# 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<br>(CAS No. 83055-99-6)<br>Rice Specific | DuPont™ Londax® Herbicide | 1,479.76 | 369 | 30,925.44 | 5.5% | 52,052 / 9.4% |
| Bispyribac-sodium<br>(CAS No. 125401-92-5) | Regiment® CA Herbicide | 2,376.09 | 1,393 | 81,752.99 | 14.6% | 93,783/ 17% |
| Carfentrazone-ethyl<br>(CAS No. 128639-02-1) | Shark® Herbicide | 1,303.56 | 163 | 13,225.06 | 2.3% | 10,967/ 2% |
| Clomazone<br>(CAS No. 81777-89-1)<br>Rice Specific | Cerano® 5 MEG | 74,192.61 | 2,174 | 154,099.73 | 27.5% | 205,176/ 37% |
| Cyhalofop-butyl<br>(CAS No. 122008-85-9)<br>Rice Specific | Clincher® CA | 24,402.11 | 1,072 | 76,145.06 | 13.6% | 90,180/ 16.3% |
| 2,4-D<br>(CAS No. 20940-37-8) | Various names | 4,224.11 | 235 | 22,584,49 | 4.0% | 13,571/ 2.5% |
| Glyphosate:<br>Diammonium salt<br>(CAS No. 69254-40-6)<br>Isopropylamine salt<br>(CAS No. 38641-94-0)<br>Potassium salt<br>(CAS No. 70901-12-1) | Roundup®,<br>Touchdown® | 2,963.82 | 51 | 3,708.05 | 0.66% | 6,090/ 1.1% |
| Halosulfuron<br>(CAS No. 100784-20-1) | Sempra® CA Herbicide | 193.39 | 78 | 4,303.59 | 0.80% | 4,340/ 0.78% |
| Orthosulfamuron<br>(CAS No. 213464-77-8) | Strada® CA | 373.61 | 99 | 6,276.40 | 1.1% | 5,305/ 0,96% |
| Paraquat dichloride<br>(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

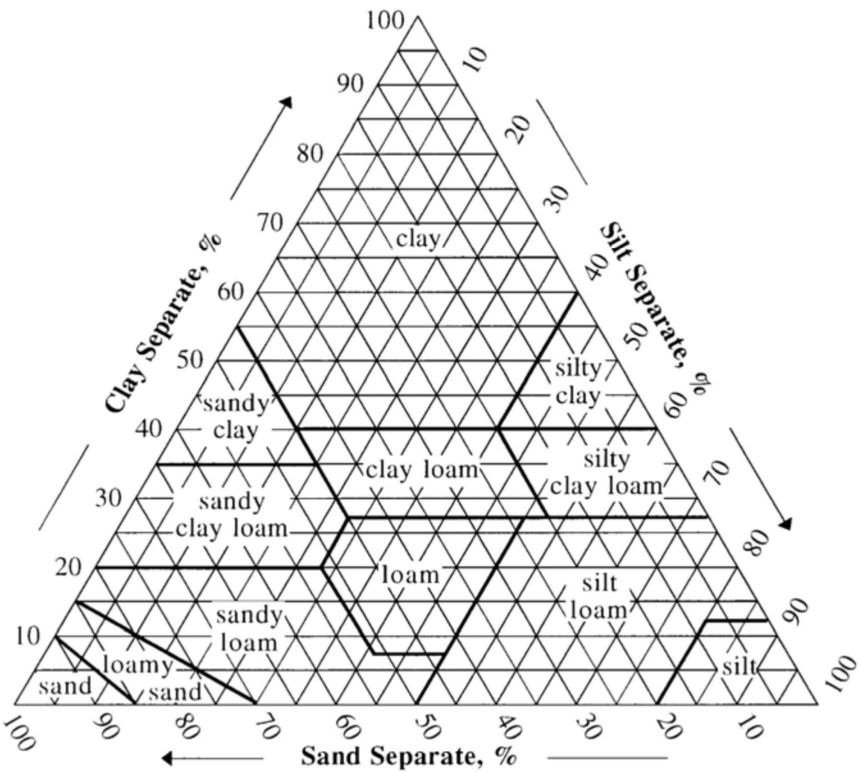
1. Definition

   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.

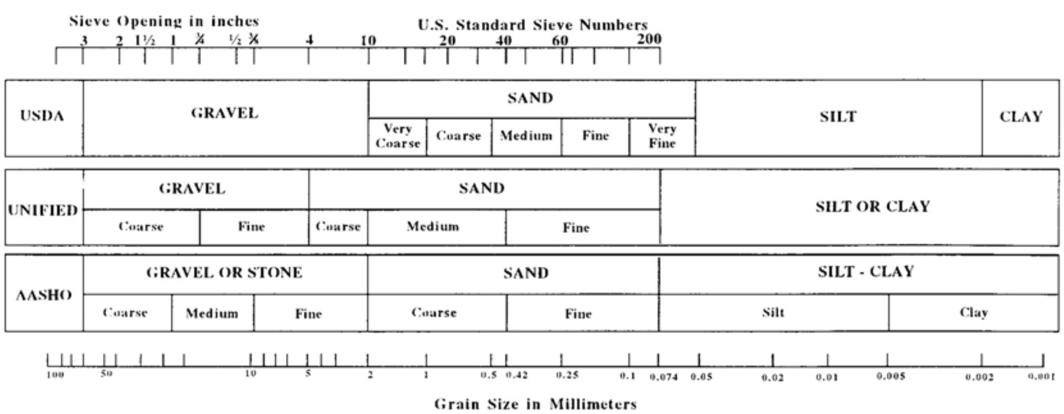
   ii. Each texture class has defined limits for each particle separate class of mineral particles less than 2 mm in effective diameter. The basic texture classes, in the approximate order of increasing proportions of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, 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

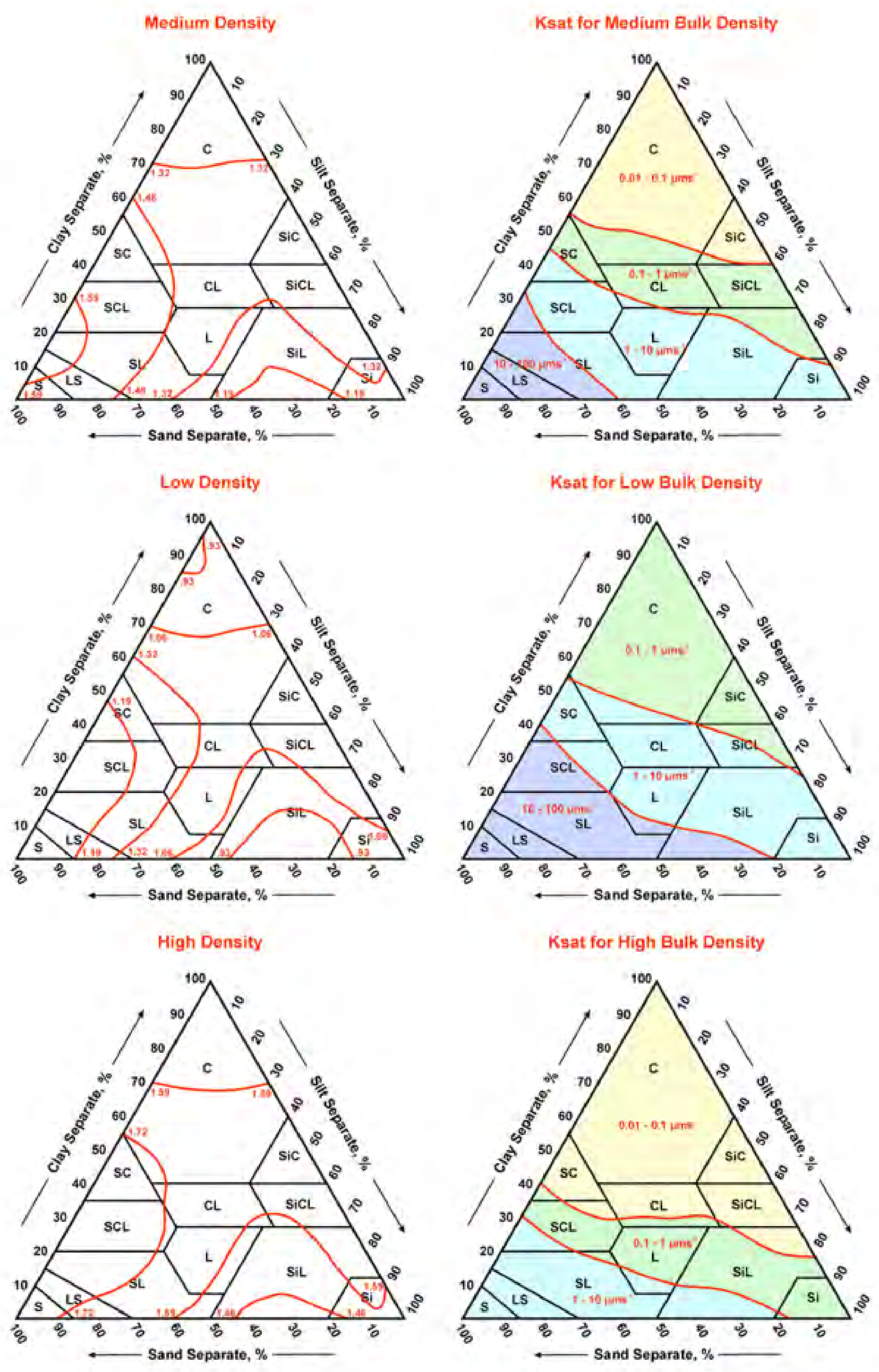



COMPARISON OF PARTICLE SIZE SCALES



## 618.88 Guide for Estimating $K_{sat}$ from Soil Properties

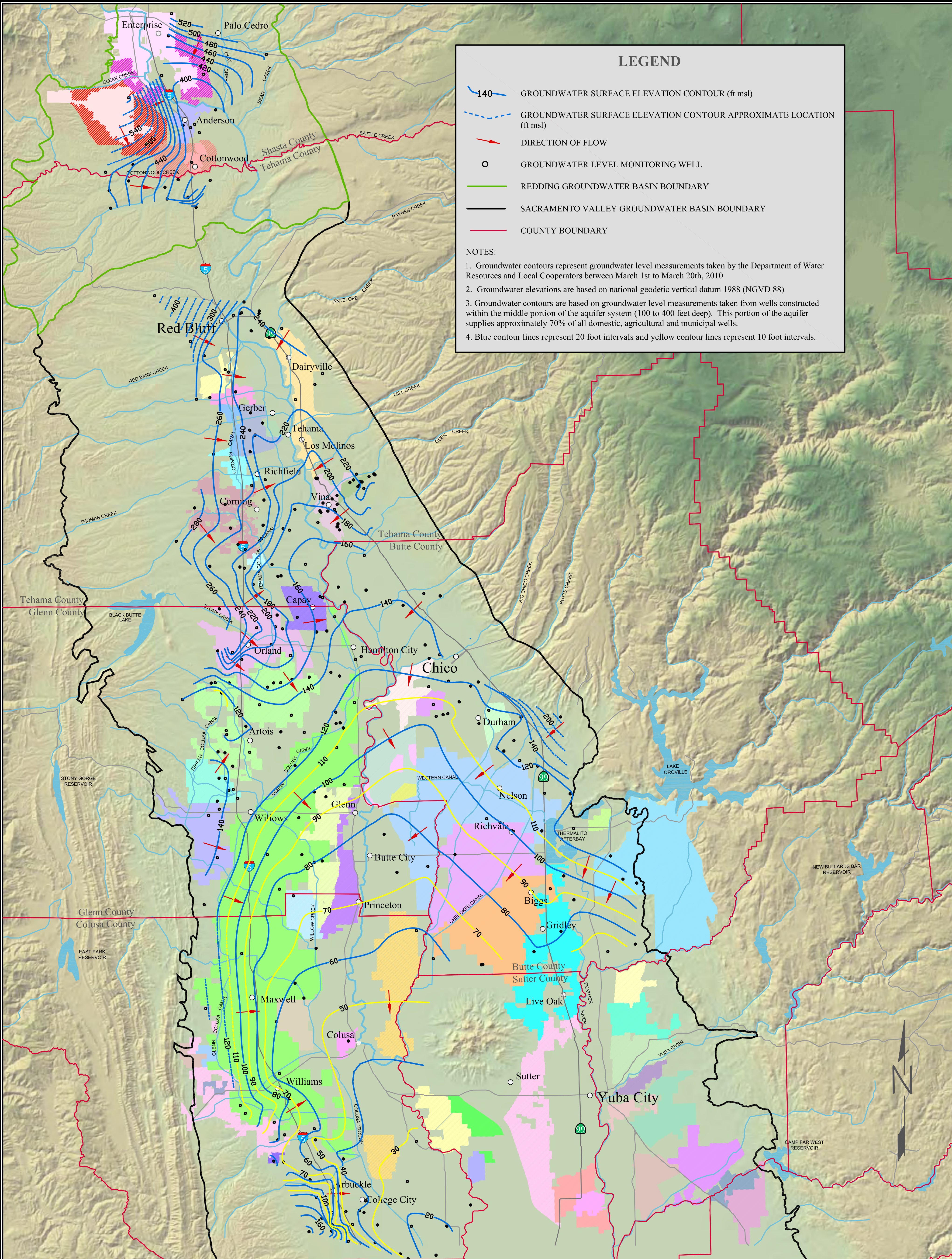
Estimate saturated hydraulic conductivity ($K_{sat}$) from soil texture by first selecting the bulk density class of medium, low, or high. Then use the corresponding textural triangle to select the range of saturated hydraulic conductivity in $\mu ms^{-1}$. Overrides follow the textural triangles.



# 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

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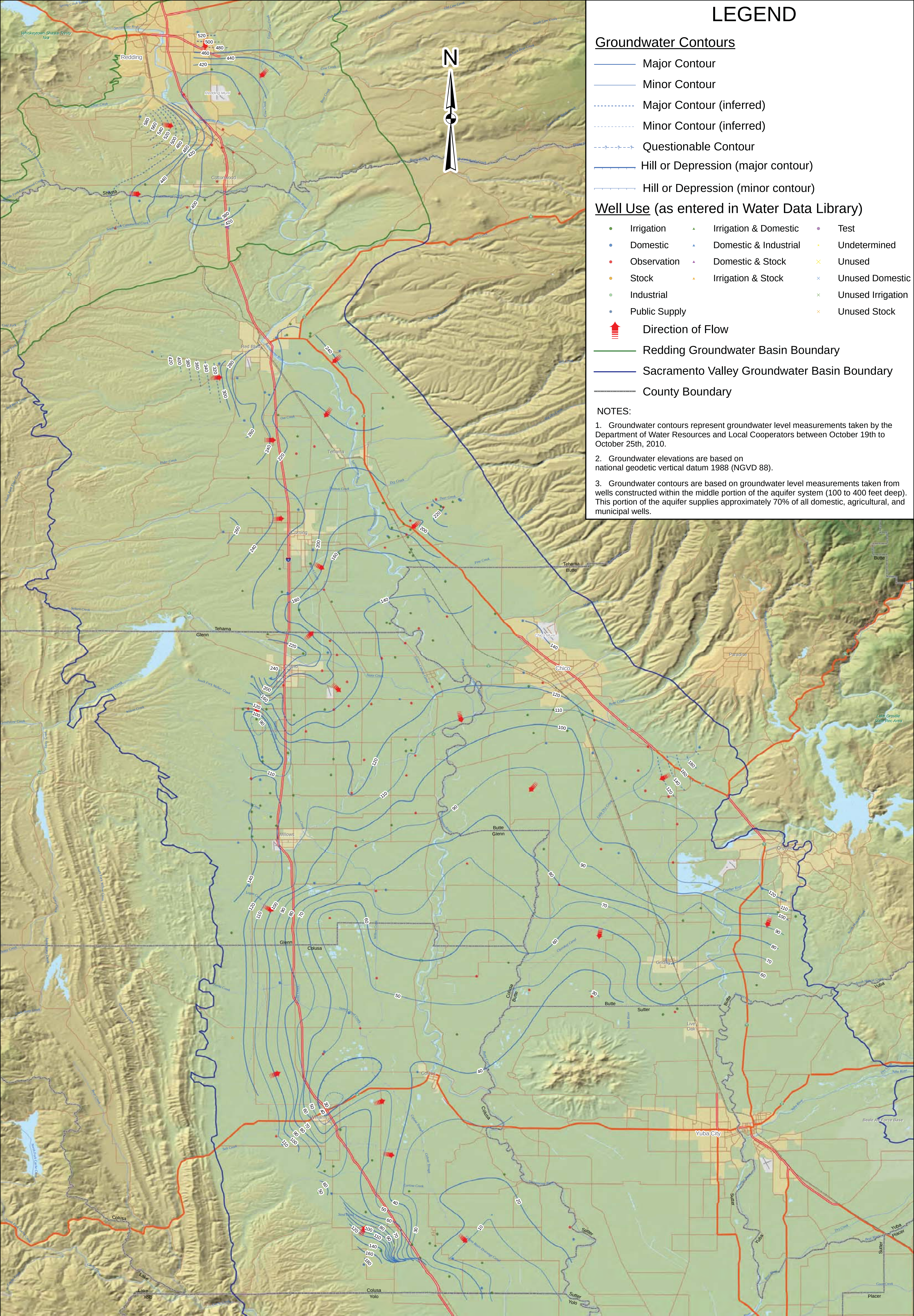
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN REGION OFFICE

# 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 |

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THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

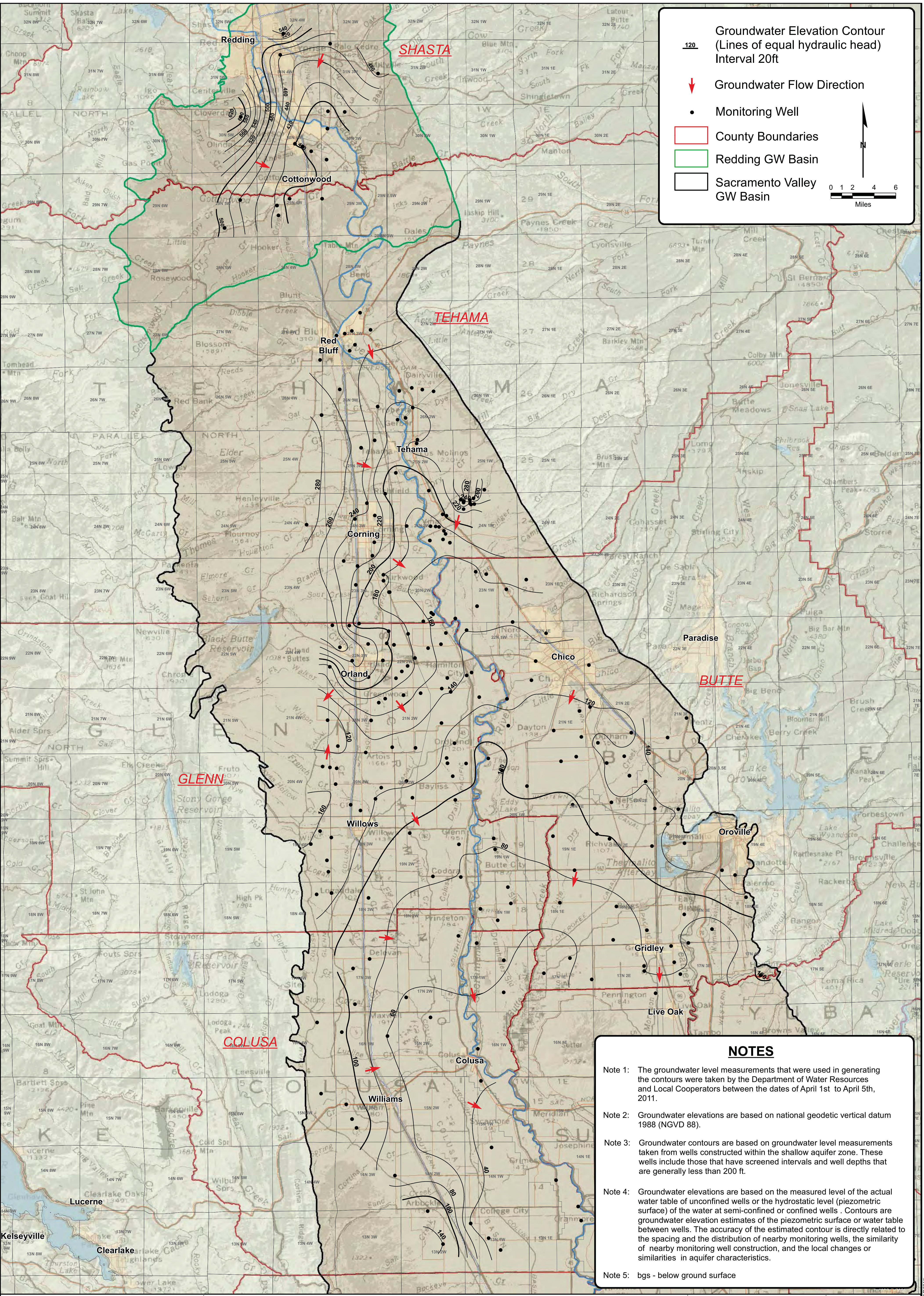
# SACRAMENTO VALLEY GROUNDWATER ELEVATION MAP
# FALL 2010

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

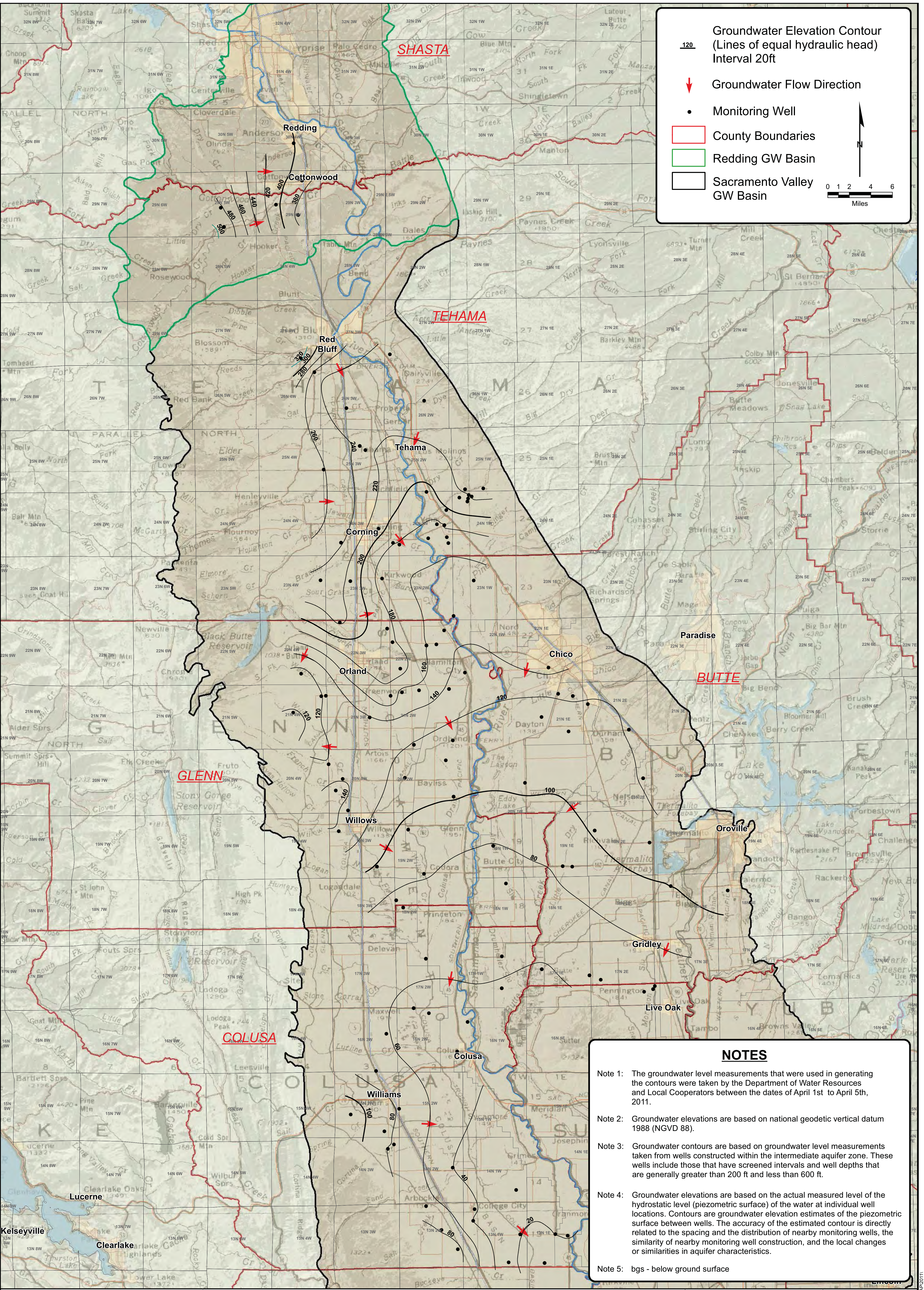
(Wells generally less than 200 ft bgs)

