amount of N at planting in drill seeded systems and the majority before the permanent flood, we included an additional split N treatment (25 kg N ha^{-1} preplant + 75 kg N ha^{-1} preflood) to assess the effects of N application timing on emissions. In addition we evaluated the application of 100 kg N/ha urea as Super U (an nitrification and urease inhibitor) (N100inhib).

Table 1. Fertilizer N treatments and rates for each system

Wet seeded		Drill seeded	
N treatment	N rate (kg/ha)	N treatment	N rate (kg/ha)
N0	0	N0	0
N80	80	N50	50
N140	140	N100	100
N260	260	N150	150
N200	200	N200	200
N140sur (80 aqua/60 surface)	80/60	N100split (N app at planting and perm flood)	25/75
N140as (80 aqua/60 kg/ha AS applied 35 DAS)	80/60	N100inhib (Super U)	100

GHG emissions for each N rate were quantified using a vented cylindrical surface chambers, with 14.7 cm diameter and varying chamber height (15.2- 30.5 cm) as rice growth progressed was placed within each N treatment plot. GHG measurement were taken at least once a week and more frequently during changes to irrigation or N management. Other ancillary soil and plant variables related to GHG emissions were measured such as soil and air temperatures, flood water depth, soil exchangeable NH_4-N and NO_3-N at 15 cm soil depth, plant N uptake, crop biomass after harvest and rice grain yields at 14% moisture content.

Results

Conventional field:

Yields ranged from 4.7 to 13.1 t/ha (Fig. 1). Yields were not significantly different for N rates above 140 kg N/ha. Cumulative seasonal CH_4 emissions varied significantly among N rates with emissions being lowest in the N0 treatment (Fig 2). CH_4 emissions were similar for all treatments where N was added, although the N260 was trending lower possibly due to the presence of a high amount of ammonium which has been reported to reduce net CH_4 fluxes in rice by enhancing CH_4 oxidation. Unlike CH_4 emissions, mean daily N_2O emissions increased as fertilizer N rate increased. At N rates >100 kg N ha^{-1}, N_2O emission increased 6 to 8 times relative to the optimal N rate and highest daily N_2O emissions were measured in the N260 treatment. Global warming potential was lowest in the N0 treatment but was similar across the treatments where N was added (Figure 3). Methane constitute mostly of the GWP value due to high emissions in this rice field. Yield-scaled GWP was lowest in the three highest N rates and highest when no N was added. This confirms data from other studies indicating that the best management practice (from a farmers and environmental point of view) to achieve the lowest yield-scaled GWP is when optimal N rates are applied. This allows for optimal yields while minimizing the amount of GHG emissions per unit of yield.

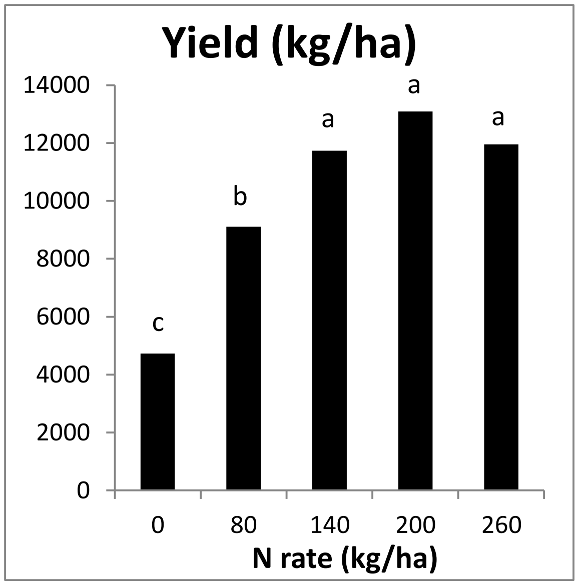

Figure 1. 2011 rice yields at the wet seeded site

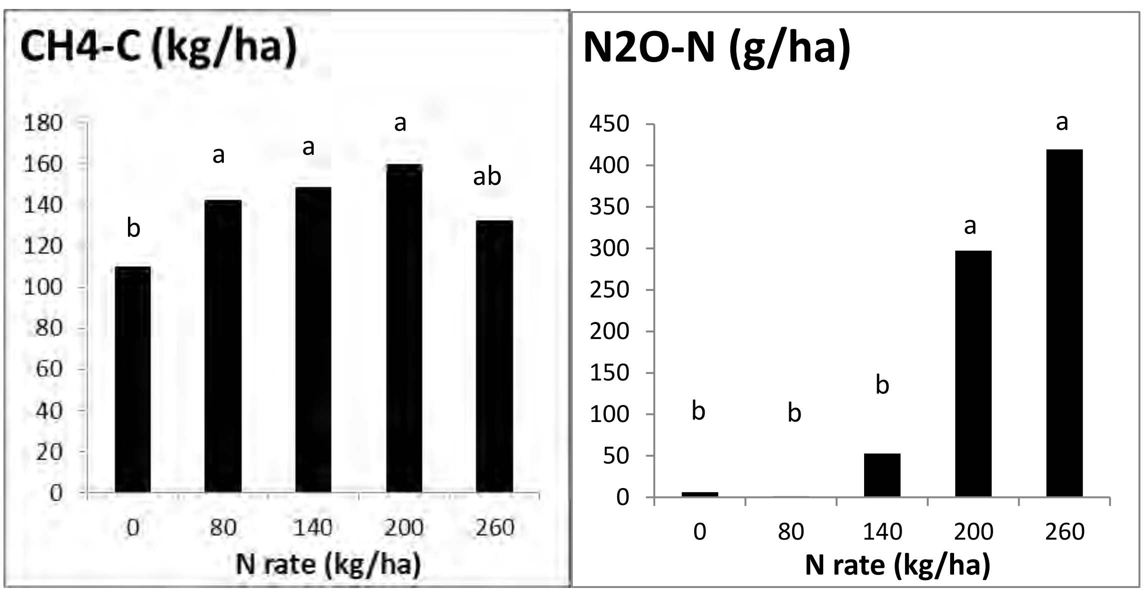

Figure 2. 2011 seasonal methane and nitrous oxide emissions from wet-seeded site.

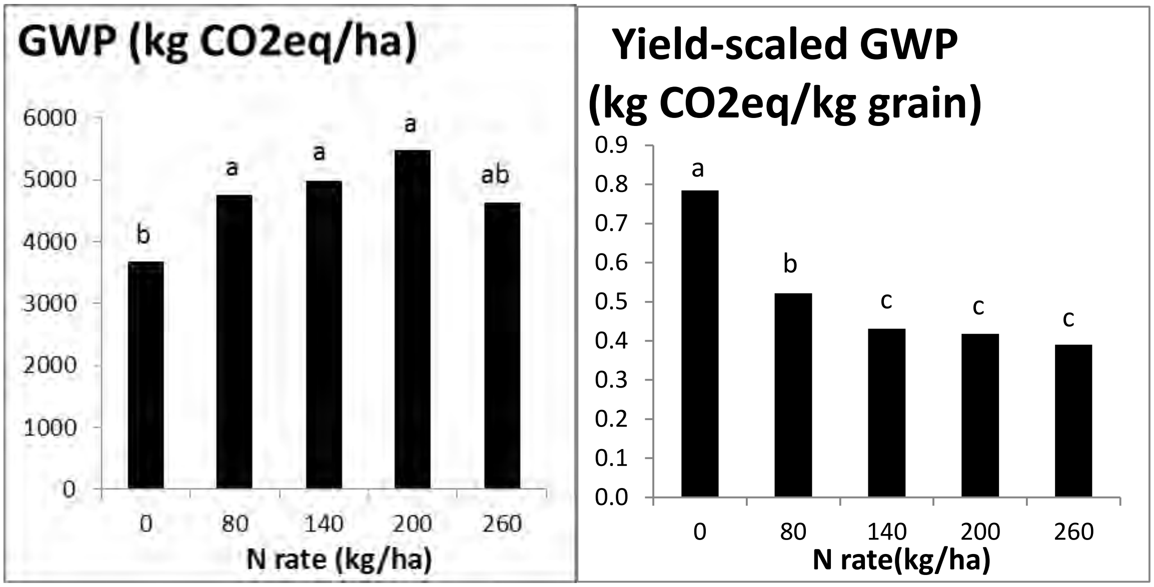

Figure 3. 2011 GWP and yield-scaled GWP for wet seeded site.

For the mitigation options, which evaluated the applying all of the N as aqua-ammonia or applying a portion of the N rate as ammonium sulfate there was no significant difference among treatments with respect to yield, GHG emissions or GWP (Table 2). The use of ammonium sulfate as alternative fertilizer N source did reduced CH_4 emissions by 7% compared to conventional liquid ammonia N (not significant) as might be expected as sulfate has been shown to reduce CH4 emissions in other studies. Other studies have also shown that deep applications of N tend to reduce CH4 emissions. While not significant, the application of aqua only is slightly lower than when some of the N was applied to the surface of the soil. The yield-scaled GWP was similar across mitigation options but significantly lower than when no N was applied.

Table 2. Evaluation of mitigation options on yield, GHG emissions and GWP at the drill seeded site.

N management	Yield	CH4	N2O	GWP	Yield-scaled GWP
	kg/ha	kg C/ha	g N/ha	kg CO2eq/ha	kg CO2eq/kg grain
0N	4723 b	110 b	6	3686 b	0.784 a
140: aqua ammonia (AA)	11739 a	149 a	53	4987 a	0.431 b
140: 80 AA/60 urea	12281 a	166 a	61	5578 a	0.454 b
140 80 AA/60 ammonium sulfate 35 DAS	11560 a	138 ab	35	4261 ab	0.398 b

Drill Seeded site:

Yields ranged from 6.0 to 9.8 t/ha (Fig. 4). The highest yields were achieved in the N100 treatment. Seasonal CH_4 emissions were similar to the wet seeded site and N_2O emissions were higher (Fig 2 and 5). Unlike the wet seeded site however, both CH4 and N2O emissions did not vary significantly across N rates; although N2O emission did tend to increase with increasing N rate as would be expected.

Mitigating N treatments such the use of urea with nitrification and urease inhibitors at 100 kg N ha^{-1} (N100) rates showed no effect on seasonal CH_4 and N_2O emissions (Table 3).

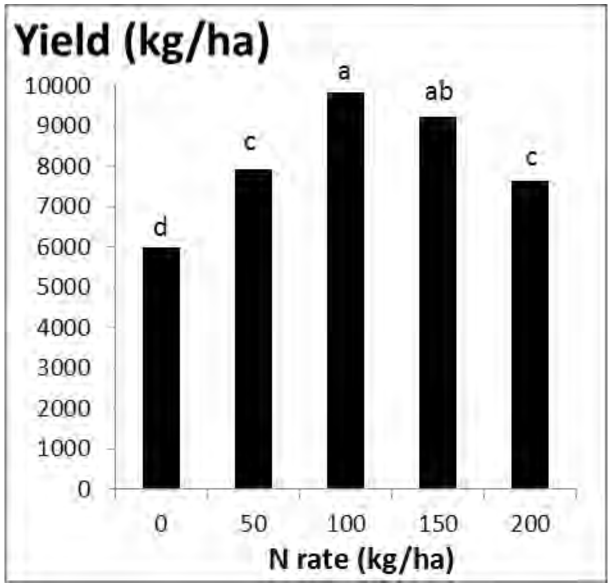

Figure 4. 2011 rice yields at the drill seeded site

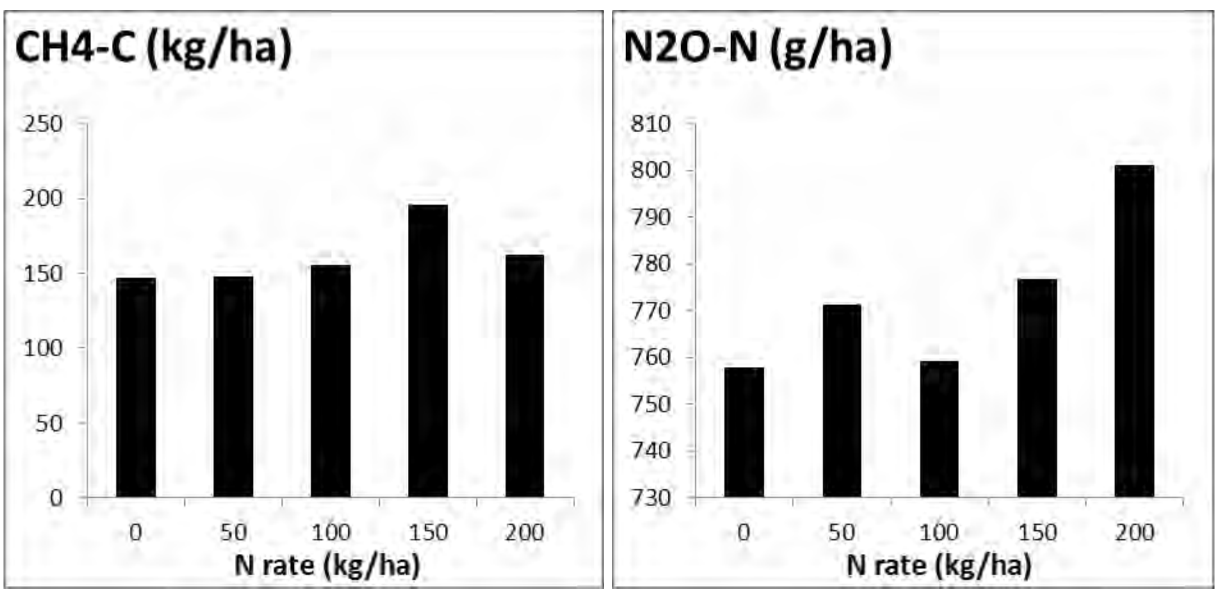

Figure 5. 2011 seasonal methane and nitrous oxide emissions from drill-seeded site. Differences among treatments were not significant.

Table 3. Evaluation of mitigation options on yield, GHG emissions and GWP at the drill seeded site.

N management	Yield	CH4	N2O	GWP	Yield-scaled GWP
	kg/ha	kg C/ha	g N/ha	kg CO2eq/ha	kg CO2eq/kg grain
0N	5996 b	147	758 b	5263	0.880 a
100: urea before permanent flood	9826 a	156	759 b	5564	0.565 b
100: 25 planting/75 permanent flood	8821 a	150	255 b	5140	0.602 b
100: Super U urea before permanent flood	9689 a	168	770 b	5969	0.618 b

As with the seasonal GHG emissions, there was not a significant effect of N rate (Fig 6) or mitigation strategy (Table 3) on either GWP or yield-scaled GWP (Fig. 6). However, similar to the wet-seeded site, yield scaled GWP was lowest when N rates were optimal (N100).

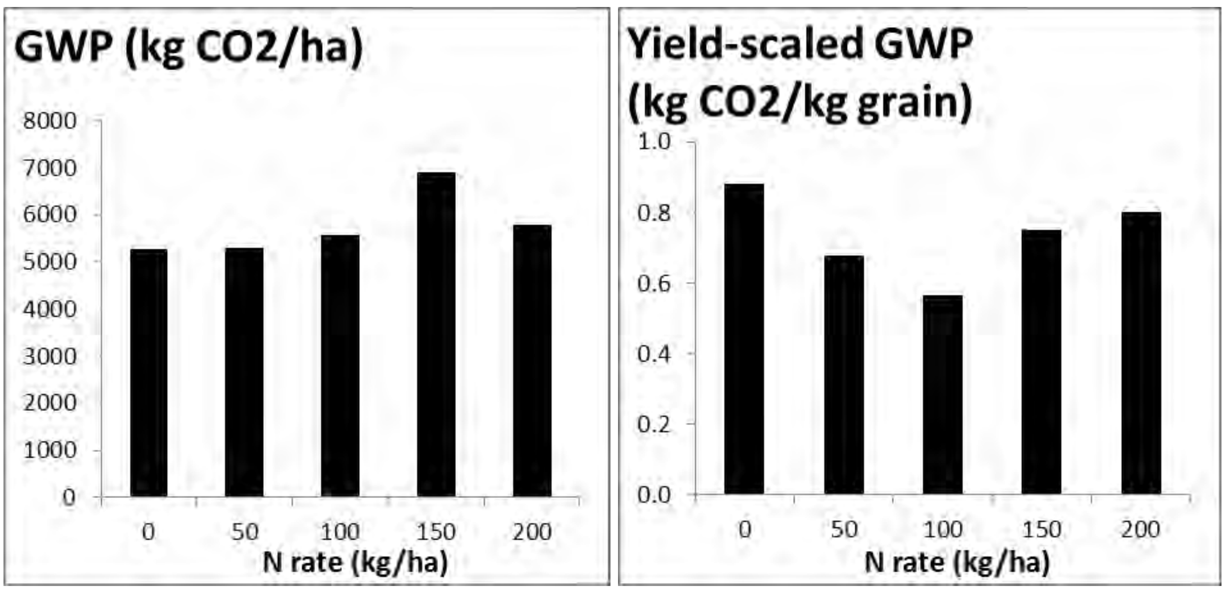

Figure 6. 2011 GWP and yield-scaled GWP for drill seeded site. Differences among treatments were not significant.

Summary

1. Seasonal CH_4 emissions and GWP were similar between the two establishment practices, unlike 2010 results which showed the drill seeded system to have lower emissions.
2. Seasonal N_2O emissions were higher in the drill seeded site as was also found in 2010.
3. For both systems, the lowest yield-scaled GWP occurred when N was applied at rates suitable for optimal yields – also similar to 2010 results.
4. The mitigation strategies tested in 2011 for either site did not have a significant impact on either CH_4 or N_2O emissions; although the trends were what we expected.

OBJECTIVE 2: QUANTIFY N LOSSES DUE TO NO_3 LEACHING IN CALIFORNIA RICE SYSTEMS

The irrigated lands program may begin putting water quality restrictions on agricultural management practices that allow NO_3 to enter surface and ground waters. In a previous CALFED funded project we have addressed NO_3 in surface waters. This project will now focus on ground water and NO_3 leaching. There is very little data available that quantifies NO_3 leaching is flooded rice systems. Some studies from Asia have reported NO_3 leaching below the root zone in rice systems (Yoon et al., 2006 and Zhu et al., 2000); however the methodology employed in these studies may have caused this leaching. In another study, Bouman et al. (2002) reported potential leaching beneath rice fields but that it was minimal compared to other systems. In California, rice soil are relatively impermeable and it is thought that the potential for NO_3 leaching is minimal due to the slow percolation of water downward and the fact that the anaerobic conditions in flooded soils would cause the NO_3 to denitrify (lost to the atmosphere as gas) before it had a chance to leach beyond the rice rooting zone. While this is a good theory it has not been proven in the field. The objective of our study is to quantify NO_3 leaching losses in rice fields.

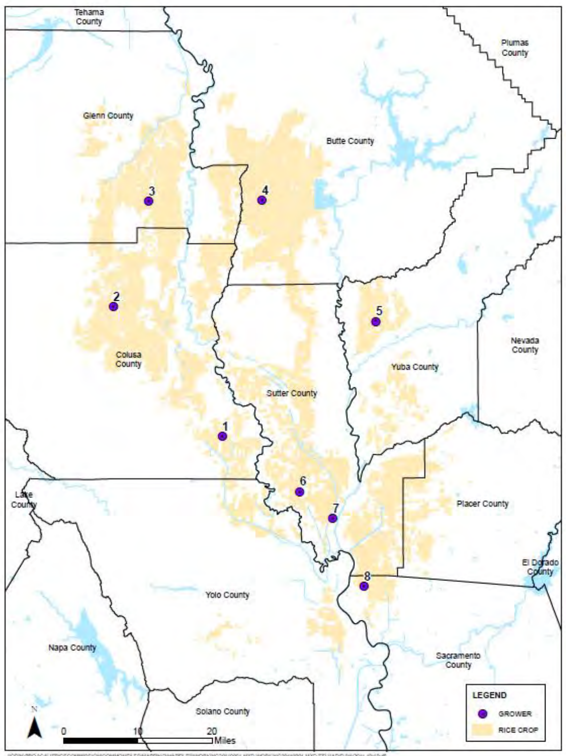

Figure 1. Location of field sites where soils samples were collected for NO_3 analysis.

In 2010, we collected soil samples to a depth of 2 m (7 ft) from 7 fields that represented typical rice fields and one field that was very sandy (#7 unrepresentative) (Fig. 1 and Table 1). Soil samples were collected in April of 2010 when it is expected that soil NO_3 levels are at their highest of the year. Soil samples were stored in a cold room until NO_3 analysis (all soils were analyzed within one week of sampling). The soil samples were divided into the following sections: 0-15 cm, 15-33 cm, 33-66 cm, 66-100 cm, 100-133 cm, 133-166 cm and 166-200 cm. Soil samples were extracted and analyzed for NO_3 using 2M KCl. Additionally we determined the denitirifcation potential of the surface soils. We hypothesized that when soils are flooded any NO_3 will be rapidly denitrified and thus will not be available for leaching. The denitrification study was conducted in the laboratory. For this we used 10 g soil and added 15 ug NO_3-N/g soil, added 15 ml of water, removed air from head space in tube and incubated at 30^{o}C for various period of time up to 12 days. Nitrate remaining in the soil was determined after extraction with 2M KCl.

Additional soil cores were sampled from the 20-30 cm soil layer (the layer just below the rooting zone of rice) for determination of bulk density and hydraulic conductivity. After removing top soil brass rings (8.25 cm in diameter and 6 cm deep) were pushed into the soil and the soil within the brass ring removed. Five rings per site were taken. Soils within the ring were saturated with 0.01M $CaCl_2$ in preparation for determination of hydraulic conductivity. Hydraulic conductivity was determined using the falling head method. After determination of hydraulic conductivity the soil in the brass rings were oven dried at 110^{o}C and weighed for determination of bulk density.

Table 1. Soil classification and map unit for the study sites. Numbers refer to those in Figure 1. Bulk density and hydraulic conductivity is for the soil layer immediately below the root zone (20-30 cm). Results are the mean of five samples.

Site	Soil map unit	Soil classification	Bulk density	Hydraulic conductivity	
			g/cm^3	cm/d (std. dev)	inches/120d
1	Clear Lake clay	Fine, smetic, thermic Xeric Endoaquerts	1.21	0.011(0.005)	0.34
2	Hillgate clay loam	Fine, smetic, thermic Typic Palexeralfs	1.46	0.003 (0.002)	0.14
3	Willows clay	Fine, thermic Typic Calciaquolls	1.58	0.027 (0.038)	1.28
4	Lofgren-Blavo complex	Very-fine, smetic, thermic Xeric Epiaquerts	1.15	0.074 (0.121)	3.49
5	San Joaquin loam	Fine, mixed, thermic Abruptic Durixeralfs	1.64	0.062 (0.030)	2.92
6	Clear Lake clay	Fine, montmorillonitic, thermic Typic Pelloxererts	1.22	0.037 (0.051)	1.74
7	Columbia fine sandy loam	Coarse-loamy, mixed, thermic Typic Xerofluvents	1.49	1.741 (1.284)	82.23
8	Clear Lake clay	Fine, montmorillonitic, thermic Xeric Epiaquerts	1.56	0.007 (0.007)	0.52

Nitrate concentrations in excess of 10 ppm NO_3-N is considered a health hazard by the EPA. In our study the highest NO_3 levels we found were 4.2 ppm and this was in the surface soil (Fig 2). In general, surface soils had more NO3 than subsurface soils ranging from about 0.4 to 4.2 ppm. These levels are relatively low most likely due to immobilization of N by rice straw and uptake of N by winter weeds. Below the rooting zone nitrate levels were all 3 ppm or less. In most cases nitrate levels were less than 0.5 ppm. This suggests that NO_3-N in subsurface ground waters is not a big concern in CA rice systems. At two sites NO_3 levels were above 2 ppm below the rooting zone. These locations are near Robbins, CA where rice is rotated with other crops. NO_3 is likely a bigger problem for other crops as there is usually a lot more NO_3 in the soil and N fertilizers are applied as NO_3 or rapidly convert to NO_3.

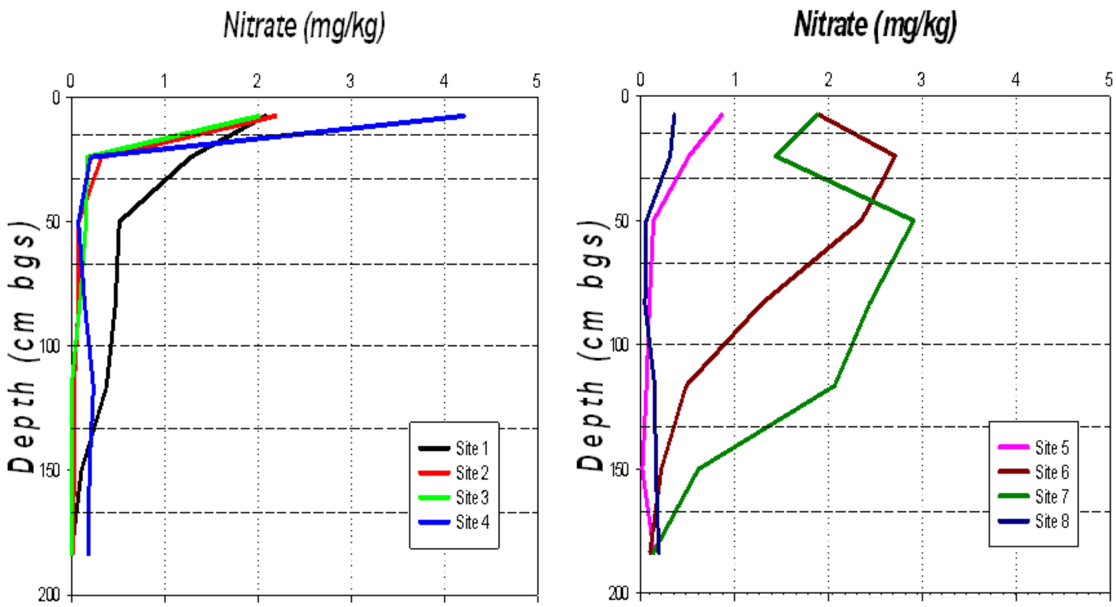

Figure 2. Soil NO_3 across soil depths in 8 California rice soils. Site numbers refer to those in Table 1and Figure 1.

In a laboratory study, the top soil from each of these sites was used to determine the rate at which NO_3 dentirifies. When NO_3 dentirifies it is lost to the atmosphere as N gas. Our results show that by 1.5 days over 98% of the NO_3 that was in the soil was lost as gas (Fig 3). This shows that upon flooding a rice field most of the NO_3 that is present in the soil does not have time to leach as it is lost to the atmosphere via denitrification.

Finally the hydraulic conductivity of these rice soils was extremely low and ranged from 0.003 to 0.074 cm/day for the "typical" rice soils (Table 1). In the sandy loam soil which is not typical f California rice soils the hydraulic conductivity was much higher (1.74 cm/day). These data suggest that given the rapid denitirification of NO_3 in flooded soils there is not adequate time for NO_3 to leach.

