DRAFT Technical Memorandum

Monitoring Well Thresholds

SAN JOAQUIN RIVER RESTORATION PROGRAM

January, 10 2011

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List of Abbreviations and Acronyms

CCID	Central California Irrigation District
CF	capillary fringe
cfs	cubic feet per second
CR	Capillary Rise
DWR	California Department of Water Resources
$Elevation_{FieldGS}$	Elevation of the ground surface in the adjacent field
$Elevation_{WellGS}$	Elevation of the ground surface at a monitoring well
ET	evapotranspiration
$h_{Capillary\ Fringe}$	Height of Capillary Fringe
$h_{IrrigationBuffer}$	Height of the buffer for leaching irrigation
$h_{Root\text{-}Zone}$	Depth of the Root Zone
IDW	inverse distance weighting
ITRC	Irrigation Training and Research Center
LiDAR	Light Detection And Ranging
NAVD	North America Vertical Datum
Reclamation	United States Bureau of Reclamation
SJRRP	San Joaquin River Restoration Program
TM	Technical Memorandum
UC ANR	University of California Division of Agriculture and Natural Resources
USGS	United States Geological Survey

1.0 Introduction

The purpose of this memorandum is to describe the development of thresholds for monitoring wells as required in the San Joaquin River Restoration Program (SJRRP) Stipulation of Settlement in Natural Resources Defense Council, et al., v. Rodgers, et al., (Settlement). The Settlement provides for releases of both Interim and Restoration Flows. The Interim Flows program began on October 1, 2009 pursuant to State Water Resources Control Board Order WR-2009-0058-DWR and continued for a second year starting October 1, 2010 pursuant to State Water Resources Control Board Order WR-2010-0029-DWR. Condition 7 of the State Water Resources Control Board Order WR-2010-0029-DWR states, in part:

> *As part of implementing the Seepage Monitoring Plan, Reclamation shall publish the then-current well locations, monitoring / buffer groundwater thresholds, and proposed process for development of and updates to action thresholds on the SJRRP website by January 10, 2011 for public review and comment and shall also provide this information to the Division. In the event that written comments are submitted within 20 calendar days, Reclamation shall consider these comments and provide written responses, which may include revisions to the thresholds, by March 1, 2011. Comments, responses, and then-current thresholds shall be published on the SJRRP website by March 1, 2011, and also provided to the Deputy Director for Water Rights for review, modification and approval.*

This Technical Memorandum includes monitoring thresholds to identify groundwater levels of concern and buffer zones to add a safety factor protecting crop root zones. It also includes the proposed process for development of and updates to action thresholds. Current well locations are published on the website in the Monitoring Well Atlas, which is available on the SJRRP website at www.restoresjr.net/flows/groundwater/groundwater.html.

1.1 Background

The purpose of seepage management is to convey flows from Friant Dam to the Merced Confluence of the San Joaquin River while avoiding material adverse impacts as a result of groundwater seepage.

The United States Bureau of Reclamation (Reclamation) developed a Seepage Monitoring and Management Plan (Plan) in the Water Year 2010 Environmental Assessment and continues to work on refinement in coordination with landowners. The Plan includes potential seepage types, locations of known seepage prone areas, as well as thresholds, operational criteria and response actions.

Consistent with the Plan, Reclamation has installed over 100 wells adjacent to the San Joaquin River. The network of monitoring wells includes transects spaced approximately every 8 to 10 miles along the San Joaquin River along with numerous wells at seepage prone areas as identified by landowners and local water districts. Groundwater elevations are monitored at each well in real-time, weekly measurements, or seasonal measurements depending on the well location and the potential for material adverse impacts.

Reclamation calculated the draft thresholds described in this document for each monitoring well. If groundwater levels increase above a threshold, Reclamation will conduct a site visit to evaluate the potential seepage conditions at the site. Based on the results of the site visit, Reclamation may increase the monitoring frequency, reduce or divert Interim Flows, or change types of monitoring at the monitoring well. Analysis of monitoring results determines if a threshold should be modified or if Reclamation should establish an operational criterion (formerly known as an action threshold) to limit the release of flows. Monitoring during 2010 Interim Flow releases also provides an opportunity to check groundwater rise predictions made for operations and helps to refine these predictions.