PLATE 1S

Date: February 2012

BY: G. Gordon

Location: R:\Sections\GCM\CONTOUR_MAP\2011\




## 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)

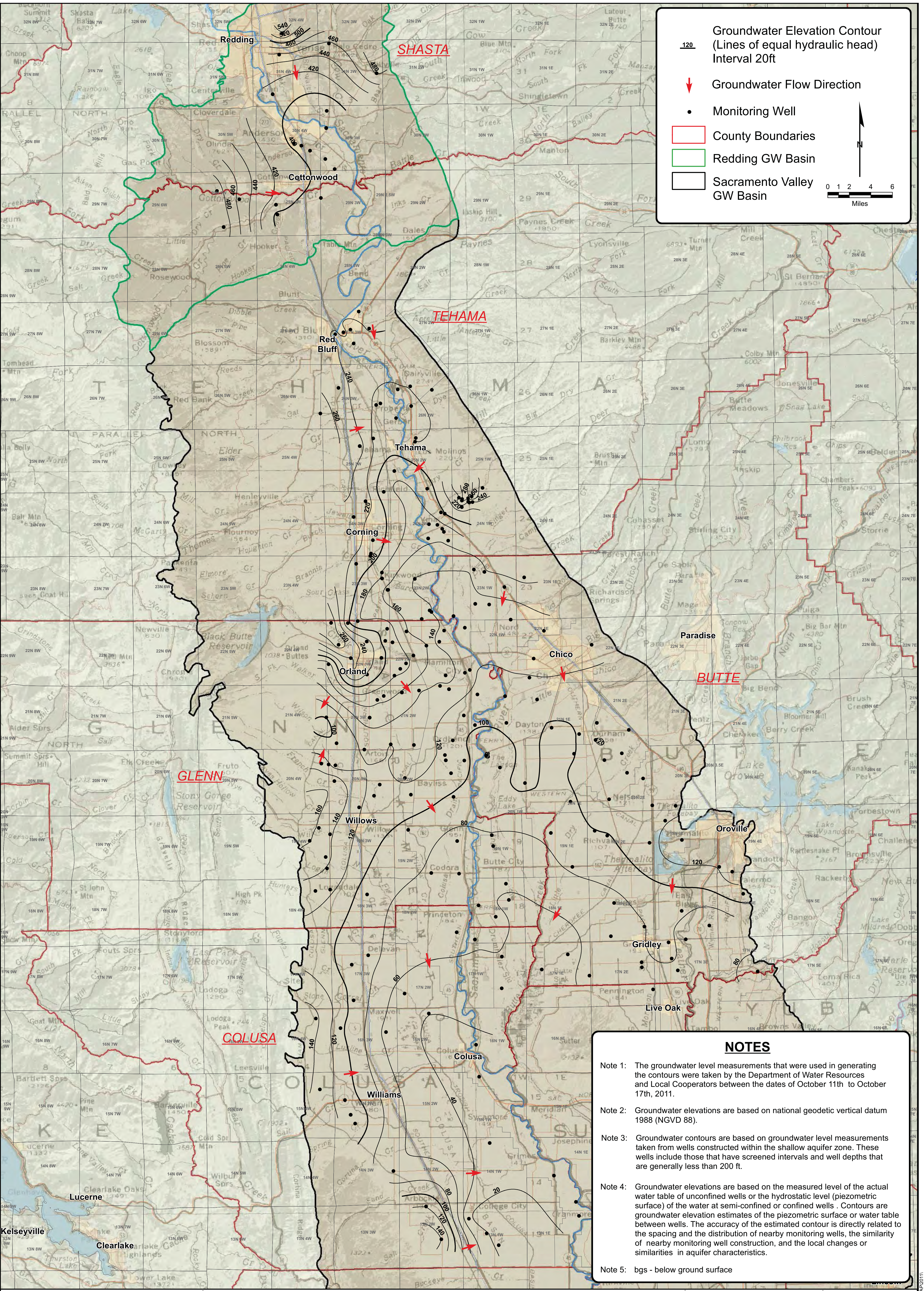
PLATE 1I

Date: February 2012

BY: G. Gordon

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 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)

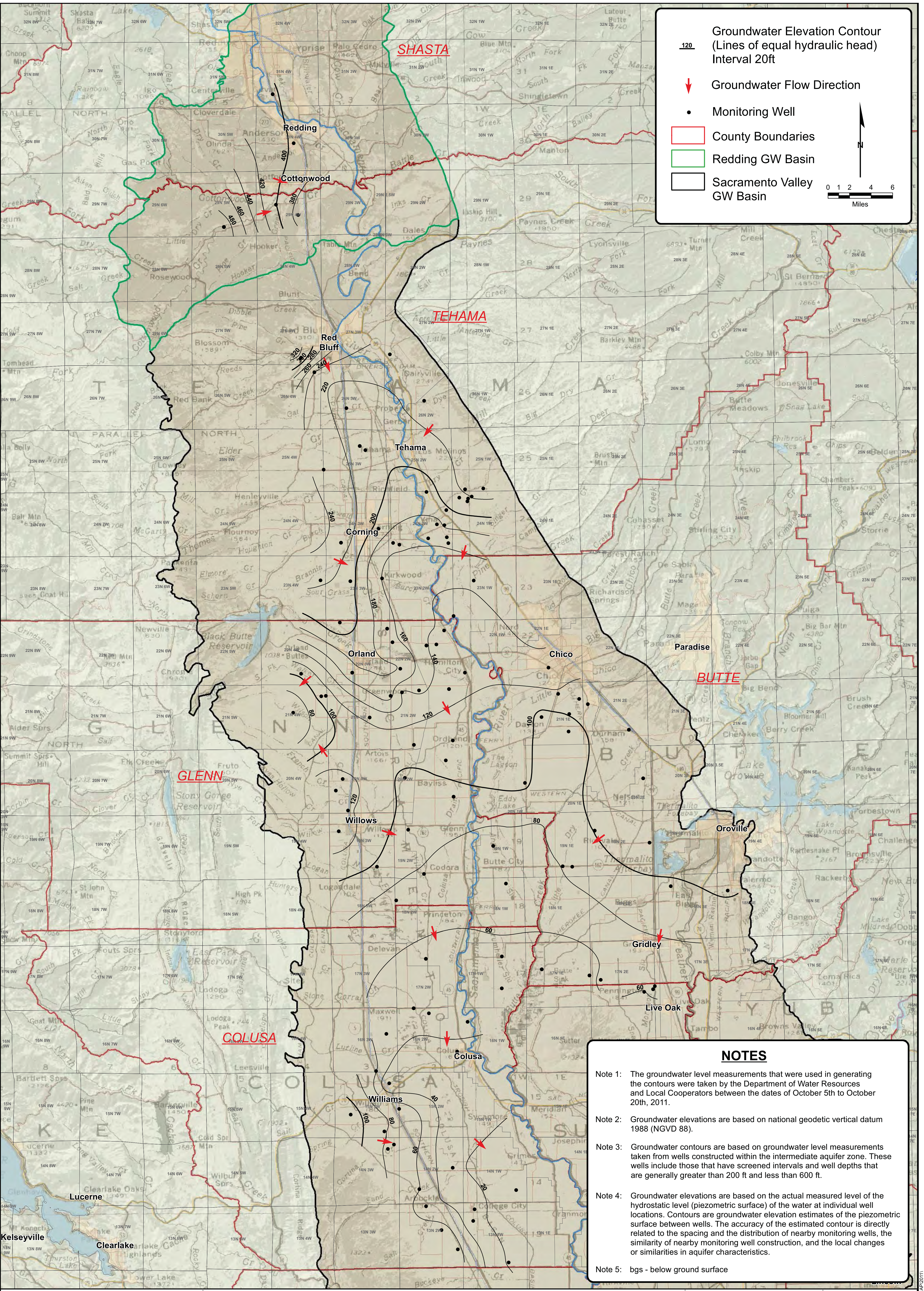
PLATE 3S

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

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# 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).

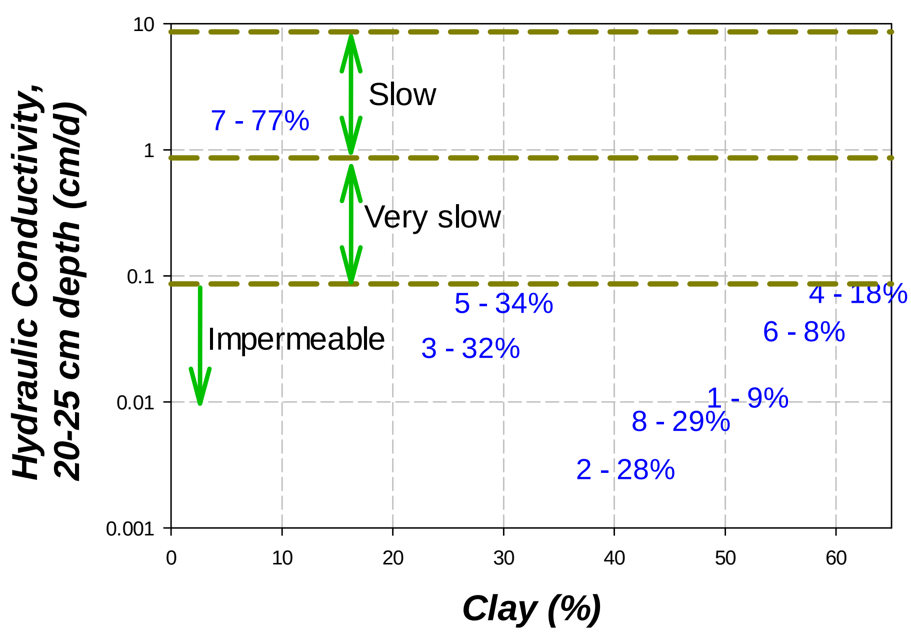

**Figure 1. Average hydraulic conductivity (measured on four to six, 2-inch long, undisturbed soil cores from about a foot depth each site) for soils representing a wide range of Sacramento Valley geographic locations, landscape positions, and soil textural conditions. Points are plotted as "# - x%",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

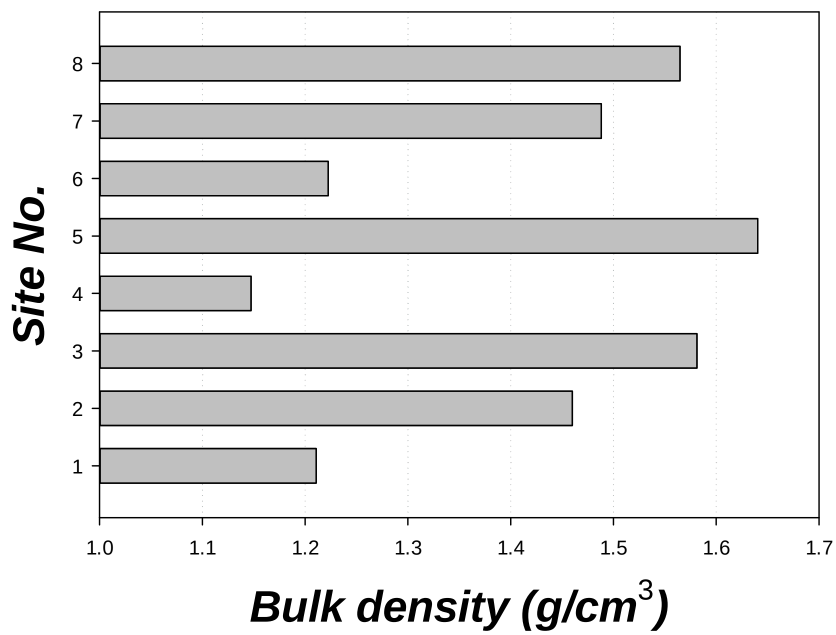


**Figure 2. Bulk density for soils at sites shown in Figure 1.**

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).

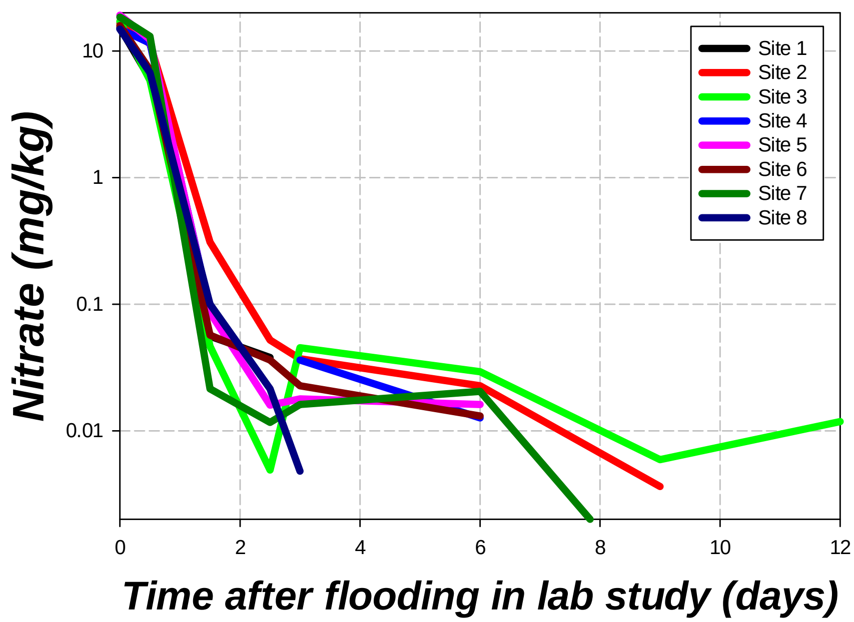


**Figure 3 (from Linquist et al. 2011). Transformation of nitrate-N in flooded rice fields after the initiation of flooding.**

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.

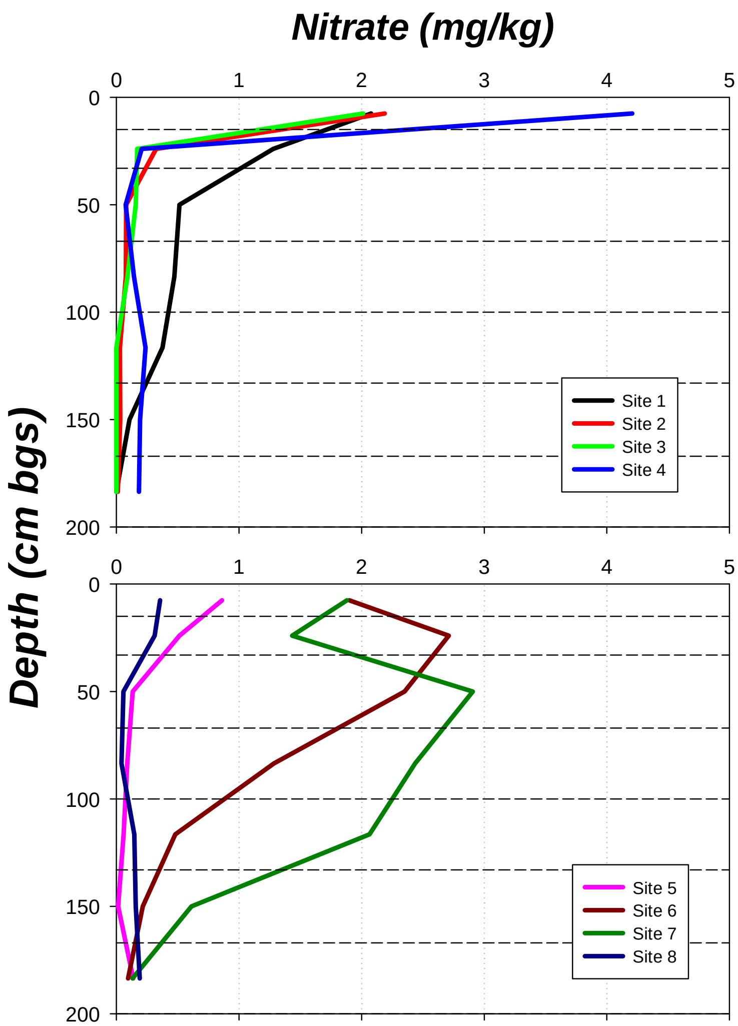


**Figure 4 (from Linquist et al., 2011). Vertical distribution of nitrate-N on eight soil profiles sampled in the spring, pre-flooding.**

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.

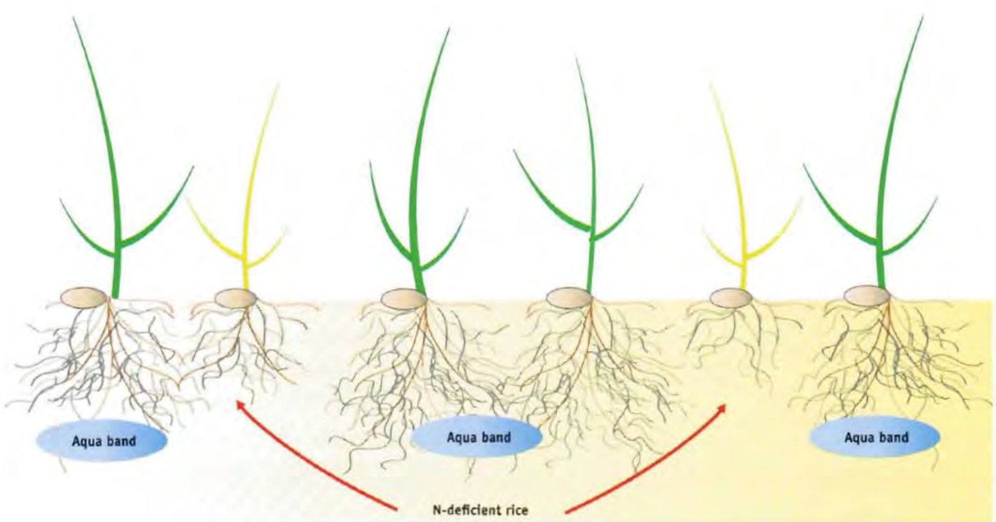


**Figure 4.10.** Diagramatic representation of streaking, showing how aqua placed too deeply in a nitrogen-deficient field may result in deficiency symptoms in seedlings that grow between the aqua bands and whose roots have not yet reached the aqua. These deficient plants will occur in fairly regular 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.

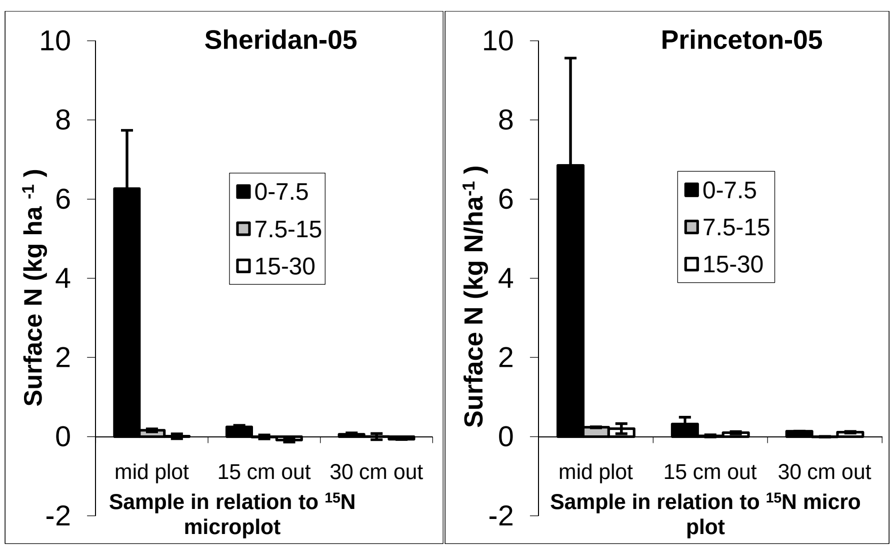


**Figure 5. From Linquist (2012), showing the fate of fertilizer N in soil profile in two rice fields. $^{15}N$ was applied as a starter fertilizer, broadcast to the soil surface at the beginning of the growing season. At the end of the season soil samples were taken to a depth of 30 cm from the center 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).