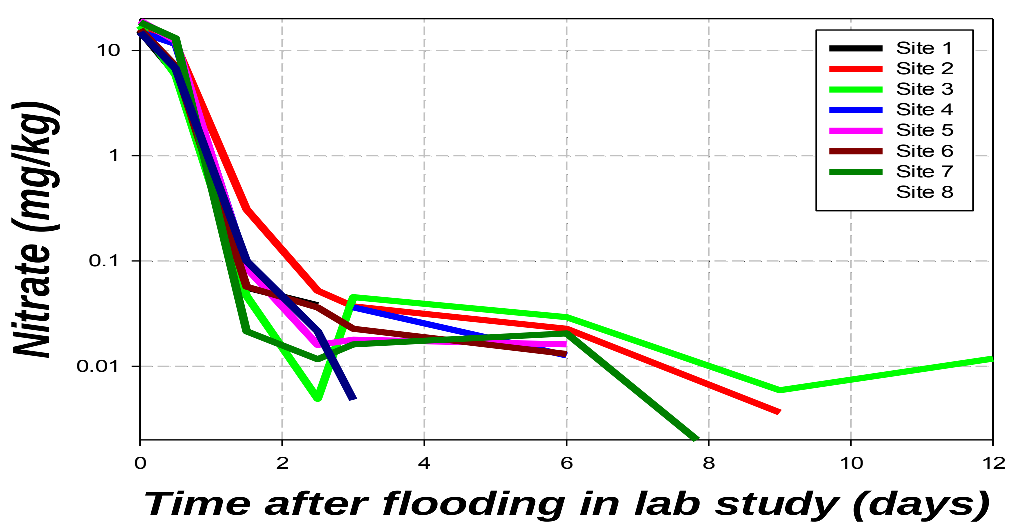

Figure 3. Soil NO3 during a 12 day anaerobic laboratory incubation. Site numbers refer to those in Table 1and Figure 1.

Research summary

If leaching is a potential problem in these fields we would expect to see higher NO_3 concentrations below the rooting zone. In summary, we found that soil NO_3 beneath the root zone of rice was low. The reasons that NO_3 levels are low may be due to one or more of the following factors:

- Soil nitrate levels are low in the surface soil to begin with (0.4 to 4.2 ppm)
  - Winter weeds take up
  - Straw immobilization
- Growers do not (should not) apply NO_3 fertilizer
- Soils remain flooded for much of the season preventing nitrification (NH_4 to NO_3)
- Denitrification rates are very high (NO_3 to N gas) resulting in the loss of NO_3 to the atmosphere as N gas rather than leaching
- Hydraulic conductivity is very low in most rice fields preventing downward movement of NO_3 .

OBJECTIVE 3: DEVELOPMENT OF A WEB BASED DECISION TOOL TO HELP GROWERS DETERMINE HOW LONG THEY WILL NEED TO KEEP THEIR FIELDS FLOODED FOR DIFFERENT WEEDS-BASED ON P APPLICATIONS AND TEMPERATURE AND WEEDS.

Summary

The overarching goal of this research is to develop a site-specific, web-based decision support tool that assists rice growers in planning for and implementing alternative stand establishment systems for weed control by predicting the minimum time to emergence for *Echinochloa spp*. and *Cyperus difformis* (smallflower umbrellasedge). Our hypothesis is that early-season temperatures within the Sacramento Valley are spatially and temporally dependent; therefore site-specific, real-time temperatures will improve regional emergence predictions for *Echinochloa spp.* and *C. difformis*. In 2011 we: 1) quantified the spatial variability of species-specific physiological temperatures for for the period of rice establishment in the Sacramento Valley; 2) quantified the field-scale variability of weed emergence predictions (variability between years, between locations and within a single field) in stale-seedbed and drill-seeded fields; and 3) initiated construction of an online interface that will deliver the information from these particular emergence models to rice growers and serve as a platform for the delivery of information from future rice-related models. This work is being done in cooperation with Albert Fischer and his students and serves as an initial step toward applying, in the field, the more elaborate germination, emergence and early growth models that have been/are being developed at the lab and greenhouse scales.

Regional variability of physiological temperatures during the period of rice establishment

Physiological temperatures refer to a range of temperatures that optimizes growth for a particular plant species. Each species (and biotype) has a distinct range of optimum temperatures. Using preliminary base temperatures for California biotypes of *Echinochloa spp*. and *C. difformis* (8C for *Echinochloa spp*. and 15.5C for *C. difformis;* A. Fischer, personal communication), in combination with daily maximum and minimum air temperatures accurate to $4km^2$ (Coast to Mountain Environmental Transect, COMET; comet.ucdavis.edu) we produced average, site-specific ($4km^2$) thermal unit accumulation for the period of rice establishment (4/15-5/31) between 2004-2010 in the Sacramento Valley (Figure 1).

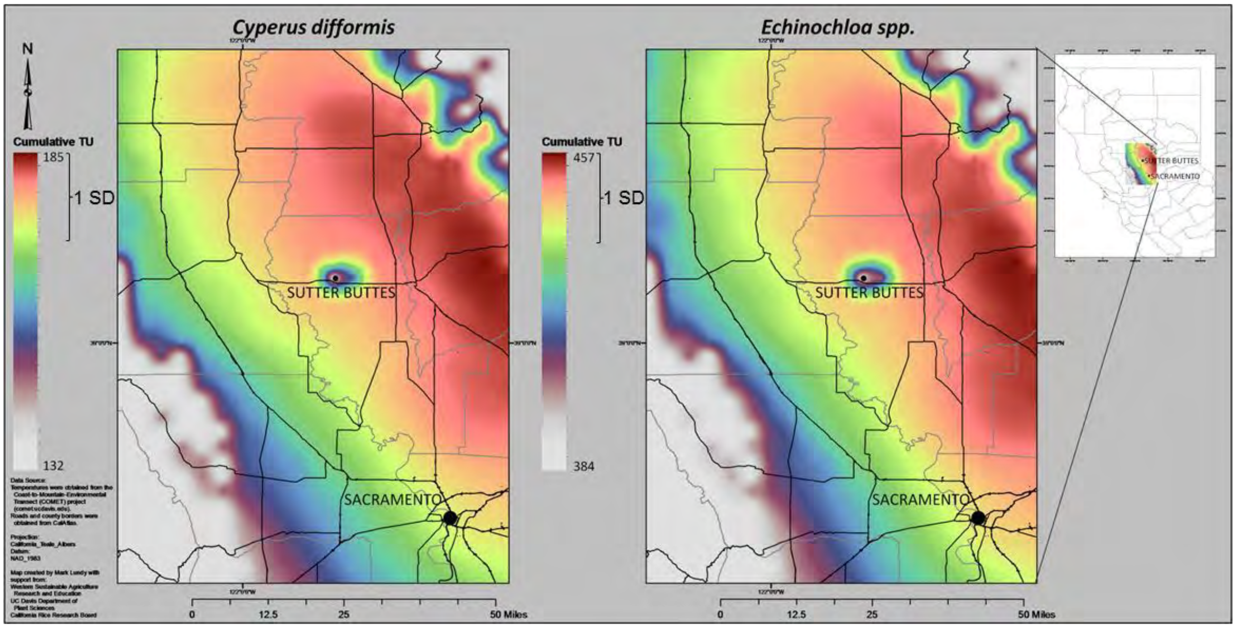

Figure 1. *Average cumulative thermal unit accumulation for Echinochloa spp. and C. difformis for the period of rice establishment (4/15-5/31) between 2004-2010 using base temperatures of 8C and 15.5C (respectively) and maximum and minimum air temperatures accurate to 4kim^2. SD = standard deviation.*

Average physiological temperatures for both *Echinochloa spp*. and *C. difformis* were spatially heterogeneous between 4/15 and 5/31 for the years 2004-2010, with 2.60 and 2.52 standard deviations (respectively) separating the warmest and coolest areas of the rice growing region (Figure 1). However, the distribution of the heterogeneity differed between species. The higher base temperature of *C. difformis* relative to *Echinochloa spp*. had the effect of increasing the relative thermal unit accumulation NNE of Sutter Buttes (as depicted by the increased red shading in Figure 1) due to higher average minimum temperatures in this area. In addition to being species-bound, it is likely that the spatial distribution of physiological temperatures is also temporally sensitive. Weed emergence occurs within a much smaller period of time than the multiple year, multiple day average depicted in Figure 1. Thus, the spatial heterogeneity of physiological temperatures is likely to change both within and between years. The extent of these interactions and the degree to which they influence the accuracy of model predictions will be determined via multi-year simulations using the emergence models presented below. However, this work is not yet complete. While it is important to emphasize that the relationships are not as static as indicated by the averages in Figure 1, the spatial relationships presented do, nonetheless, provide a rationale for using site-specific temperatures to improve the accuracy of species-specific weed emergence predictions.

Variability of *Echinochloa spp*. and *C. difformis* emergence predictions between years, locations, and within fields

During the 2010 and 2011 field seasons we observed *Echinochloa spp*. and *C. difformis* emergence in 3 fields: a spring-tilled, stale seedbed field located in Glenn County and two drill-seeded fields located in Sutter County for a total of 4 year-field combinations. The water in each field was managed similarly, with 2 to 3 flushes of irrigation over the course of a 20-30 day period to create a saturated but aerobic seedbed. Emergence was observed in 5-7 plots per field from the first day of flooding until no further emergence had occurred in a field for four days. Each plot contained four 0.09m^2 subplots, and the plots were located to maximize both the within field variability in water depth and timing as well as the number of observable weeds based on historical occurrence. The emergence observations were expressed as the average proportional emergence of the four subplots. They were fit to a non-linear mixed model of the form:

emergence = $1 / 1 + \exp-[((T - T_{base}) - (t_{50}))/ E_{rate}] + RE_{year} + RE_{location} + RE_{field} +$ Residual, where:

$T - T_{base}$ = site-specific cumulative air temperature above a physiological base temperature (8C and 15.5C for *Echinochloa spp*. and *C. difformis*, respectively); t_{50} = time to 50% emergence; E_{rate} = slope; and RE = normally distributed, random error.

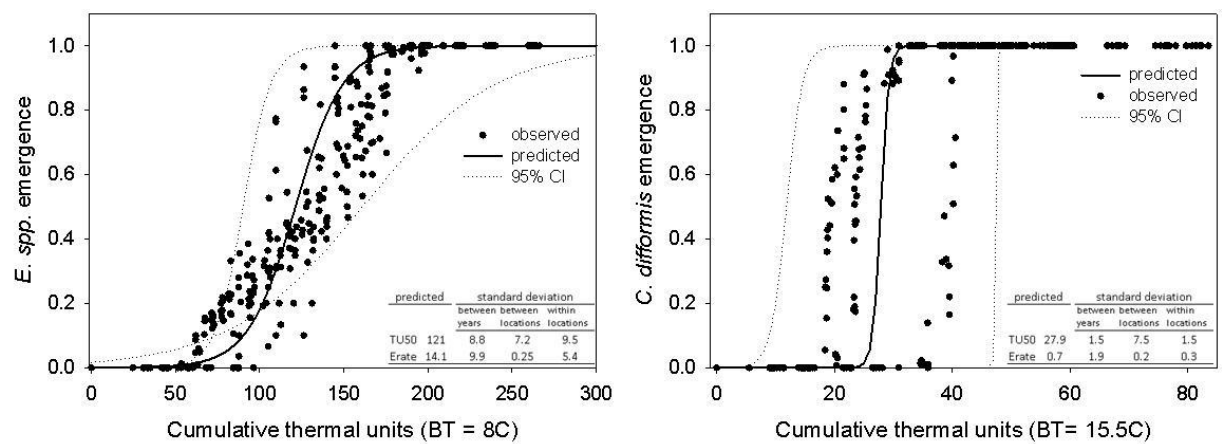

***Figure 2**. Echinochloa spp. and C. difformis emergence over two seasons (2010, 2011) in fields that were managed as spring-till stale seedbeds or drill-seeded. Sources of error as modeled via mixed nonlinear regression.*

For *Echinochloa spp*., variability in the time to 50% emergence was relatively small (6-8% of the predicted time) and consistent between years, locations and within fields (Figure 2). In contrast, the rate of emergence for *Echinochloa spp*. was much more variable between years and between locations within the same year (70% and 38% of predicted rate, respectively). Similarly, the predicted rate of emergence for *C. difformis* was more variable across years, locations and within fields than was the time to 50% emergence (Figure 2). Predicted time to 50% emergence was much more variable between locations (27% of predicted time) than between years and within fields (6%) for *C. difformis*. Multi-year simulations run using the above models will quantify spatial, inter-, and intra-annual variability of rate of emergence and time to 50% emergence for these two species. Identifying the magnitude of spatio-temporal variation of these parameters will enable us to determine how much accuracy is added to the emergence predictions by using site-specific temperatures. As the accuracy of the models improves, the importance of site-specific temperatures will increase.

As these models are further refined and their predictions are validated, we will begin using them to relate information on weed emergence patterns via a web-based tool. The tool would enable a grower to choose their location within the valley, their weed of interest, and the date of the first post-tillage flush of water. The tool would then return the real-time percent emergence (with confidence intervals) as well as a historical average time to 100% emergence (in days) for the chosen date. Although the tool is still under development, Figure 3 is included to roughly approximate how an interface might appear. Eventually, this interface could serve as a platform to deliver other temperature-based modeling related to California rice, whether weed-related or not.

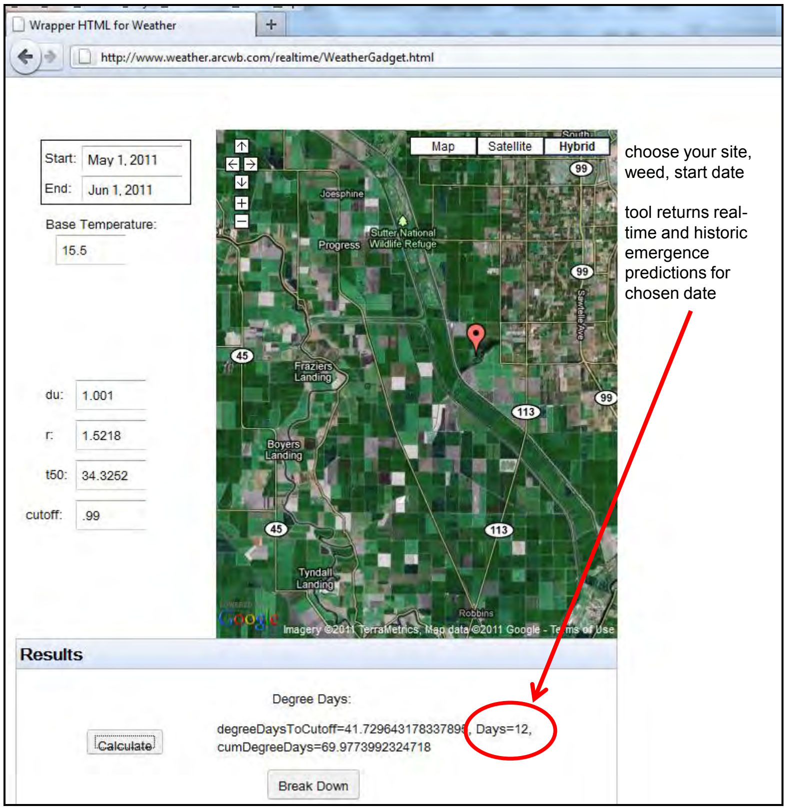

***Figure 3**. Beta version of web-based decision support tool for predicting Echinochloa spp. and C. difformis emergence using site-specific air temperatures.*

PUBLICATIONS:

Rice publications (2009 - 2011):

1. Linquist, B.A., J.E. Hill, R.G. Mutters, C.A. Greer, C. Hartley, M.D. Ruark and C. van Kessel. (2009). Assessing the necessity of surface applied pre-plant nitrogen fertilizer in rice systems. Agronomy Journal 101:906-915.
2. Ruark, M.D., B.A. Linquist, J. Six, C. van Kessel, C.A. Greer, R.G. Mutters, and J.E. Hill. (2010). Seasonal losses of dissolved organic carbon and total dissolved solids from rice production systems in northern California. Journal of Environmental Quality 39:304-313.
3. Lundy, M, A. Fisher, C. van Kessel, J.E. Hill, M. Ruark, and B.A. Linquist. 2010. Surface-applied calcium phosphate stimulates weed emergence in flooded rice. Weed Technology 24:295-302.
4. Linquist, B.A., K. Koffler, J.E. Hill and C.van Kessel. (2011). The impact of rice field drainage on nitrogen management. California Agriculture 65:80-84.

5. Linquist, B.A., M.D. Ruark, and J.E. Hill. (2011). Soil order and management practices control soil phosphorus fractions in managed wetland ecosystems. Nutrient Cycling in Agroecosystems 90:51-62.
6. Linquist, B.A. and M.D. Ruark. 2011. Re-evaluating diagnostic phosphorus tests for rice systems based on soil phosphorus fractions and field level budgets. Agronomy Journal103:501-508.
7. Krupa, M., R.G.M. Spencer, K.W. Tate, J. Six, C. van Kessel, and B.A. Linquist. 2011. Controls on dissolved organic carbon composition and export from rice dominated systems. Biogeochemistry Journal (doi:10.1007/s10533-011-9610-2).
8. Wild, P., C. van Kessel, J. Lundberg and B.A. Linquist. 2011. Nitrogen availability from poultry litter and pelletized organic amendments for organic rice production. Agronomy Journal 103:1284-1291.
9. M. Krupa, K.W. Tate; C. Kessel; N. Sarwar; B.A .Linquist. 2011. Water quality in rice-growing watersheds in a Mediterranean climate. Agriculture, Ecosystems and Environment 144:290-301.
10. Linquist, B., K.J. van Groenigen, M.A. Adviento-Borbe, C. Pittelkow, and C. van Kessel (2011). An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biology doi:10.1111/j.1365-2486.2011.02502.x

Is nitrate leaching a problem in California rice fields?

2012 Research

Bruce Linquist

Objective: To determine the extent of NO_3 leaching in California rice fields.

<u>Sites:</u>

Research will occur at 8 rice fields (same as those where we took soil samples to 2 m depth in 2010 to determine NO_3 leaching potential). These sites represent well rice fields in the Sacramento Valley rice region. Results from those sites show that NO_3 levels were less than 3 ppm down to 2 m. In 6 of the sites NO_3 levels were lower than 1 ppm below the rice root zone. These data suggest that NO_3 is not an issue but we did not measure leaching directly.

(1) <u>Soil sampling:</u>

In March/April 2012 we will return to these fields and take soil cores to a depth of 0.9 m. Cores will be kept in cold room until analysis. All samples will be analyzed within a week of sampling. Cores will be divided into the following sections: 0-15, 15-30, 30-60 and, 60-90 cm. Each of these soil fractions will be analyzed for NO_3, NH_4 and dissolved organic N (DON). This data will indicate the various forms of N within the soil profile.

(2) <u>Soil pore water sampling:</u>

In the approximate location of the soil core sample taken above we will set up three microplots that have been labeled with ^{15}N tracer. The ^{15}N will allow us to trace the movement of fertilizer N within the rice soil system. Importantly, we will be able to determine the amount and form of fertilizer N movement below the root zone. Before flooding we will apply ^{15}N fertilizer at a depth of 7.5 cm (3 inches) below the soil surface (similar to the depth N is normally applied). Pore-water samplers will be positioned at 7.5 cm (root zone) and 25 cm and 50 cm (below the root zone). Pore-water samples will be taken at regular intervals during the rice growing season (once a week for a month after planting and then once a month thereafter). Pore-water samples will be analyzed for NO_3, NH_4, DON and ^{15}N-NO_3.

(3) <u>Soil sampling for ^{15}N:</u>

At the end of the season (Oct/Nov 2012) a soil core will be taken to a depth of 1 m from each of the ^{15}N micro-plots discussed above. Cores will be divided into the portions (0-15, 15-30, 30-60 and, 60-90 cm) and analyzed for ^{15}N which will further quantify redistribution of N within and below the root zone.

Interpretation of results:

High NO_3 values below the root zone suggest the possibility of NO_3 leaching. However, NO_3 may also move to that location via lateral or upward flow. Soil cores taken to a depth of 0.9 m will indicate solid and liquid phase N distribution, and re-distribution of N applied in 2012. These data in turn can be analyzed to quantify the rate of NO_3 leaching through the root zone, and to quantify the proportion of this NO_3 that is from recently applied fertilizer.

Soil pore water sampling will allow us to describe fertilizer N dynamics in and below the root zone. Based on our understanding of N dynamics in rice systems we would expect:

1. Moderate NO_3 levels in the root zone before the field is flooded for planting due to buildup of soil NO_3 during spring. Additionally, we will have considerable NH_4 from the fertilizer N that was applied. Shortly after flooding we would expect to see NO_3 soil levels drop to near zero due to denitrification. If NO_3 increases in the below-root-zone layer, then leaching may be the cause.
2. NH_4 in the root zone will slowly decline over a two-month period due to plant uptake. The CEC of these soils is generally high, retarding movement of positively charged ions like NH4, so we do not expect to see large changes in NH_4 concentrations below the root zone.
3. Due to the presence of O_2 in the rhizosphere, there will be some nitrification resulting in NO_3 that could be leached; however much of this should be taken up by the crop. Analysis of pore water samples for ^{15}N-NO_3 will help to quantify fertilizer N is leaching below the root zone.

At the end of the season we will take soil samples to a depth of 0.9 m. ^{15}N below the root zone in these soil samples would indicate leaching of fertilizer N applied in 2012. Previous studies using this same approach found that fertilizer N remained in the top 7.5 cm where it was applied (Fig. 1).

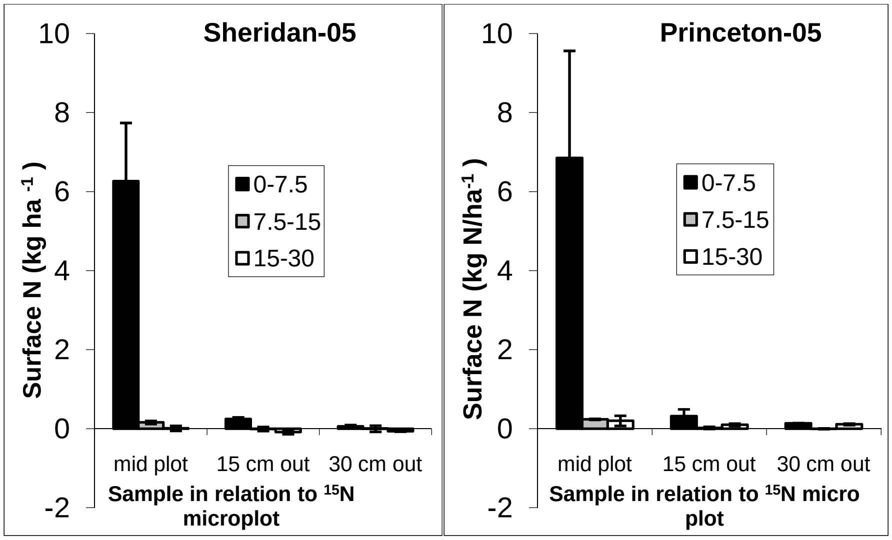

Figure 1. Fate of fertilizer N in soil profile in two rice fields. ^{15}N was applied as a starter fertilizer, broadcast to the soil surface at the beginning of the growing season. At the end of the season soil samples were taken to a depth of 30 cm from the center of the micro-plot, and 15 and 30 cm from the edge of the micro-plot to determine if there was lateral movement of N.

Appendix E-1
Shallow Groundwater Quality Data Summary

Shallow Groundwater Quality Data Summary

PREPARED FOR: California Rice Commission

PREPARED BY: Summer Bundy/CH2M HILL
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REVIEWED BY: Peter Lawson/CH2M HILL

DATE: September 5, 2012

Background

The California Rice Commission (CRC) is a Coalition Group under the Central Valley Regional Water Quality Control Board's (RWQCB) Irrigated Lands Regulatory Program (ILRP). The CRC Coalition Group boundary is the area in which rice is grown in the Sacramento Valley. The ILRP is entering a long-term phase that will include a groundwater monitoring and protection component. The CRC, in consultation with RWQCB staff, has undertaken a nitrogen groundwater quality data collection and analysis effort to aide in the development of technical recommendations for a rice-specific monitoring program.

As currently planned, the RWQCB will consider adoption of rice-specific Waste Discharge Requirements (WDR) in mid-2013. Along with adoption of the WDR, a rice-specific Monitoring and Reporting Program (MRP) will be issued to the CRC Coalition Group. The MRP will be based on the technical analysis of existing groundwater quality data in the rice-growing areas, information about hydrogeology and land use vulnerabilities areas, data gaps, and the programmatic requirements of the WDR.

This Technical Memorandum (TM) serves as Appendix E1 to the Groundwater Assessment Report (GAR). The GAR was developed to analyze and present existing groundwater quality data and identify data gaps to assist in developing a groundwater monitoring program under the RWQCB's Long-Term ILRP. This TM presents data from shallow groundwater monitoring wells that were collected by the U.S. Geological Survey (USGS) in the Sacramento Valley rice farmland.

TM Objective

The purpose of this TM is to present nitrogen groundwater quality data collected by the USGS at 28 shallow wells that were constructed to evaluate groundwater conditions in areas of the Sacramento Valley where rice is farmed. This TM focuses on shallow nitrogen concentrations, specifically, nitrite and nitrate concentrations, which are reported in units of milligrams per liter mg/L of nitrogen (NO2+NO3-N). Well information, raw data, maps, and trend plots are presented, followed by observations.

Study Area

Rice is grown in nine Sacramento Valley counties (Butte, Colusa, Glenn, Placer, Sacramento, Sutter, Tehama, Yolo, and Yuba). Rice is also farmed in counties outside the Sacramento Valley; however, the acreages are generally small and rice is not the dominant crop in these areas. Areas outside the Sacramento Valley are excluded from the CRC Coalition Group. For the purposes of the rice-specific IRLP, the study area is defined as the nine rice-producing counties in the Sacramento Valley.

Shallow Groundwater Well Information

In 1997, the USGS installed and sampled 28 shallow monitoring wells in rice areas in the Sacramento Valley as part of the National Water-Quality Assessment Program (NAWQA), also referred to as "RICE wells". The purpose of the study was to assess shallow groundwater quality and to determine whether any water quality impacts could be related to human activities and particularly rice agriculture. These 28 wells are considered representative of shallow groundwater conditions in the vicinity of the rice farmlands in which they are located.

The summary results of the 1997 study are published in a USGS Water-Resources Investigation Report entitled *Shallow Ground-Water Quality Beneath Rice Areas in the Sacramento Valley, California, 1997* (Dawson, 2001) and provisional raw data are available for download through the USGS NAWQA website (USGS, 2011).