Operational criteria specify a groundwater level, river stage, or flow rate which limits the release of Interim Flows. In Spring 2010, Reclamation operated to limit flows in Reach 4A at 700 cubic feet per second (cfs). In Fall 2010, Reclamation operated to limit flows in Reach 4A at a 99.7 foot river stage elevation measured at the Washington Road gage.

The Seepage Monitoring and Management Plan may undergo revisions as Reclamation monitors conditions, collects additional information, and responds to stakeholder comments.

1.2 Purpose

- To describe the development of thresholds for SJRRP wells.

1.3 Objectives

The objectives of monitoring well thresholds development include:

- Determine the appropriate components to include in threshold development.
- Determine the appropriate values to use for each of the components.
- Obtain stakeholder input and comments on each threshold component.

1.4 Approach

Reclamation has developed three different methods to determine monitoring well thresholds. These include approaches based on idealized agricultural practices, historical groundwater levels, and drainage.

A conceptual model has been developed for determining thresholds based on idealized agricultural practices. This model is based on input from landowners and water district managers. The model considers several different components including site characteristics, farming practices, and physical processes.

The components of the threshold model, as illustrated in Figure 1-1, include:

- a root zone, to provide an unsaturated zone to avoid waterlogging;
- a ground surface buffer, to represent field groundwater levels and adjust for differences in elevation between the ground surface of the field and the location of the monitoring well so that wells can be located in areas most convenient for landowners rather than in the most critical seepage location;
- an irrigation buffer, to allow space for furrow irrigation or leaching treatments to drain;
- a capillary fringe component, to allow for the saturated portion of the capillary rise (CR) and maintain an aerated root zone;

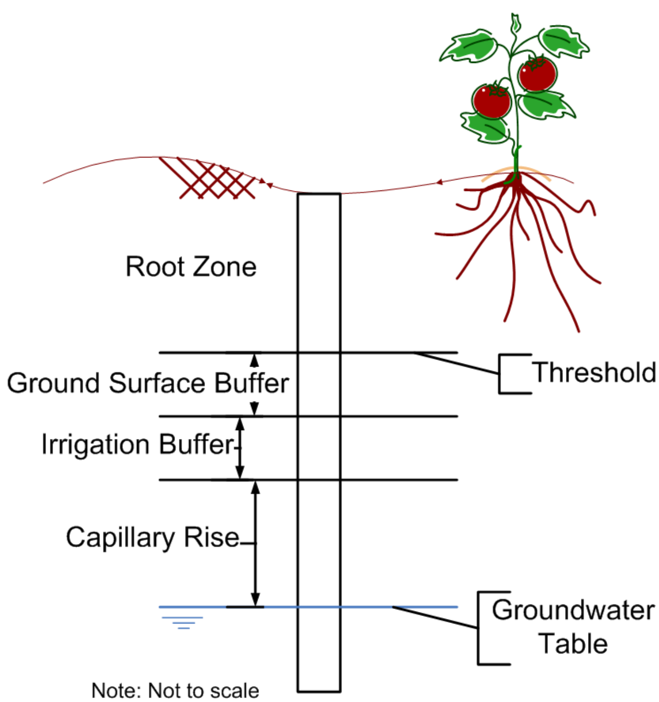

Figure 1-1
Schematic Diagram of Idealized Agricultural Practices Threshold Model

The following sections detail the approaches for each of these components. A threshold is defined according to the following:

$$\text{Threshold} = h_{\text{Root-Zone}} + h_{\text{Capillary Fringe}} + h_{\text{IrrigationBuffer}} + (\text{Elevation}_{\text{WellGS}} - \text{Elevation}_{\text{FieldGS}}),$$

Where $h_{\text{Root-Zone}}$ = depth of the root zone

$h_{\text{Capillary Fringe}}$ = height of capillary fringe

$h_{\text{IrrigationBuffer}}$ = height of the buffer for leaching irrigation

$\text{Elevation}_{\text{WellGS}}$ = elevation of the ground surface at a monitoring well

$\text{Elevation}_{\text{FieldGS}}$ = elevation of the ground surface in the adjacent field

Thresholds also consist of a time component, resulting in different thresholds in spring than during other times throughout the year.