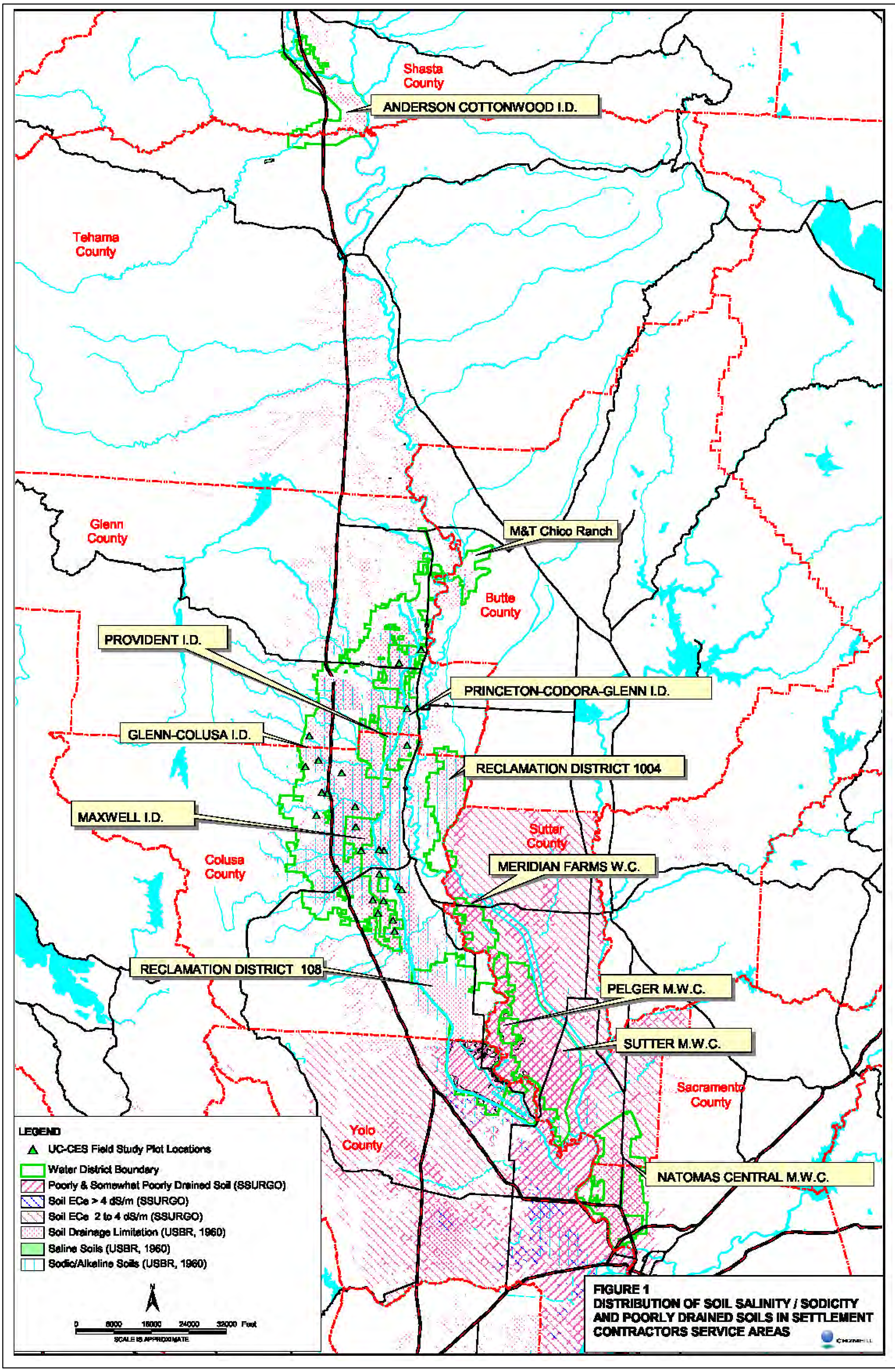


**FIGURE 1**
**DISTRIBUTION OF SOIL SALINITY / SODICITY AND POORLY DRAINED SOILS IN SETTLEMENT CONTRACTORS SERVICE AREAS**

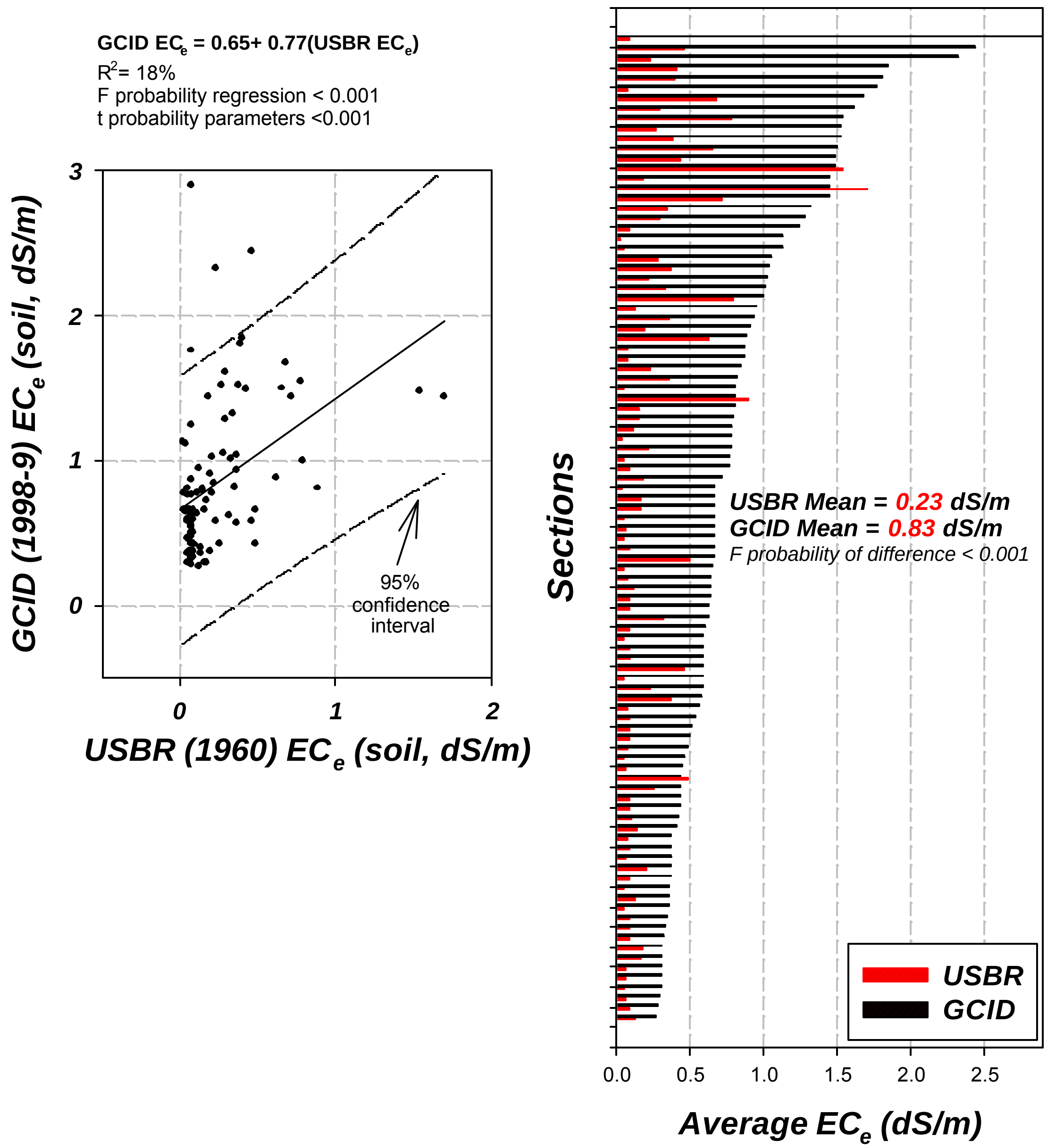


Figure 2. Change in soil salinity between 1960 and 1998 samplings. The shallow (0.77) slope suggests that areas with relatively less initial salinity were affected the most. This is apparent when you compare the length of red (USBR, 1960) and black (GCID, 1999) bars in each pair throughout the range 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.

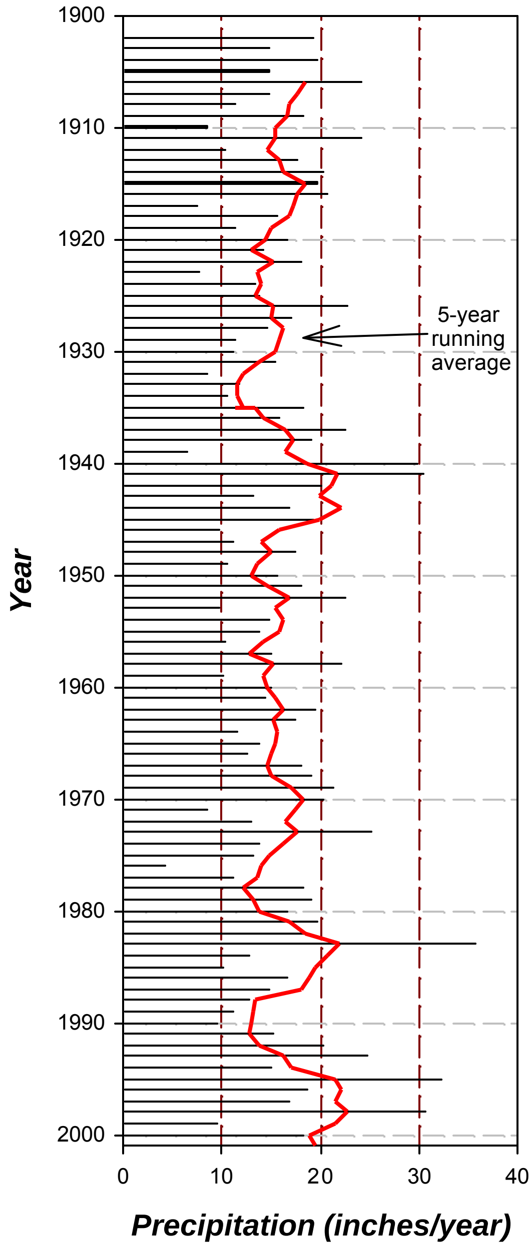


Figure 3. Annual and 5-year moving average precipitation at Colusa. Missing data were estimated from nearby stations.

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?

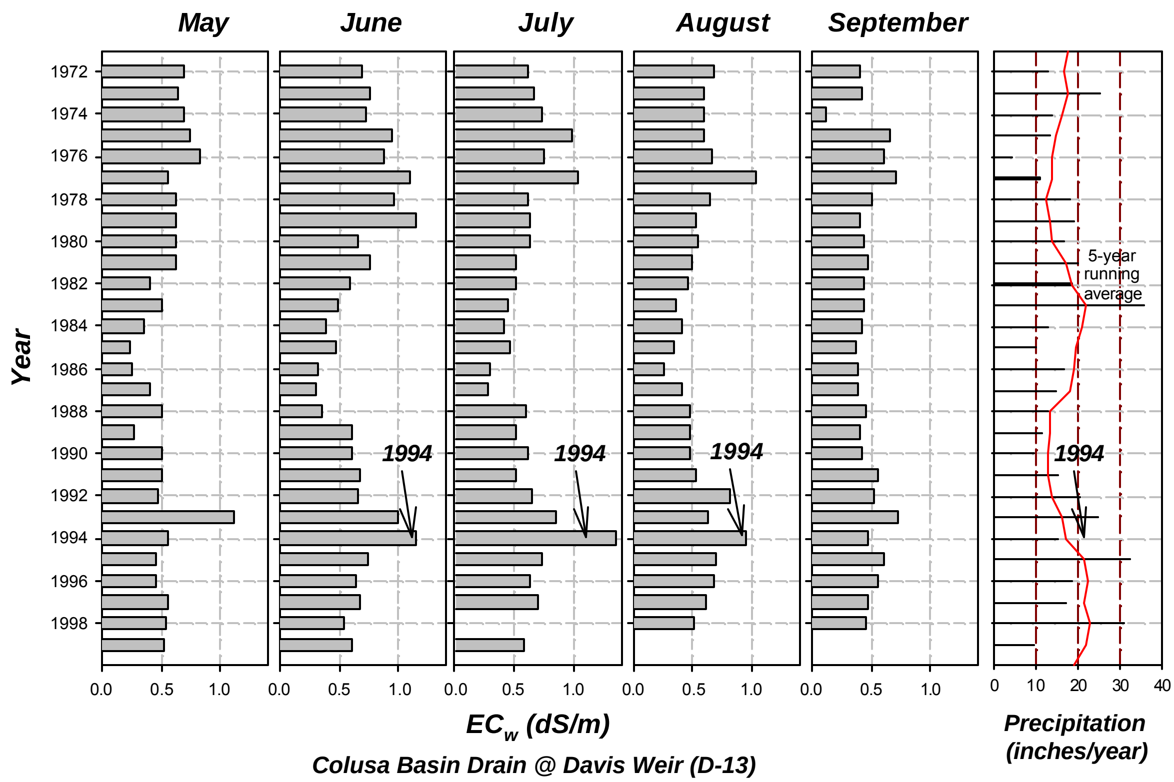


Figure 4. Salinity in the Colusa Basin Drain from 1972 to 1999. In a general sense, this represents the salinity concentrations entering drainage tributaries from surface flow out of lower checks and shallow groundwater seepage. GCID data from Scardaci et al. (1999) through 1997; 1998-9 data from Van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

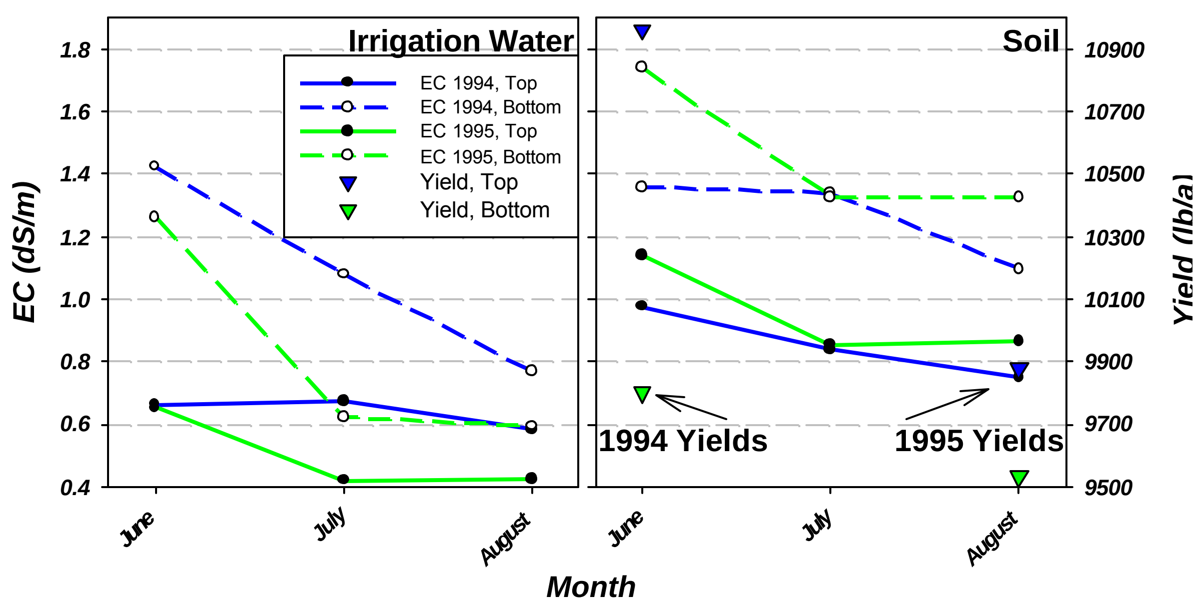


Figure 5. Water and soil electrical conductivity, and rice yield, response to distance from freshwater input to the field. Data from 1994 and 5 (Scardaci, et al., 1999).

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.

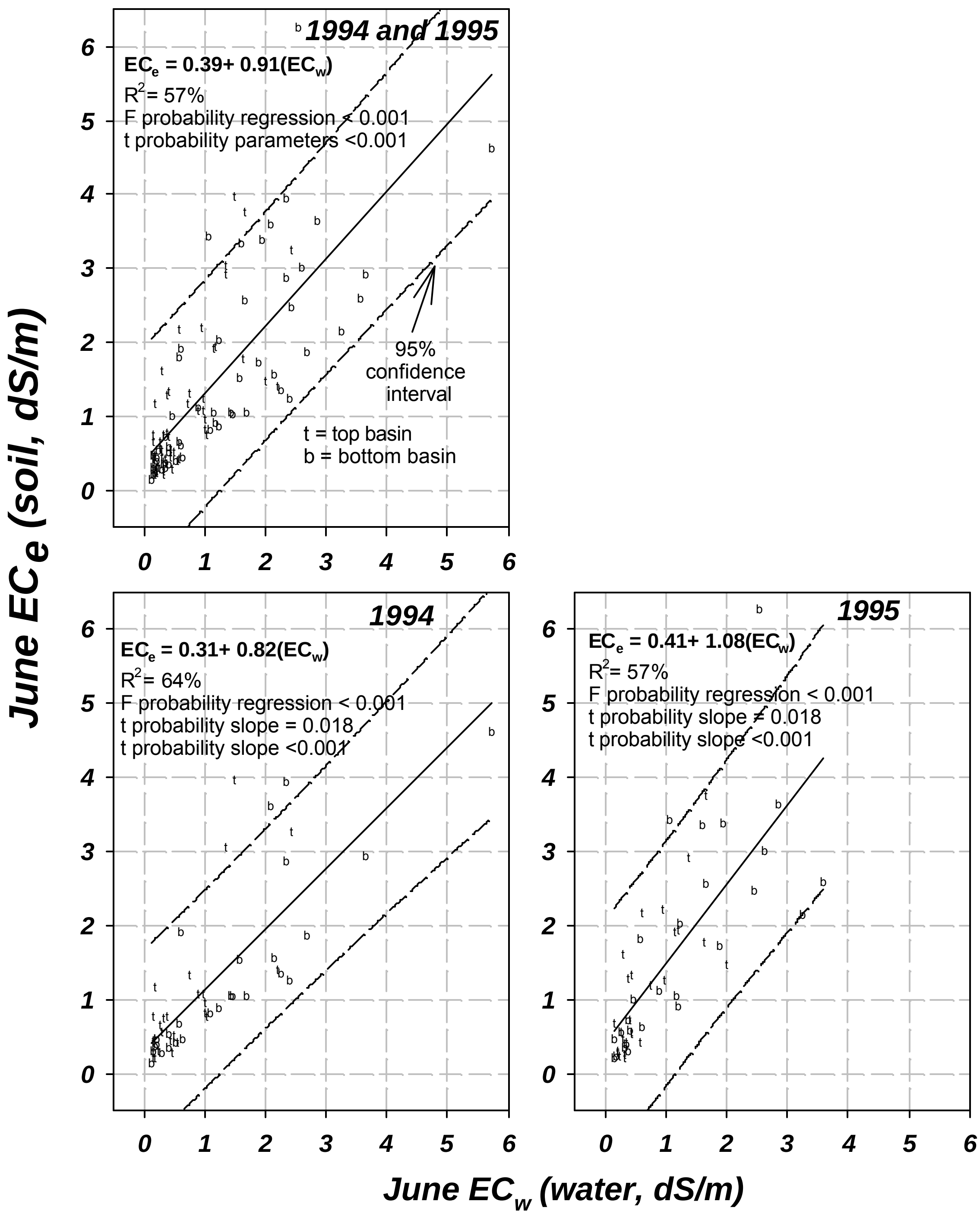


Figure 6. Relationship between water supply salinity and soil salinity in fields sampled in 1994 and 1995 (Scardaci et al., 1999).

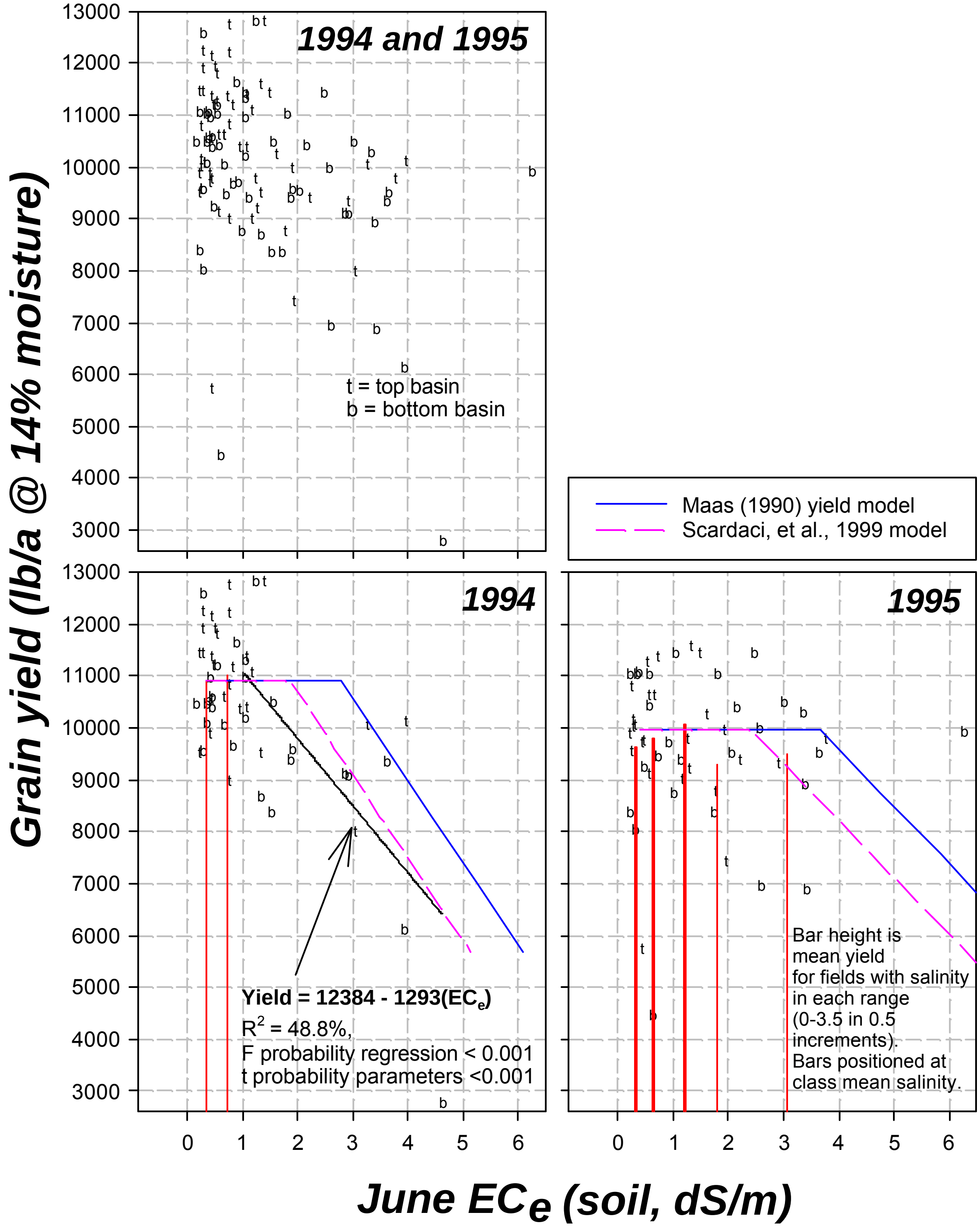


Figure 7. Rice grain yield response to salinity, 1994 and 1995 (data from Scardaci et al., 1999). Note that the $EC_e$ levels shown for the vertical bars are the average $EC_e$ of checks in each 0.5-dS / m increment along the x axis.

## 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.

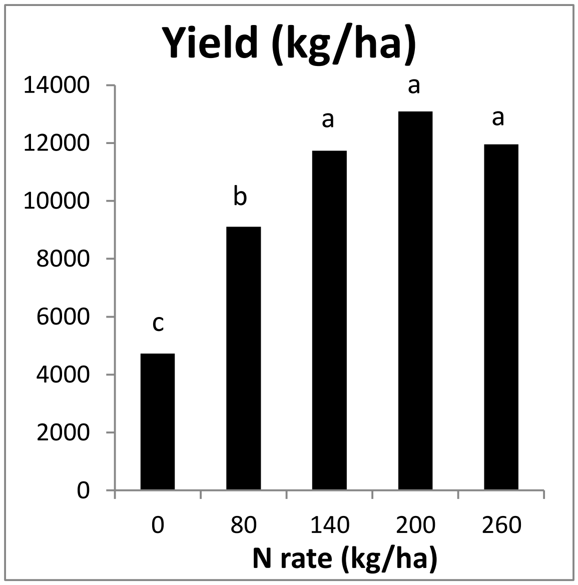


*Figure 1. 2011 rice yields at the wet seeded site*

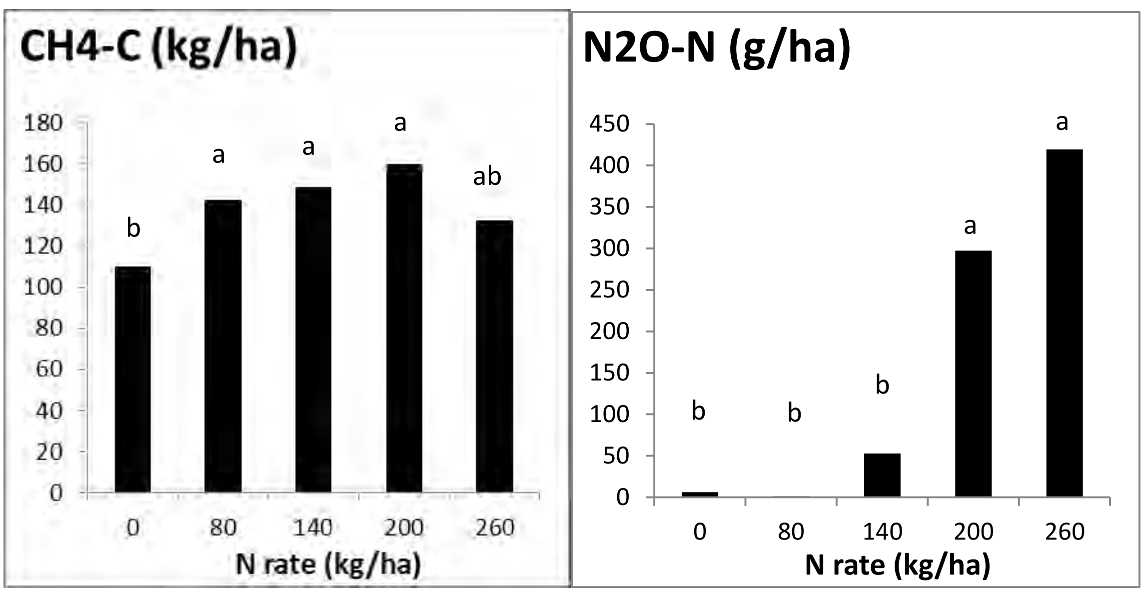


*Figure 2. 2011 seasonal methane and nitrous oxide emissions from wet-seeded site.*

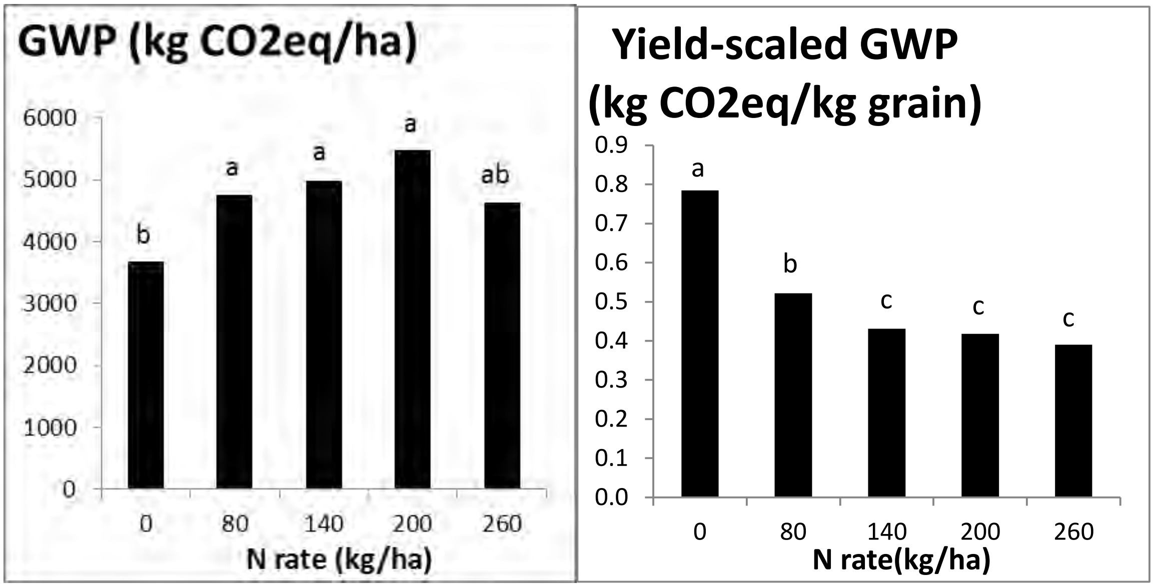


*Figure 3. 2011 GWP and yield-scaled GWP for wet seeded site.*

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).