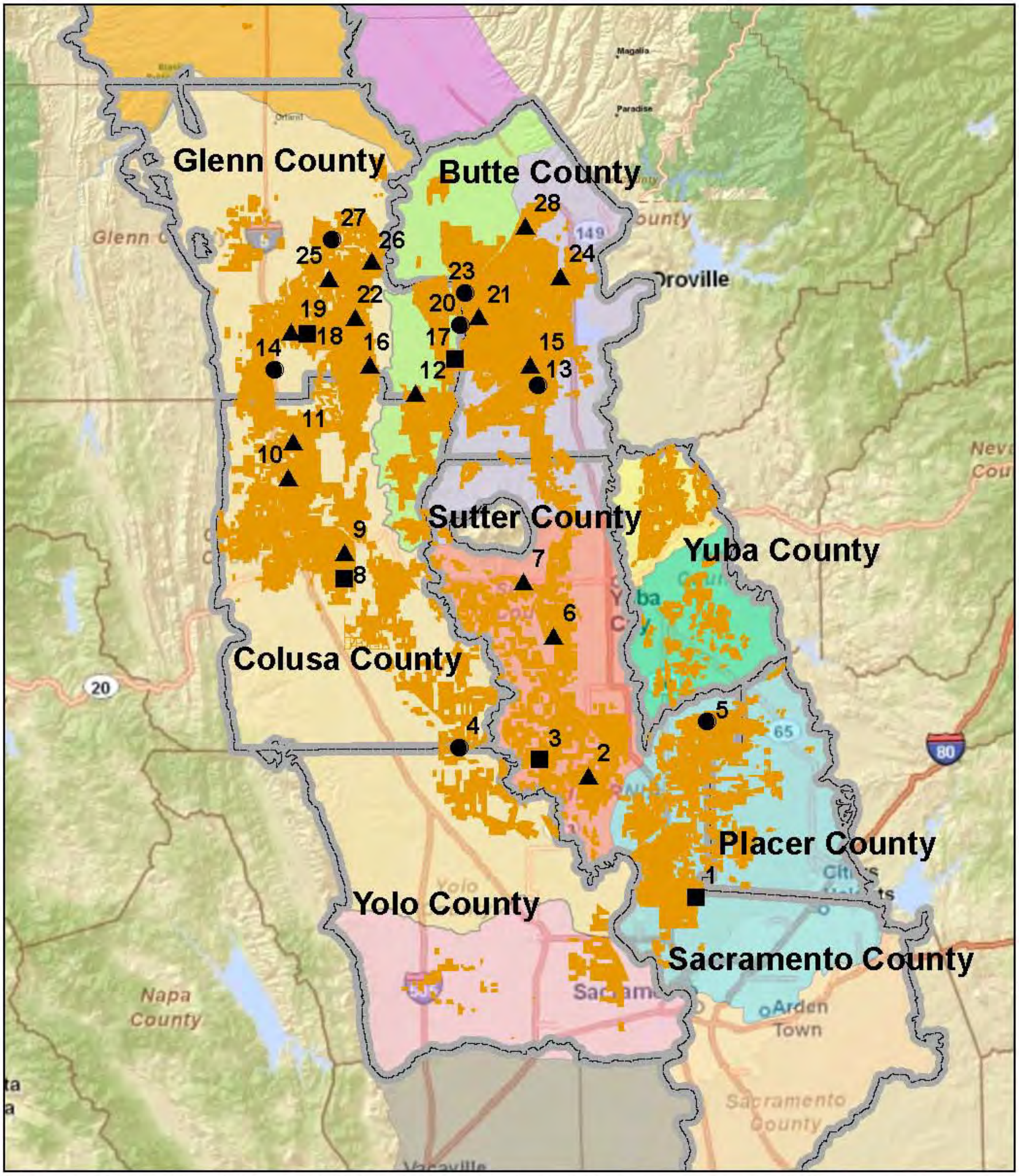
Since 1997, additional sampling has been conducted by USGS at some of the original 28 wells. A total of 84 samples have been collected from the 28 wells between 1997 and 2010. Five of the wells have been sampled an additional eight times since 1997, and 15 of the wells were sampled one additional time as part of the 2006 USGS Groundwater Ambient Monitoring & Assessment Program (Schmitt et al., 2008).

Well Locations

The 28 wells were sited by USGS using the guidelines established in Lapham et. al. (1997). Well selection criteria were used to ensure that wells selected for groundwater analyses accurately represent the water chemistry of the hydrogeologic system delineated for study. The criteria that were used to select the wells were:

- Located in deposits that make up the Sacramento Valley aquifer.
- Surrounded by at least 75% rice farmland within 1640 feet.

The USGS performed a GIS analysis to select the locations for well installation. Department of Water Resources (DWR) land use data showing lands farmed in rice was divided into 30 equal-area grids. A computer program randomly selected and ordered sites located in each of the 30 cells. The USGS contacted landowners and obtained permission for well drilling on private lands or within county rights of way. Field surveys were performed to confirm that the well site was surrounded by at least 75 percent rice farmland. In cases where permission could not be obtained near the randomly selected points, the search was expanded to other locations within the cell or adjacent cells. Seven wells were located in rights-of-way areas next to rice fields, and the remaining 21 wells were located adjacent to rice fields along field roads or rice equipment areas, or in farm or home yards surrounded by rice fields. Figure 1 shows the locations of the 28 shallow groundwater monitoring wells, rice lands, county lines, and groundwater basins, and indicates the frequency of monitoring for each site.



Data Sources: Counties (USGS); "RICE" Wells (CH2M HILL 2011); Groundwater Basins (California DWR); Basemap (ESRI 2011). Datum is NAD83.

Figure 1. Shallow "RICE" Well Locations

Well Construction Information

Detailed information is available for the wells, including altitude of ground surface, drilled well depth, extent of screened interval (top and bottom of perforation), and depth to groundwater. Table 1 includes the minimum, maximum, and average depths to top and bottom of the perforated well casing for the 28 wells. Well installation depths ranged from 28.9 to 49.9 feet below ground surface, and screened intervals varied. Figure 2 provides a graphic demonstration of the well depths, screened interval and average depth to water level measured over the period of record. Table 2 lists the well number used in Dawson (2001), the USGS and State well ID, location (latitude and longitude), well depth, depth of screened interval, and the location's corresponding groundwater basin and county.

TABLE 1
Maximum, Minimum and Average Perforation Depths

	Top of Perforation feet below land surface (meters below land surface)	**Bottom of Perforation feet below land surface (meters below land surface)**
Minimum	23 (7)	24 (7.3)
Maximum	40 (12.2)	44.9 (13.7)
Average	27.6 (8.4)	33.1 (10.1)

Well Sampling Results

Water Level Data

Water levels were recorded for each sampling event. Figure 3 shows the average depth to groundwater for each monitored well location. This map gives a spatial representation of the measured shallow groundwater levels in the rice producing areas of the Sacramento Valley.

The measurements recorded at the five wells that have been sampled nine times (wells 1, 3, 8, 17, and 18) are shown in Figure 4. Water levels in four of the five wells were very shallow, ranging from about 1.6 to 7.2 feet below land surface. Well 1 depth to groundwater is deeper, ranging from 11.5 to 29 feet. Well 1 also exhibits seasonal variations in groundwater levels. The water levels are shallower in the winter months and deeper in the summer months. This variation correlates with the climatic and land use variations in the valley and shows the response to recharge in the shallow groundwater zone. Seasonal variations are not as clear for the wells that have shallower groundwater levels than well 1.

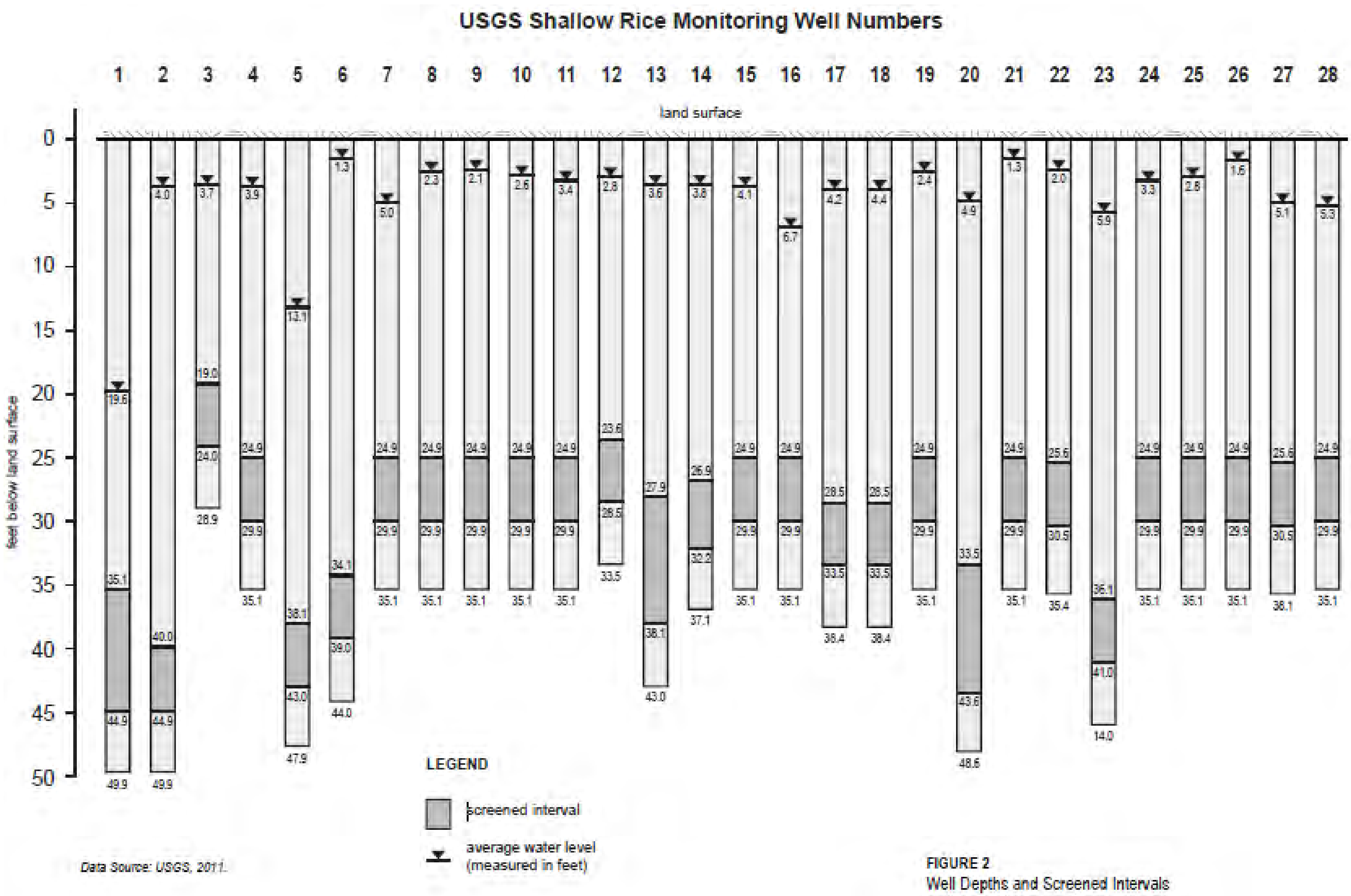


FIGURE 2
Well Depths and Screened Intervals
California Rice Commission Shallow Groundwater Data Technical Memo

TABLE 2
Well Characteristics
Source: Dawson, 2001

Dawson (2001) Well ID	USGS Well ID	DWR Well #	LAT	LON	Land Surface Altitude (fasl)	Well depth (fbls)	Screened interval (fbls)	Max Nitrate + Nitrite as N	Min Nitrate + Nitrite as N	Number of Nitrate Samples (1991 through 2010)	Number of Results >0.5 times MCL and < MCL (years)	Basin	County
1	384330121293901	010N004E13F001M	38°43'30.42"N	121°29'43.59"W	22.0	49.9	35.1-44.9	6.22	2.49	9	1 (1997)	North American	Sacramento
2	385314121401701	012N003E18H001M	38°53'12.90"N	121°40'21.88"W	22.0	49.9	40.0-44.9	<0.06	<0.05	2	0	Sutter	Sutter
3	385431121451401	012N002E09B002M	38°54'30.56"N	121°45'18.24"W	22.0	28.9	19.0-24.0	5.97	0.65	9	2 (2004, 2008)	Sutter	Sutter
4	385528121532001	012N001E05C001M	38°55'30.19"N	121°53'25.14"W	23.0	35.1	24.9-29.9	<0.05	--	1	0	Colusa	Yolo
5	385720121282401	013N004E24Q001M	38°57'20"N	121°28'24"W	66.9	47.9	38.1-43.0	1.13	--	1	0	North American	Sutter
6	390416121433601	014N002E10R001M	39°04'15.43"N	121°43'39.14"W	36.1	44.0	34.1-39.0	0.92	0.88	2	0	Sutter	Sutter
7	390832121463601	015N002E20D001M	39°08'32.69"N	121°46'38.78"W	41.0	35.1	24.9-29.9	2.35	1.72	2	0	Sutter	Sutter
8	390856122044301	015N002W16R001M	39°08'54.05"N	122°04'45.38"W	55.1	35.1	24.9-29.9	0.99	0.53	9	0	Colusa	Colusa
9	391059122043601	015N002W03E001M	39°10'59.40"N	122°04'41.10"W	48.9	35.1	24.9-29.9	<0.06	<0.05	2	0	Colusa	Colusa
10	391653122101401	017N003W35M001M	39°16'54.46"N	122°10'18.83"W	74.1	35.1	24.9-29.9	0.28	0.17	2	0	Colusa	Colusa
11	391947122094501	017N002W14G001M	39°19'44.4"N	122°9'46.79"W	80.1	35.1	24.9-29.9	0.33	0.08	2	0	Colusa	Colusa
12	392328121571501	018N001W27B001M	39°23'27.50"N	121°57'19.11"W	67.9	33.5	23.6-28.5	0.04	<0.05	2	0	West Butte	Glenn
13	392358121450301	018N002E21G001M	39°23'57.38"N	121°45'00.52"W	81.0	43.0	27.9-38.1	0.56	--	1	0	East Butte	Butte
14	392524122113401	018N003W09R001M	39°25'22.92"N	122°11'37.58"W	96.1	37.1	26.9-32.2	1.22	--	1	0	Colusa	Glenn
15	392542121452501	018N002E09L001M	39°25'35.40"N	121°45'41.96"W	86.0	35.1	24.9-29.9	0.8	0.47	2	0	East Butte	Butte
16	392545122015201	018N002W12G002M	39°25'44.41"N	122°01'56.53"W	78.1	35.1	24.9-29.9	0.36	0.28	2	0	Colusa	Glenn
17	392604121531801	018N001E08D001M	39°26'05.43"N	121°53'18.16"W	71.9	38.4	28.5-33.5	0.08	0.02	9	0	West Butte	Glenn
18	392810122080901	019N003W25R001M	39°28'14.87"N	122°08'12.71"W	97.1	38.4	28.5-33.5	0.85	0.52	9	0	Colusa	Glenn
19	392824122091401	019N003W25E001M	39°28'22.76"N	122°09'51.42"W	98.1	35.1	24.9-29.9	0.97	0.3	2	0	Colusa	Glenn
20	392848121523901	019N001E20R001M	39°28'47.46"N	121°52'43.45"W	83.0	48.6	33.5-43.6	0.38	--	1	0	West Butte	Glenn
21	392924121504801	019N001E22B001M	39°29'24.94"N	121°50'51.37"W	86.0	35.1	24.9-29.9	1.83	1.64	2	0	East Butte	Butte
22	392931122031701	019N002W23E001M	39°29'29.75"N	122°03'21.01"W	80.1	35.4	25.6-30.5	<0.06	<0.05	2	0	Colusa	Glenn
23	393119121521001	019N001E09C001M	39°31'19.16"N	121°52'12.66"W	90.9	45.9	36.1-41.0	0.21	--	1	0	West Butte	Glenn
24	393230121422201	020N002E35J002M	39°32'29.95"N	121°42'27.88"W	124.0	35.1	24.9-29.9	0.21	< 0.06	2	0	East Butte	Butte
25	393235122055301	020N002W32J001M	39°32'34.52"N	122°05'56.82"W	107.9	35.1	24.9-29.9	3.82	3.12	2	0	Colusa	Glenn
26	393353122013501	020N002W25A001M	39°33'52.51"N	122°01'39.34"W	96.1	35.1	24.9-29.9	2.25	0.4	2	0	Colusa	Glenn
27	393538122053201	020N002W16D001M	39°35'37.92"N	122°05'40.19"W	125.0	35.4	25.6-30.5	2.34	--	1	0	Colusa	Glenn
28	393630121455401	020N002E08A001M	39°36'29.27"N	121°45'56.86"W	136.2	35.1	24.9-29.9	1.84	0.27	2	0	East Butte	Butte

Notes: Green indicates that well was sampled 9 times, yellow indicates that the well was sampled twice.
The datum for LAT/LON is NAD83.

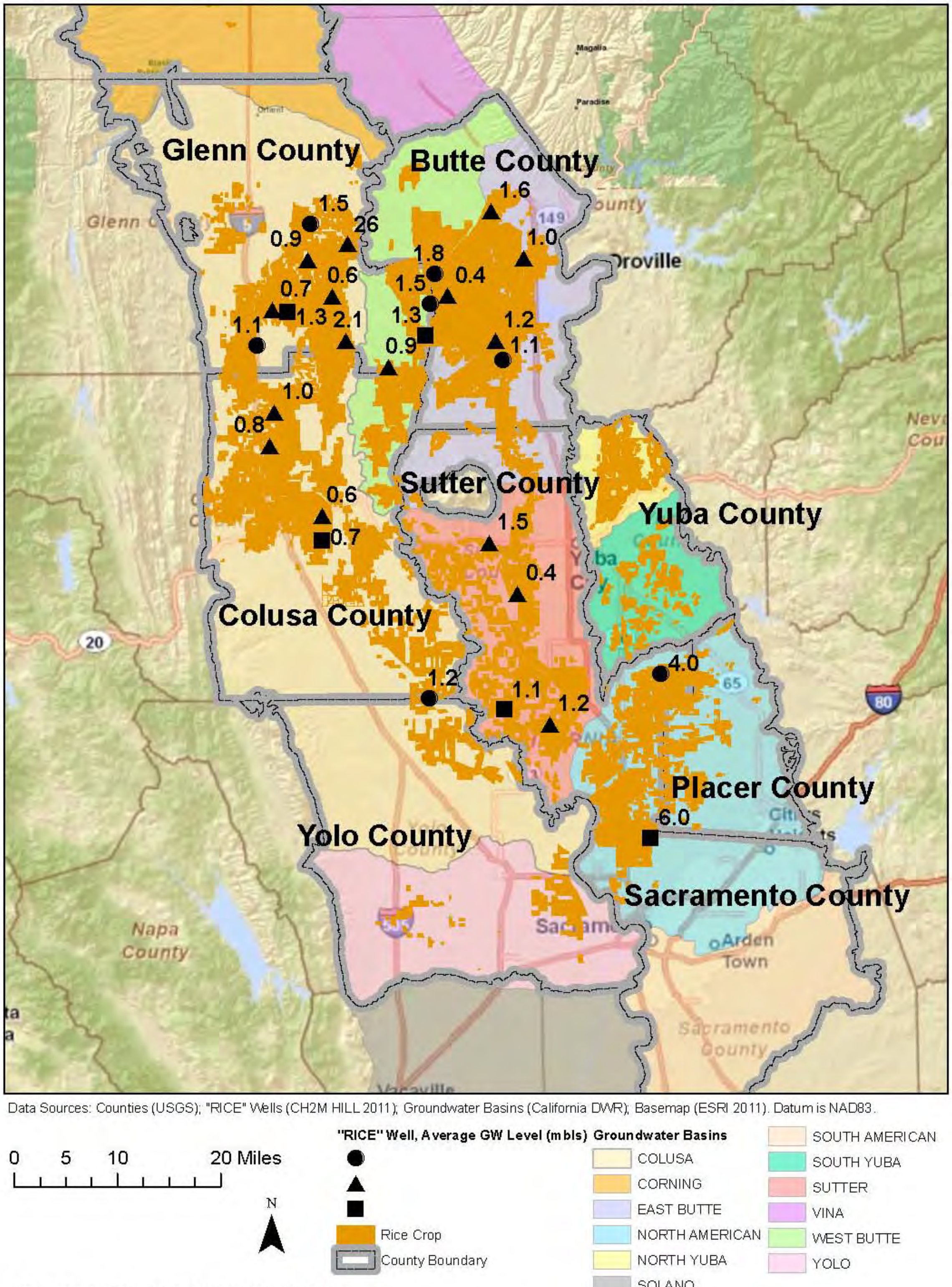


Figure 3. Shallow "RICE" Wells, Average Groundwater Level (mbls)

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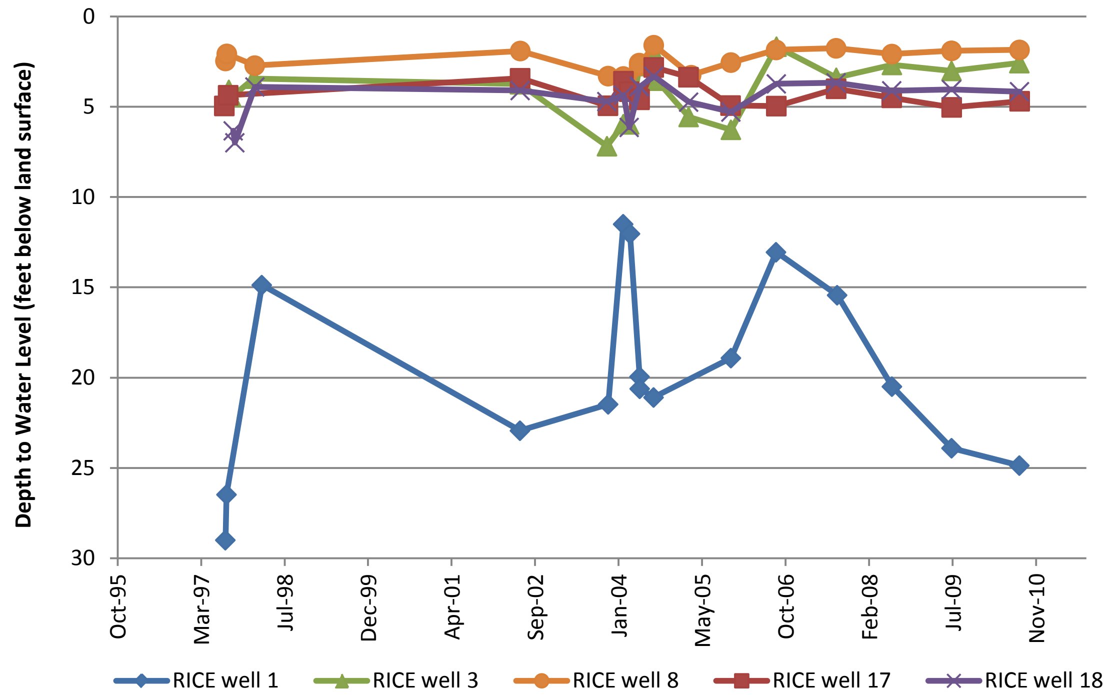
Figure 4. Depth to Water Level at Selected RICE Wells



Water Quality Data

Table 3 presents the raw NO2+NO3-N data collected at each of the 28 wells since 1997. Figure 4 presents the maximum concentration measured at each well over the period of record. The California Department of Public Health has established MCLs for nitrate in drinking water. The MCLs, in 22 CCR §63341, are 45 milligrams per liter (mg/L) for nitrate as NO3 (equivalent to 10 mg/L for nitrate as N), 10 mg/L for nitrate plus nitrite as N, 1 mg/L for nitrite as N. Results less than one-half the MCL (nitrate plus nitrite as N) are shown on Figure 4 in green, and results between one-half the MCL (5 mg/L NO2+NO3-N) and the MCL are shown in yellow. No results exceeded the MCL.

TABLE 3
Reported Nitrate Concentrations

Dawson (2001) Well ID	Nitrite + Nitrate Concentration NO2+NO3-N (mg/L)								
	Aug & Sept 1997	June 2002	Nov 2003	Feb 2004	May 2004	Aug 2004	Aug 2006	Jul 2008	Aug 2010
1	**6.22**	4.33	3.76	3.65	3.91	3.61	2.92	2.92	2.49
2	< 0.05						< 0.06		
3	3.15	2.42	2.75	2.17	2.82	a	3.77	**5.97d**	0.65
4	< 0.05								
5	1.13								
6	0.92						0.88		
7	2.35						1.72		
8	0.56	0.53	0.67	0.60	0.61	0.66	0.88	0.99	**0.99**
9	< 0.05						< 0.06		
10	0.28						0.17		

TABLE 3
Reported Nitrate Concentrations

Dawson (2001) Well ID	Nitrite + Nitrate Concentration NO2+NO3-N (mg/L)								
	Aug & Sept 1997	June 2002	Nov 2003	Feb 2004	May 2004	Aug 2004	Aug 2006	Jul 2008	Aug 2010
11	0.328						0.084		
12	< 0.05						E 0.04		
13	0.56								
14	1.22								
15	0.8						0.47		
16	0.28						0.36		
17	**0.08**	< 0.05	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	E 0.02	< 0.04
18	0.63	**0.85**	0.76	0.52	0.77	0.78	0.71	0.72	0.63
19	0.97						0.3		
20	0.38								
21	1.64						1.83		
22	< 0.05						< 0.06		
23	0.21								
24	0.21						<0.06		
25	3.12						3.82		
26	2.25						0.4		
27	2.34								
28	1.84						0.27		

Source: USGS 2011

Notes:
a The value reported for the August 2004 sampling of Well 3 was excluded from this analysis, due to a comment in the raw data download that reported that this sample was compromised by a broken bottle cap.
Data flags (reported by USGS):
E – "estimated"
d – "diluted sample: method high range exceeded"
< – "less than"

Figure 6 shows the NO2+NO3 trends for the five wells that have been sampled nine times. The following summarizes trends for each well:

- **Well 1** had a peak concentration of 6.22 mg/L in 1997, and has shown a general decline in concentration since then. The most recent concentration measured at Well 1 was 2.49 mg/L.
- **Well 3** concentrations ranged from 2.17 to 2.82 mg/L through January 2004. From 2006 to 2008, concentrations increased from 3.77 to 5.79 mg/L, reaching a peak concentration slightly above the half MCL value of 5 mg/L. The 2011 concentration was 0.65 mg/L, which is a significant decrease from the 2008 concentration.
- **Well 8** samples have all resulted in concentrations less than 1 mg/L. A concentration of 0.56 mg/L was measured in 1997, and the most recent measurement was 0.99 mg/L. The peak concentration is also 0.99 mg/L.
- **Well 17** showed a concentration of 0.08 mg/L in 1997. Since 1997, all results have been less than the detection limit.