In some locations along the San Joaquin River, historical groundwater measurements show elevations above the computed threshold. In locations where thresholds estimated using the outlined approach above are deeper than historical groundwater levels, the average historical groundwater level will be used. This second method results in more localized thresholds rather than generalizations.

Thresholds, as a component of the Seepage Monitoring and Management Plan, may undergo revisions as additional information becomes available.

1.5 Next Steps

The continued development of thresholds would benefit from landowner input and knowledge. Consistent with the State Water Resources Control Board Order WR-2010-0029-DWR, comments are due within 20 calendar days, or by January 31, 2011. Comments must be in writing, and may be emailed to interimflows@restoresjr.net, or mailed to San Joaquin River Restoration Program, MP-170, 2800 Cottage Way W1727, Sacramento, California 95825. Reclamation will provide written responses, which may include updates to thresholds, by March 1, 2011. All comments will be accepted; however threshold development may especially benefit from landowner input and knowledge in the following areas.

- **New well locations –** Shallow groundwater monitoring wells are used to monitor key areas of concern for potential seepage. The well network could benefit from suggestions for additional locations of concern not represented by the existing network.

- **Historical Irrigation Records –** The thresholds consider irrigation records to set an irrigation buffer, lowering groundwater levels prior to irrigation may allow drainage. Local irrigation practices for leaching, furrow, and drip irrigation would better inform buffer size.

- **Irrigation and Planting Times –** The thresholds allow for a timing component of thresholds to allow for irrigation and leaching. Information submitted regarding timing of leaching irrigation can better inform the thresholds.

- **Areas of poorly drained soil –** Reclamation does not currently know of any specific areas of poorly drained soil without artificial drainage requiring an irrigation buffer during leaching times. These buffers may be added as more information is obtained on poorly drained soil areas.

- **Crop types near monitoring wells –** Root zones depend on crop types. Information regarding local crops may help to inform future buffers.

- **Local references for appropriate root zones –** The thresholds consider root zones based on crop type. Local root zone information may be more accurate.

2.0 Components of Thresholds

The following section describes the components of threshold development including the crop root zone, ground surface buffer, irrigation buffer, and capillary rise.

2.1 Crop Root Zone Objectives

The objectives for crop root zones include the following:

- Identify different root zones based on crop type to expand upon the existing crop root zones in the 2009 Seepage Monitoring and Management Plan to.
- Include multiple root zones for each crop based on young and mature plants if information is available.

2.1.1 Approach

The type of crop, soil texture, irrigation practices, and depth to the groundwater table affect crop rooting depth. Poorly drained soils restrict crop root growth (Sands, 2001). Fine-grained soils can restrict crop root growth, as shown in Table 2-1 below (Westlands, 2009). Irrigation practices can result in more roots near the top of the soil column and fewer roots at depth (Speigel-Roy, 1996).

A literature review was conducted to identify sources of crop root depths. References found include:

- Westlands Irrigation District
- Allen et al., Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements
- Food and Agriculture Organization of the United Nations, 2009
- U.S. Department of the Interior, Bureau of Reclamation (Reclamation) Drainage Manual
- University of California Division of Agriculture and Natural Resources Small Grains Production Manual Publication 8167

The Reclamation Drainage Manual (page 48) does not make recommendations by crop type but generalizes to state 2 feet for the shallow-rooted crops such as potatoes and vegetables, to 6 feet for peach, walnut, and avocado trees. For most irrigated crops, a 3 to 4 foot root zone can be used. The Reclamation Drainage Manual assumes adequate drainage and leaching for salinity control are provided.

Local information is available on tomato root zones from the Irrigation Training and Research Center (ITRC) report (Burt, 2010). This local information was used over other sources. Other crops were split into two groups, permanent and annual. Thresholds used root depths on the higher end of typical values for permanent crops as their roots are deep early in the season. Annual crops generally have shallower root zones.