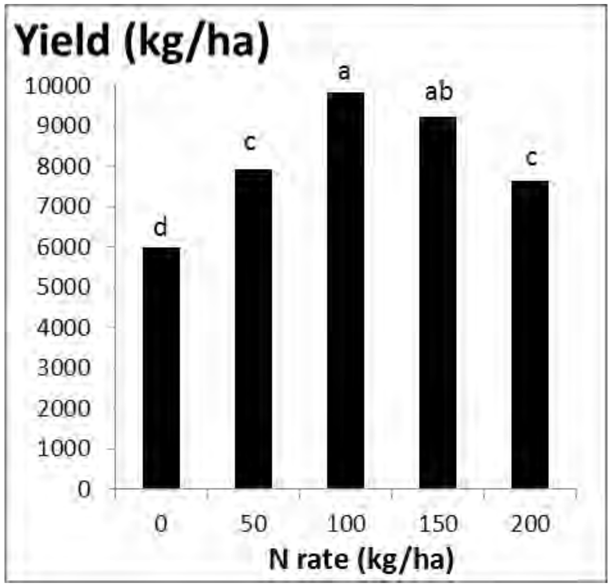


*Figure 4. 2011 rice yields at the drill seeded site*

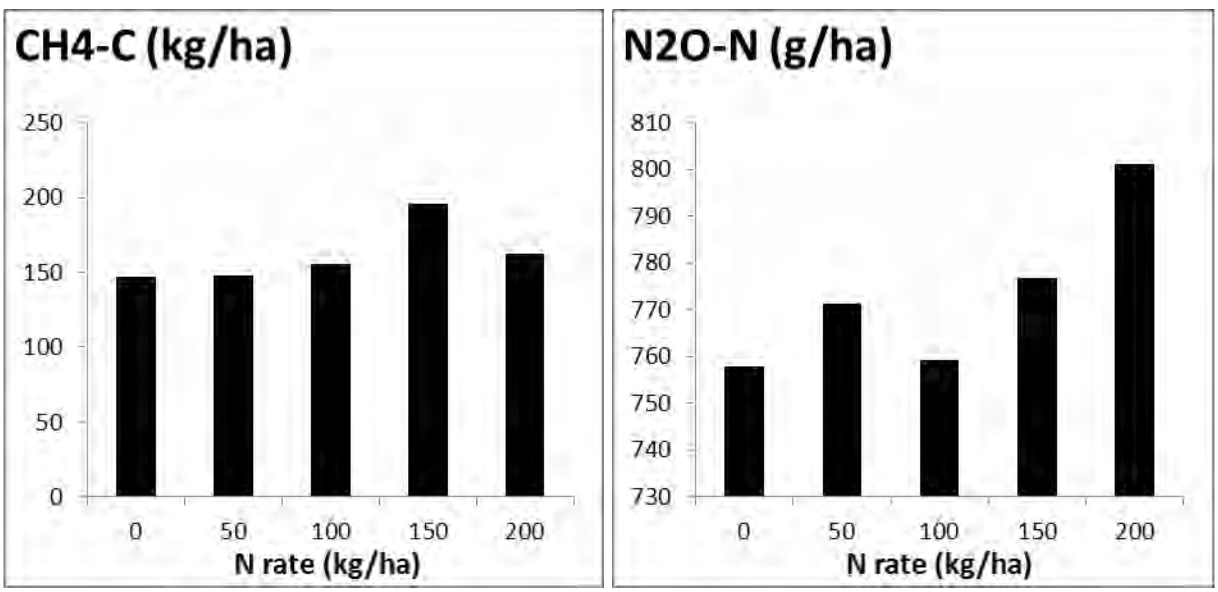


*Figure 5. 2011 seasonal methane and nitrous oxide emissions from drill-seeded site. Differences among treatments were not significant.*

*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).

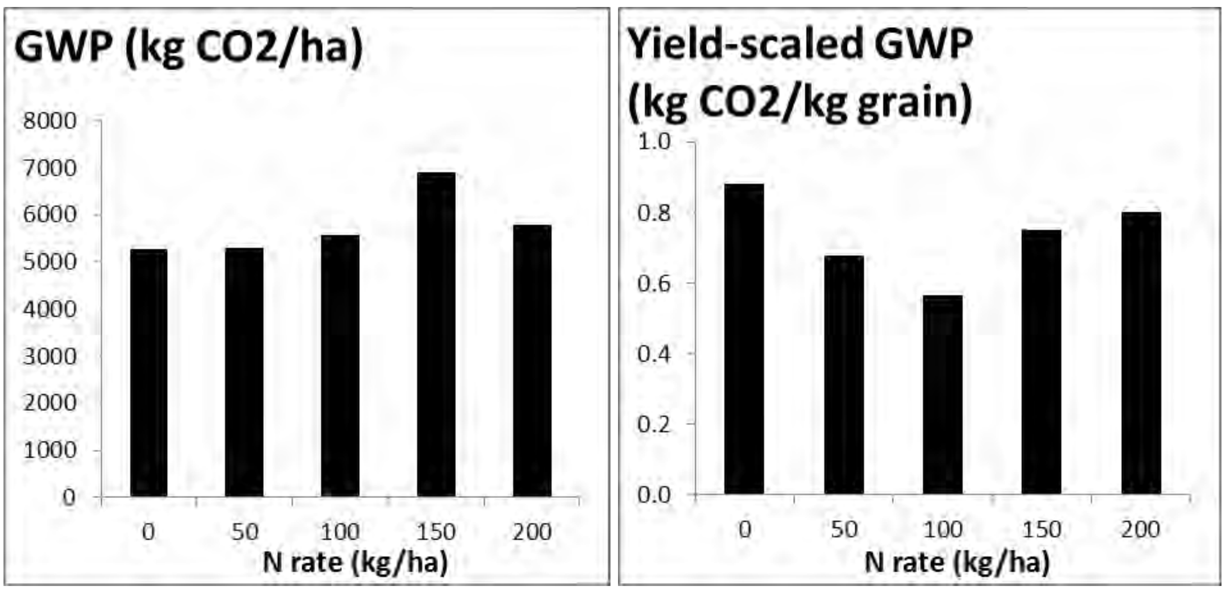


*Figure 6. 2011 GWP and yield-scaled GWP for drill seeded site. Differences among treatments were not significant.*

*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.

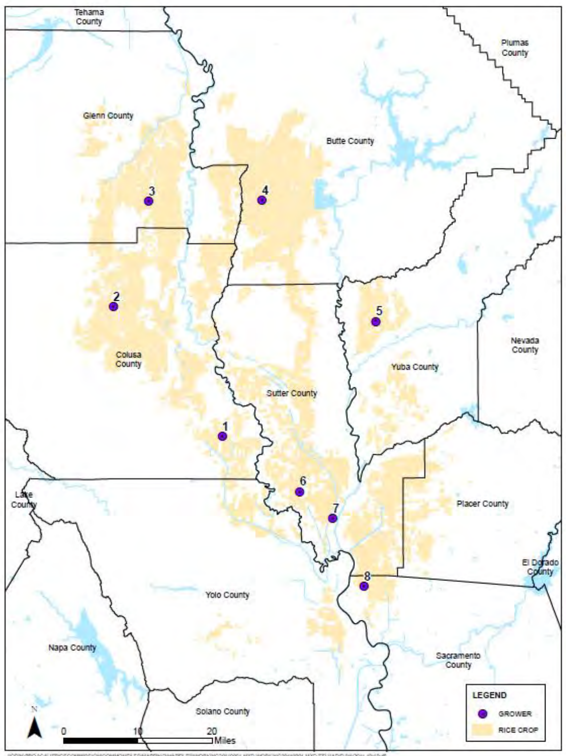


*Figure 1. Location of field sites where soils samples were collected for $NO_3$ analysis.*

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$^oC$ 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$^oC$ 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 $NO_3$.

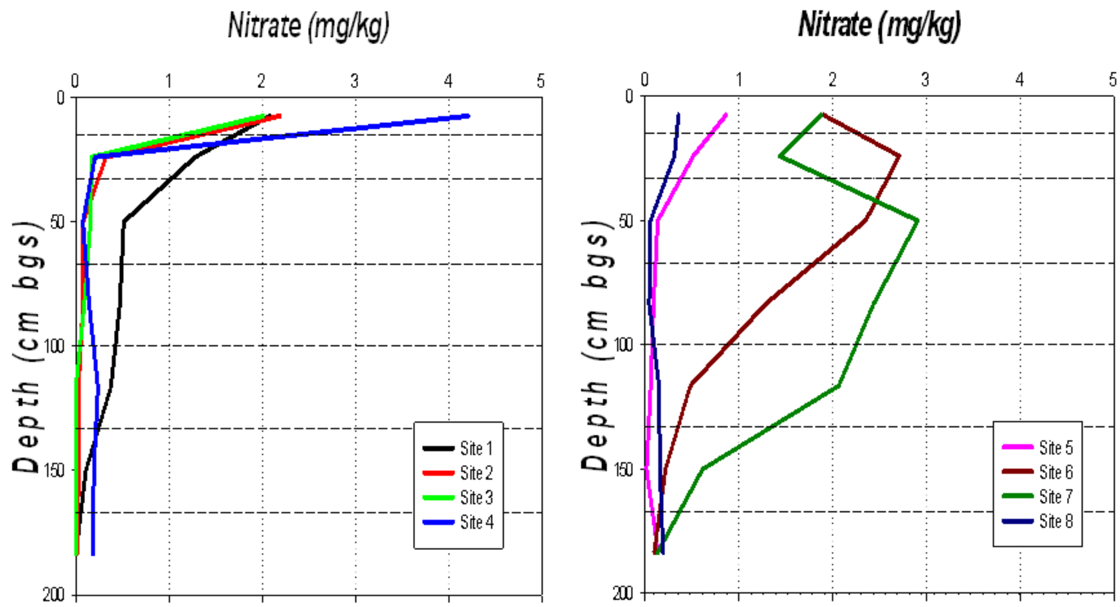


*Figure 2. Soil $NO_3$ across soil depths in 8 California rice soils. Site numbers refer to those in Table 1and Figure 1.*

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.

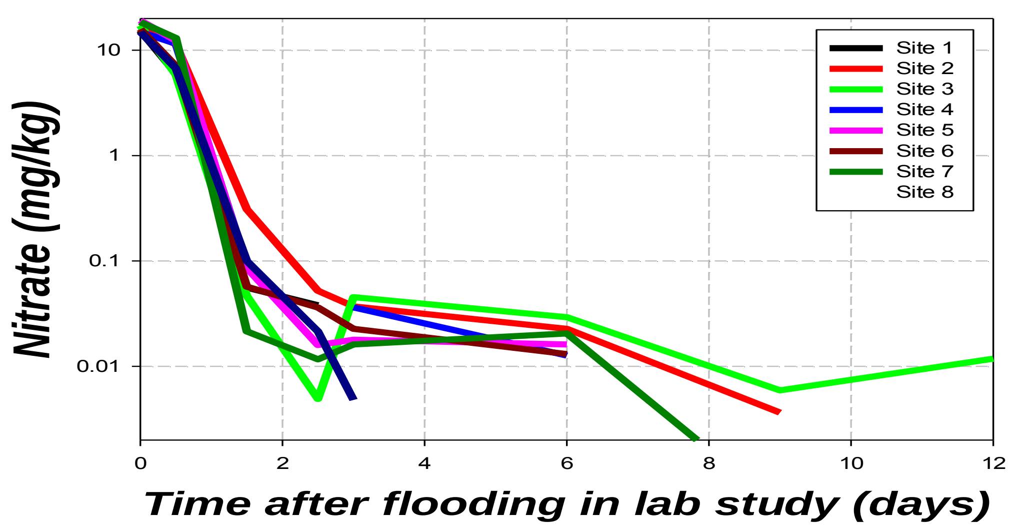

*Figure 3. Soil NO3 during a 12 day anaerobic laboratory incubation. Site numbers refer to those in Table 1and Figure 1.*

*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).

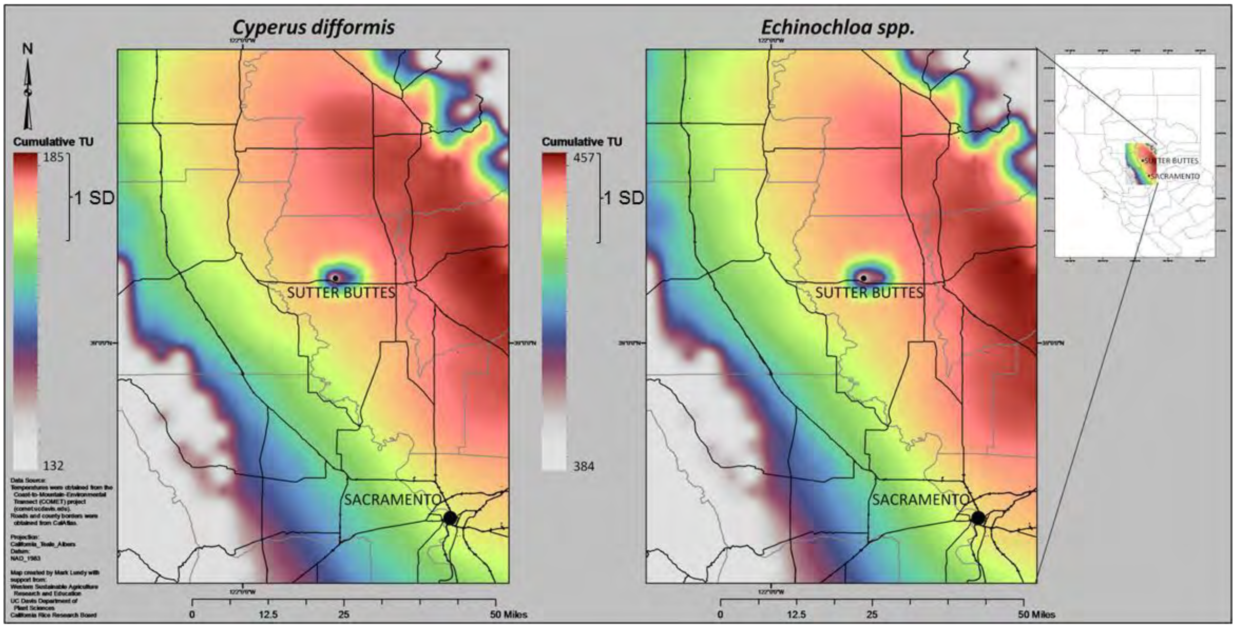


***Figure 1****. Average cumulative thermal unit accumulation for Echinochloa spp. and C. difformis for the period of rice establishment (4/15-5/31) between 2004-2010 using base temperatures of 8C and 15.5C (respectively) and maximum and minimum air temperatures accurate to 4kim$^2$. SD = standard deviation.*

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.

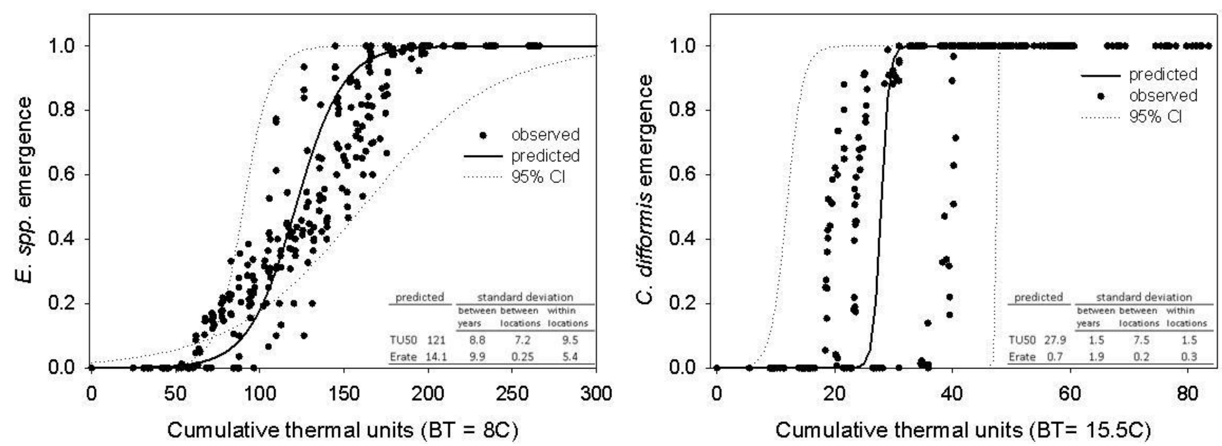


***Figure 2***. *Echinochloa spp. and C. difformis emergence over two seasons (2010, 2011) in fields that were managed as spring-till stale seedbeds or drill-seeded. Sources of error as modeled via mixed nonlinear regression.*

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.

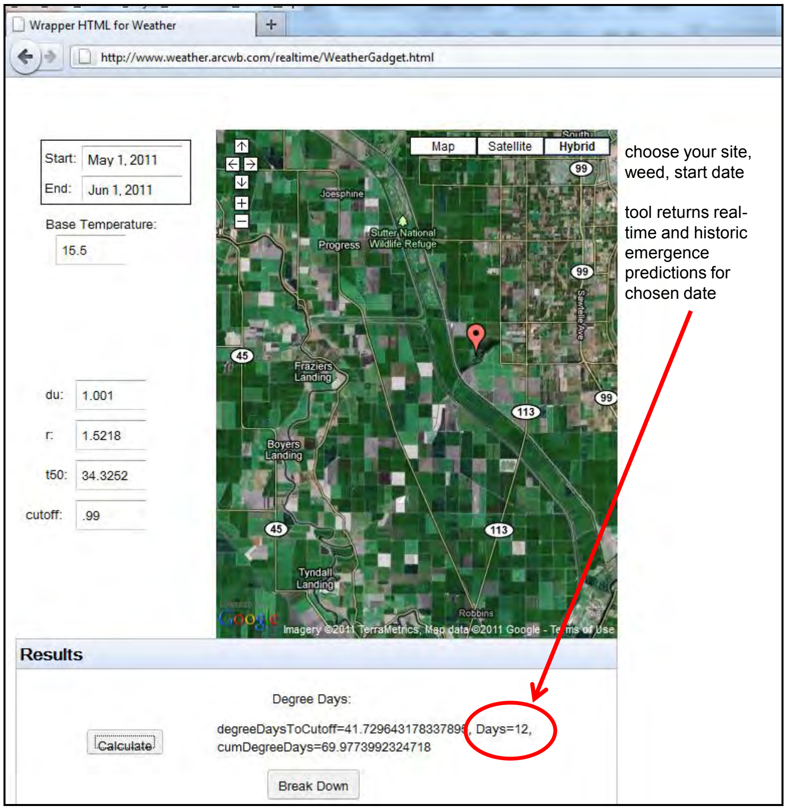


***Figure 3***. *Beta version of web-based decision support tool for predicting Echinochloa spp. and C. difformis emergence using site-specific air temperatures.*

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 $^{15}N\text{-}NO_3$.

(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).

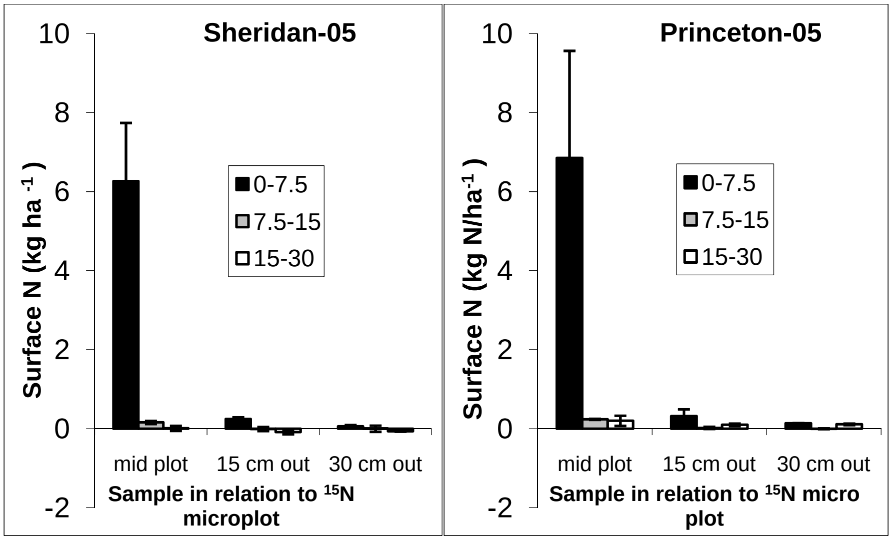


*Figure 1. Fate of fertilizer N in soil profile in two rice fields. $^{15}N$ was applied as a starter fertilizer, broadcast to the soil surface at the beginning of the growing season. At the end of the season soil samples were taken to a depth of 30 cm from the center of the micro-plot, and 15 and 30 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

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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).