- **Well 18** samples have all resulted in concentrations less than 1 mg/L. A concentration of 0.63 mg/L was measured in 1997, and the most recent measurement was 0.63 mg/L. The peak concentration, measured in 2002, was 0.86 mg/L.

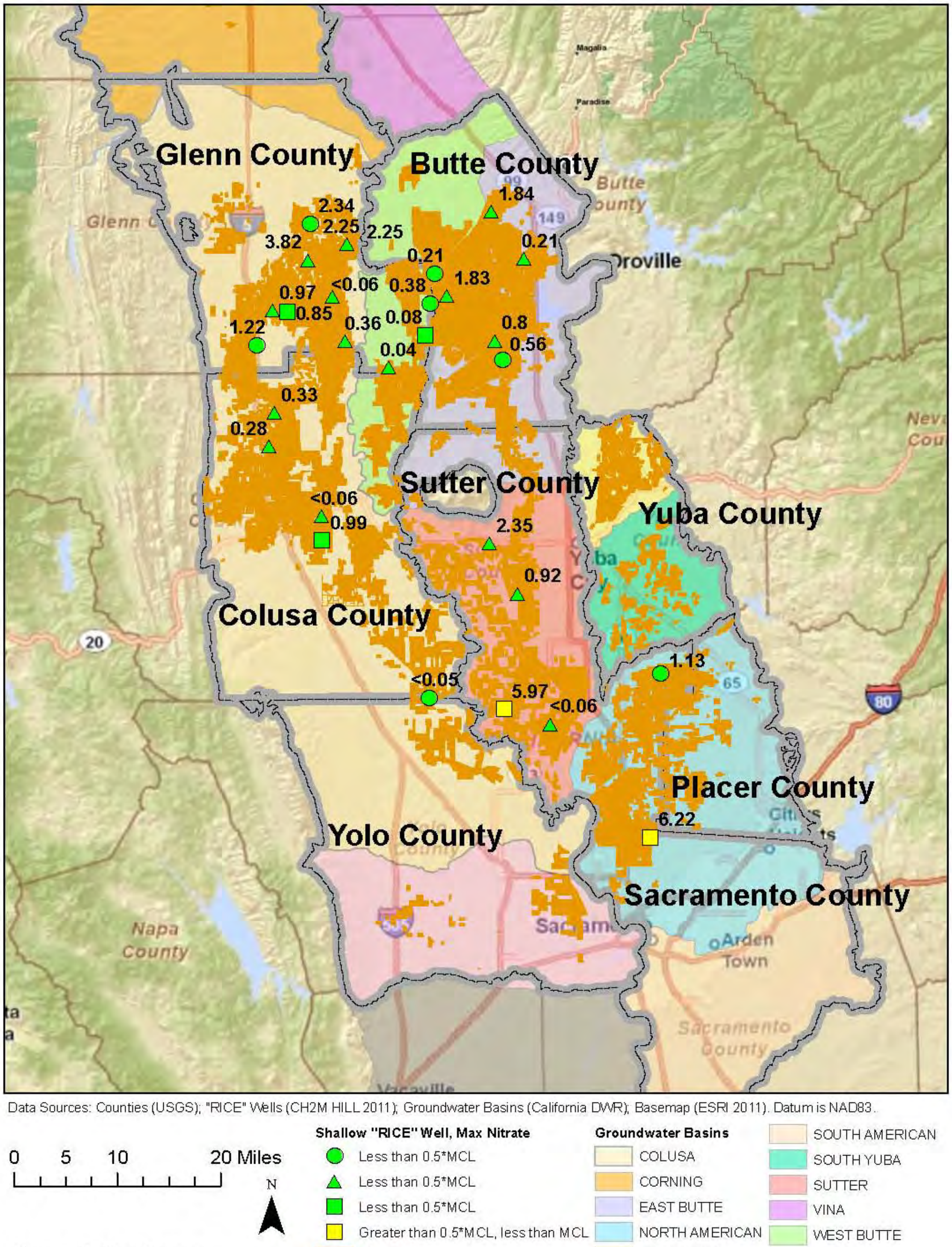


Figure 5. Maximum NO2+NO3-N Concentration (mg/L)

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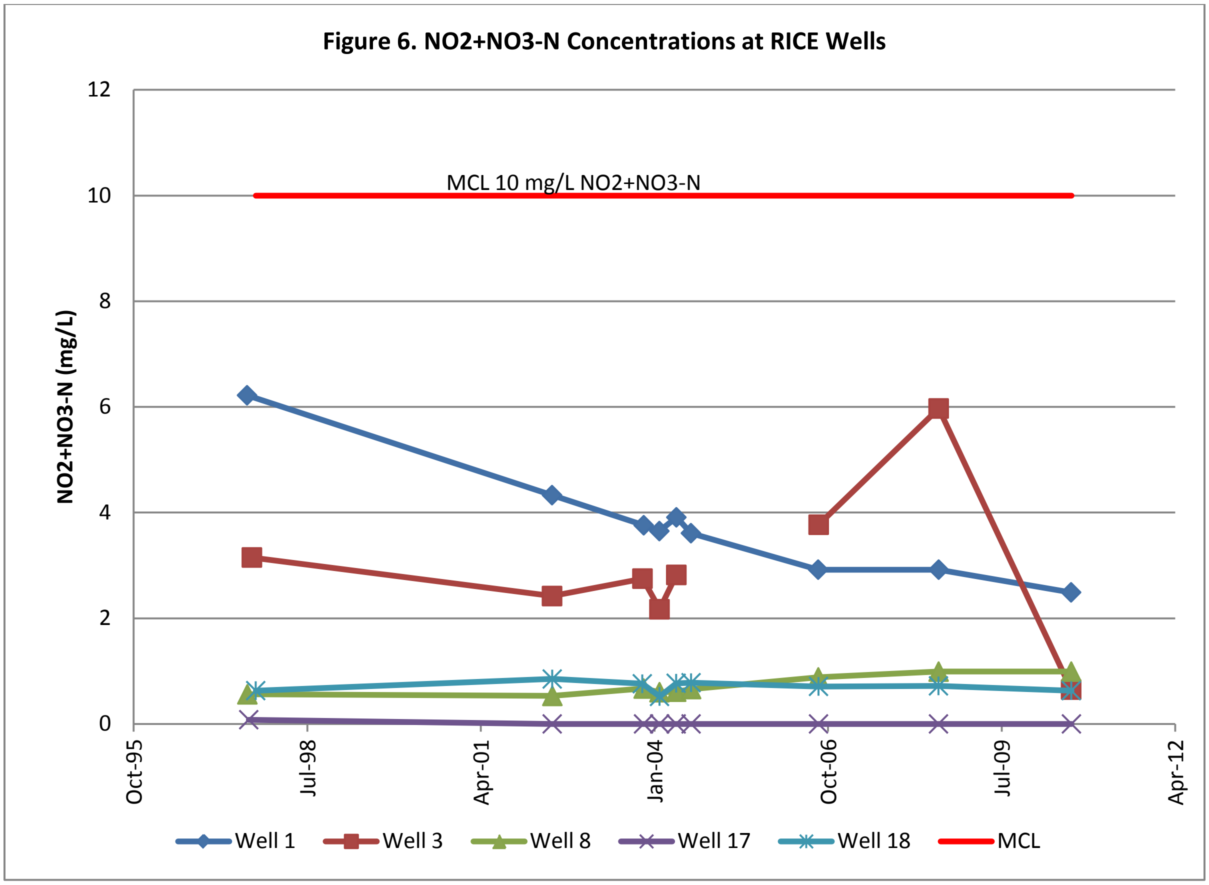

Observations

This USGS dataset is the most comprehensive currently available to characterize shallow groundwater conditions in Sacramento Valley rice growing areas. A few observations can be made concerning water levels, water quality, and spatial representation.

Water Levels

One of the objectives of the ILRP is to protect groundwater quality. By reviewing shallow groundwater quality data, the risks posed by rice agriculture to deeper groundwater, which could potentially be used as domestic or municipal supply, can be evaluated.

The hydrogeology in the Sacramento Valley rice areas is not well characterized in the literature. What is known is that rice is primarily grown in heavy clay soils with low permeability, due to their ability to maintain the flooded irrigation conditions that are necessary for rice agriculture. Rice crops remain flooded from about April through fall of each year, are drained in fall, and are re-flooded following harvest for rice decomposition. The screened intervals of the RICE wells ranged from 19 to 44.9 feet and the water level measurements ranged from 1.6 to 26.2 feet below land surface. These values represent very shallow groundwater conditions in the rice areas. It is anticipated that if rice farming has an impact on groundwater quality, this shallow zone would show the greatest impact. Therefore, the water quality sampling of this shallow groundwater provides a good indication of the potential impacts to the overall groundwater system from rice agriculture.

Water Quality

The data generally show low concentrations of nitrate in the sampled shallow groundwater wells sited near rice farmlands. Of 84 samples collected since 1997, two samples were greater than one-half the MCL (Well 1 and Well 3) and no detections were observed at levels at or above the MCL. No direct correlation was observed between groundwater levels and nitrate concentration in these shallow wells.

Spatial Representation

Table 4 shows the number of groundwater wells that are located within each groundwater basin. The Colusa basin is the most intensively sampled of the basins, with 13 of 28 wells, including two wells that were sampled nine times. In addition, four groundwater basins were represented by at least two wells (East Butte, West Butte, Sutter, North American), and three of these were sampled nine times (West Butte, Sutter, North American). Four of the wells located in East Butte were sampled twice, and one was sampled once. The North Yuba, South Yuba, and Yolo groundwater basins do not include shallow RICE wells.

TABLE 4
Locations of Shallow Groundwater Monitoring Wells

Groundwater Basin	Corresponding Counties	Number of Shallow RICE Groundwater Wells Total	Number of Shallow RICE Groundwater Wells Sampled 9 Times
Colusa	Glenn, Colusa	13	2
East Butte	Butte, Sutter	5	0
West Butte	Butte	4	1
Sutter	Sutter	4	1
North American	Sutter, Placer, Sacramento	2	1
North Yuba	Yuba	0	0
South Yuba	Yuba	0	0
Yolo	Colusa, Yolo	0	0
	TOTALS	**28**	**5**

References

Dawson, B.J.M. 2001. Shallow Ground-Water Quality Beneath Rice Areas in the Sacramento Valley, California, 1997. U.S. Geological Survey Water-Resources Investigations Report 01-4000. National Water-Quality Assessment Program. Available at http://ca.water.usgs.gov/archive/reports/wrir014000/

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard procedures for studies of ground-water quality: Selection and installation of wells, and supporting documentation: U.S. Geological Survey Water-Resources Investigation Report 96-4233, 110 p.

Schmitt, S.J., Fram, M.S., Milby Dawson, B.J., Belitz, K., 2008, Ground-water quality data in the middle Sacramento Valley study unit, 2006—results from the California GAMA program: U.S. Geological Survey Data Series 385, 100 p. Available at http://pubs.usgs.gov/ds/385

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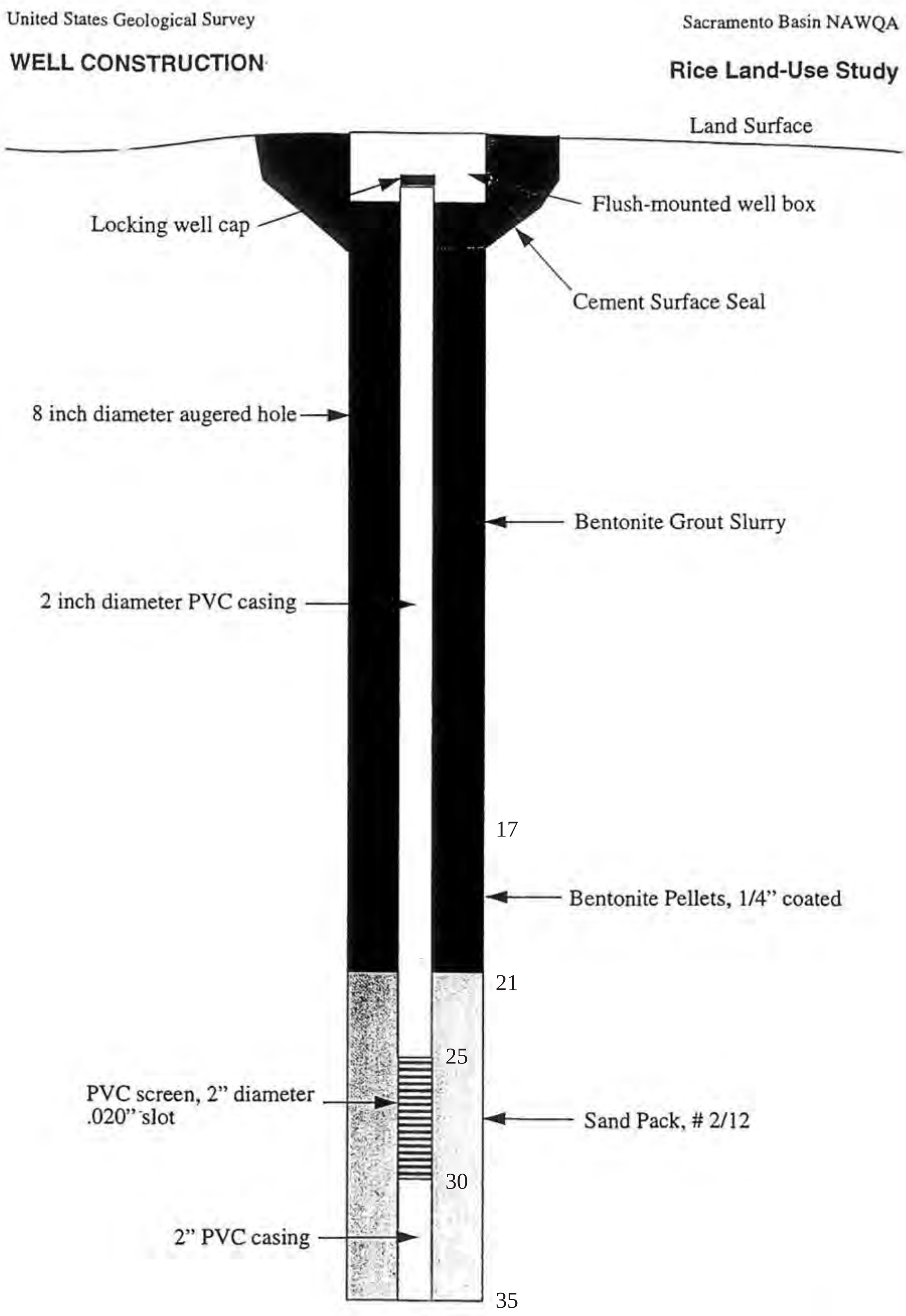
Appendix E-2
USGS Rice Wells Construction Detail Example



APPENDIX E-2
USGS Rice Well Construction Detail
Rice-specific Groundwater Assessment Report

Note: Depth below ground surface measured in feet.

Appendix E-3
Land Use Surrounding USGS Rice Wells

APPENDIX E-3

Land Use Surrounding the USGS Rice Wells

The purpose of this appendix is to provide a summary of pertinent features of each of the USGS Rice Wells, including:

- Location relative to the rice fields
- Other land uses besides rice farming surrounding the well, such as
    - agricultural uses other than rice
    - non-agricultural uses (e.g. riparian vegetation)
    - urban and rural residential developments.

The relative location of each well on the groundwater flow path was assessed by reviewing regional groundwater contour maps (see Appendix C) and the regional locations of the wells (Figure 3-1). The nitrate plus nitrite concentrations as monitored and reported by the USGS for the wells are also summarized from Appendix E1. The figures in this appendix show land use surrounding each well within a few miles. These characteristics are used to confirm that Rice Wells adequately represent groundwater quality beneath rice fields.

Rice Well 1

- Located in a rice field but closer to the boundary with rice fields on the north and west sides of the well. Approximately 1,900 feet to the east of the well, dispersed unused land and urban development and about 1,900 feet to the northwest, moderate expanse of wild, non-agricultural land.
- Downgradient of other land uses and urban areas.
- Of the nine groundwater samples between 1997 and 2010, the maximum NO2+NO3-N concentration detected was 6.22 mg/L in the first monitoring event in 1997, while all other detections since then were less than 5 mg/L. This highest detection of 6.22 mg/L was also the maximum concentration detected in a USGS Rice Well.
- Well 1 might represent not only rice farming impacts, but also the influence of other upgradient land uses.

Rice Well 2

- Located in and surrounded by rice fields.
- Downgradient of Sutter Basin rice fields.
- Both groundwater samples in 1997 and 2006 show less than 0.06 mg/L NO2+NO3-N.
- Well 2 represents rice farming.

Rice Well 3

- Located in and surrounded by rice fields.
- Downgradient of Sutter Basin rice fields.

- Of the nine groundwater samples between 1997 and 2010, the maximum NO2+NO3-N concentration detected was 5.97 mg/L in the monitoring event in 2008. All other detections were less than 5 mg/L.
- Well 3 represents rice farming.

Rice Well 4

- Located in and surrounded by rice fields.
- Close proximity to and downgradient of other agricultural fields.
- Sampled only once in 1997 with a reported NO2+NO3-N concentration of less than 0.05 mg/L.
- Well 4 might represent not only rice farming impacts, but also the influence of other upgradient land uses.
- Currently abandoned.

Rice Well 5

- Located in and surrounded by a small area of rice fields. Approximately 5,000 feet to the north, vast stretch of other agricultural land use.
- Upgradient of North American Basin rice fields.
- Sampled only once in 1997 with a reported nitrate concentration of 1.13 mg/L.
- Well 5 might represent not only rice farming impacts, but also the influence of other upgradient land uses.
- Currently abandoned.

Rice Well 6

- Located in and surrounded by a small area of rice fields to the north and south.
- Close proximity to and downgradient of a vast area of other agricultural fields to the east and urban development of Yuba City to the northeast.
- Sampled twice in 1997 and 2006 with reported concentrations of less than 1 mg/L.
- Well 6 might represent not only rice farming impacts, but also the influence of other upgradient land uses.

Rice Well 7

- Located in a rice field but mostly bordered by rice fields tot eh south. Vast area of unused and other agricultural land to the north and urban development of Sutter to the northeast.
- Upgradient of Sutter Basin rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 2.35 mg/L.
- Well 7 might represent not only rice farming impacts, but also the influence of other upgradient land uses.

Rice Well 8

- Located in and surrounded by rice fields. Moderate expanse of wild, non-agricultural land within 5,500 feet to the east (Colusa National Wildlife Refuge).

- Downgradient of Colusa Basin rice fields.
- All nine samples between 1997 and 2010 showed nitrate detections of less than 1 mg/L.
- Well 8 represents rice farming.

Rice Well 9

- Located in and surrounded by rice fields. Well 9 is located approximately 12,700 feet directly north of Well 8 and is characterized by similar surrounding land uses.
- Downgradient of Colusa Basin rice fields.
- Sampled twice in 1997 and 2006 with reported nitrate concentrations of less than 1 mg/L.
- Well 9 represents rice farming.

Rice Well 10

- Located in and surrounded predominantly by rice fields. Relatively close to the Coast Range on the west side. Close proximity to the town of Maxwell to the west. Moderate expanse of wild, non-agricultural area to the northeast (Delevan National Wildlife Refuge).
- Upgradient of Colusa Basin rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 0.28 mg/L.
- Well 10 represents rice farming.

Rice Well 11

- Located in and surrounded predominantly by rice fields. Relatively close to the Coast Range on the west side. Close proximity to the town of Maxwell to the west. Vast expanse of wild, non-agricultural area to the north and a moderate area to southeast (Sacramento National Wildlife Refuge and Delevan National Wildlife Refuge).
- Upgradient of Colusa Basin rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 0.33 mg/L.
- Well 11 represents rice farming.

Rice Well 12

- Bordered by a vast area of other agricultural land use and little rice to the north and rice fields to the south.
- Upgradient of rice fields.
- Sampled twice in 1997 and 2006 with nitrate concentrations of less than 0.05 mg/L.
- Well 12 might be influenced by land uses other than rice farming.

Rice Well 13

- Located in and surrounded predominantly by rice fields. Relatively close to the Sierra foothills on the east side. Large areas of other agricultural land use to the east.
- Downgradient of rice fields.
- Sampled only once in 1997 with a reported nitrate concentration of 0.56 mg/L.

- Well 13 might be influenced by land uses other than rice farming.
- Currently abandoned.

Rice Well 14

- Surrounded by rice fields to the west and by a vast area of wild and other agricultural land to the east (including Sacramento National Wildlife Refuge).
- Downgradient of rice fields.
- Sampled only once in 1997 with a reported nitrate concentration of 1.22 mg/L.
- Well 14 represents rice farming since it is located downgradient of rice fields.
- Currently abandoned.

Rice Well 15

- Located in and surrounded by rice fields, predominantly to the north and west. Relatively close to the Sierra foothills on the east side and some urban developments (notably Oroville). Approximately 10,000 feet northwest of well 13 and is characterized by similar surrounding land uses.
- Downgradient of rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 0.8 mg/L.
- Well 15 represents rice farming since it is located downgradient of rice fields.

Rice Well 16

- Located in and predominantly surrounded by rice fields. Close proximity to a small area of other agricultural land uses to the northeast. Sacramento River is to the east.
- Downgradient of rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 0.36 mg/L.
- Well 16 represents rice fields since it is located downgradient of rice fields.

Rice Well 17

- Located in a rice field but bounded by a moderate stretch of wild, non-agricultural land to the north and south of the well.
- Downgradient of East Butte Basin rice fields.
- Sampled nine times between 1997 and 2010 with a detected maximum nitrate concentration of 0.08 mg/L.
- Well 17 represents rice farming.

Rice Well 18

- Located in and predominantly surrounded by rice fields; moderate stretch of wild, non-agricultural land within approximately 7,000 feet to the southwest (Sacramento National Wildlife Refuge).
- Downgradient of rice fields.

- Sampled nine times between 1997 and 2010 with a reported maximum nitrate concentration of 0.85 mg/L.
- Well 18 represents rice farming.

Rice Well 19

- Well 19 is approximately 7,800 feet west of Well 18 and is characterized by similar surrounding land uses; moderate stretch of wild, non-agricultural land within about 3,500 feet to the south (Sacramento National Wildlife Refuge).
- Downgradient of rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 0.3 mg/L.
- Well 19 represents rice farming.

Rice Well 20

- Located in a rice field but bounded by a small area of wild, non-agricultural land beyond which it is surrounded predominantly by rice fields.
- Downgradient of East Butte rice fields.
- Sampled only once in 1997 with a reported nitrate concentration of 0.38 mg/L.
- Well 20 represents rice farming.

Rice Well 21

- Located in and predominantly surrounded by rice fields.
- Downgradient of East Butte rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 1.83 mg/L.
- Well 21 represents rice farming.

Rice Well 22

- Located in and predominantly surrounded by rice fields.
- Downgradient of rice fields.
- Sampled twice in 1997 and 2006 with both detected nitrate concentrations of less than 0.06 mg/L.
- Well 22 represents rice farming.

Rice Well 23

- Located in and predominantly surrounded by rice fields. A small area of wild, non-agricultural land to the southwest.
- Downgradient of Butte Basin rice fields.
- Sampled only once in 1997 with a reported nitrate concentration of 0.21 mg/L.
- Well 23 represents rice farming.
- Currently abandoned.

Rice Well 24

- Located in and predominantly surrounded by rice fields; close to the Sierra foothills to the east; small area of other agricultural land use approximately 3,000 feet to the north.
- Upgradient of East Butte rice fields.
- Sampled twice in 1997 and 2006 with a maximum and most recent nitrate concentration of 2.4 mg/L.
- Well 24 might be influenced by land uses other than rice farming.

Rice Well 25

- Not located in a rice field but predominantly surrounded by rice fields.
- Upgradient of rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 3.82 mg/L.
- Well 25 represents rice farming.

Rice Well 26

- Located in a rice field and rice fields are largely present to the west. Sacramento River to the east.
- Downgradient of rice fields and some other agricultural land use.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 2.25 mg/L and a recent detection of 0.4 mg/L.
- Well 26 might be influenced by land uses other than rice farming.

Rice Well 27

- Located in and surrounded by some rice fields; in the vicinity of large other agricultural land uses to the west.
- Upgradient of rice fields and some other agricultural land uses.
- Sampled only once in 1997 with a reported nitrate concentration of 2.34 mg/L.
- Well 27 might be influenced by land uses other than rice farming.

Rice Well 28

- Located in and surrounded by some rice fields; close to the Sierra foothills to the east; large area of other agricultural land use within 5,000 feet both to the north and west.
- Upgradient of East Butte rice fields.
- Sampled twice in 1997 and 2006 with a maximum nitrate concentration of 1.84 mg/L.
- Well 28 might be influenced by land uses other than rice farming.

APPENDIX E-3
Land Use Surrounding USGS Rice Well 1
CRC Groundwater Assessment Report

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APPENDIX E-3
Land Use Surrounding USGS Rice Well 2
CRC Groundwater Assessment Report

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APPENDIX E-3
Land Use Surrounding USGS Rice Well 3
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North

0 1,250 2,500
Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 4
CRC Groundwater Assessment Report

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APPENDIX E-3
Land Use Surrounding USGS Rice Well 5
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North

0 1,250 2,500
Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 6
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 7
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 8
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 9
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 10
CRC Groundwater Assessment Report

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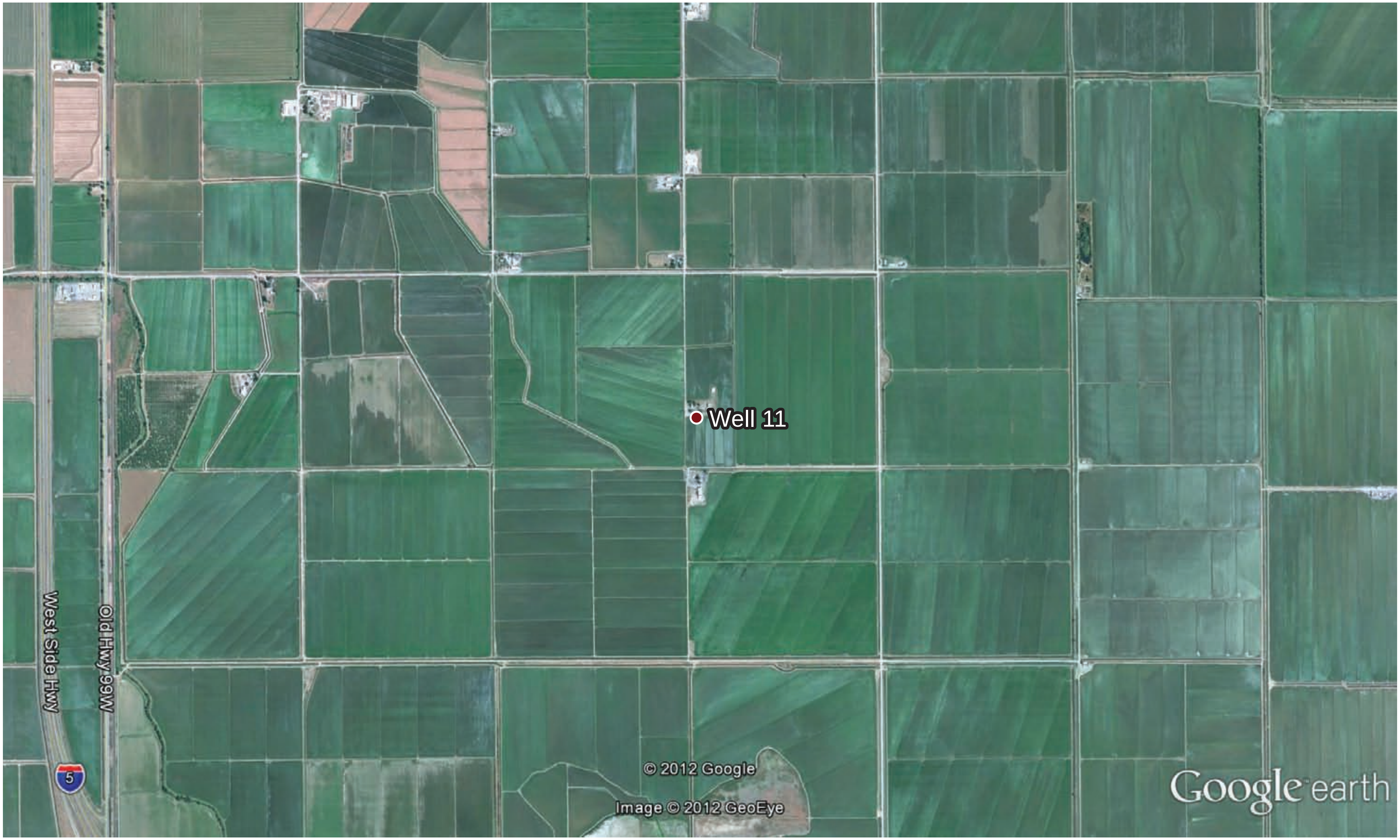

North

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Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 11
CRC Groundwater Assessment Report

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APPENDIX E-3

Land Use Surrounding USGS Rice Well 12

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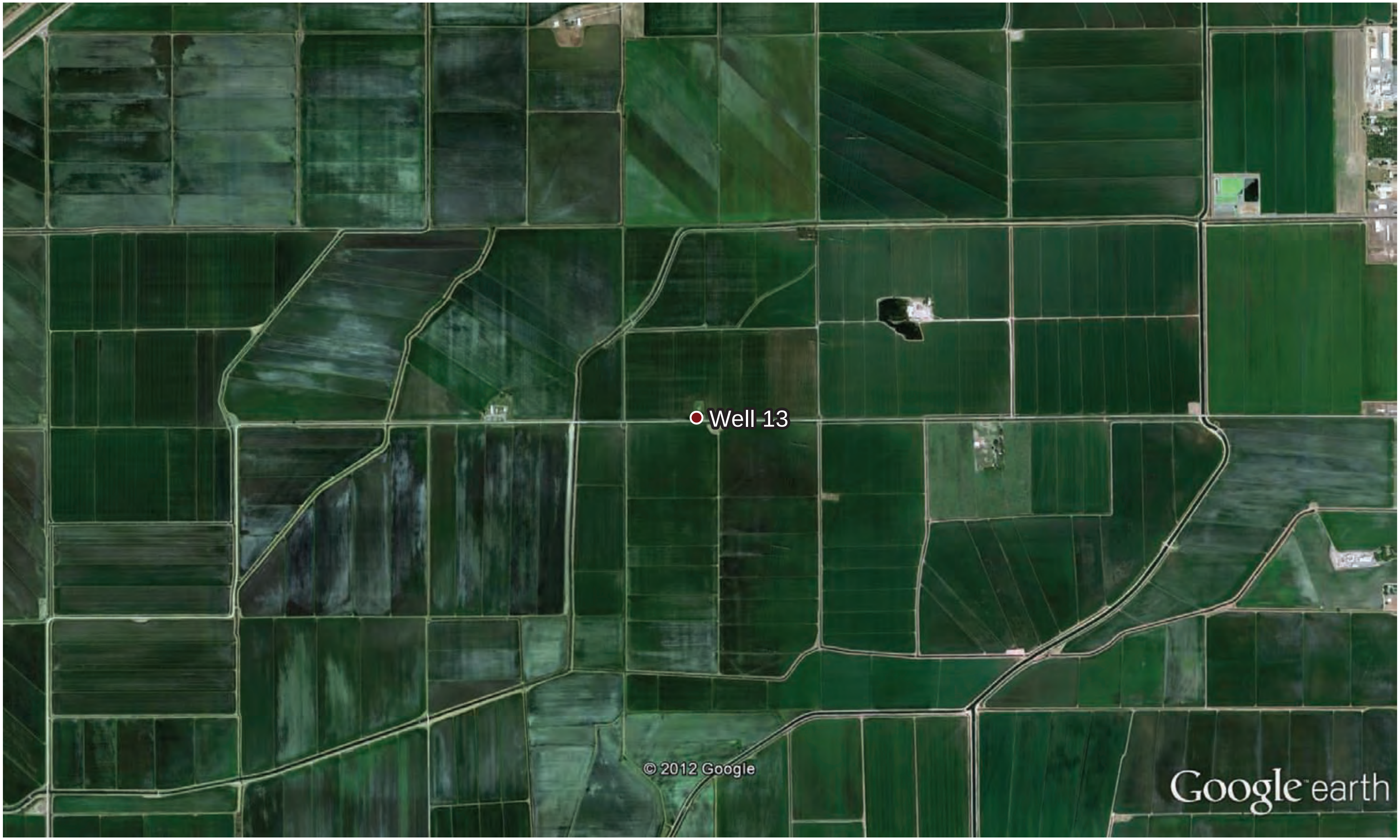

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Land Use Surrounding USGS Rice Well 13
CRC Groundwater Assessment Report

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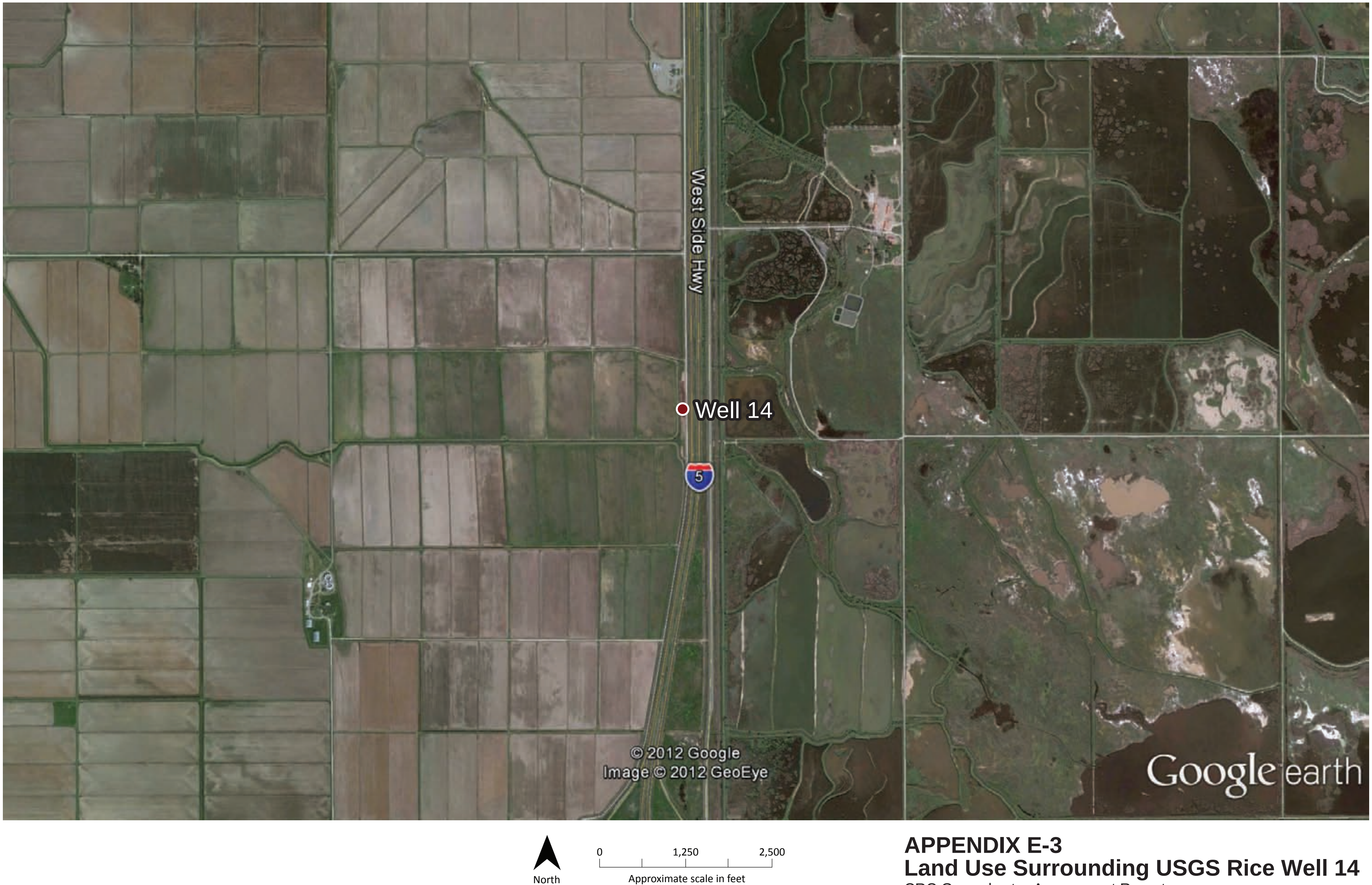

APPENDIX E-3
Land Use Surrounding USGS Rice Well 14
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North

0 1,250 2,500
Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 15
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 16
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 17
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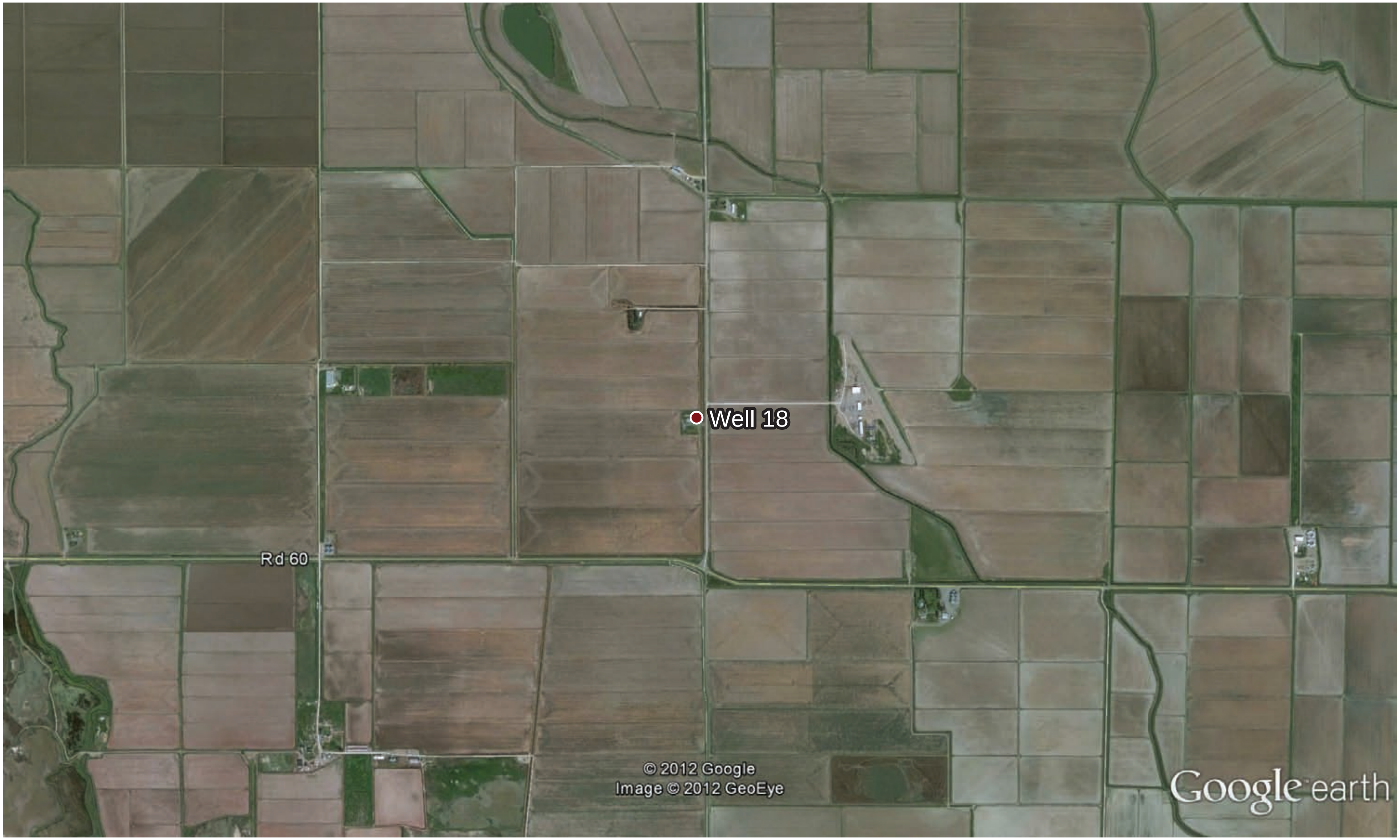

APPENDIX E-3
Land Use Surrounding USGS Rice Well 18
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 19
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 20
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North

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Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 21
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North

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Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 22
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North

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Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 23
CRC Groundwater Assessment Report

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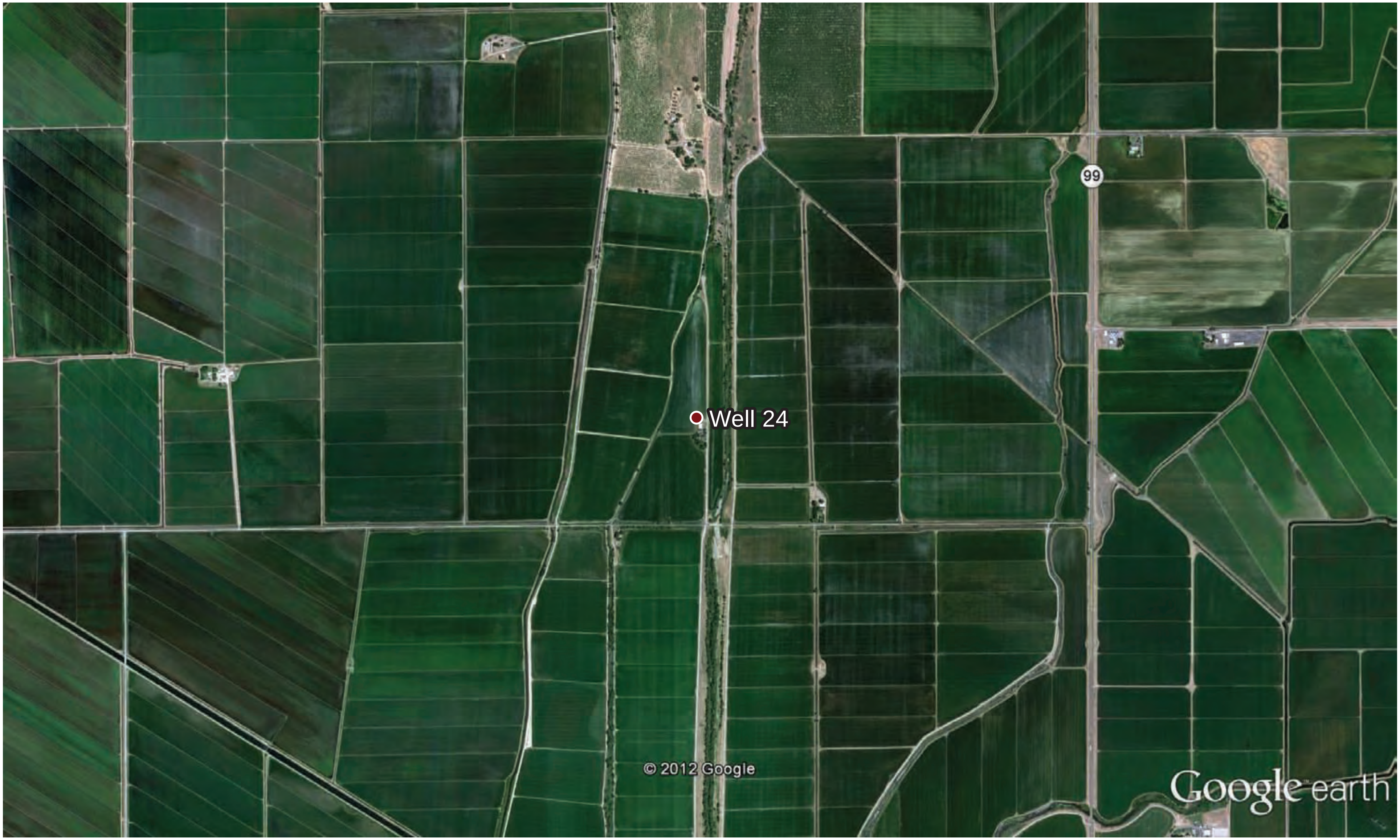

North

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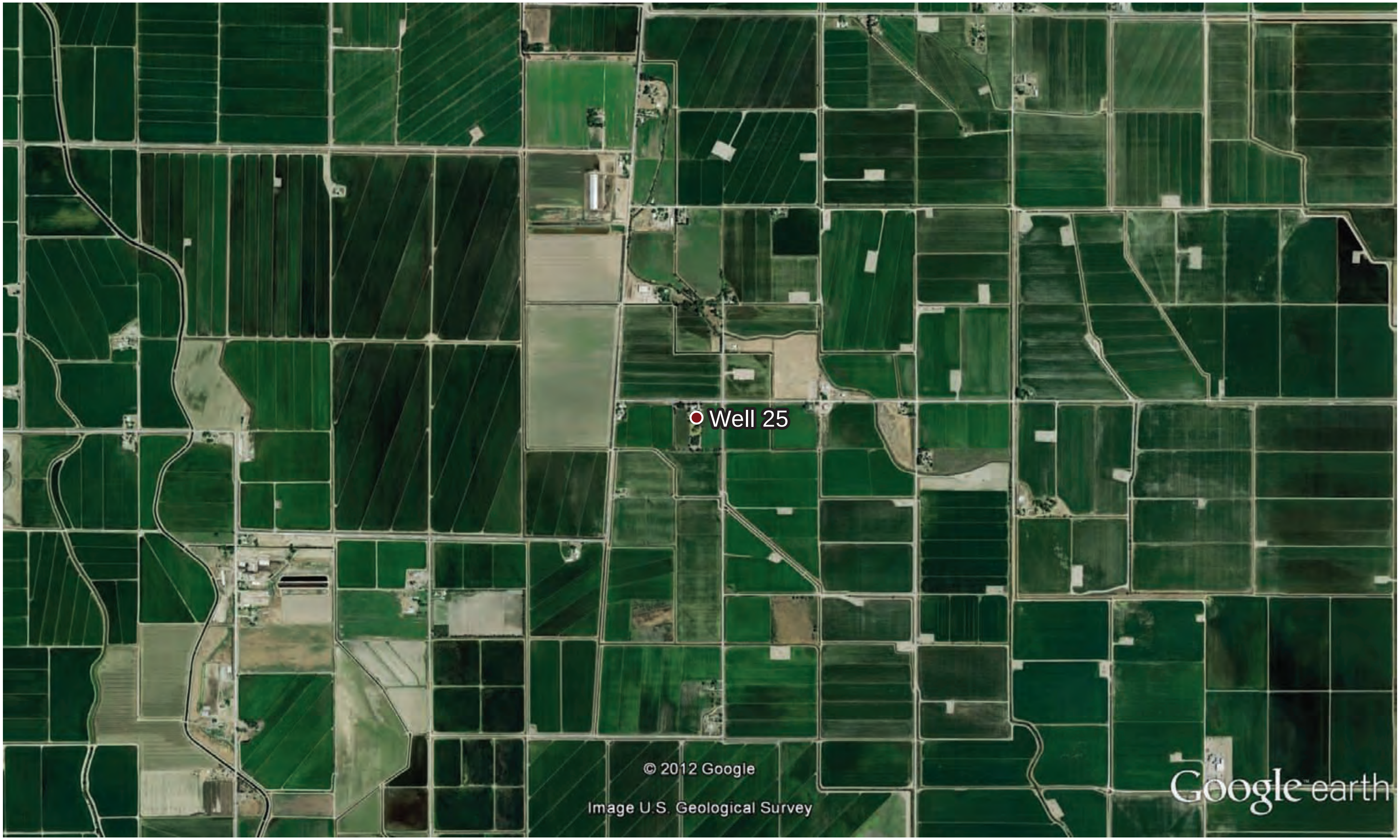
Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 24
CRC Groundwater Assessment Report



APPENDIX E-3
Land Use Surrounding USGS Rice Well 25
CRC Groundwater Assessment Report

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North

0 1,250 2,500
Approximate scale in feet

APPENDIX E-3
Land Use Surrounding USGS Rice Well 26
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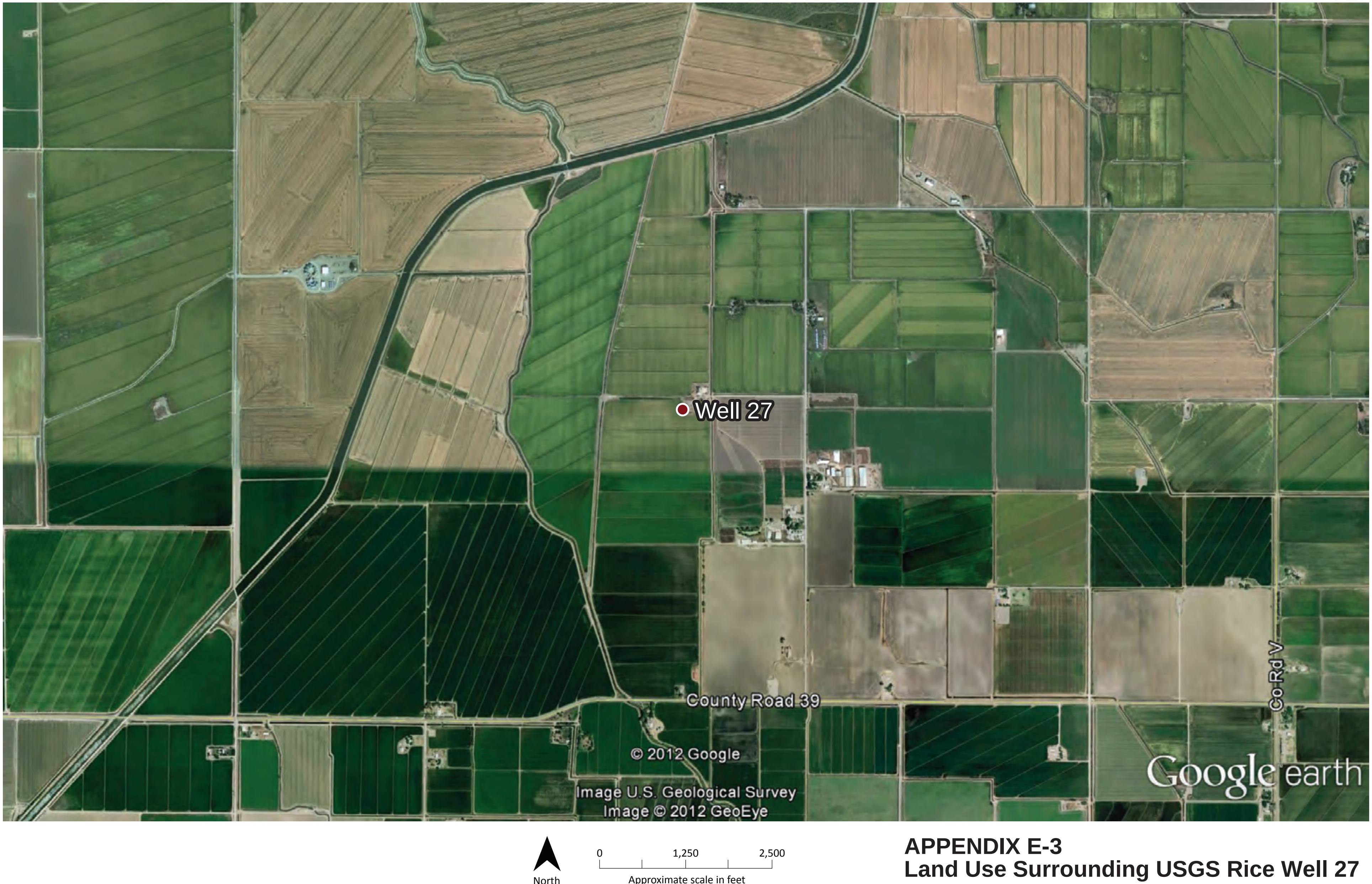

APPENDIX E-3
Land Use Surrounding USGS Rice Well 27
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APPENDIX E-3
Land Use Surrounding USGS Rice Well 28
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Appendix F
Groundwater Management Plans in the Sacramento Valley

APPENDIX F

Groundwater Management Plans in the Sacramento Valley

Groundwater management in California occurs at the local level because no statewide groundwater use permitting system exists. Locally, groundwater is managed and regulated through a variety of mechanisms, such as groundwater management plans (GWMP), special act districts, county ordinances, and court adjudications. In the Sacramento Valley, each county and most irrigation and water districts have adopted GWMPs to help ensure the continued availability and quality of groundwater for all beneficial uses.

Local and countywide GWMPs include groundwater monitoring networks that help assess the change in groundwater storage and groundwater quality in the Sacramento Valley subbasins. For the purposes of analyzing the potential effects of rice agriculture on shallow groundwater , county network wells screened in the shallow groundwater zone and near rice-growing areas would be useful to determine the groundwater conditions underlying or downgradient of rice-growing areas. This Section provides an overview of GWMPs in the Sacramento Valley Counties that grow rice. The county monitoring networks are described in Section 3.

Overview of GWMPs

Assembly Bill 3030 (AB 3030), Water Code Section 10750 (Groundwater Management Act), permitted local agencies to develop GWMPs that covered certain aspects of management. Subsequent legislation has amended this water code section to make the adoption of a management program mandatory if an agency is to receive public funding for groundwater projects, which created an incentive for implementation of local GWMPs.