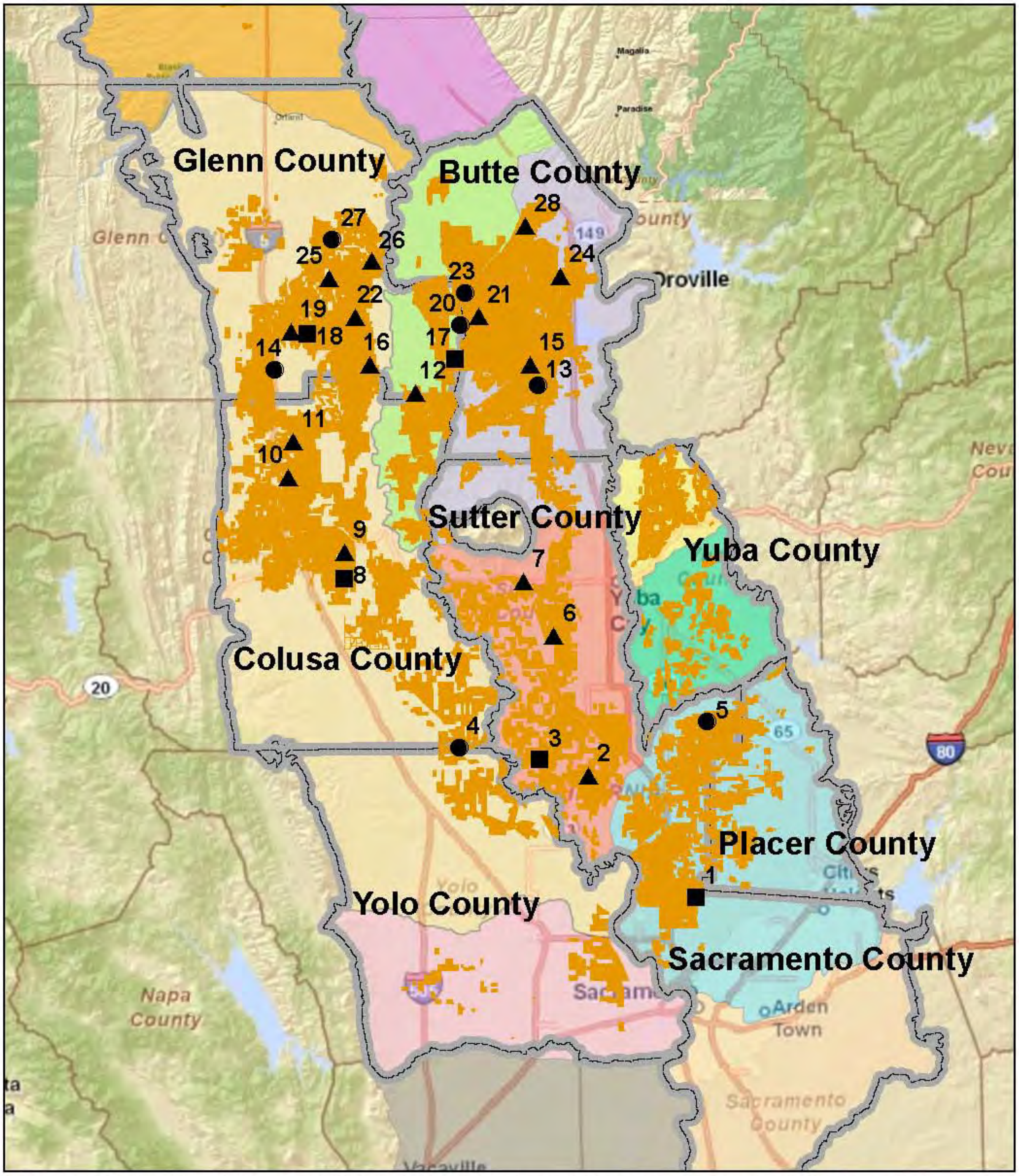
Since 1997, additional sampling has been conducted by USGS at some of the original 28 wells. A total of 84 samples have been collected from the 28 wells between 1997 and 2010. Five of the wells have been sampled an additional eight times since 1997, and 15 of the wells were sampled one additional time 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.

0 5 10 20 Miles

N

**Figure 1. Shallow "RICE" Well Locations**

"RICE" Well and ID Number

No. of Samples

- ● 1
- ▲ 2
- ■ 9
- Rice Crop
- County Boundary

Groundwater Basins

- COLUSA
- CORNING
- EAST BUTTE
- NORTH AMERICAN
- NORTH YUBA
- SOLANO
- SOUTH AMERICAN
- SOUTH YUBA
- SUTTER
- VINA
- WEST BUTTE
- YOLO

### 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.

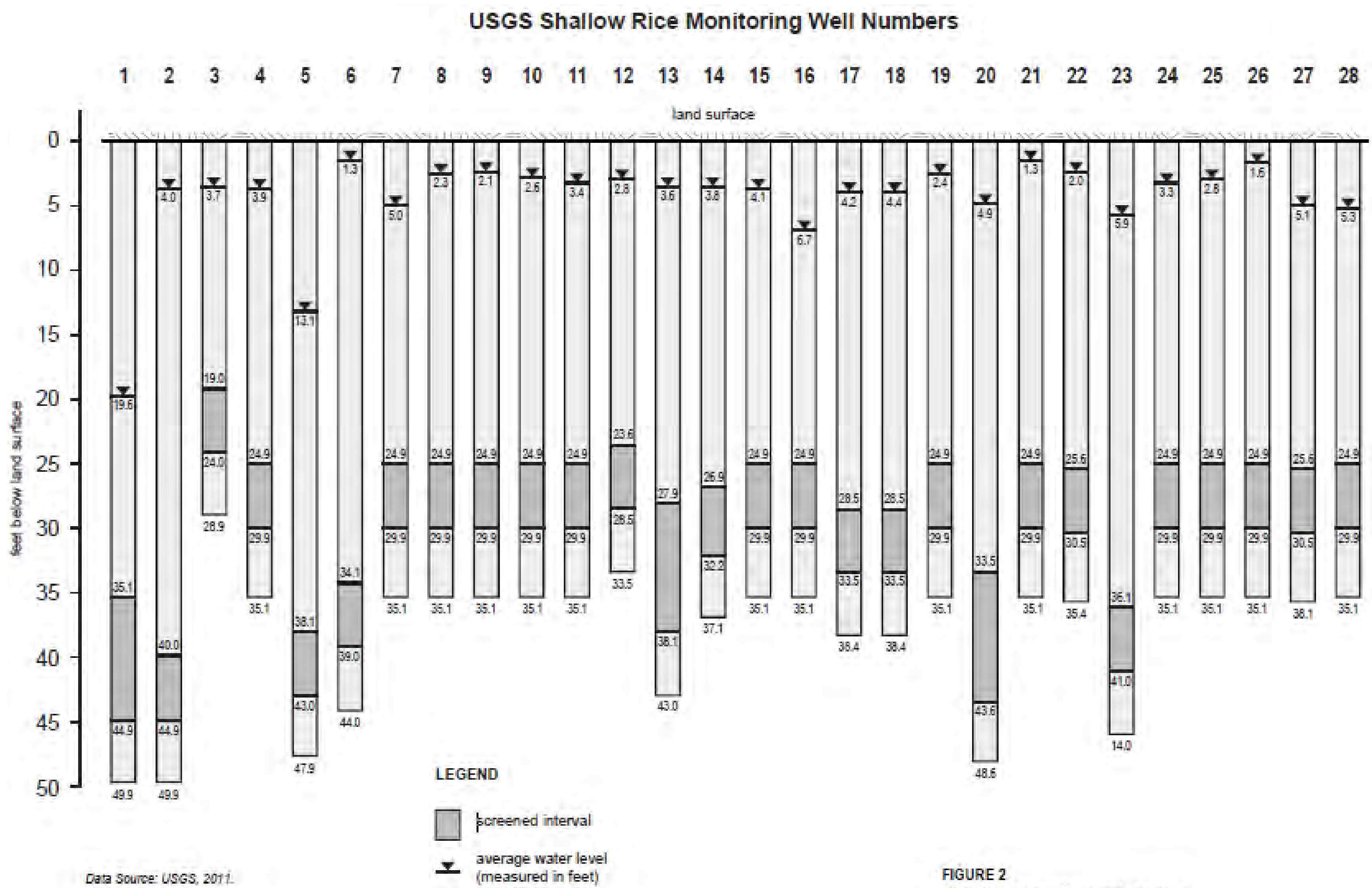



**FIGURE 2**
Well Depths and Screened Intervals
*California Rice Commission Shallow Groundwater Data Technical Memo*

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.

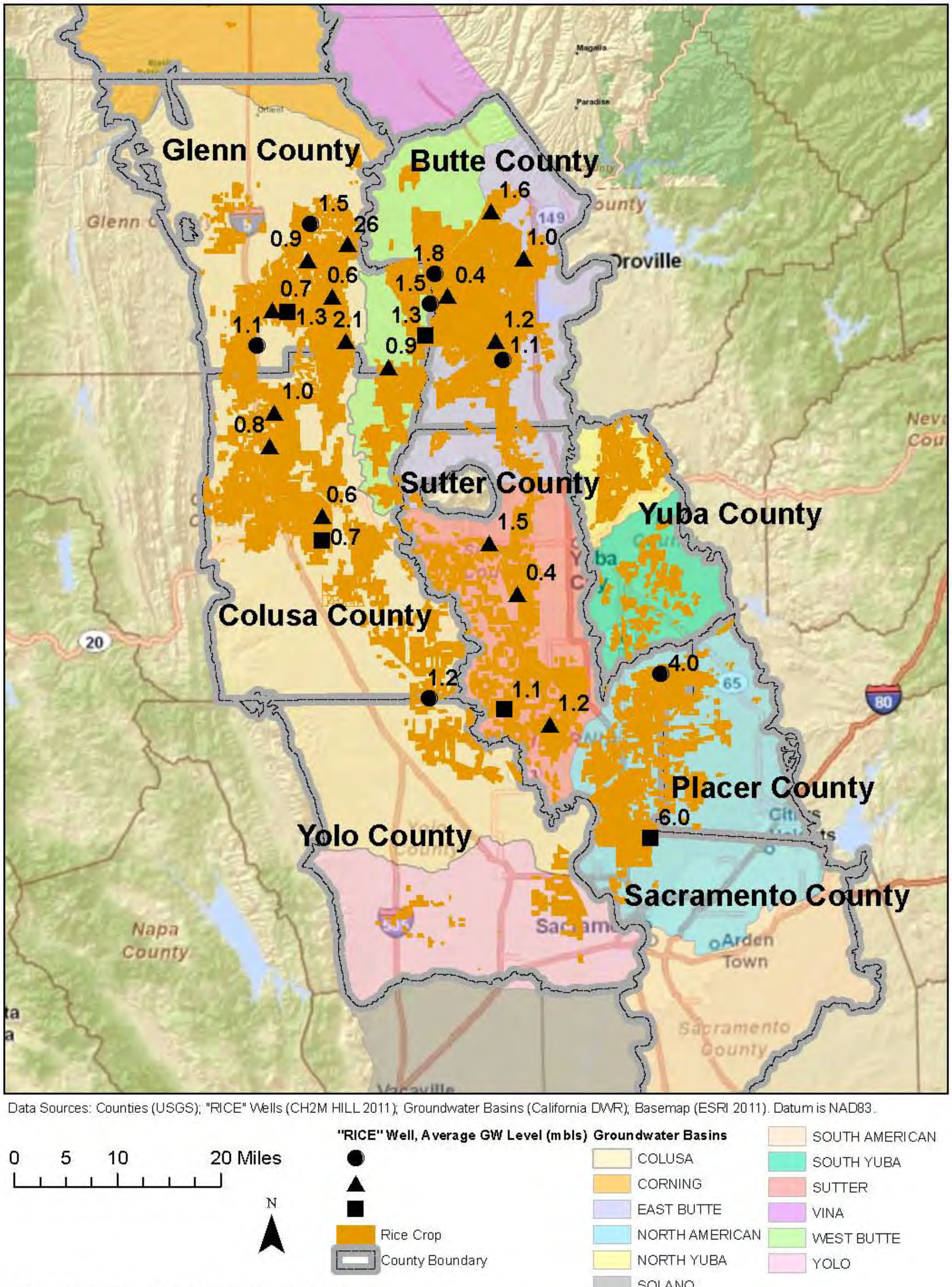



**Figure 3. Shallow "RICE" Wells, Average Groundwater Level (mbls)**

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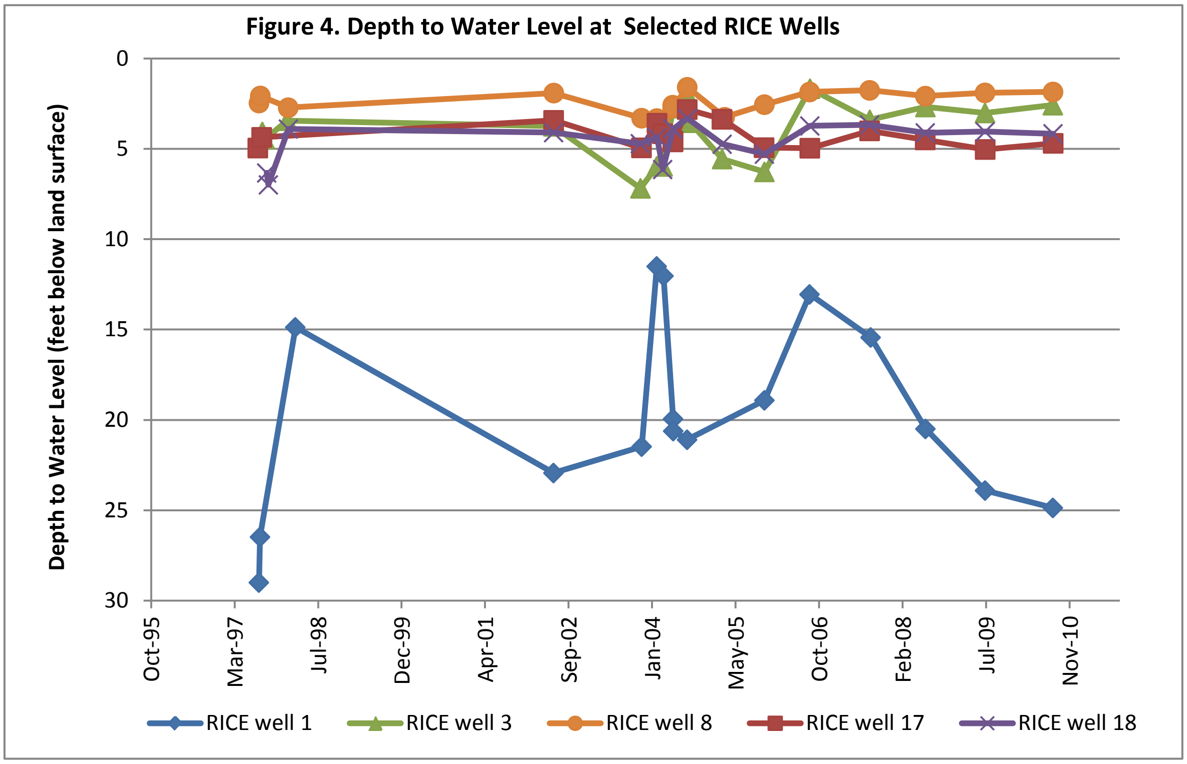



## Water Quality Data

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.

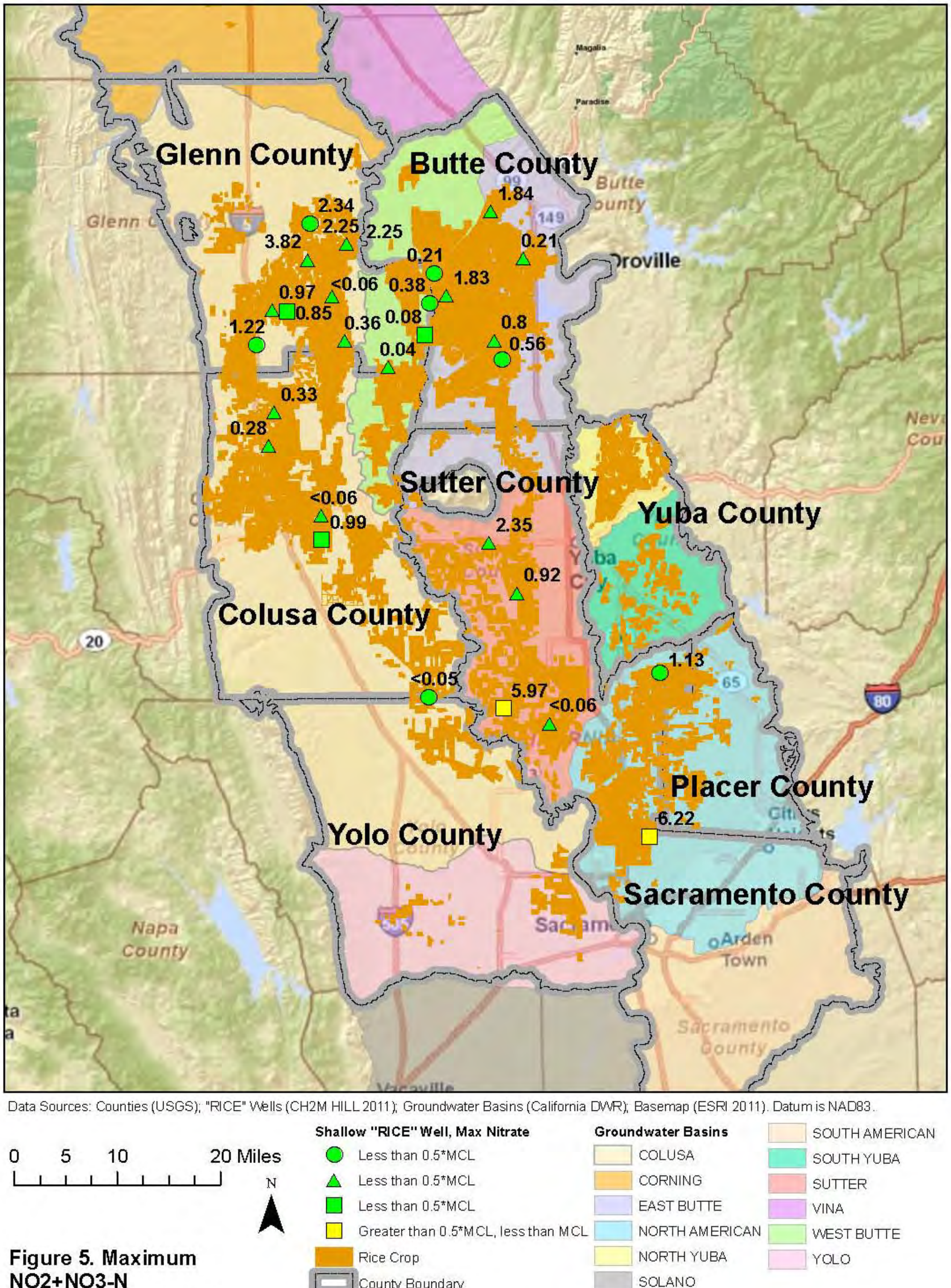
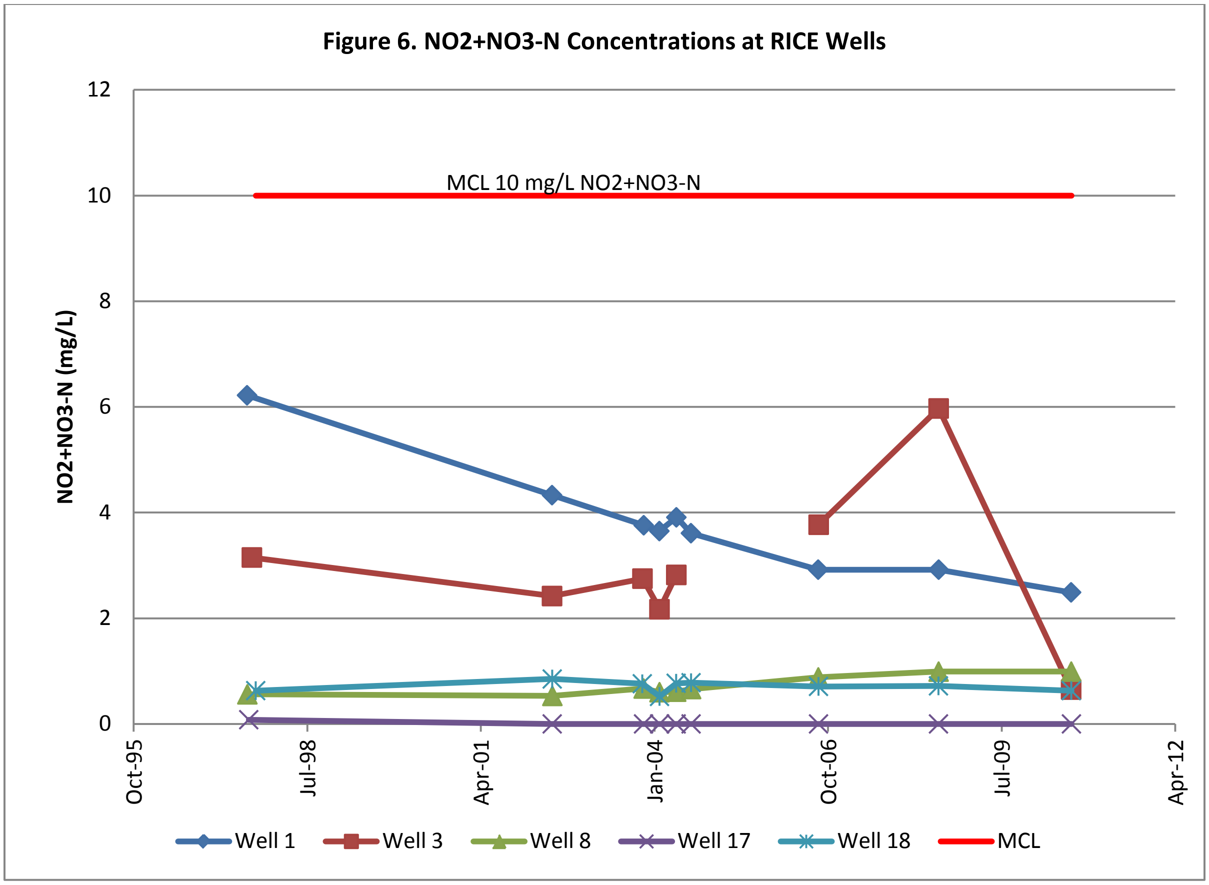



**Figure 5. Maximum NO2+NO3-N Concentration (mg/L)**

N:\EThatcher\Rice\CaliforniaRiceCommision_TM1_Figure5.mxd ethatche 11/29/2011




## 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

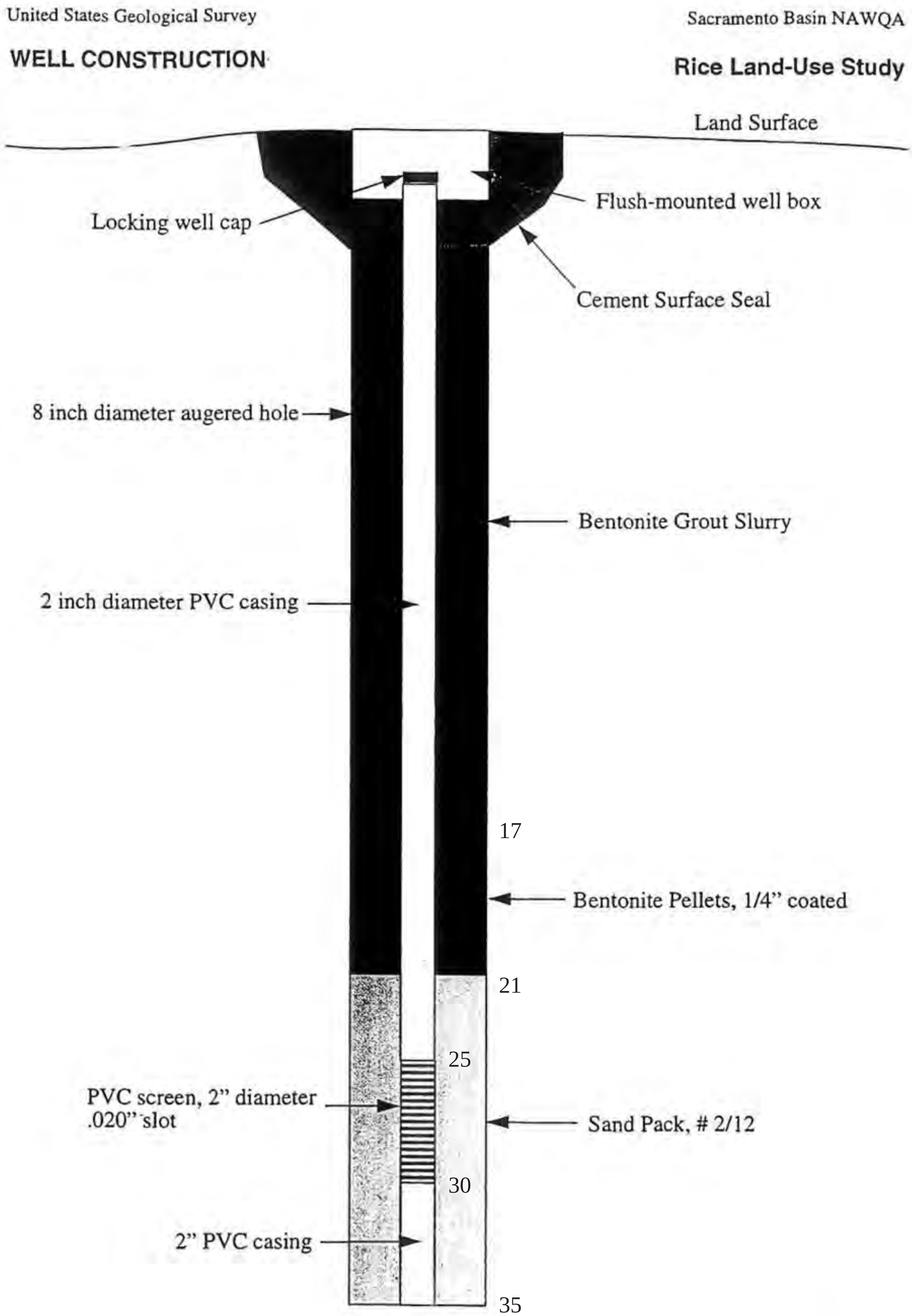
Dawson, B.J.M. 2001. Shallow Ground-Water Quality Beneath Rice Areas in the Sacramento Valley, California, 1997. U.S. Geological Survey Water-Resources Investigations Report 01-4000. National Water-Quality Assessment Program. Available at http://ca.water.usgs.gov/archive/reports/wrir014000/

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

USGS. 2001. National Water Quality Assessment Groundwater Master Database. http://infotrek.er.usgs.gov/nawqa_queries/gwmaster/index.jsp. Accessed October 2011.