Senate Bill 1938 (SB 1938), Water Code Section 10753.7, requires local agencies seeking state funds for groundwater construction or groundwater quality projects to have the following information and resources:

- A developed and implemented GWMP that includes basin management objectives (BMO) and addresses the monitoring and management of groundwater levels, groundwater quality degradation, inelastic land subsidence, and surface water–groundwater interaction
- A plan addressing cooperation and working relationships with other public entities
- A map showing the groundwater subbasin the project is in, neighboring local agencies, and the area subject to the GWMP
- Protocols for monitoring groundwater levels, groundwater quality, inelastic land subsidence, and groundwater/surface water interaction
- GWMPs with the components listed above for local agencies outside the delineated DWR Bulletin 118 groundwater subbasins

AB 3030, the Groundwater Management Act, encourages local water agencies to establish local GWMPs and lists 12 elements (in Water Code Section 10753) that can be included in the plans to ensure efficient use, good groundwater quality, and safe production of water:

- Control of saline water intrusion

- Identification and management of well-head protection areas and recharge areas
- Regulation of the contaminated groundwater migration
- Administration of a well abandonment and destruction program
- Mitigation of overdraft conditions
- Replenishment of groundwater extracted by water producers
- Monitoring of groundwater levels and storage
- Facilitation of water management operations
- Identification of well construction policies
- Construction and operation (by the local agency) of groundwater contamination cleanup, recharge, storage, conservation, water recycling, and production projects
- Development of relationships with state and federal regulatory agencies
- Review of land use plans and coordination with land use planning agencies to assess activities that create a reasonable risk of groundwater contamination

Once the plan is adopted, rules and regulations must be adopted to implement the program called for in the plan.

Table E lists the available GWMPs in the Sacramento Valley counties that grow rice. Because any agency that applies for funding is required to prepare a GWMP, a long list of plans is available in the rice-farming area. The major GWMPs are those developed by the counties (boldfaced in Table E), which include countywide monitoring networks and basin management objectives. Each county's GWMP objectives are highlighted below.

TABLE E
Sacramento Valley Local GWMPs Summary

County	GWMP Title	Lead Agency	Status	Status Date
Butte	Biggs–West Gridley Water District GWMP	Biggs-West Gridley Water District	Adopted	11/15/1995
Butte	Butte Water District GWMP	Butte Water District	Adopted	5/13/1996
Butte	Richvale Irrigation District GWMP	Richvale Irrigation District	Adopted	12/20/1995
Butte	GWMP for Thermalito Irrigation District	Thermalito Irrigation District	Adopted	3/29/1995
Butte	**Butte County Groundwater Management (AB3030) Plan**	**Butte County Department of Water and Resource Conservation**	**Adopted**	**9/28/2004**
Butte, Glenn	WCWD GWMP	Western Canal Water District	Adopted	3/21/1995
Colusa	**Colusa County Groundwater Management Plan**	**Colusa County**	**Adopted**	**11/18/2008**
Colusa, Yolo	Reclamation District No. 108 Groundwater Management Plan	Reclamation District No. 108	Amended	11/14/2006

TABLE E
Sacramento Valley Local GWMPs Summary

County	GWMP Title	Lead Agency	Status	Status Date
Glenn	Glenn-Colusa Irrigation District GWMP AB 3030	Glenn-Colusa Irrigation District	Adopted	5/26/1995
Glenn	Glenn County Groundwater Management Plan	Glenn County	Adopted	2/15/2000
Placer	City of Lincoln GWMP	Lincoln, City of	Adopted	11/12/2003
Placer	West Placer GWMP	Placer County Water Agency	Updated	11/6/2003
Placer	Olympic Valley Groundwater Management Plan	Squaw Valley Public Service District	Adopted	5/29/2007
Placer	**Western Placer County Groundwater Management Plan**	**Roseville, Lincoln, Placer County Water Agency, California American Water Agency**	**Adopted**	**8/1/2007**
Placer, Nevada	GWMP Phase 1 Martis Valley Groundwater Basin No. 6-67 Nevada and Placer Counties	Truckee-Donner Public Utility District	Adopted	1/31/1995
Placer, Nevada	Martis Valley Groundwater Management Plan	Placer County Water Agency	Updated	11/6/2003
Sacramento	Central Sacramento County GWMP	Sacramento County Water Agency (Central)	Adopted	11/8/2006
Sacramento	SCWA GWMP	Sacramento County Water Agency	Adopted	11/2/2004
Sacramento	**Sacramento Groundwater Authority GWMP**	**Sacramento Groundwater Authority**	**Updated**	**12/11/2008**
Sacramento	GWMP Initial Phase	Sacramento Metropolitan Water Authority	Unknown	—
Sacramento	Southeast Sacramento County Agricultural Water Authority GWMP	Southeast Sacramento County Agricultural Water Authority	Adopted	12/3/2002
Sutter	GWMP of Feather Water District	Feather Water District	Adopted	11/8/2005
Sutter	Groundwater Management Report	Reclamation District No.1500	Adopted	9/30/1997
Sutter	Sutter Extension WD GWMP	Sutter Extension Water District	Adopted	8/15/1995
Sutter	**Sutter County Draft Groundwater Management Plan**	**Sutter County**	**Draft**	**10/12/2011**
Yolo	Dunnigan Water District GWMP	Dunnigan Water District	Adopted	11/8/2007
Yolo	RD787 GWMP	Reclamation District No. 787	Amended	11/16/2005
Yolo	**Water Management Plan**	**Yolo County Flood Control and Water Conservation District**	**Adopted**	**6/6/2006**
Yolo	RD 2035 GWMP	Reclamation District No. 2035	Adopted	4/25/1995
Yolo, Solano	Maine Prairie Water District GWMP	Maine Prairie Water District	Adopted	1/21/1997

TABLE E
Sacramento Valley Local GWMPs Summary

County	GWMP Title	Lead Agency	Status	Status Date
Yolo, Solano	RD2068 GWMP	Reclamation District No. 2068	Adopted	12/8/2005
Yuba	**Yuba County Water Agency GWMP**	**Yuba County Water Agency**	**Adopted**	**12/28/2010**

Note: **Boldface** identified the major GWMPs developed by the counties, which include countywide monitoring networks and basin management objectives

Butte County GWMP

Adopted in September 2004, the Butte County GWMP has the following management objectives:

- Minimize the long-term drawdown of groundwater levels
- Protect groundwater quality
- Prevent inelastic land surface subsidence resulting from groundwater pumping
- Minimize changes to surface water flows and quality that directly affect groundwater levels or quality
- Minimize the effect of groundwater pumping on surface water flows and quality
- Evaluate groundwater replenishment and cooperative management projects
- Provide effective and efficient management of groundwater recharge projects and areas

These management objectives were used to develop quantitative BMOs within 16 defined sub-inventory units overlying the groundwater basin by February 2005. These BMOs included the following monitoring objectives:

- Groundwater levels
- Water quality (pH, temperature, and EC)
- Inelastic land subsidence

Sutter County GWMP

In October 2011, Sutter County developed a draft GWMP that lists the following specific BMOs:

- Improve the understanding of groundwater quality in Sutter County
- Avoid ongoing declines in groundwater levels during water year types identified by DWR to be “above normal” or “wet” for the Sacramento Valley
- Avoid problematically high groundwater levels
- Provide assistance with assessing problems and resolve disputes related to groundwater levels;
- Avoid inelastic land subsidence that is linked to declines in groundwater levels
- Improve the understanding of the relationship between surface water and groundwater

- Avoid changes in surface water flow and surface water quality that directly affect groundwater levels or are caused by groundwater pumping
- Avoid changes in surface flow and surface water quality that directly affect groundwater quality; and
- Coordinate County groundwater management efforts with other groundwater management efforts within and surrounding Sutter County

Yuba County GWMP

The Yuba County Water Agency (YCWA) adopted an updated GWMP in December 2010. The GWMP outlines the conditions of the Upper and Lower Yuba groundwater basins, and it intends to lay the framework for the management of groundwater resources "for the beneficial use of the people of Yuba County." To achieve its groundwater management goals, YCWA developed the following seven BMOs:

- Maintain groundwater elevations that provide for sustainable use of the groundwater basin
- Protect against potential inelastic land surface subsidence
- Maintain and improve groundwater quality in the Yuba basin for the benefit of groundwater users
- Manage groundwater to protect against adverse impacts to surface water flows in the Yuba River, Feather River, Honcut Creek, and Bear River within Yuba County
- Improve communication and coordination among Yuba groundwater basin stakeholders
- Maintain local control of the Yuba groundwater basin
- Improve understanding of the Yuba groundwater basin and its stressors

Placer County GWMP

The City of Roseville, the City of Lincoln, Placer County Water Agency, and the California American Water Company jointly prepared the Western Placer County GWMP. Although Placer County was involved in the development of the Western Placer County GWMP, it has not joined as a full partner. The Western Placer County GWMP was adopted in November 2007.

The GWMP's overall goal is to maintain the quality and ensure the long-term availability of groundwater to meet backup, emergency, and peak demands without adversely affecting other groundwater users in the service area. To achieve this goal, the GWMP lists the following five BMOs:

- Manage the groundwater basin so as not to have a significant adverse effect on groundwater quality
- Manage groundwater elevations to ensure an adequate groundwater supply for backup, emergency, and peak demands without adversely impacting adjacent areas
- Participate in State and Federal land surface subsidence monitoring programs
- Protect against adverse impacts to surface water flows in creeks and rivers due to groundwater pumping
- Ensure groundwater recharge projects comply with state and federal regulations and protect beneficial uses of groundwater

Sacramento County GWMP

The Sacramento Groundwater Authority (SGA) was formed by a joint powers agreement signed by the cities of Citrus Heights, Folsom, Sacramento, and by Sacramento County in 1998. The joint powers agreement provides the SGA with authority to manage the area known as the North Area Groundwater Basin (part of the North American Basin), which spans northern Sacramento County (and includes the rice land use areas). The SGA adopted a revised GWMP for the North Area Groundwater Basin in December 2008. The GWMP lists the following BMOs:

- Maintain or improve groundwater quality to ensure sustainable use of the groundwater basin
- Maintain groundwater elevations that provide for sustainable use of the groundwater basin
- Protect against potential inelastic land surface subsidence
- Manage groundwater to protect against adverse impacts to surface water flows in the American River, the Sacramento River, and other surface water bodies within the SGA area
- Protect against adverse impacts to surface or groundwater quality resulting from interaction between groundwater in the basin and surface water flows in the American River, the Sacramento River, and other surface water bodies within the SGA area
- Educate on the need to achieve recharge to the aquifer of appropriate quality and quantity to ensure basin sustainability
- Maintain a sustainable groundwater basin to help mitigate potential water supply impacts resulting from an uncertain climate future and an increasingly unreliable state and federal water delivery system
- Maintain a sustainable groundwater basin underlying the SGA area through coordination and collaboration with adjacent groundwater basin management efforts

Yolo County GWMP

In June 2006, the Yolo County Flood Control and Water Conservation District adopted its GWMP, which has the following *quantitative* BMOs:

- Water quantity
- Water quality
- Inelastic land subsidence
- Integrated ground and surface water model (IGSM)

The GWMP also includes the following *qualitative* BMOs:

- Minimize the long-term drawdown of groundwater levels
- Protect groundwater quality
- Minimize changes to surface water flows and quality that directly affect groundwater levels or quality
- Facilitate groundwater replenishment and cooperative management projects, including subsidence monitoring

- Work collaboratively with and understand the goals and objectives of entities engaged in groundwater management in surrounding areas

Colusa County GWMP

Colusa County adopted a GWMP in November 2008; it lists the following BMOs:

- Groundwater levels
- Water quality
- Inelastic land subsidence
- Surface water and wetlands

More specifically, the GWMP lists two BMOs pertaining to groundwater quality:

- Avoid and mitigate adverse impacts to groundwater quality
- Maintain or improve groundwater quality

Glenn County GWMP

Glenn County adopted a GWMP in February 2000; it includes the following management objectives:

- Protect groundwater quality
- Adopt a monitoring program for groundwater levels, groundwater quality, and land subsidence
- Establish a water quality monitoring network

For each sub-area, the GWMP lists the following BMOs:

- Groundwater levels
- Water quality
- Inelastic land subsidence

Appendix G
Drinking Water Standards Tables

APPENDIX G
Drinking Water Standards Tables

The following MCLs derived from Title 22 of the California Code of Regulations are included as part of this rice-specific review:

- Primary MCLs for inorganic chemicals (Table 64431-A)
- Primary MCLs for organic chemicals that are registered for use on rice (selected from Table 64444-A)
- Secondary MCLs (Tables 64449-A and Tables 64449-A)

The MCLs for the primary drinking water chemicals shown in Table 64444-A shall not be exceeded in the water supplied to the public.

TABLE 64444-A
Maximum Contaminant Levels Organic Chemicals (pesticides registered for use on rice)

Chemical	Maximum Contaminant Level, mg/L
Non-Volatile Synthetic Organic Chemicals (SOCs)	
Carbofuran	0.018
2,4-D	0.07
Glyphosate	0.7
Thiobencarb	0.07

Public water systems shall comply with the primary MCLs in Table 64431-A.

TABLE 64431-A
Maximum Contaminant Levels
Inorganic Chemicals

Chemical	Maximum Contaminant Level, mg/L
Aluminum	1.0
Antimony	0.006
Arsenic	0.010
Asbestos	7 MFL*
Barium	1.0
Beryllium	0.004
Cadmium	0.005
Chromium	0.05
Cyanide	0.15

TABLE 64431-A
Maximum Contaminant Levels
Inorganic Chemicals

Chemical	**Maximum Contaminant Level, mg/L**
Fluoride	2.0
Mercury	0.002
Nickel	0.1
Nitrate (as NO_3)	45.0
Nitrate+Nitrite (sum as nitrogen)	10.0
Nitrite (as nitrogen)	1.0
Perchlorate	0.006
Selenium	0.05
Thallium	0.002

* MFL=million fibers per liter; MCL for fibers exceeding 10 µm in length.

The secondary MCLs shown in Tables 64449-A and 64449-B shall not be exceeded in the water supplied to the public by community water systems.

TABLE 64449-A
Secondary Maximum Contaminant Levels
"Consumer Acceptance Contaminant Levels"

Constituents	**Maximum Contaminant Levels/Units**
Aluminum	0.2 mg/L
Color	15 Units
Copper	1.0 mg/L
Foaming Agents (MBAS)	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Methyl-*tert*-butyl ether (MTBE)	0.005 mg/L
Odor-Threshold	3 Units
Silver	0.1 mg/L
Thiobencarb	0.001 mg/L
Turbidity	5 Units
Zinc	5.0 mg/L

TABLE 64449-B
Secondary Maximum Contaminant Levels
"Consumer Acceptance Contaminant Level Ranges"

	Maximum Contaminant Level Ranges		
Constituent, Units	**Recommended**	**Upper**	**Short Term**
Total Dissolved Solids, mg/L	500	1,000	1,500
or			
Specific Conductance, µS/cm	900	1,600	2,200
Chloride, mg/L	250	500	600
Sulfate, mg/L	250	500	600

Appendix H
Data Assessment in Support of Vulnerability and Data Gap Analysis

APPENDIX H

Data Assessment in Support of Vulnerability and Data Gap Analyses

This appendix presents a detailed discussion of the data introduced in Section 6. The initial State Water Resources Control Board (SWRCB) hydrogeologic vulnerable areas (initial HVAs), Department of Pesticide Regulation (DPR) leaching areas, Department of Water Resources (DWR) rice land use data, and Natural Resources Conservation Service (NRCS) Soil Drainage Classification data were incorporated into a Geographic Information System (GIS) analysis.

Rice Acres within Initial HVAs

GIS analysis calculated the acres of rice grown on initial HVAs within Sacramento Valley rice growing counties. Table H-1 includes the results of this calculation.

TABLE H-1
Rice Acres within Initial HVAs

County	Number of USGS Rice Wells per County	Acres of Rice not within an Initial HVA	Acres of Rice within an Initial HVA
Butte	5	102,270	3,261
Colusa	4	136,114	11,202
Glenn	13	88,204	2,440
Placer	0	20,953	402
Sacramento	1	11,254	158
Sutter	4	131,958	7,904
Yolo	1	28,486	1,913
Yuba	0	18,142	20,771
Total	28	537,381	48,051

Drainage Classifications of Well Sites

GIS analysis identified the NRCS Drainage Classification at the location of each well from the three USGS datasets (see Map H-2) and identified if other drainage classifications were located within 1 mile of the well. Tables H-2, H-3, and H-4 include the results of this review for the USGS Rice Wells, Shallow Domestic Wells, and USGS GAMA Wells, respectively. Table H-5 is a summary of the wells associated with each of the NRCS Soil Drainage Classifications.

TABLE H-2
Soil Drainage Classes Associated with USGS Rice Wells

Well ID	NRCS Soil Drainage Classification	Two or More Other Drainage Classifications within 1 Mile
1	Moderately well drained	Somewhat poorly drained/Well drained
2	Poorly drained	No
3	Poorly drained	No

TABLE H-2
Soil Drainage Classes Associated with USGS Rice Wells

Well ID	NRCS Soil Drainage Classification	Two or More Other Drainage Classifications within 1 Mile
4	Poorly drained	No
5	Well drained	No
6	Poorly drained	Moderately well drained/Well drained
7	Poorly drained	Somewhat poorly drained/Moderately well drained/Well drained
8	Moderately well drained	Well drained/Poorly drained
9	Poorly drained	No
10	Poorly drained	Moderately well drained/Well drained
11	Poorly drained	No
12	Well drained	Somewhat poorly drained/Poorly drained
13	Poorly drained	No
14	Poorly drained	No
15	Poorly drained	No
16	Somewhat poorly drained	No
17	Somewhat poorly drained	Excessively drained/Well drained/Poorly drained
18	Well drained	Somewhat poorly drained/Poorly drained/Somewhat excessively drained/Excessively drained
19	Somewhat poorly drained	Poorly drained/Well drained
20	Somewhat poorly drained	Moderately well drained/Poorly drained/Excessively drained
21	Somewhat poorly drained	No
22	Poorly drained/Somewhat poorly drained	Well drained/Moderately well drained
23	Moderately well drained	Excessively drained/Poorly drained/Somewhat poorly drained
24	Poorly drained	No
25	Somewhat poorly drained	Poorly drained/Moderately well drained/Well drained
26	Poorly drained	Somewhat poorly drained/Moderately well drained/Well drained
27	Poorly drained	Somewhat poorly drained/Moderately well drained/Well drained
28	Poorly drained	No

TABLE H-3
Soil Drainage Classes Associated with Shallow Domestic Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
1	Somewhat poorly drained	Moderately well drained/Well drained
2	Moderately well drained	No

TABLE H-3
Soil Drainage Classes Associated with Shallow Domestic Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
3	Moderately well drained	No
4	Well drained	Moderately well drained/Somewhat excessively drained/Water
5	Well drained	Moderately well drained/Somewhat excessively drained/Water
6	Somewhat poorly drained	Well drained/Moderately well drained/Poorly drained/Water
7	Well drained	Moderately well drained/Somewhat excessively drained/Water
8	Well drained	Somewhat excessively drained/Somewhat poorly drained
9	Moderately well drained	No
10	Well drained	No
11	Somewhat poorly drained	Moderately well drained/Water
12	Well drained	Somewhat poorly drained/Poorly drained
13	Well drained	No
14	Poorly drained	No
15	Well drained	No
16	Somewhat poorly drained	Somewhat excessively drained/Well drained/Moderately well drained
17	Well drained	No
18	Well drained	No
19	Well drained	Moderately well drained/Poorly drained
20	Well drained	No
21	Well drained	Moderately well drained/Poorly drained
22	Moderately well drained	No
23	Moderately well drained	Well drained/Poorly drained
24	Well drained	Somewhat poorly drained/Moderately well drained/Water
25	Moderately well drained	No
26	Moderately well drained	Well drained/Poorly drained
27	Well drained	Poorly drained/Somewhat poorly drained
28	Moderately well drained	No
29	Outside study area	Unknown
30	Outside study area	Unknown
31	Somewhat excessively drained	Moderately well drained/Water

TABLE H-4
Soil Drainage Classes Associated with USGS GAMA Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
ESAC-01	Well drained	Moderately well drained/Somewhat poorly drained
ESAC-02	Well drained	Moderately well drained/Poorly drained
ESAC-03	Moderately well drained	Somewhat excessively drained/Poorly drained
ESAC-04	Outside study area	Unknown
ESAC-05	Moderately well drained	No
ESAC-06	Poorly drained	Moderately well drained/Somewhat poorly drained
ESAC-07	Outside study area	Unknown
ESAC-08	Well drained	Somewhat poorly drained/Moderately well drained/Excessively drained
ESAC-09	Poorly drained	No
ESAC-10	Moderately well drained	No
ESAC-11	Somewhat poorly drained	No
ESAC-12	Well drained	Moderately well drained/Poorly drained
ESAC-13	Outside study area	Unknown
ESAC-14	Moderately well drained	Poorly drained/Well drained
ESAC-15	Outside study area	Unknown
ESAC-16	Outside study area	Unknown
ESAC-17	Moderately well drained/Well drained	Somewhat excessively drained/Somewhat poorly drained
ESAC-18	Moderately well drained	Poorly drained/Well drained/Somewhat poorly drained
ESAC-19	Moderately well drained	Poorly drained/Well drained
ESAC-20	Moderately well drained	No
ESAC-21	Poorly drained	Well drained/Somewhat excessively drained/Somewhat poorly drained/Moderately well drained/Water
ESAC-22	Outside study area	Somewhat poorly drained/Well drained
ESAC-23	Well drained	Somewhat poorly drained/Somewhat excessively drained/Moderately well drained
ESAC-24	Poorly drained	Somewhat poorly drained/Moderately well drained
ESAC-25	Outside study area	Somewhat poorly drained/Moderately well drained
ESAC-26	Somewhat poorly drained	Poorly drained/Moderately well drained/Water
ESAC-27	Well drained/Somewhat poorly drained	Somewhat excessively drained/Water
ESAC-28	Somewhat poorly drained	No
ESAC-29	Somewhat poorly drained	Poorly drained/Well drained/Water

TABLE H-4
Soil Drainage Classes Associated with USGS GAMA Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
ESAC-30	Somewhat poorly drained	Poorly drained/Moderately well drained/Water
ESAC-31	Poorly drained	No
ESAC-32	Well drained	Somewhat excessively drained/Somewhat poorly drained/Water
ESAC-33	Outside study area	Unknown
ESAC-34	Poorly drained	No
ESAC-35	Poorly drained	Well drained/Moderately well drained
ESAC-FP-01	Moderately well drained	No
ESAC-FP-02	Outside study area	Unknown
ESAC-FP-03	Poorly drained	Somewhat poorly drained/Moderately well drained
ESAC-FP-04	Poorly drained	Somewhat poorly drained/Moderately well drained
ESAC-FP-05	Well drained	Somewhat poorly drained/Excessively drained
ESAC-FP-06	Well drained	Somewhat poorly drained/Excessively drained
ESAC-FP-07	Well drained	Somewhat poorly drained/Excessively drained
WSAC-01	Well drained	Somewhat excessively drained/Excessively drained
WSAC-02	Excessively drained	Somewhat excessively drained/Well drained/Moderately well drained/Somewhat poorly drained
WSAC-03	Well drained	Somewhat excessively drained/Excessively drained/Moderately well drained/Poorly drained
WSAC-04	Somewhat excessively drained	Excessively drained/Well drained/Moderately well drained
WSAC-05	Well drained	Somewhat excessively drained/Excessively drained/Moderately well drained/Somewhat poorly drained/Water
WSAC-06	Well drained	Excessively drained/Somewhat poorly drained/Water
WSAC-07	Well drained	Somewhat excessively drained/Moderately well drained/Somewhat poorly drained/Water
WSAC-08	Somewhat excessively drained/Well drained	Excessively drained/Somewhat excessively drained OR Well drained
WSAC-09	Well drained	Excessively drained/Poorly drained/Somewhat excessively drained
WSAC-10	Well drained	Somewhat excessively drained/Moderately well drained
WSAC-11	Well drained	Somewhat poorly drained/Somewhat excessively drained
WSAC-12	Moderately well drained	Well drained/Poorly drained/Somewhat poorly drained
WSAC-13	Poorly drained	No

TABLE H-4
Soil Drainage Classes Associated with USGS GAMA Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
WSAC-14	Poorly drained	No
WSAC-15	Well drained	Somewhat poorly drained/Excessively drained
WSAC-16	Somewhat poorly drained	Moderately well drained/Water
WSAC-17	Somewhat poorly drained	Poorly drained/Water
WSAC-18	Well drained	Moderately well drained/Poorly drained/Somewhat poorly drained
WSAC-19	Somewhat poorly drained	Poorly drained/Well drained
WSAC-20	Well drained	No
WSAC-21	Well drained	Somewhat poorly drained/Moderately well drained/Water
WSAC-22	Well drained	Poorly drained/Somewhat excessively drained
WSAC-23	Moderately well drained	Well drained/Somewhat poorly drained/Water
WSAC-24	Somewhat poorly drained	Moderately well drained/Well drained/Poorly drained
WSAC-25	Well drained	Somewhat poorly drained/Poorly drained/Moderately well drained/Water
WSAC-26	Well drained	Excessively drained/Somewhat excessively drained
WSAC-27	Well drained	Poorly drained/Somewhat poorly drained/Moderately well drained
WSAC-28	Somewhat excessively drained	Well drained/Moderately well drained
WSAC-29	Well drained	No
WSAC-30	Well drained	Somewhat poorly drained/Poorly drained/Moderately well drained/Water
WSAC-31	Poorly drained	Moderately well drained/Somewhat poorly drained/Water
WSAC-32	Well drained	Somewhat poorly drained/Excessively drained/Moderately well drained
WSAC-33	Well drained	Moderately well drained/Somewhat poorly drained/Poorly drained
WSAC-34	Well drained	Somewhat poorly drained/Excessively drained/Moderately well drained
WSAC-35	Well drained	No
WSAC-36	Somewhat poorly drained	No
WSAC-FP-01	Moderately well drained	Well drained/Excessively drained/Somewhat excessively drained
WSAC-FP-02	Somewhat excessively drained	Excessively drained/Well drained
WSAC-FP-03	Somewhat excessively drained	Excessively drained/Well drained

TABLE H-4
Soil Drainage Classes Associated with USGS GAMA Wells

Well ID	NRCS Soil Drainage Classification	Two or more other drainage classifications within 1 mile
WSAC-FP-05	Moderately well drained	Well drained/Poorly drained
WSAC-FP-04	Somewhat poorly drained	Well drained/Moderately well drained/Poorly drained/Water
WSAC-FP-06	Somewhat poorly drained	Well drained/Moderately well drained/Poorly drained/Water
WSAC-FP-07	Somewhat poorly drained	Moderately well drained/Well drained/Poorly drained
WSAC-FP-08	Somewhat poorly drained	Moderately well drained/Well drained/Poorly drained

TABLE H-5
Summary of Soil Drainage Classes Associated with USGS Wells

		Number of Wells		
NRCS Soil Drainage Classification	**Rice Acres**	**USGS Rice Wells**	**Shallow Domestic Wells**	**USGS GAMA Wells**
Excessively drained	416	0	0	1
Somewhat excessively drained	314	0	1	5
Well drained	86,672	3	15	32
Moderately well drained	105,257	3	8	13
Somewhat poorly drained	87,643	7	4	14
Poorly drained	303,838	15	1	12
Very poorly drained	—	0	0	0
Outside Study Area	—	0	2	9
Totals	**584,140**	**28**	**31**	**86**

Table H-5 shows that the majority of the USGS Rice Wells are located on poorly drained and on somewhat poorly drained soils on the valley floor. The majority of the shallow domestic wells are located on well drained and moderately well drained soils which correspond to the slightly coarser soils present on the eastern basin fringe areas. The GAMA wells are spread amongst the well drained to poorly drained soils.