# 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 $NO_2$+$NO_3$-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 $NO_2$+$NO_3$-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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North

0 1,250 2,500
Approximate scale in feet

**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 2**
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## APPENDIX E-3
## Land Use Surrounding USGS Rice Well 3
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**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 4**
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 5
CRC Groundwater Assessment Report

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**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 6**
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**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 7**
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 8
CRC Groundwater Assessment Report

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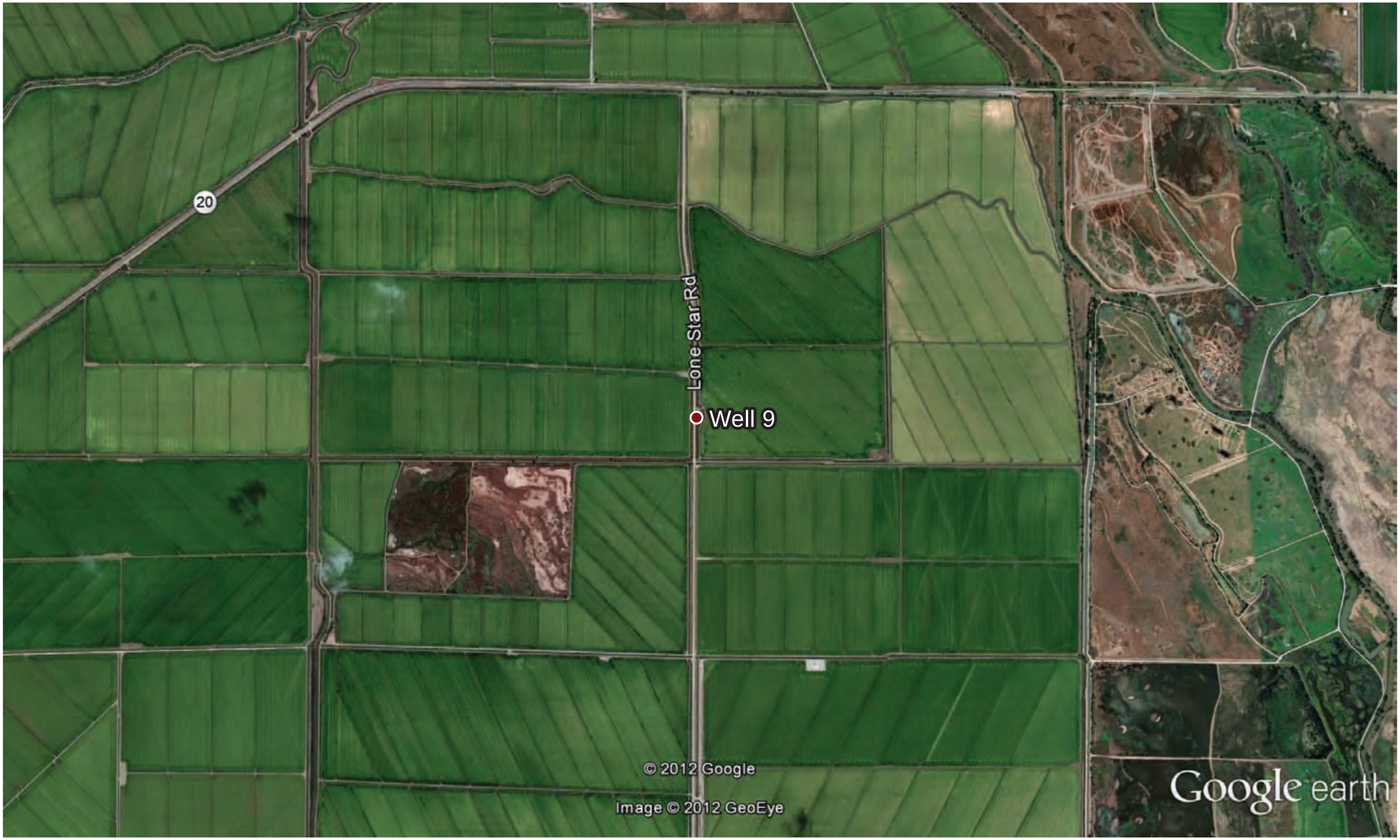


North

0 1,250 2,500
Approximate scale in feet

**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 9**
CRC Groundwater Assessment Report

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**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 10**
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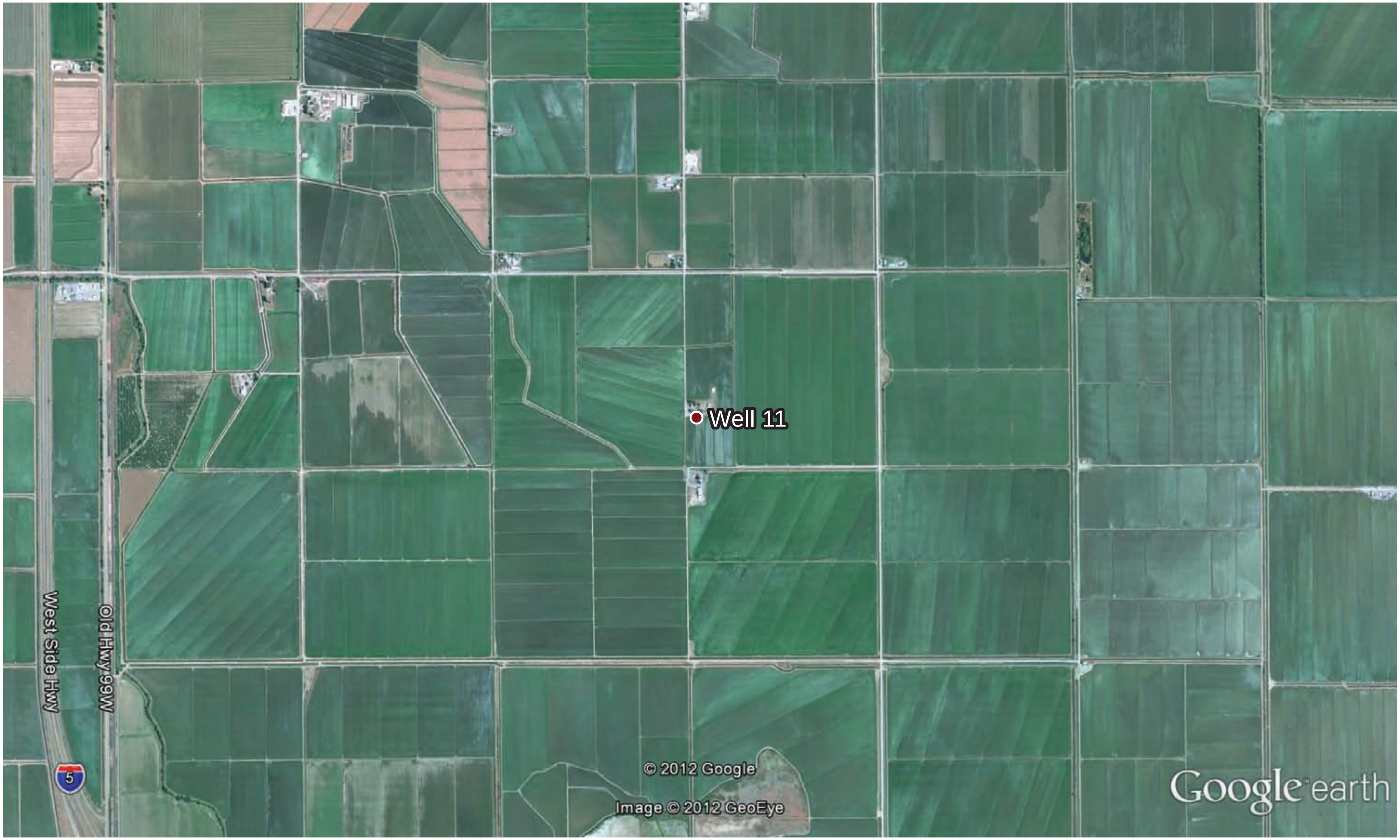


North

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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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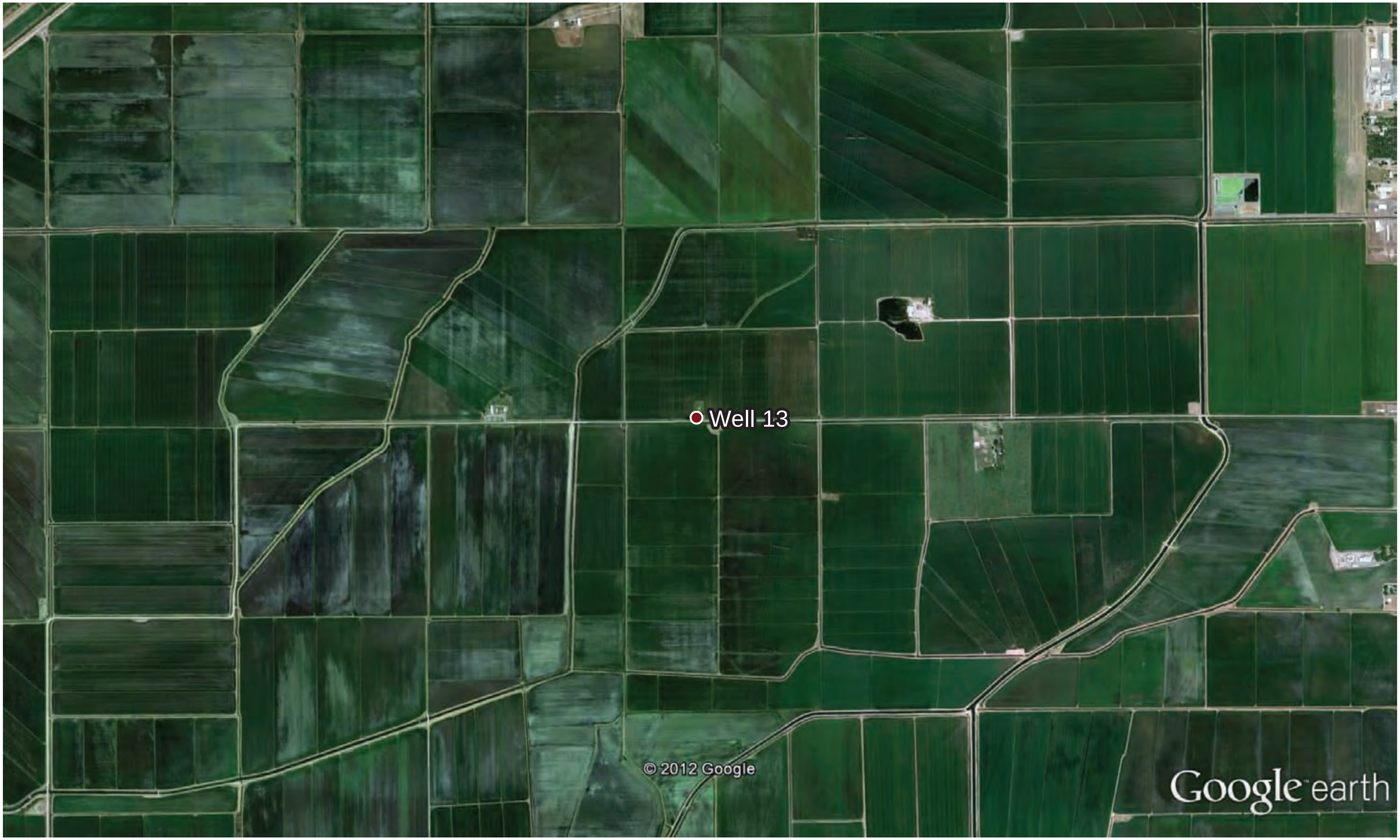


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Approximate scale in feet

## APPENDIX E-3
## Land Use Surrounding USGS Rice Well 13
CRC Groundwater Assessment Report

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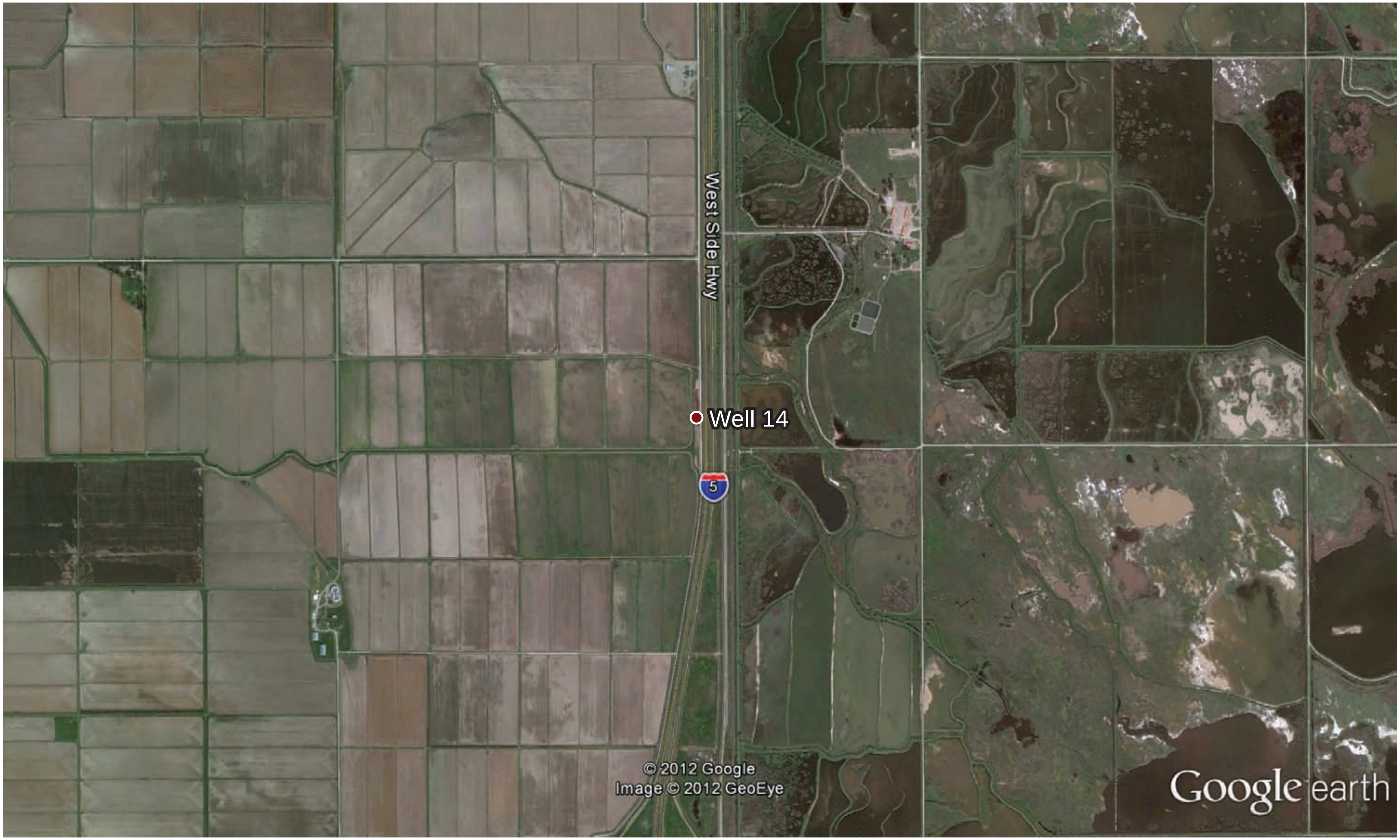


North

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Approximate scale in feet

## APPENDIX E-3
## Land Use Surrounding USGS Rice Well 14
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 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**
CRC Groundwater Assessment Report

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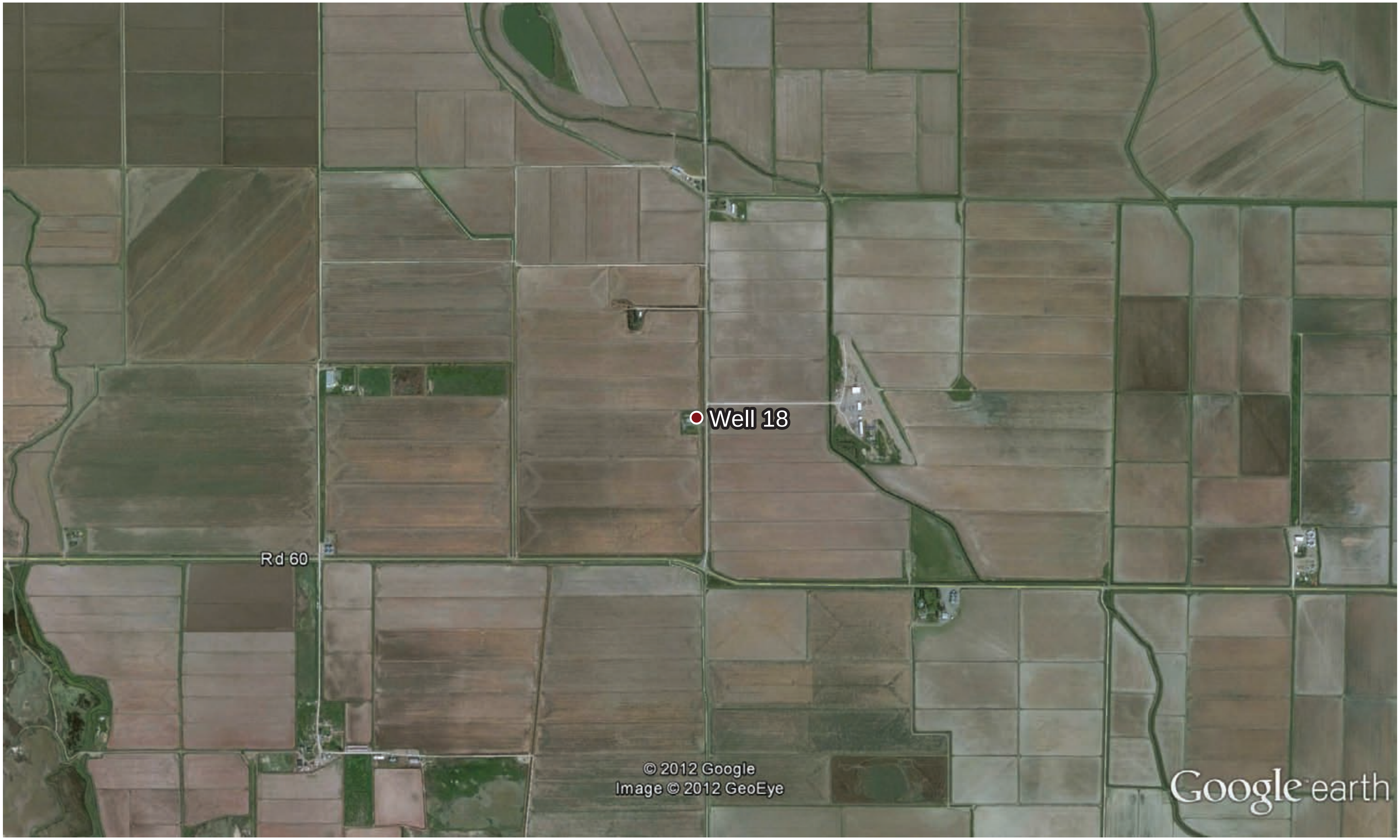


North

0 1,250 2,500
Approximate scale in feet

**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 18**
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 19
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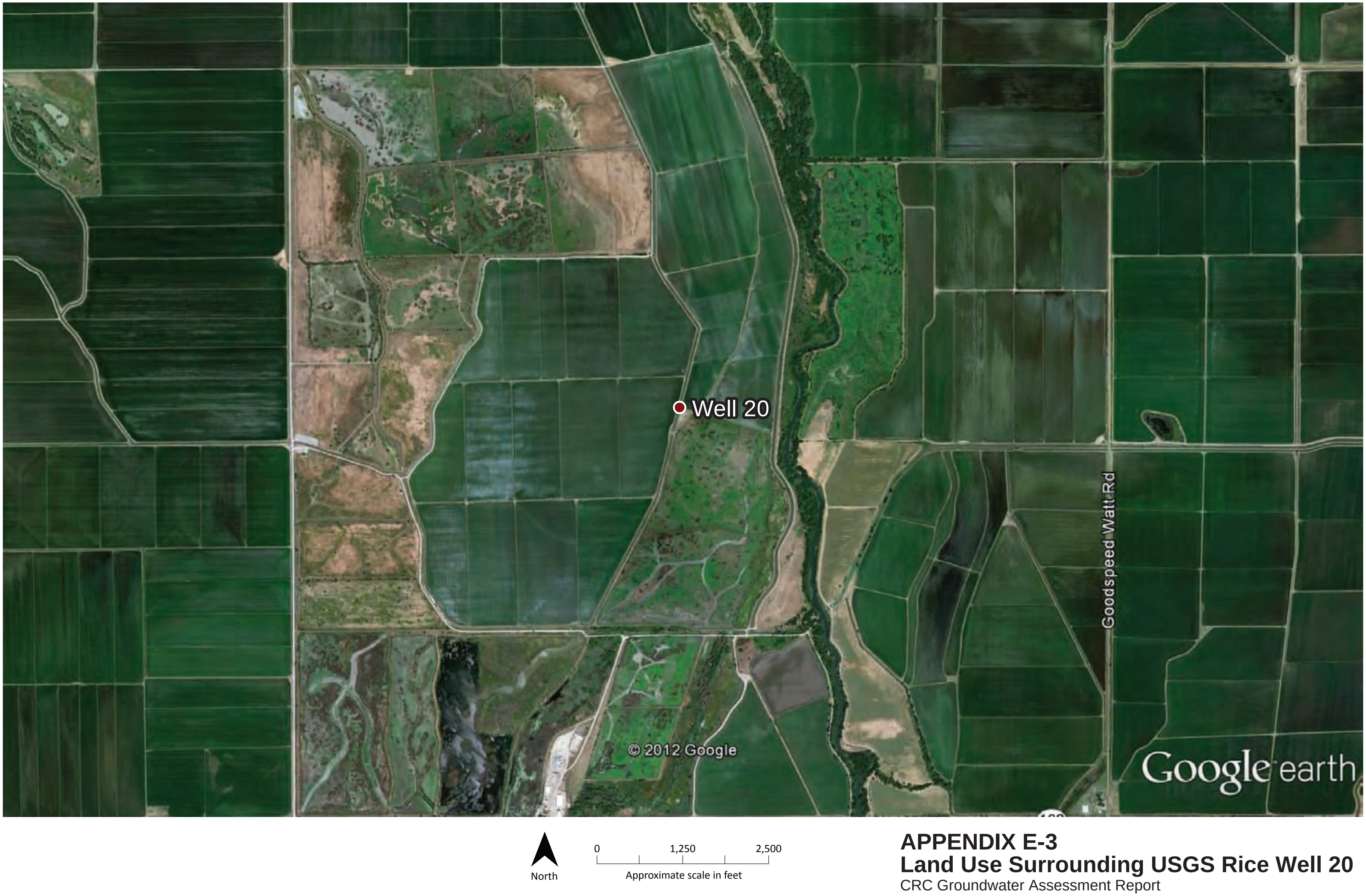


**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 20**
CRC Groundwater Assessment Report

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## APPENDIX E-3
## Land Use Surrounding USGS Rice Well 21
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 22**

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## APPENDIX E-3
## Land Use Surrounding USGS Rice Well 23
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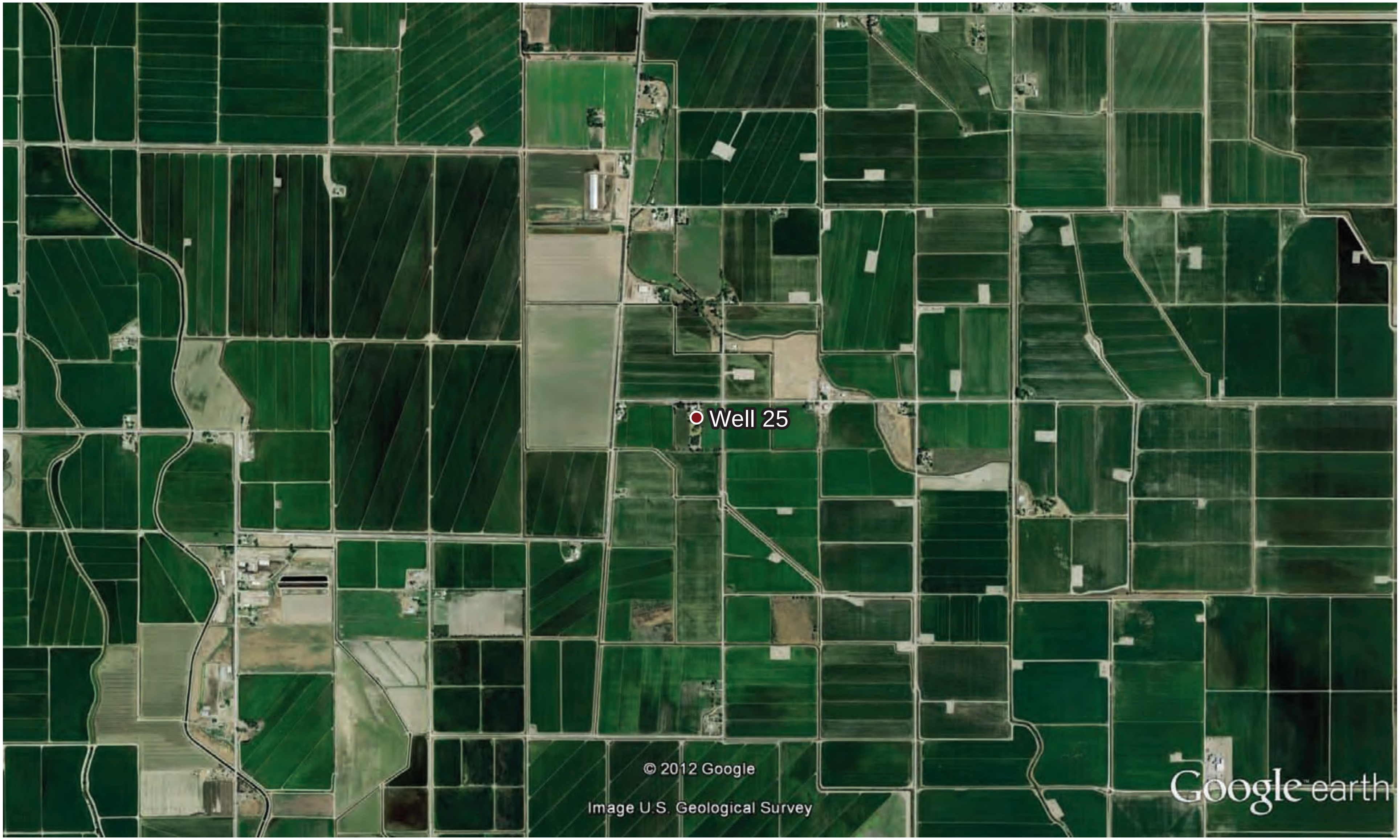
**APPENDIX E-3**

**Land Use Surrounding USGS Rice Well 24**

CRC Groundwater Assessment Report




North

0 1,250 2,500
Approximate scale in feet

## 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
CRC Groundwater Assessment Report

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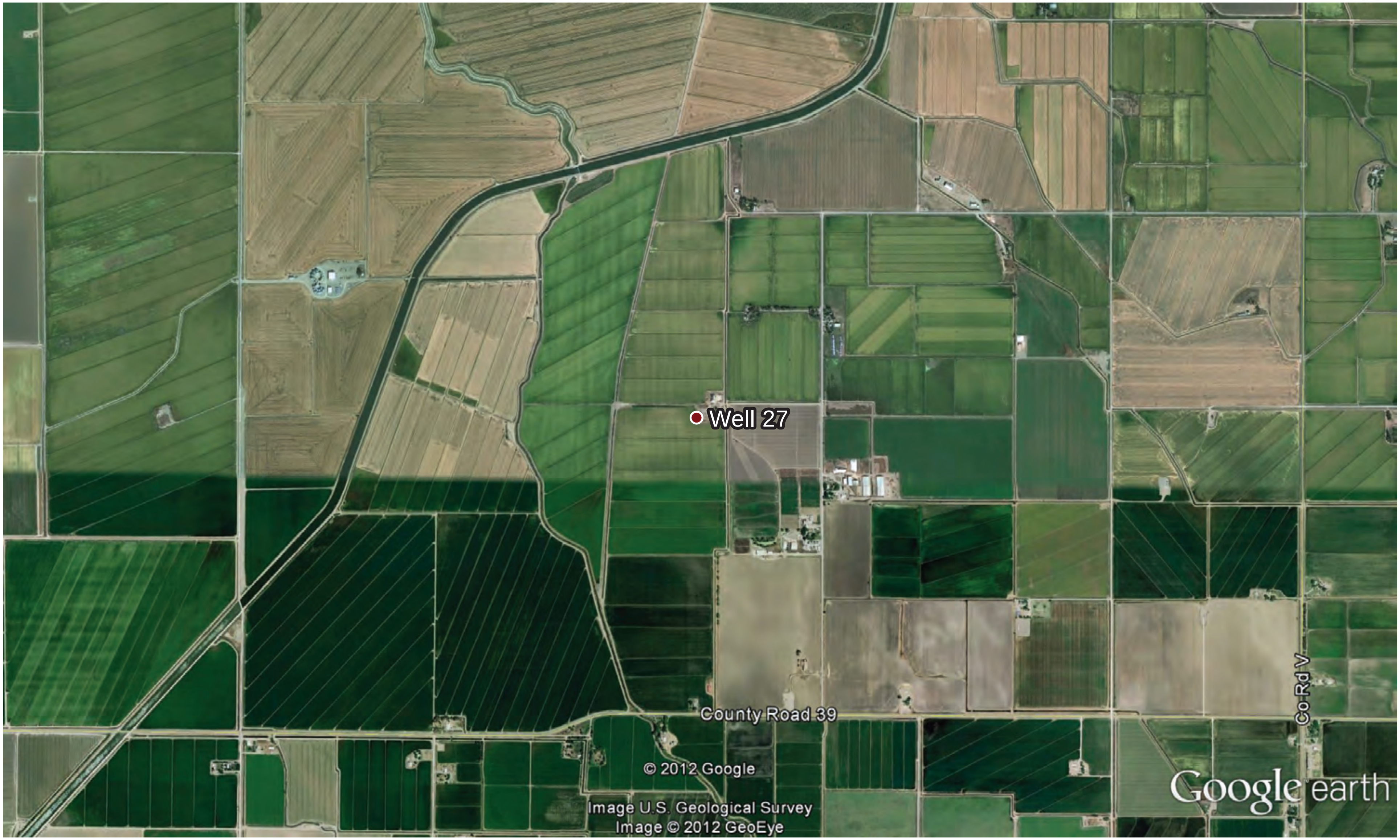


North

0 1,250 2,500
Approximate scale in feet

**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 27**
CRC Groundwater Assessment Report

CH2MHILL


North

0 1,250 2,500
Approximate scale in feet

**APPENDIX E-3**
**Land Use Surrounding USGS Rice Well 28**
CRC Groundwater Assessment Report

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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.

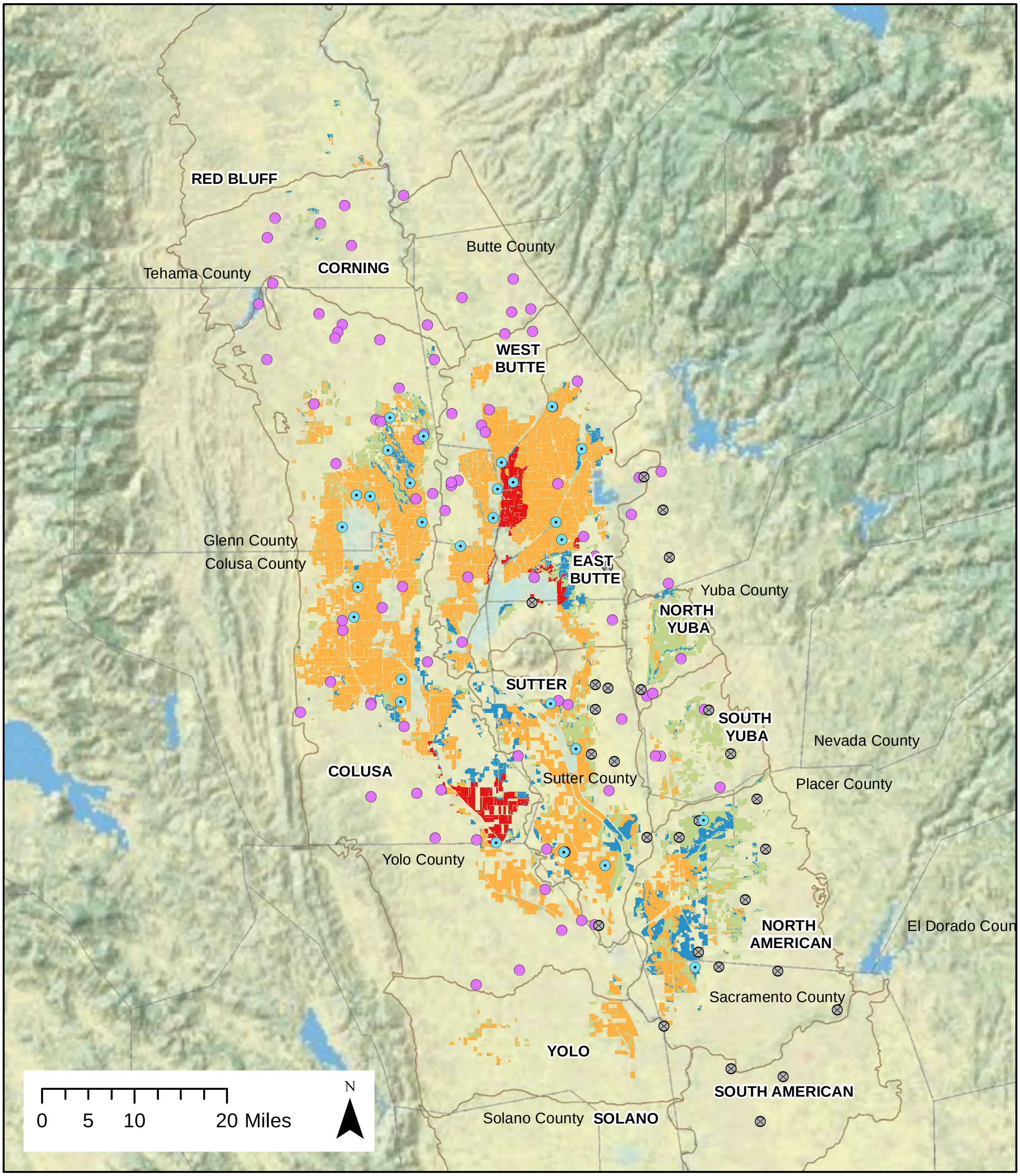
One component of these data is the depth to duripan. A duripan is a soil horizon cemented by silica into a subsurface hardpan. A duripan constitutes a restrictive layer to vertical movement of water and constituents, with very low hydraulic conductivity. For this analysis, depth to duripan is characterized 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 | | |
|---|---|---|---|---|---|
| | | | <60 Inches bgs | >60 Inches bgs | Unreported |
| 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

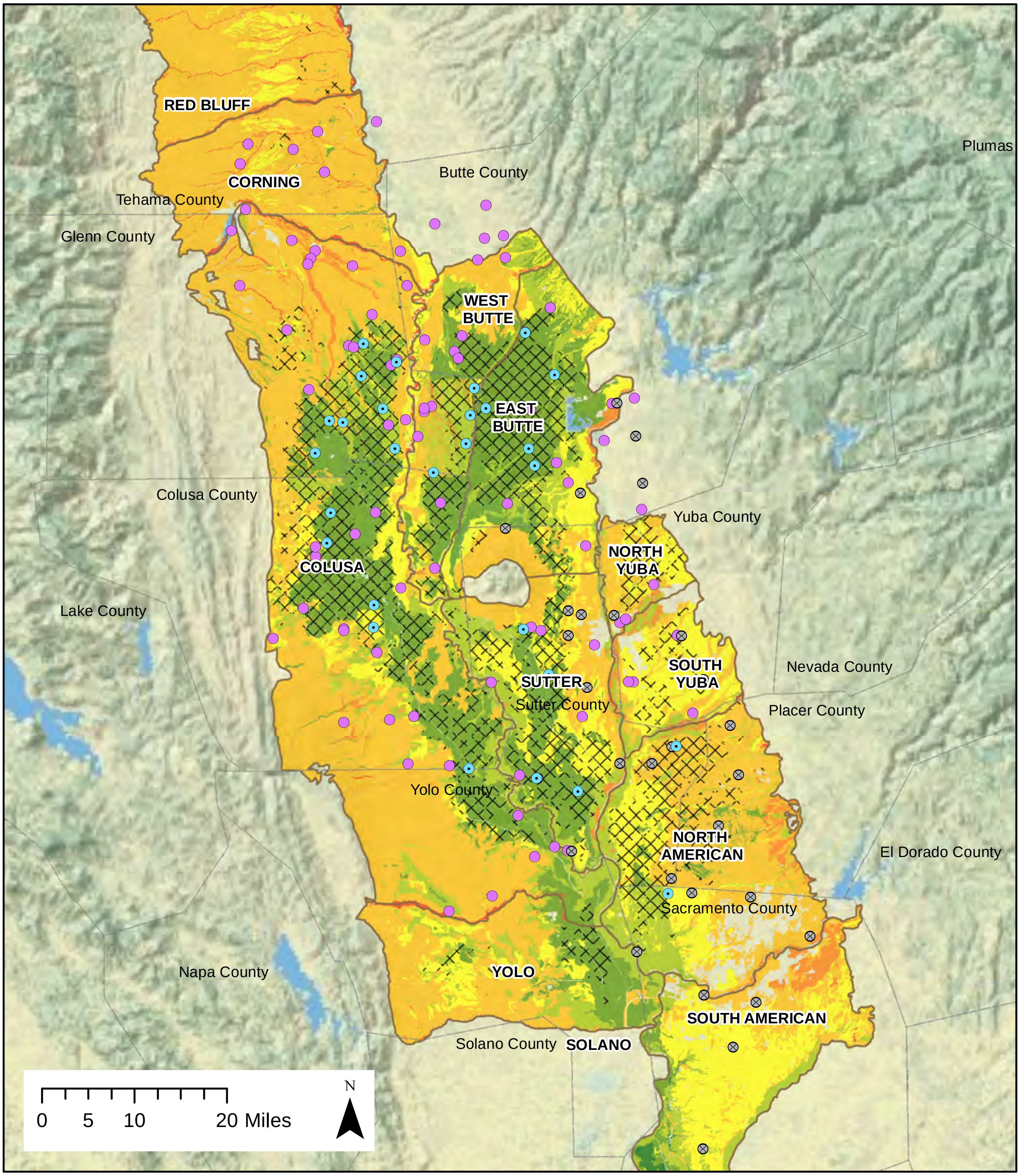
- USGS Rice Wells
- Shallow Domestic Wells
- GAMA Wells
- County Boundary
- Groundwater Basins

**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

Rice-Specific Groundwater Assessment Report




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)

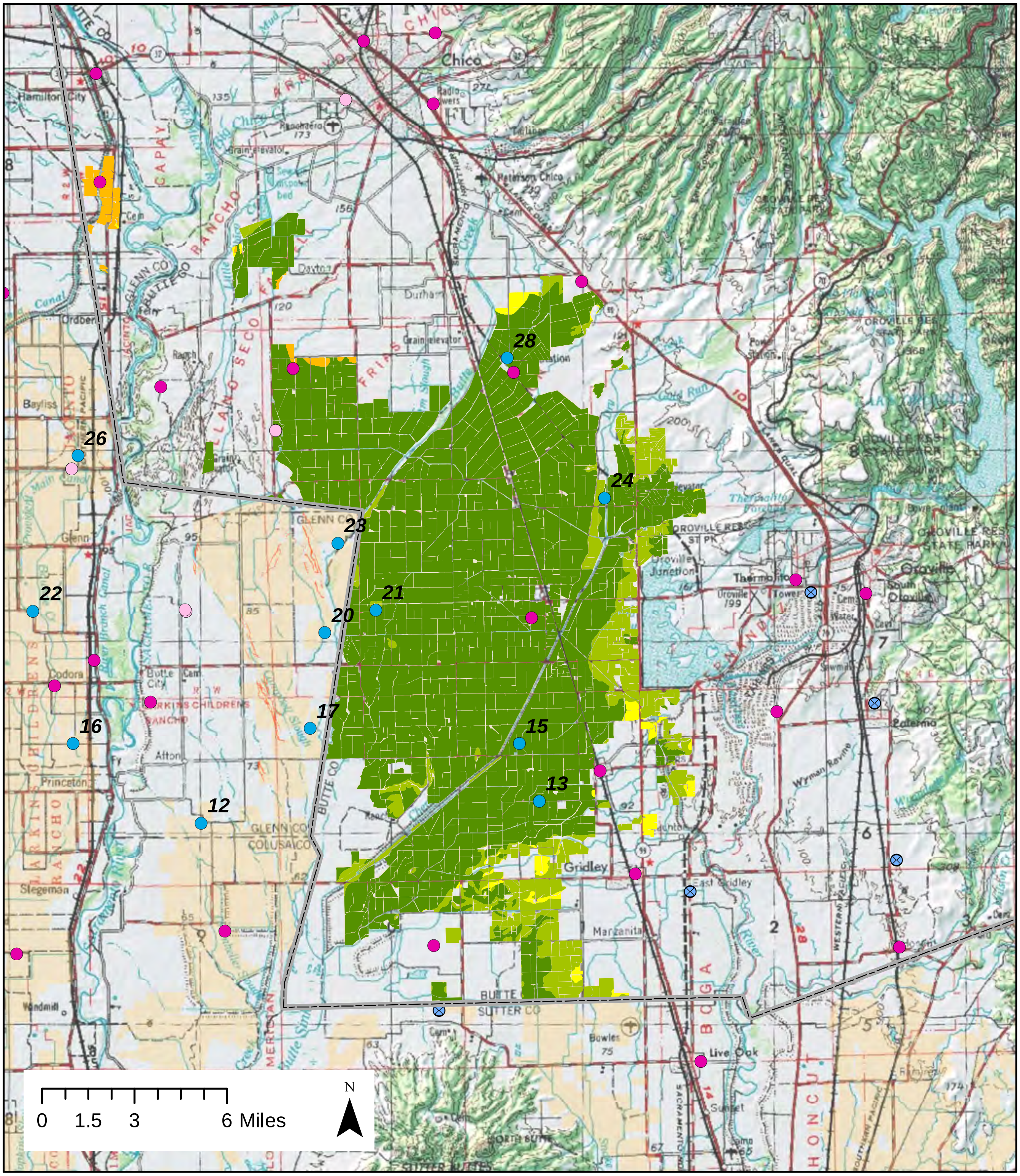
NRCS Soil Drainage Class

- 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



CH2MHILL.




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

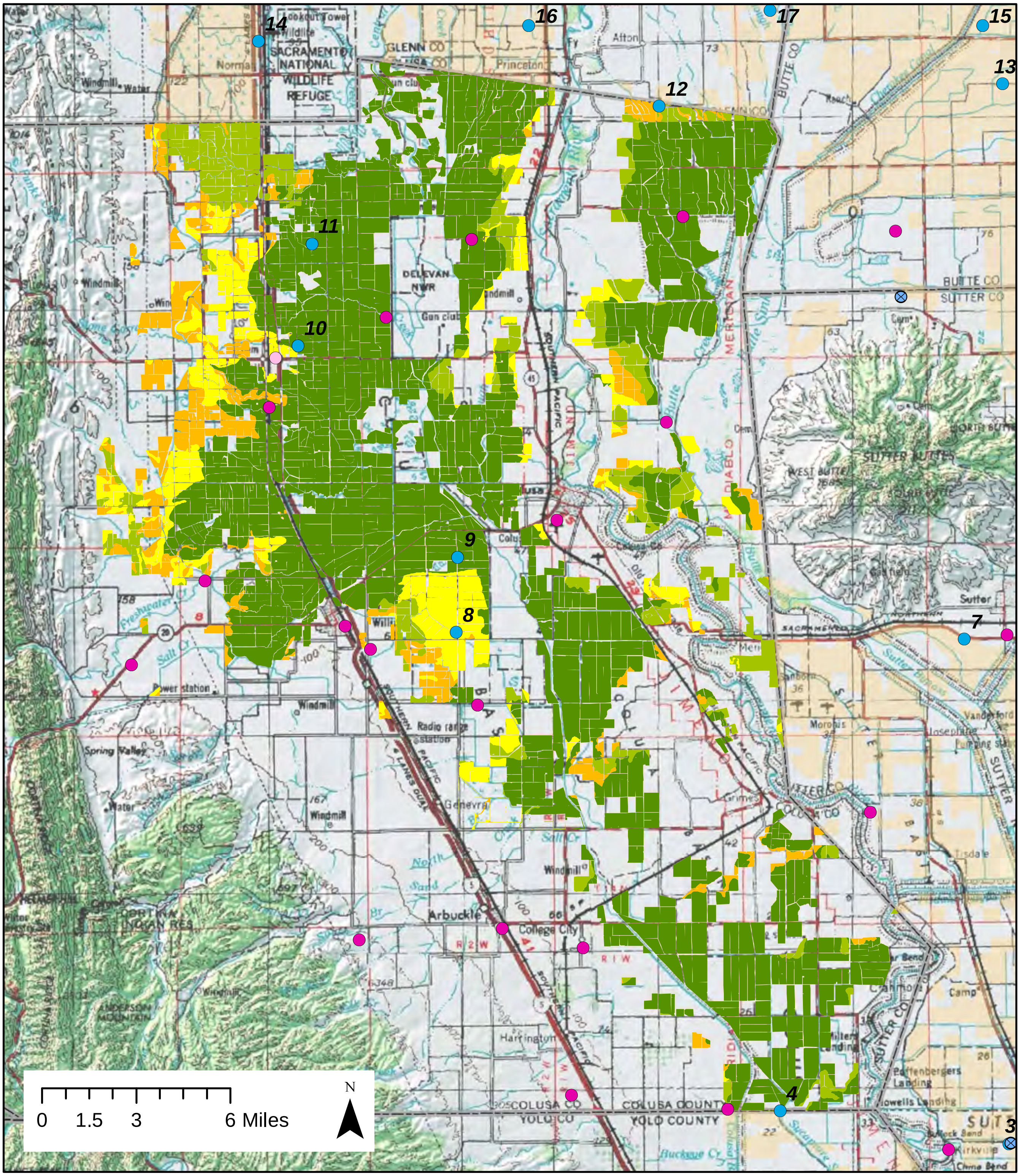
**NRCS Soil Drainage Classification**

- 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

CH2MHILL.