Maps H-3 to H-10 (provided at the end of this appendix) show the locations of the well networks in comparison to the soil drainage classes for each county in which rice is grown. These maps provide a detailed visual representation of the soils representativeness of the USGS well networks in rice country and aid in the development of the rice-specific Trend Monitoring network.

Depth to Duripan

The NRCS Soil Survey Geographic (SSURGO) Dataset was used for a more in-depth analysis of soils in Yuba County by reviewing the detailed map unit description information. The map units were queried for Yuba County and results are shown in Table H-6. This table shows the predominant map units in Yuba County, the acres of rice grown on each map unit, and the acres of rice overlying the approximate 21,000 acres of initial HVAs on each map unit.

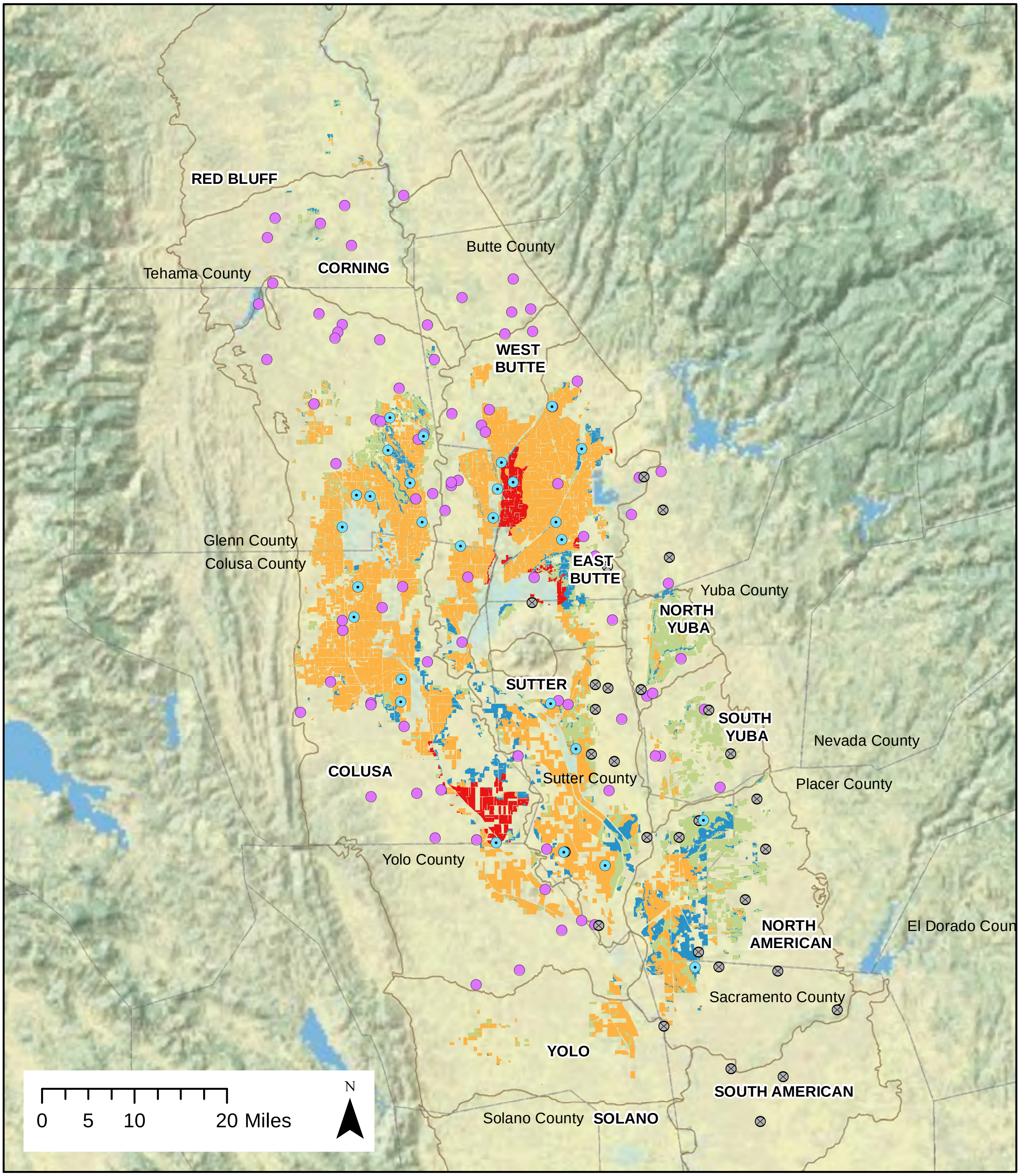
One component of these data is the depth to duripan. A duripan is a soil horizon cemented by silica into a subsurface hardpan. A duripan constitutes a restrictive layer to vertical movement of water and constituents, with very low hydraulic conductivity. For this analysis, depth to duripan is characterized in three ways: less than 60 inches bgs, greater than 60 inches bgs, and unreported. Rice acres overlying initial HVAs characterized as having a duripan less than 60 inches bgs constitute approximately 16,000 acres, or 78 percent of all initial HVA rice lands. About 1,700 acres (8 percent) are characterized as having a duripan greater than 60 inches bgs, and 2,800 acres (13 percent) had unreported depths to duripan.

TABLE H-6
Depth to Duripan on Map Units within Yuba County Initial HVAs

Map Unit Number and Name	Acres of Rice	Acres of Rice Overlying Initial HVA	Depth to Duripan		Unreported
			<60 Inches bgs	>60 Inches bgs	
214: San Joaquin loam	22,000	12,700	✓		
185: Kimball loam	4,400	900			✓
131: Hollenbeck silty clay loam	2,000	1,900	✓		
186: Kimball loam, 0 to 1 percent slopes, occasionally flooded	1,900	1,300			✓
132: Hollenbeck silty clay loam, 0 to 1 percent slopes, occasionally flooded	1,400	1,000	✓		
248: Trainer loam, 0 to 1 percent slopes, occasionally flooded	1,300	700		✓	
207: Redding gravelly loam, 0 to 3 percent slopes	900	25	✓		
216: San Joaquin loam, 0 to 1 percent slopes, occasionally flooded	700	700	✓		
203: Perkins loam, 0 to 2 percent slopes	700	300		✓	
141: Conejo loam, 0 to 2 percent slopes	500	300			✓
129: Bruella loam, 0 to 1 percent slopes	500	100		✓	
208: Redding gravelly loam, 3 to 8 percent slopes	500	100			✓
130: Capay clay loam, 0 to 1 percent slopes	400	200		✓	
209: Redding-Corning complex, 0 to 3 percent slopes	400	0.7			✓
142: Conejo loam, 0 to 1 percent slopes, occasionally flooded	300	300		✓	
197: Oakdale sandy loam, 0 to 5 percent slopes	300	70		✓	
183: Kilaga clay loam, hardpan substratum, 0 to 1 percent slopes	200	200			✓

TABLE H-6
Depth to Duripan on Map Units within Yuba County Initial HVAs

Map Unit Number and Name	Acres of Rice	Acres of Rice Overlying Initial HVA	Depth to Duripan		Unreported
			<60 Inches bgs	>60 Inches bgs	
182, 204, 254, 133, 169, 137, 219, 134, 110, 217, 215	<60 each	<60 each			



Data Sources: SSURGO (NRCS 2012), Groundwater Basins, Rice Crop (California DWR 2010); Basemap, County (ESRI 2011); Wells, USGS (2001a, 2001b, 2008)
Datum is NAD83.

Legend

- USGS Rice Wells
- Shallow Domestic Wells
- GAMA Wells
- County Boundary
- Groundwater Basins

Linear Extensibility (Shrink-Swell)

- Low (0 - 3)
- Moderate (3 - 6)
- High (6 - 9)
- Very High (9 - 30, max is 12.4)

MAP H-1
Linear Extensibility (Shrink-Swell) of Rice Land Soils and Monitoring Networks

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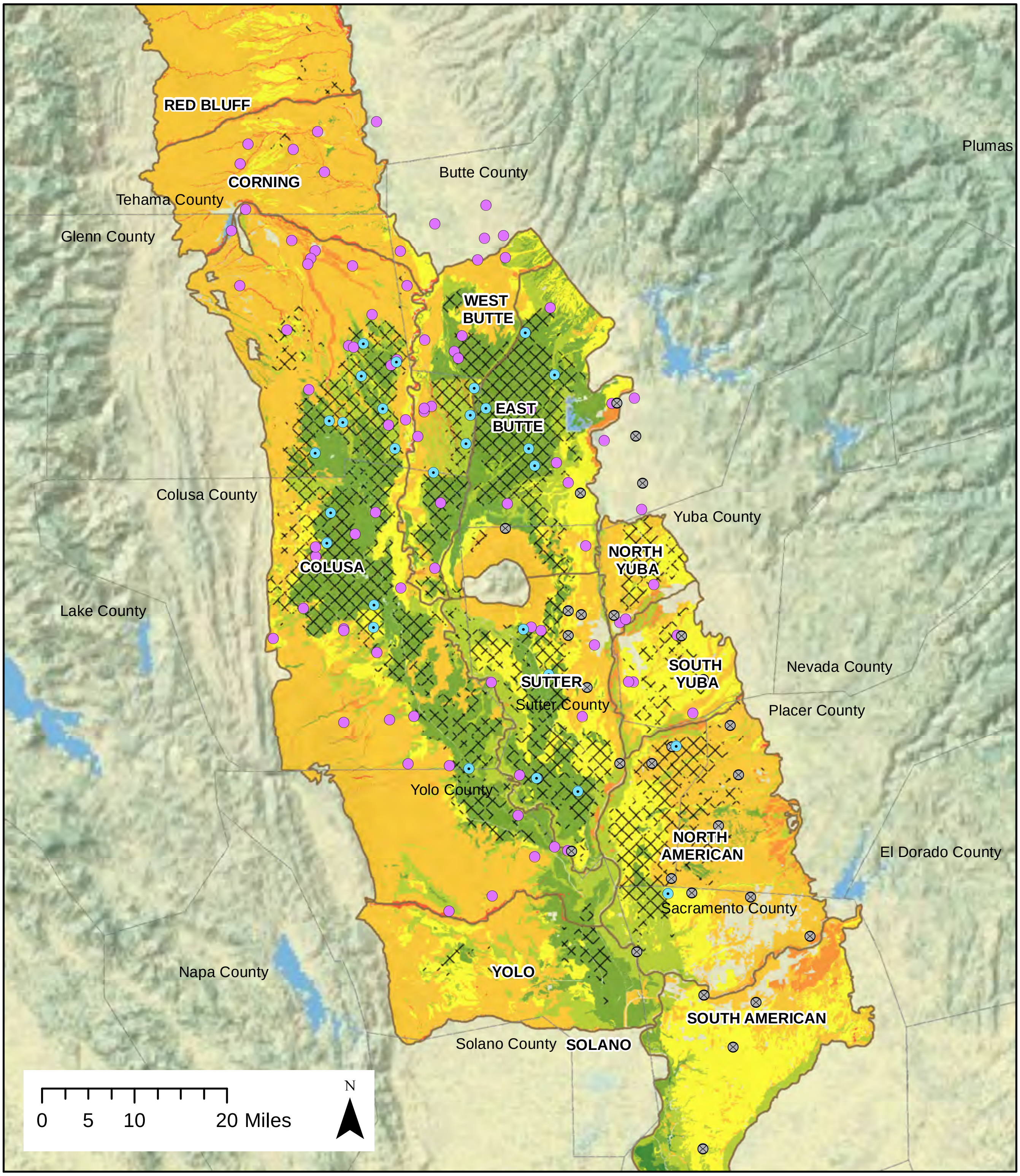


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS (2012); Basemap, County (ESRI 2011). Wells, USGS (2001a, 2001b, 2008) . Datum is NAD83.

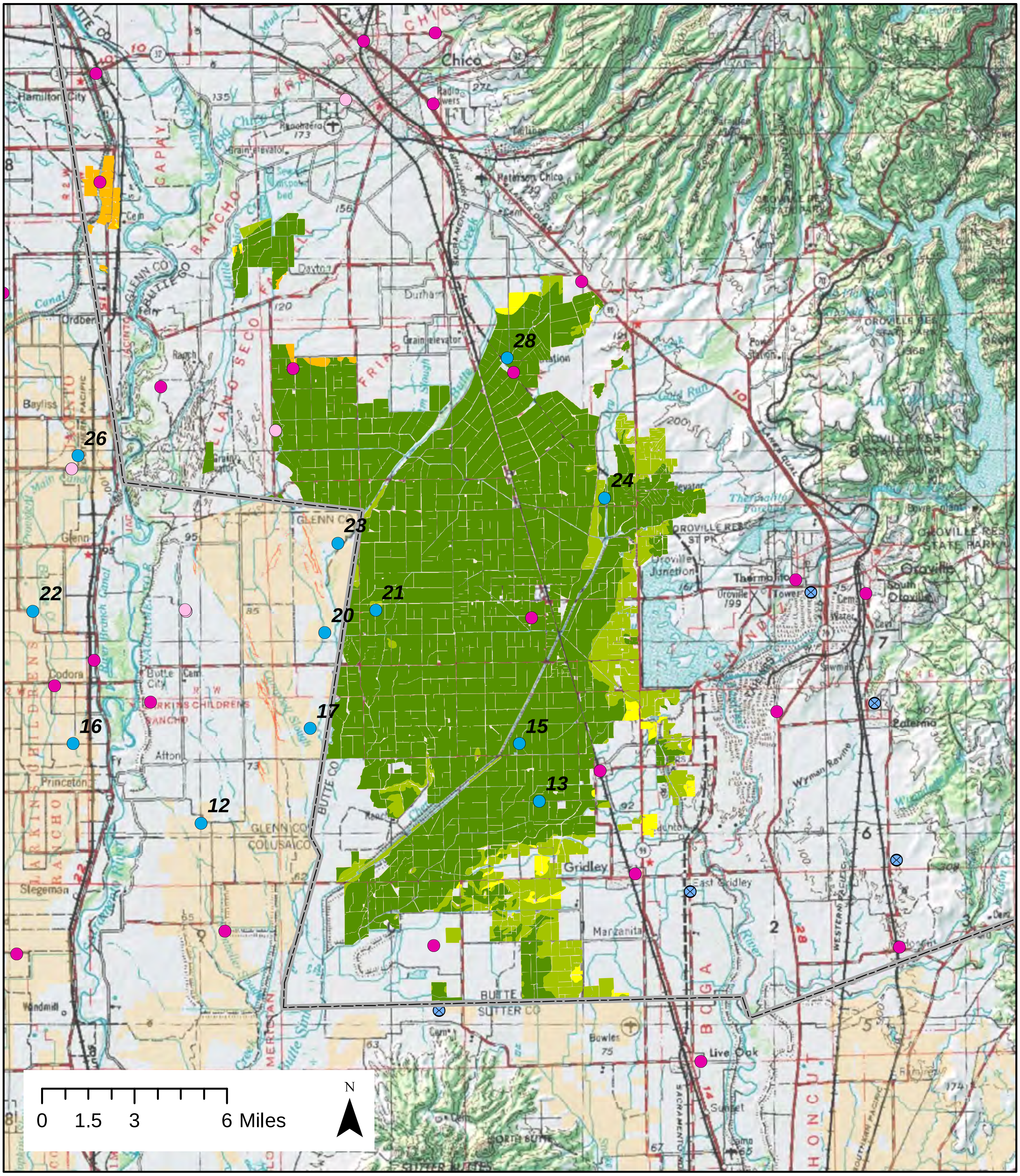
Legend

- USGS Rice Wells
- Shallow Domestic Wells
- GAMA Wells
- County Boundary
- Groundwater Basins
- Rice Lands (DWR)

NRCS Soil Drainage Class

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-2
NRCS Soil Drainage Classes with Monitoring Networks
Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-3
Butte County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

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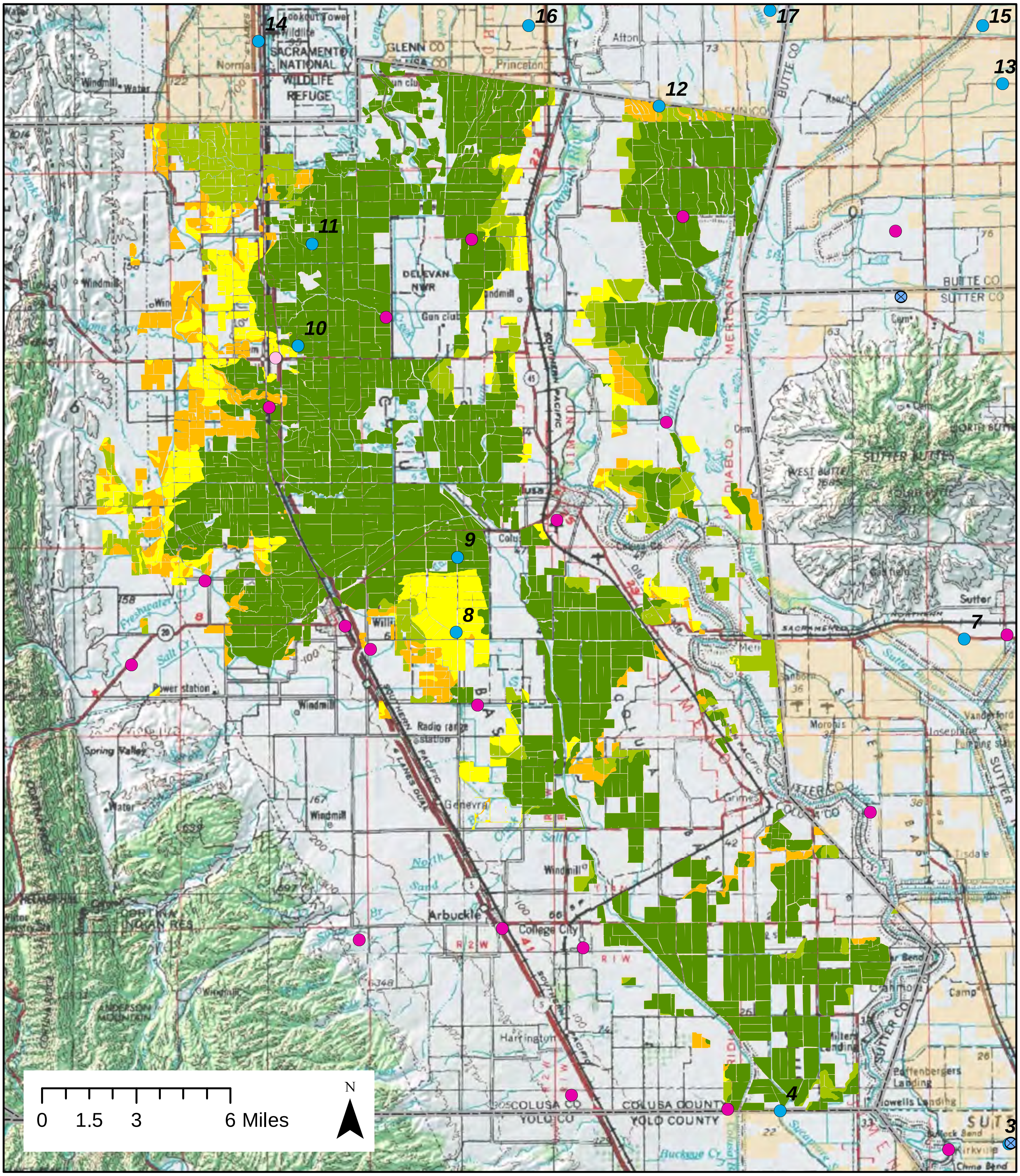

Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-4
Colusa County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

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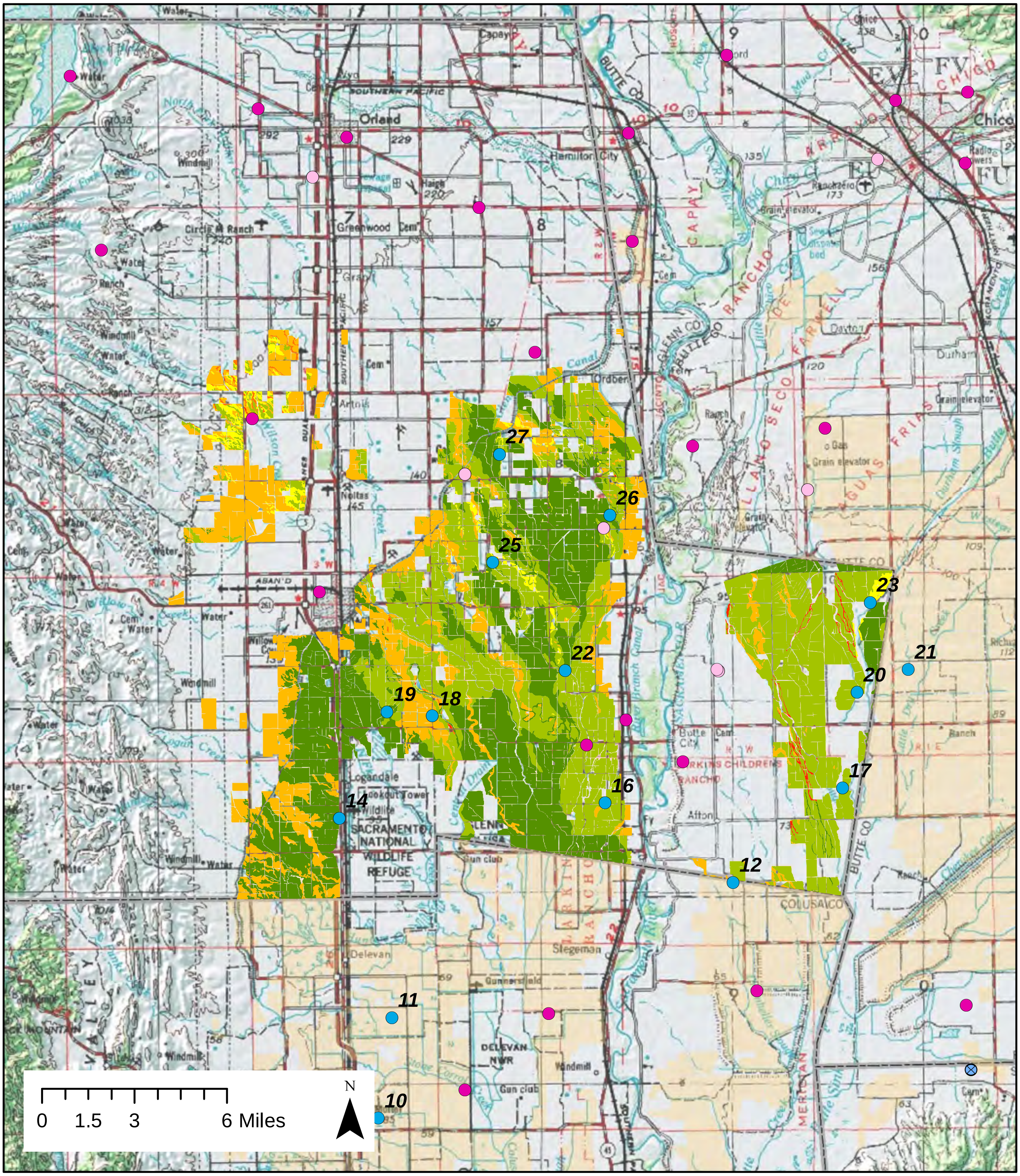


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

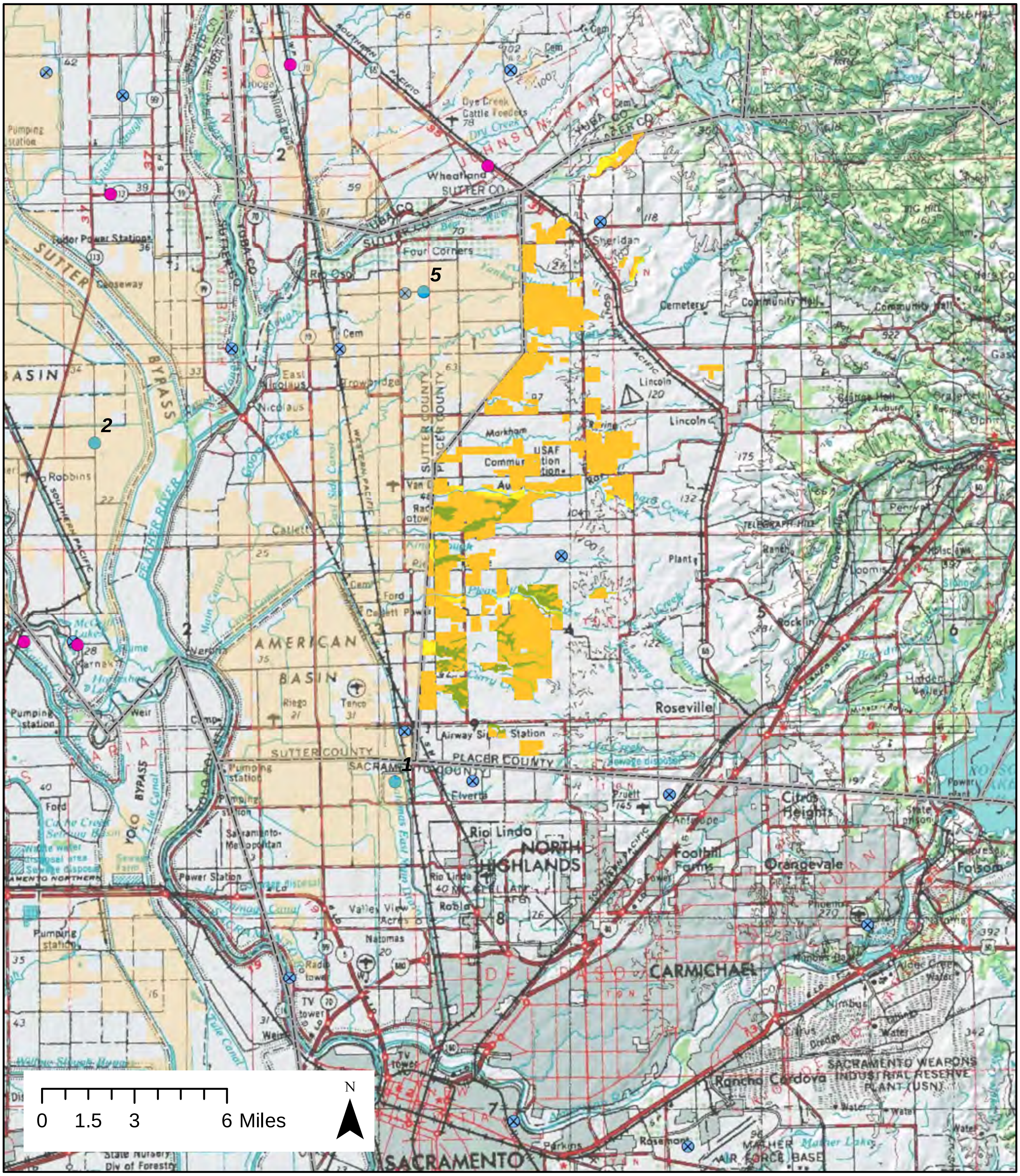
- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-5
Glenn County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-6
Placer County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

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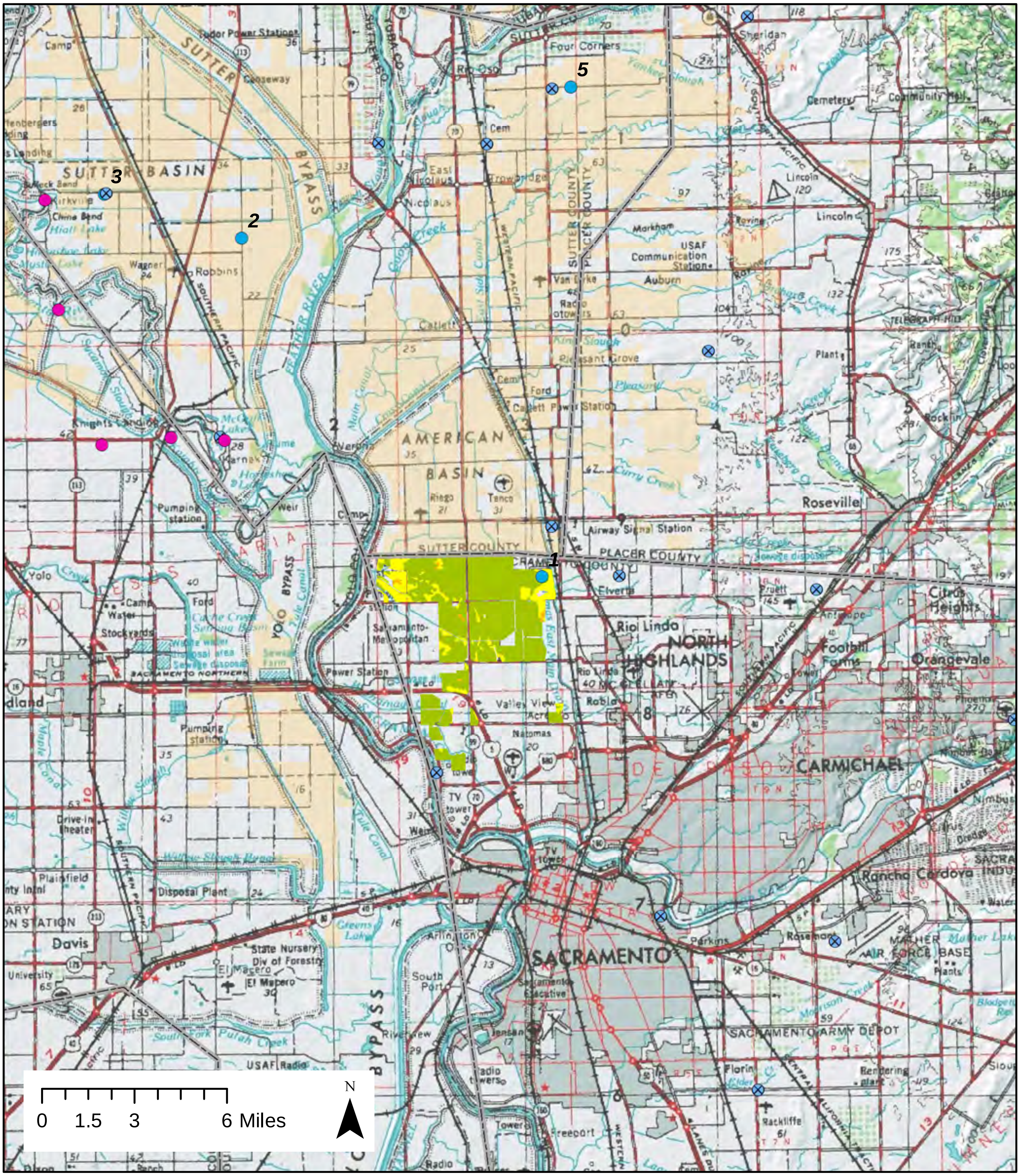


Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

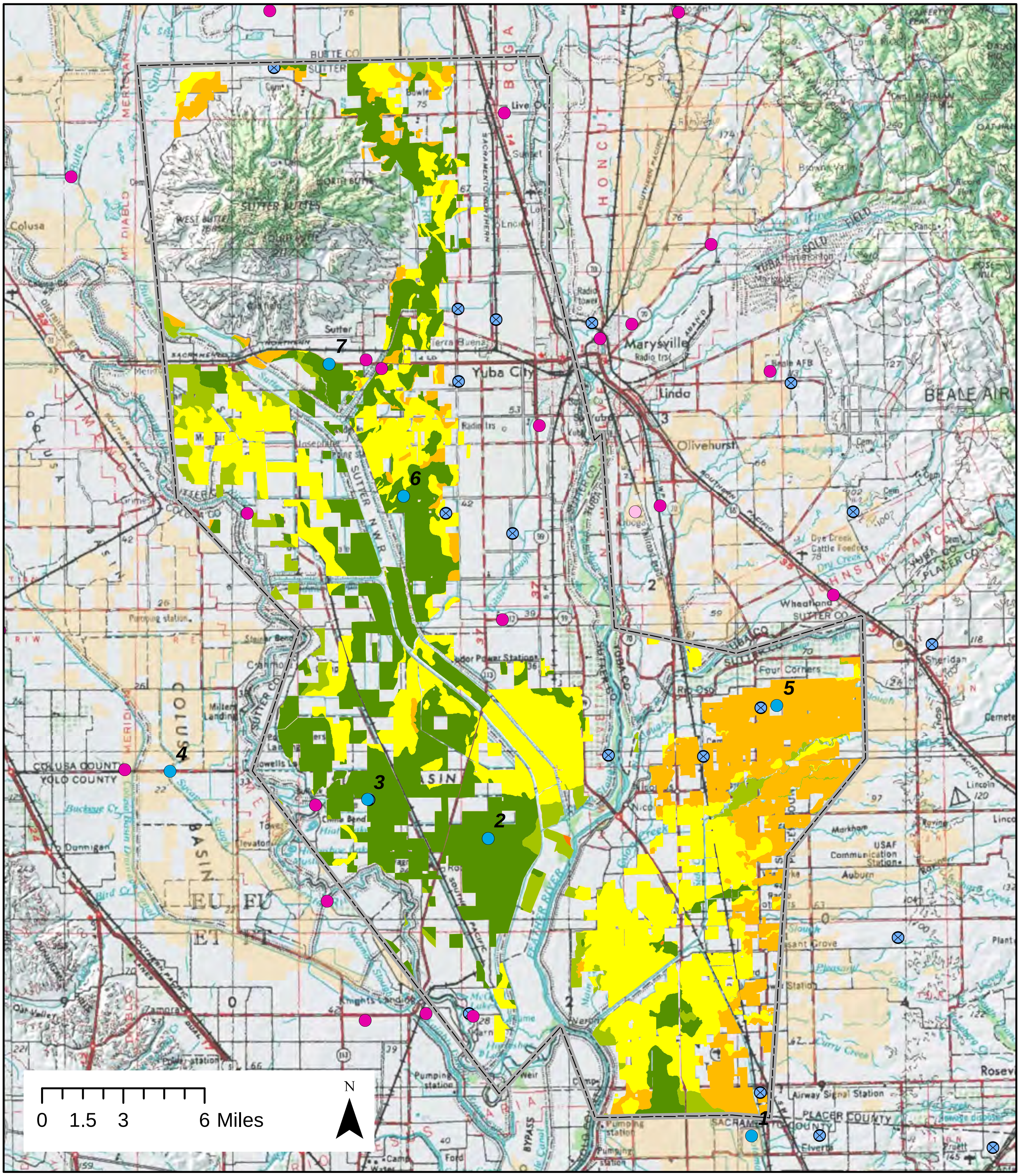
- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-7
Sacramento County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

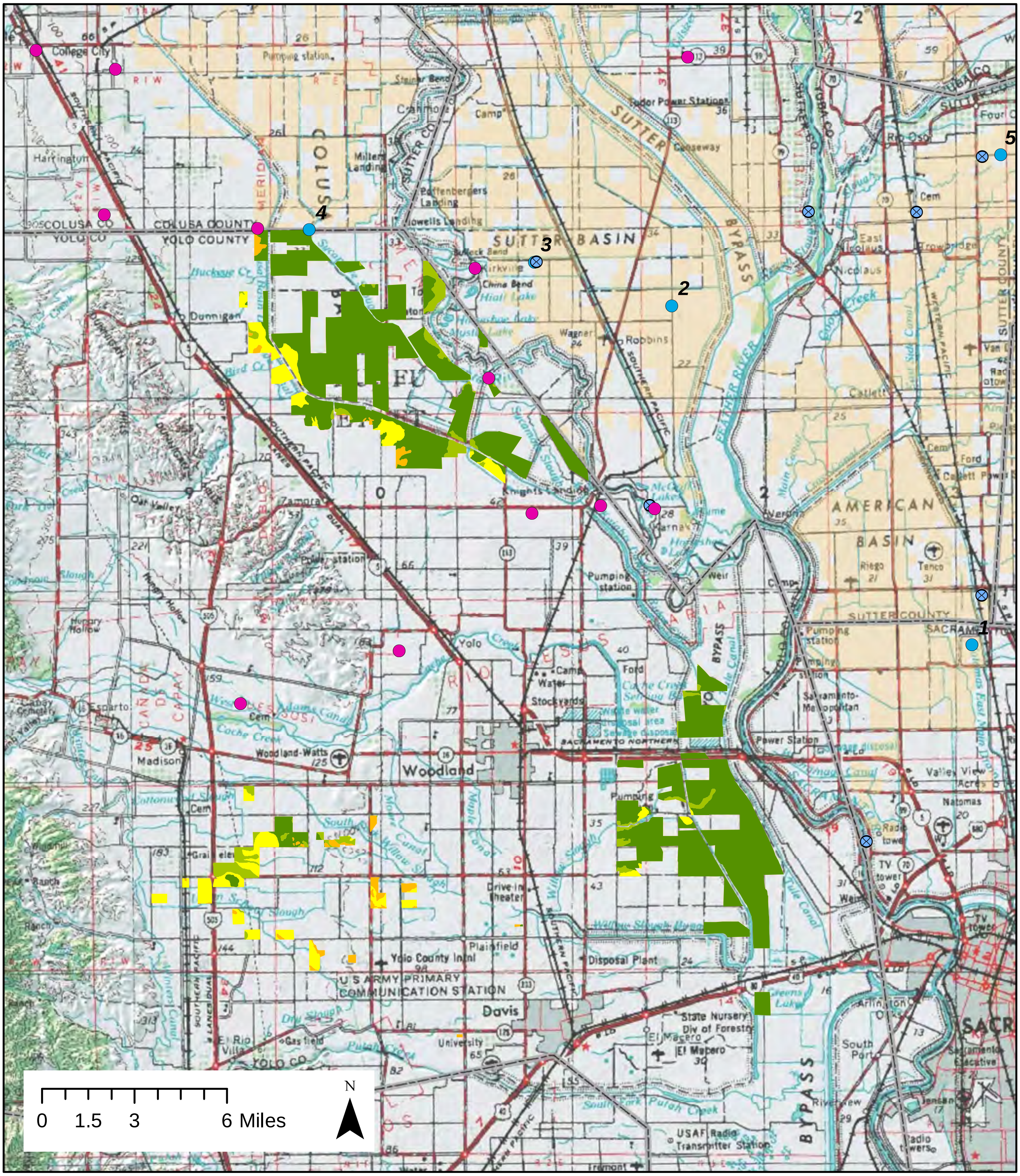
- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-8
Sutter County Rice Lands NRCS Soil Drainage Classifications, and Monitoring Networks

Rice-Specific Groundwater Assessment Report



Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Rice Wells
- USGS Shallow Domestic Wells

USGS GAMA Wells

- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-9
Yolo County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

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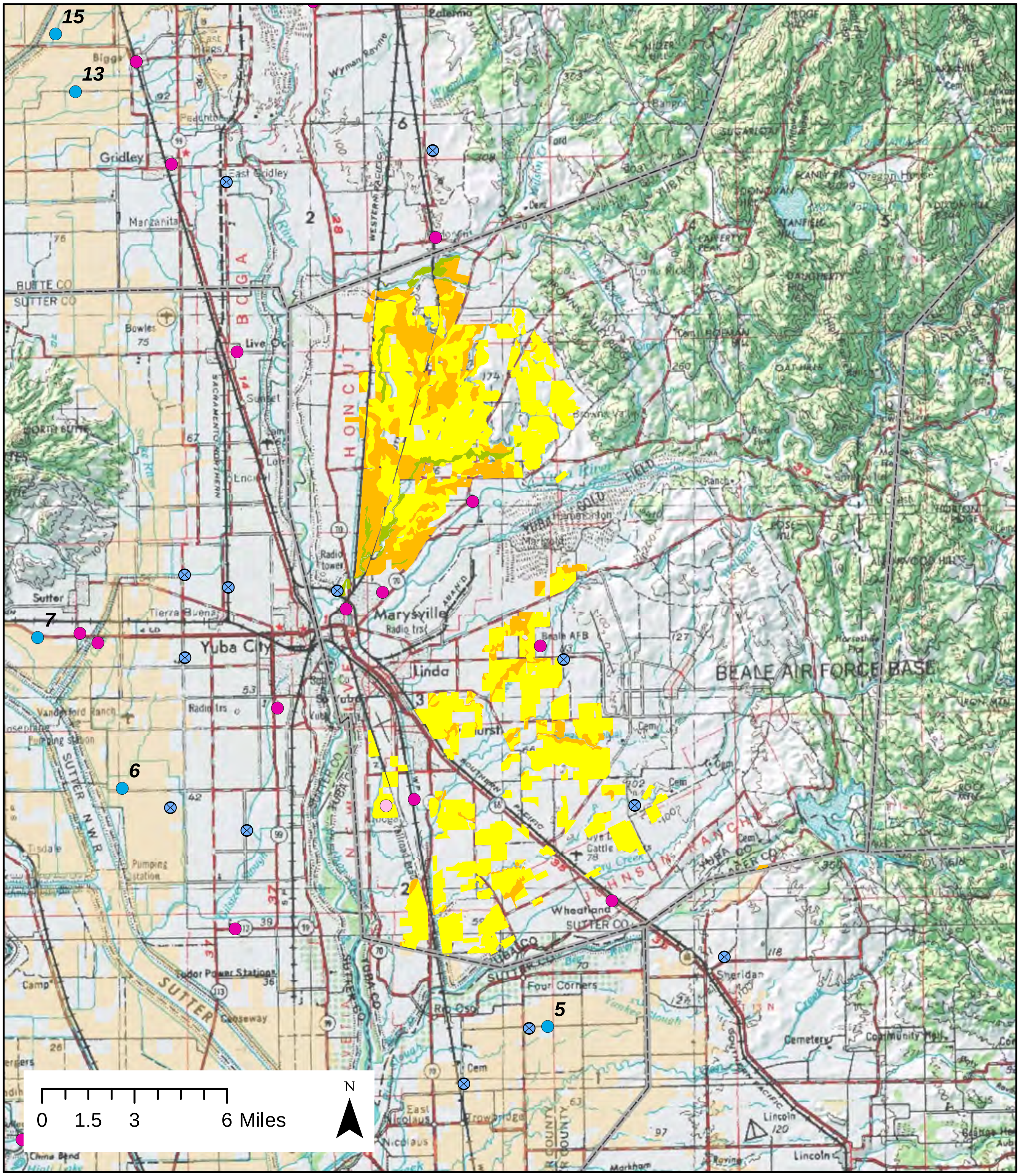

Data Sources: Groundwater Basins, Rice Crop (California DWR 2010); NRCS; Basemap, County (ESRI 2011). Datum is NAD83.

Legend

- County Boundary
- Rice Lands Outside County
- USGS Shallow Domestic Wells
- USGS Rice Wells

USGS GAMA Wells

- Grid Well
- Flow Path Well

NRCS Soil Drainage Classification

- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

MAP H-10
Yuba County Rice Lands
NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

Appendix I
Summary of GAR Requirements and Compliance

APPENDIX I

Summary of Groundwater Assessment Report Requirements and Compliance

This appendix provides additional illustration of how the California Rice Commission (CRC) has approached the need to comply with the Central Valley RWQCB's regulatory requirements to protect groundwater quality:

- The Groundwater Monitoring Advisory Workgroup's (GMAW) recommended critical questions are presented with responses and descriptions of how they relate to rice-specific areas and practices.
- The Central Valley RWQCB's Groundwater Assessment Report (GAR) requirement details are listed to illustrate how this rice-specific GAR is responsive to and compliant with each requirement, and the list provides cross-references to this GAR's specific sections, figures, and maps that support compliance.

Evaluation of Groundwater Monitoring Advisory Workgroup Questions

The GMAW, composed of groundwater experts from the State Water Resources Control Board, U.S. Geological Survey, academia, and private consultants, developed a list of seven recommended critical questions that should be addressed by groundwater monitoring as part of the Long-Term Irrigated Lands Regulatory Program (LTILRP) (collectively known as the "GMAW questions"). These questions are meant to assist Central Valley RWQCB staff identify how groundwater monitoring will be integrated into the LTILRP. This GAR provides an analysis that helps answer these questions and describes how groundwater requirements identified specifically for rice farming will be incorporated into the monitoring and reporting programs prepared for the CRC waste discharge requirements general order. The seven questions are reproduced here with answers formulated specifically for rice farming based on the analysis performed in preparation of this rice-specific GAR.

1. **What are rice farming's impacts to the beneficial use of groundwater, and where has groundwater been degraded or polluted by rice farming operations?**

A thorough analysis of root-zone studies and water quality data collected as part of several groundwater quality monitoring net works (USGS Rice Wells, Shallow Domestic Wells, USGS GAMA Wells, DPR Wells) has been presented in the GAR. This analysis evaluated several lines of evidence and found (1) low risk to groundwater posed by rice farming and (2) minimal evidence that rice farming adversely impacts groundwater quality.

A few areas of uncertainty and data gaps have been identified and can be addressed with the following approaches:

- Constituents mobilized by changing pH/redox conditions:
  - Naturally occurring elements are present throughout the vast depth of the subsurface geology. The impact that rice farming could be having on the relatively shallow depth of this geology is far surpassed by the volume of these constituents that are mobilized within the larger geological mass.
  - Reducing conditions that tend to occur under rice fields are similar to the natural historical conditions of the Sacramento Valley soils when flooding occurred regularly. Rice farming more or less maintains these historical conditions in areas where rice is farmed.
  - Reducing conditions tend to change back to oxidizing conditions when moving farther from the reducing zone. In other words, at depths below rice fields, the potential presence of oxygen could revert the conditions back to oxidizing conditions, and therefore mobile components would again be immobilized in the sediments before moving to deeper groundwater.
  - There are no rice farming management practices that would change these conditions.

  - Several mobile constituents related to rice farming and selenium are naturally occurring in California soils. However, in most other important regards, the transport, fate, and impact of naturally occurring elements related to rice farming bear no resemblance to the transport, fate, and impact of selenium in areas where it has been problematic.

- Atypical soil conditions:
  - The "atypical" Yuba County area will be evaluated in further detail as part of MRP implementation, as described in Section 7.2.

2. Which rice management practices are protective of groundwater quality, and to what extent is that determination affected by site conditions (for example, depth to groundwater, soil type, and recharge)?

Because it has been concluded that rice farming is not discharging wastes that impact groundwater quality, this step is unnecessary. Documented management practices, including nutrient management, pesticide use regulation compliance, and others contribute to the conditions that protect groundwater quality.

3. To what extent can rice farming's impact on groundwater quality be differentiated from other potential sources of impacts (such as nutrients from septic tanks or dairies)?

This question is addressed through the analysis of the USGS Rice Wells, as supplemented by the USGS Shallow Domestic Well dataset, and through use of aerial imagery to assess nearby land uses. Given the relatively contiguous nature of rice versus other crops, this is a lesser issue for evaluating rice farming than it is for other crops.

4. What are the trends in groundwater quality beneath rice areas (getting better or worse), and how can we differentiate between ongoing impact, residual impact (vadose zone), or legacy contamination?

The USGS Rice Wells provide a historical record of Trend Monitoring. These indicate relatively stable, high-quality groundwater quality conditions.

5. What properties are the most important factors resulting in degradation of groundwater quality due to rice operations (e.g., soil type, depth to groundwater, infiltration/recharge rate, denitrification/ nitrification, fertilizer and pesticide application rates, preferential pathways through the vadose zone [including well seals, abandoned or standby wells], and contaminant portioning and mobility [solubility constants])?

With regard to preferential pathways, the known soil conditions combined with the management practices do not indicate this to be a major concern. Further, water quality results do not indicate this to be a concern.

6. What are the transport mechanisms by which rice operations impact deeper groundwater systems? At what rate is this impact occurring, and are there measures that can be taken to limit or prevent further degradation of deeper groundwater while we're identifying management practices that are protective of groundwater?

Rice farming operations are not shown to be negatively impacting deeper groundwater systems. USGS GAMA wells near rice fields have provided sampling data that show high-quality groundwater. Overlying shallow groundwater is also of high quality.

7. How can we confirm that management practices implemented to improve groundwater quality are effective?

The conceptual site model (CSM) and other data showing that rice farming is not impacting groundwater quality confirm that the existing practices are effective in protecting the beneficial uses of groundwater.

Rice-Specific GAR Compliance with Requirements of Central Valley RWQCB for the LTILRP

Table I-1 provides a summary listing of GAR requirements and shows how this Rice-specific GAR complies with each. The table indicates where this report's specific sections, figures, and maps provide information in support of specific compliance requirements, and provides additional supporting remarks where relevant concerning rice-growing areas and practices.

TABLE I-1
Summary of Central Valley RWQCB GAR Requirements and Compliance Presented in the Rice-specific GAR

Central Valley RWQCB GAR Requirements	Included in Rice-specific GAR?	Section, Figure, Map	Remarks
1. Main Objectives			
Assess available data	Yes	Sections 2, 3, 4, 5	
Determine high and low vulnerability areas and establish priorities for implementation of monitoring and studies within high vulnerability areas	Yes	Section 6 (Maps 6-1 and 6-2) Section 7-2	The analysis evaluated the vulnerability of rice lands. The analysis did not result in the identification of high vulnerability areas; however, it did identify a data gap in Yuba County that will be addressed with further analysis during the MRP development phase.
Provide a basis for establishing workplans to assess groundwater quality trends	Yes	Sections 2.5, 3, 5, 7.1	
Provide a basis for establishing workplans and priorities to evaluate the effectiveness of agricultural management practices to protect groundwater quality	Yes	Sections 2.5, 3, 5	Rice farming practices are well documented.
Provide a basis for establishing groundwater quality management plans in high vulnerability areas and priorities for implementation of those plans	Yes	Sections 6 and 7	It was established that a "representative monitoring network" is not triggered based on the low vulnerability of the major constituents of concern (nitrate, pesticides).
2. GAR Components (Data Components)			
Detailed land use information, including prevalent commodities	Yes	Section 2.2, Maps 2-1, 2-3	This GAR includes only one commodity, rice. It includes detailed mapping of the commodity's farming locations.
Information regarding depth to groundwater, provided as a contour map(s)	Yes	Section 4, Appendix C	DWR groundwater level contour maps are provided.
Groundwater recharge information, including identification of areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply	Yes	Section 2.3, Map 2-13	Maps of specific recharge areas are not readily available.
Soil survey information, including significant areas of high salinity, alkalinity, and acidity	Yes	Section 2.3.1, Maps 2-7, 2-8, 2-9, 2-10, 2-11	There are no acid soils in the rice growing region. Detailed maps of soil pH, salinity, and linear extensibility are included.
Shallow groundwater constituent concentrations	Yes	Section 5	Shallow water level depths are discussed in Section 4. Constituent concentrations are presented in Section 5.
Groundwater data compilation and review (e.g. existing monitoring networks, relevant data sets, etc.)	Yes	Sections 3 and 6.2	Note Section 7.2 (Monitoring and Reporting Program Recommendations) which include data gap assessment for shallow groundwater in Yuba County and a Trend Monitoring Program.

TABLE I-1
Summary of Central Valley RWQCB GAR Requirements and Compliance Presented in the Rice-specific GAR

Central Valley RWQCB GAR Requirements	Included in Rice-specific GAR?	Section, Figure, Map	Remarks
3. GAR Data Review and Analysis			
Determine where known groundwater quality impacts exist for which irrigated agricultural operations are a potential contributor or where conditions make groundwater more vulnerable to impacts from irrigated agricultural activities	Yes	Sections 3, 5, 6.3, 6.5	
Determine the merit and feasibility of incorporating existing groundwater data collection efforts (include findings, conclusions, and rationale)	Yes	Sections 5, 7.2, Maps 7-1 and 7-2, Appendix E-1, E-2, E-3	The shallow USGS Rice Well network is a perfect example of incorporation of existing networks into the MRP.
Prepare a ranking of high vulnerability areas to provide a basis for prioritization of workplan activities.	Not applicable		As mentioned above, no high vulnerability areas have been identified, so no ranking is possible.
Discuss pertinent geologic and hydrogeologic information	Yes	Sections 2.3.2, and 2.3.3,	See corresponding figures of these sections.
4. Groundwater Vulnerability Designations			
GAR shall designate high/low vulnerability areas	Yes	Section 6	
Vulnerability designations will be made by using a combination of physical properties and management practices	Yes	Sections 2.2, 2.3, 2.5, 6	
5. Prioritization of high vulnerability groundwater areas			
The third-party may prioritize the areas designated as high vulnerability areas (see WDR for list of prioritization considerations), including conducting monitoring programs and carrying out required studies.	Yes	Sections 5, 7.2 Maps 7-1 and 7-2	The analysis of rice lands did not result in the identification of high-vulnerability areas for the primary constituents of concern; the identified data gap in Yuba County will be addressed with further (vulnerability) analysis during the MRP development phase. The GAR prioritized the entire rice farming area relative to monitoring, selecting certain USGS Rice Wells, and the additional data gap area in Yuba County.