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**

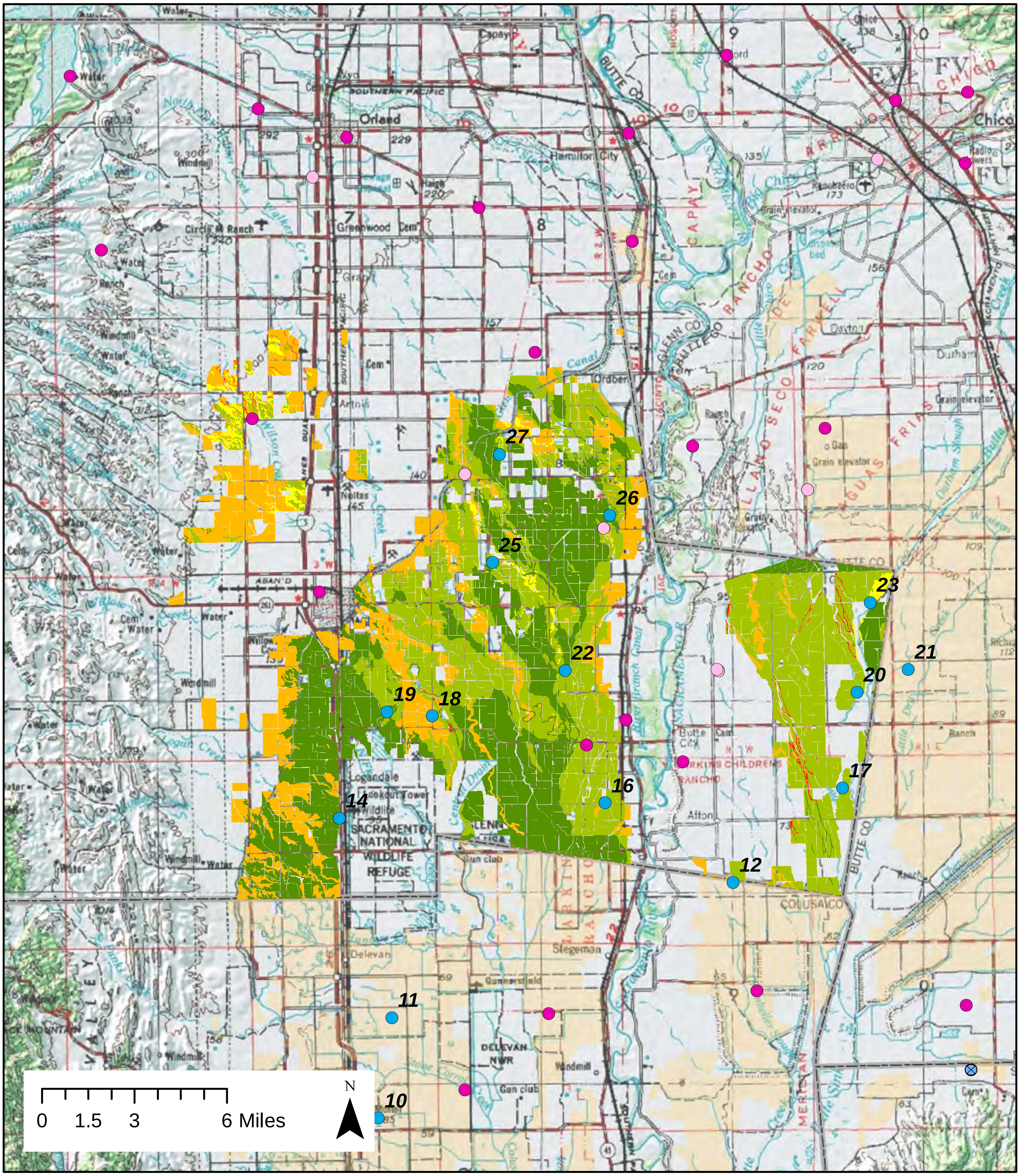
- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

# MAP H-4
# Colusa County Rice Lands
# NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report

ColusaCounty_NRCSDrainageClassifications_RiceAcres lporta 4/30/2013

CH2MHILL




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**

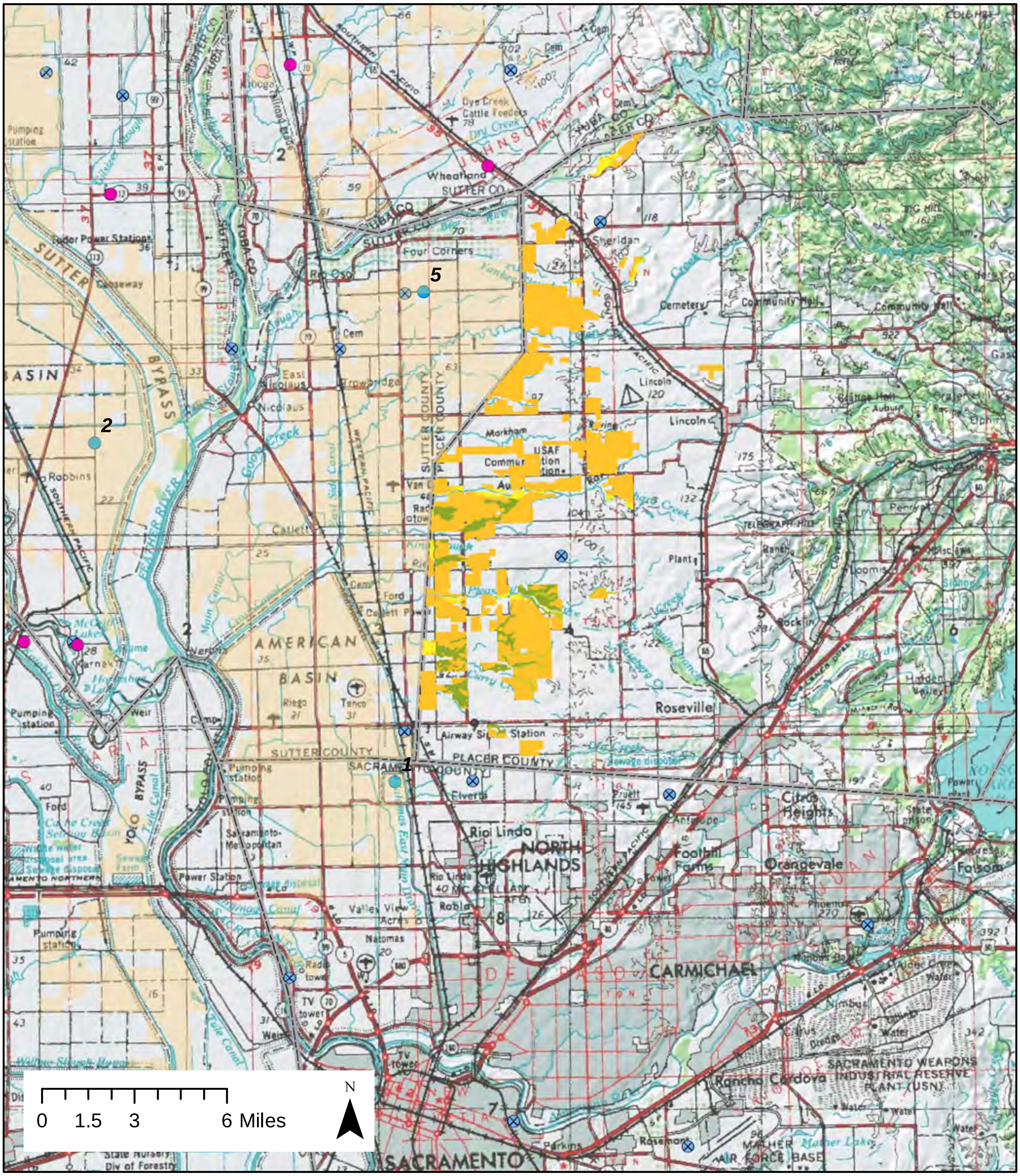
- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

## MAP H-5
## Glenn County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report



CH2MHILL




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**

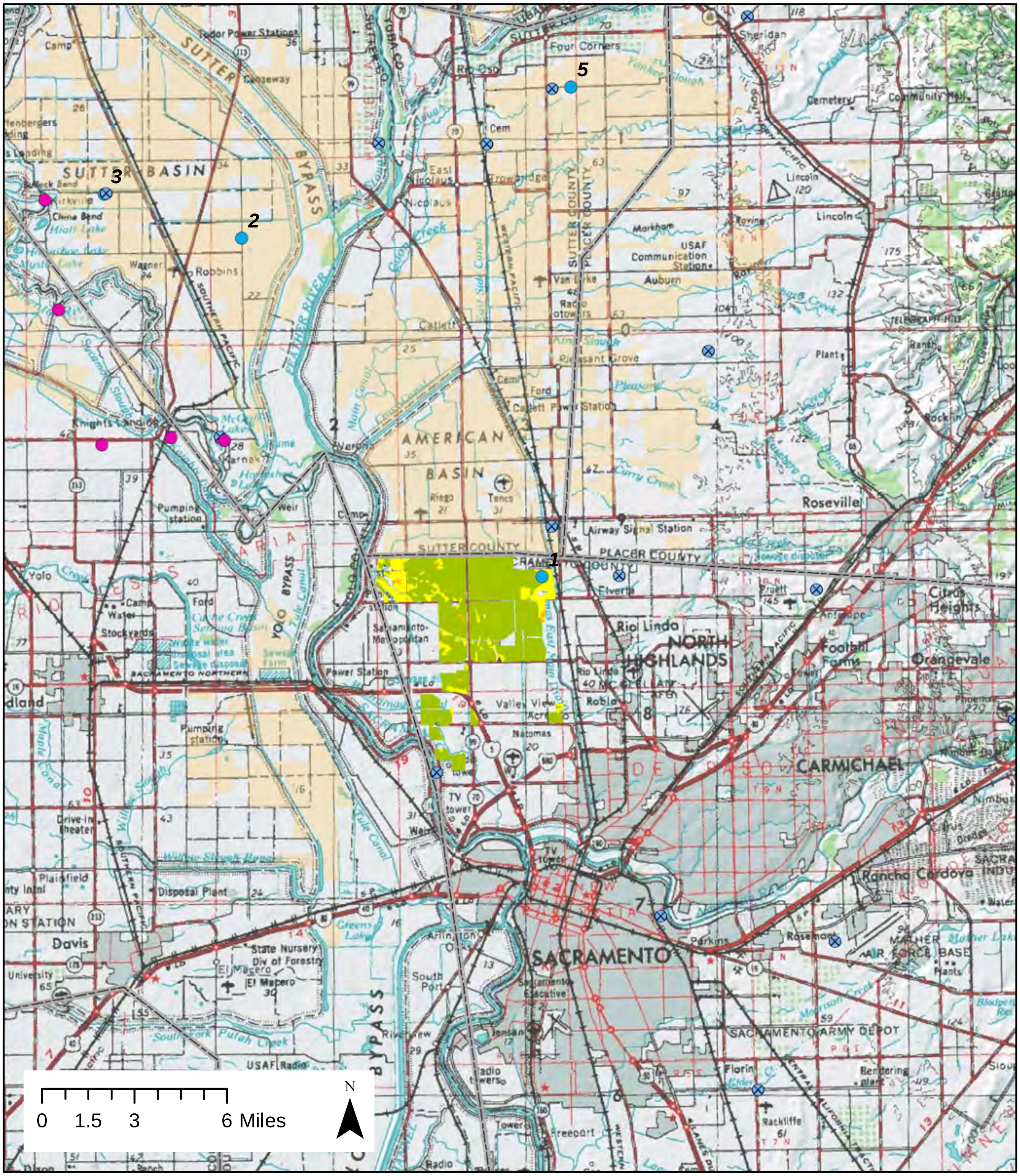
- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

## MAP H-6
## Placer County Rice Lands
## NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report



CH2MHILL.




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**

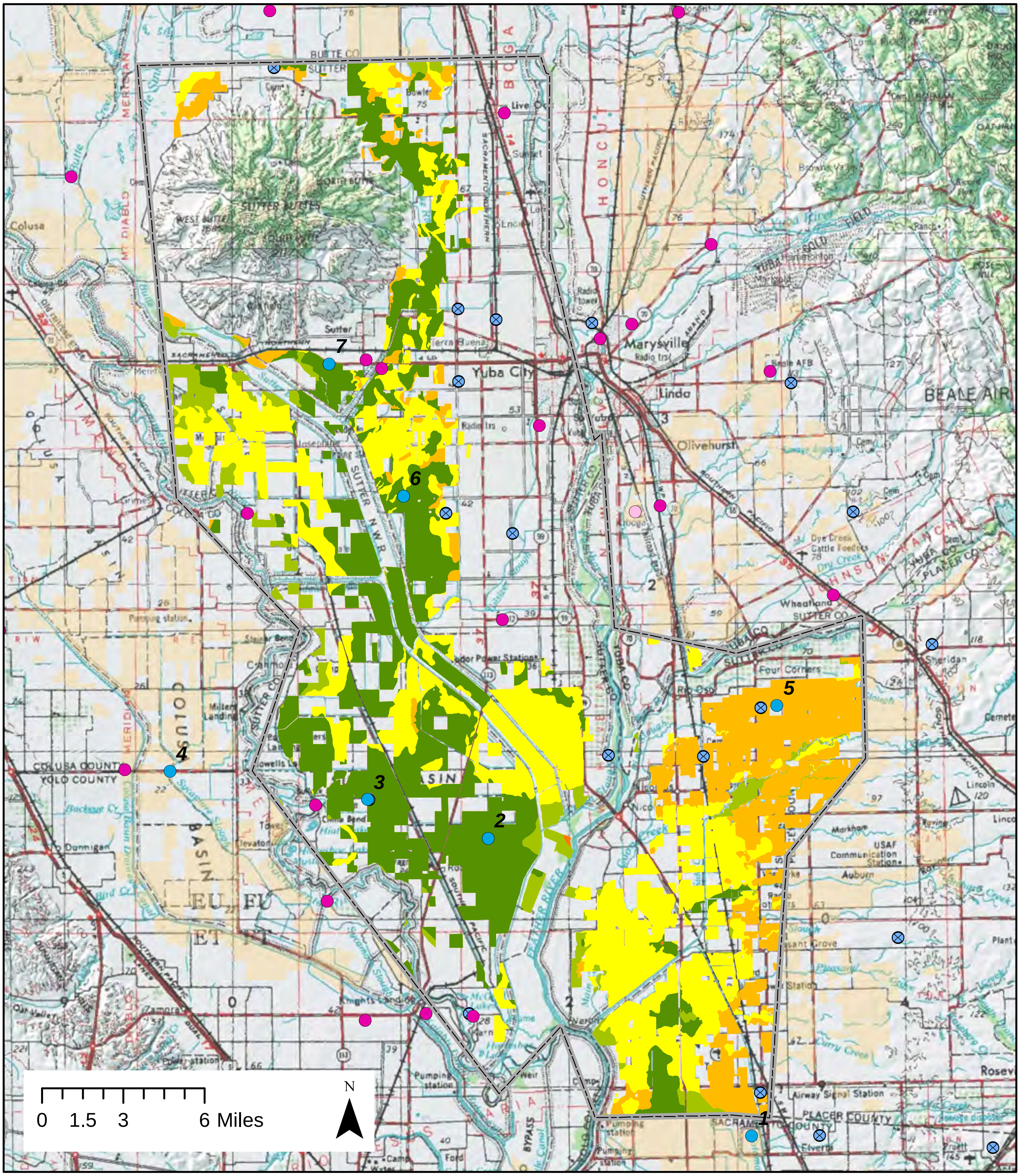
- Very poorly drained
- Poorly drained
- Somewhat poorly drained
- Moderately well drained
- Well drained
- Somewhat excessively drained
- Excessively drained

# MAP H-7
## Sacramento County Rice Lands NRCS Soil Drainage Classifications and Monitoring Networks

Rice-Specific Groundwater Assessment Report



CH2MHILL.




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

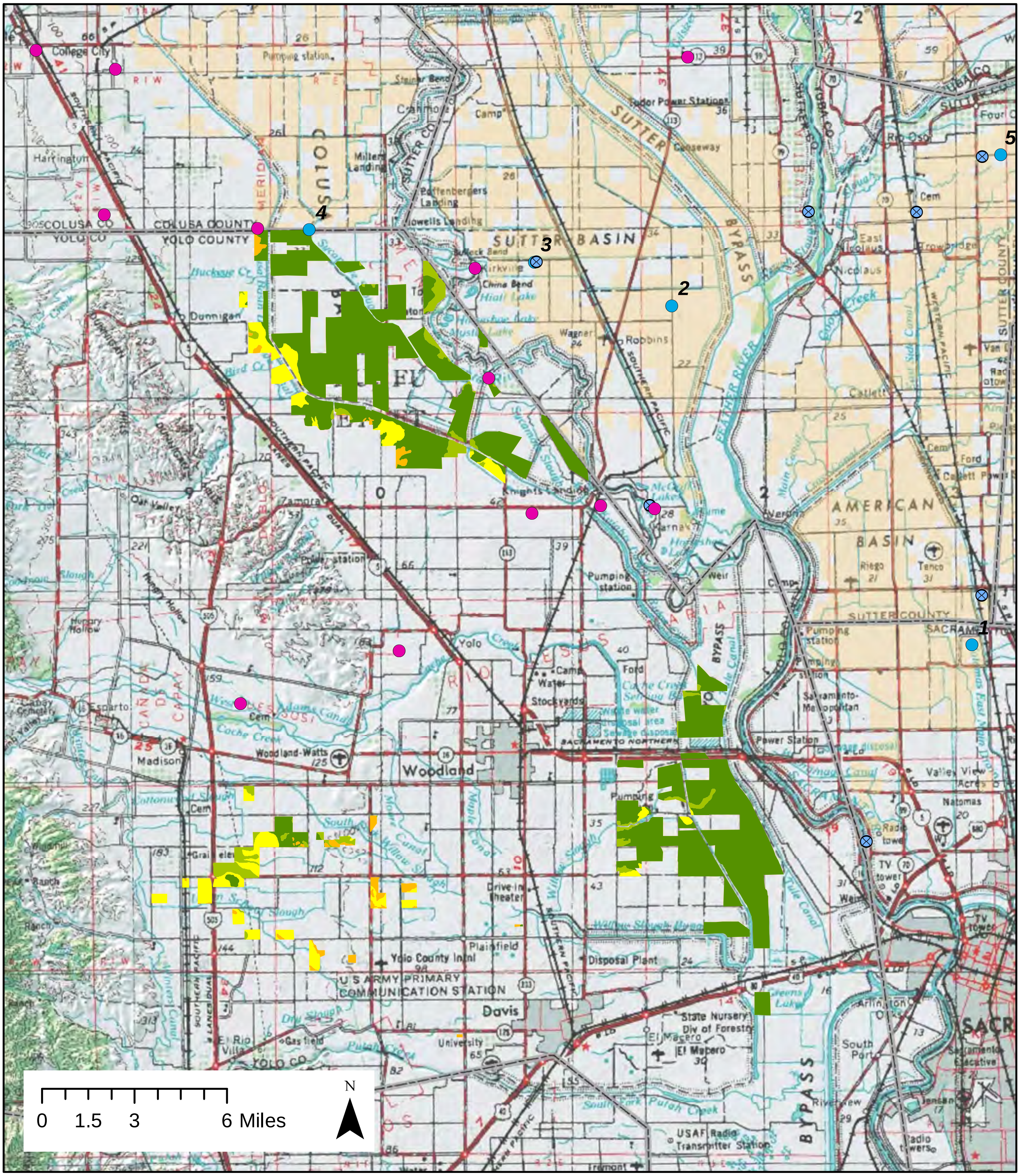
**NRCS Soil Drainage Classification**

- 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



CH2MHILL.




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**

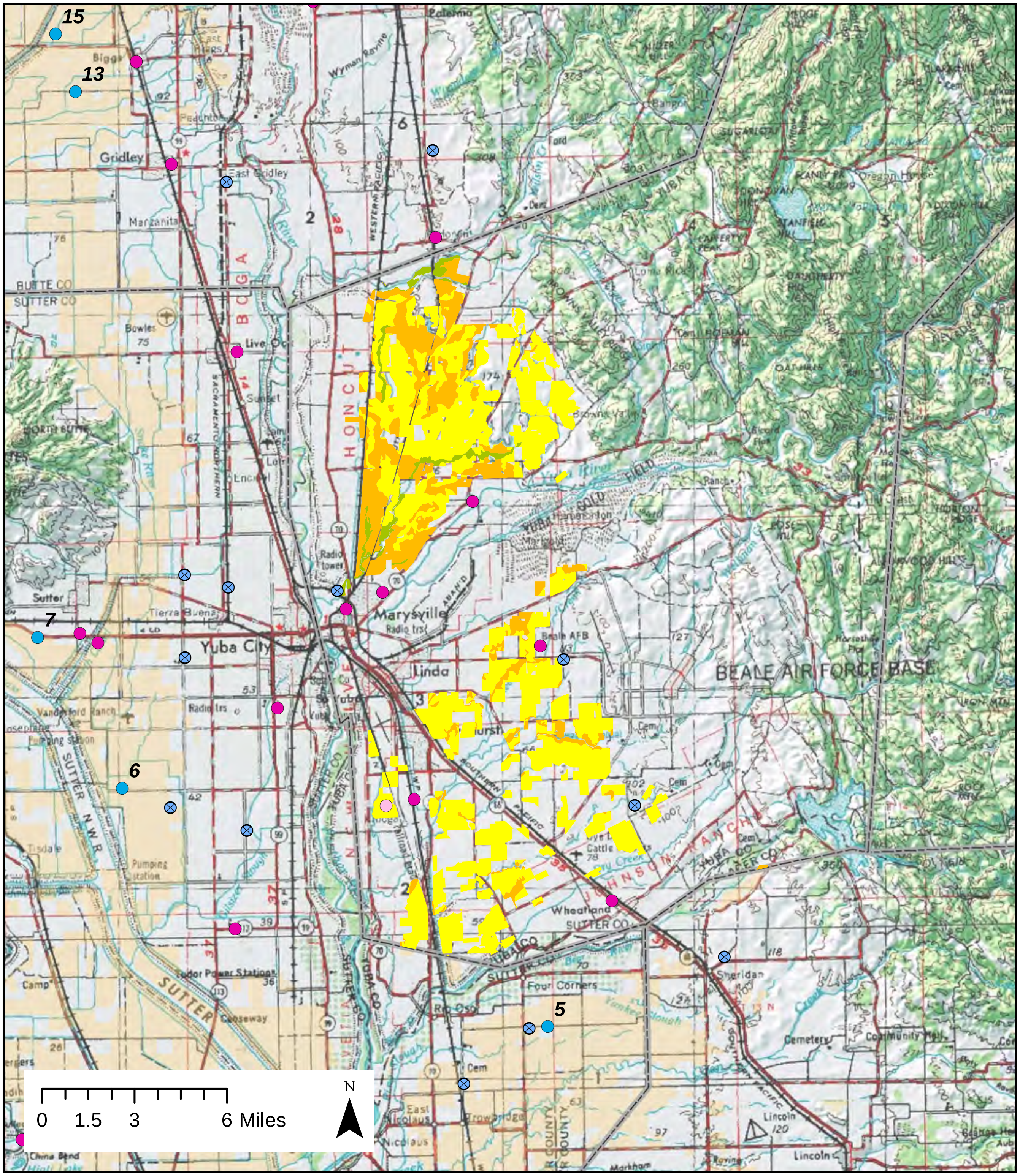
- Grid Well
- Flow Path Well

**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




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. |