2.1.2 Results

Table 2-1 below shows crop root depths by crop type, soil type, and time in the season.

Table 2-1.
Crop Root Depths

Crop	Crop Root Depth, Early Season (feet)	Crop Root Depth, Late Season (feet)	Crop Root Depth, Late (feet) – Coarse Textured Soil	Crop Root Depth, Late (feet) – Fine Textured Soil
Alfalfa (Hay)		3-6[3], 6 [1, 2]	4-6 [1, 2]	
Almonds		3-6 [3]		
Barley		3-5[3], 4 [1]	4 [1]	
Lima Beans		2-4[3]		
Cotton	1 [4]	3-5[3], 5 [1]	5-6 [1]	4-5 [1]
Grape	5 [4]	3-6 [3]		
Corn	1 [4]	3 [4]		
Melon		2-5[3], 6 [1]	5-6 [1]	
Pistachio		3-5 [3]		
Safflower		3-6[3],15 [1]	15 [1]	10 [1]
Spring Wheat Winter	1 [4]	4 [4]		
Sugar Beet	1 [4]	6 [4]	6 [1]	
Sugarcane		5 [4]		
Tomato	1 [4]	3[6], 2-5[3] , 6 [1]	5-6 [1]	
Wheat	1 [4]	3-5[5, 3] , 5[4]	4-5 [1]	4 [1]

Notes:
[1] Westlands Water District 2009
[2] Crop root depth could exceed 6 feet if unrestricted
[3] Allen et al. 1998, larger values are for soils having no significant layering or other characteristics that can restrict rooting depth
[4] Food and Agriculture Organization of the United Nations, www.fao.org
[5] University of California Division of Agriculture and Natural Resources Publication 8167
[6] Irrigation and Research Training Center, November 2010

For the purposes of the current Seepage Monitoring and Management Plan buffer zones and action level thresholds, the values that were used include:

- Alfalfa, Pistachio, and other annual crops – 4 feet
- Grapes, Almonds, and Pomegranates – 6 feet
- Tomatoes, beans, melons and corn – 3 feet

2.1.3 Limitations

Limitations of this analysis include:

- This approach does not address soil type or irrigation methods which could affect root zones.

- These values do not take into consideration the effects of a historically shallow water table on crop root depths or seasonal or long term trends in the water table. Comparison to historical groundwater levels in a later section accounts for this in a broad sense.

- The root depth buffer does not include changes in the root depth buffer based on age of crops.

- Field crops are generally rotated each year, which may require changing thresholds on an annual basis as crop types change.

2.2 Ground Surface Objectives

Adjustments due to changes in ground surface elevation intend to:

- Thresholds should represent groundwater levels below agricultural fields near to the well.

- Adjust thresholds based on the difference between the adjacent field elevation and the ground surface elevation at the monitoring well.

2.2.1 Approach

The difference between ground surface elevation at the well and in the adjacent field was determined.

All wells drilled in Fall 2009 and Spring 2010 by Reclamation have ground surface elevations surveyed in North America Vertical Datum (NAVD) 88. In addition, Reclamation monitors several hand-augered piezometers, private wells, and Central California Irrigation District (CCID) wells that have not been surveyed. For wells that are not surveyed, a ground surface elevation was interpolated from a 2008 Light Detection And Ranging [1](LiDAR) survey.

Minimum field elevations within 750 feet for the field adjacent to each well were calculated. Elevations were chosen from the 2008 LiDAR survey.

The LiDAR survey was flown within approximately ¼ to 1 mile on either side of the San Joaquin River and flood control bypasses. Figure 2-1 provides an example of one monitoring well that uses a 750 ft buffer zone that is partially missing due to the lack of

[1] An optical remote sensing technology that measures properties of scattered light to find topographic information.

available LIDAR data. Wells located outside the LiDAR data area have no ground surface buffer. Some wells used data from fields further away if there was no available LiDAR data in an adjacent field.

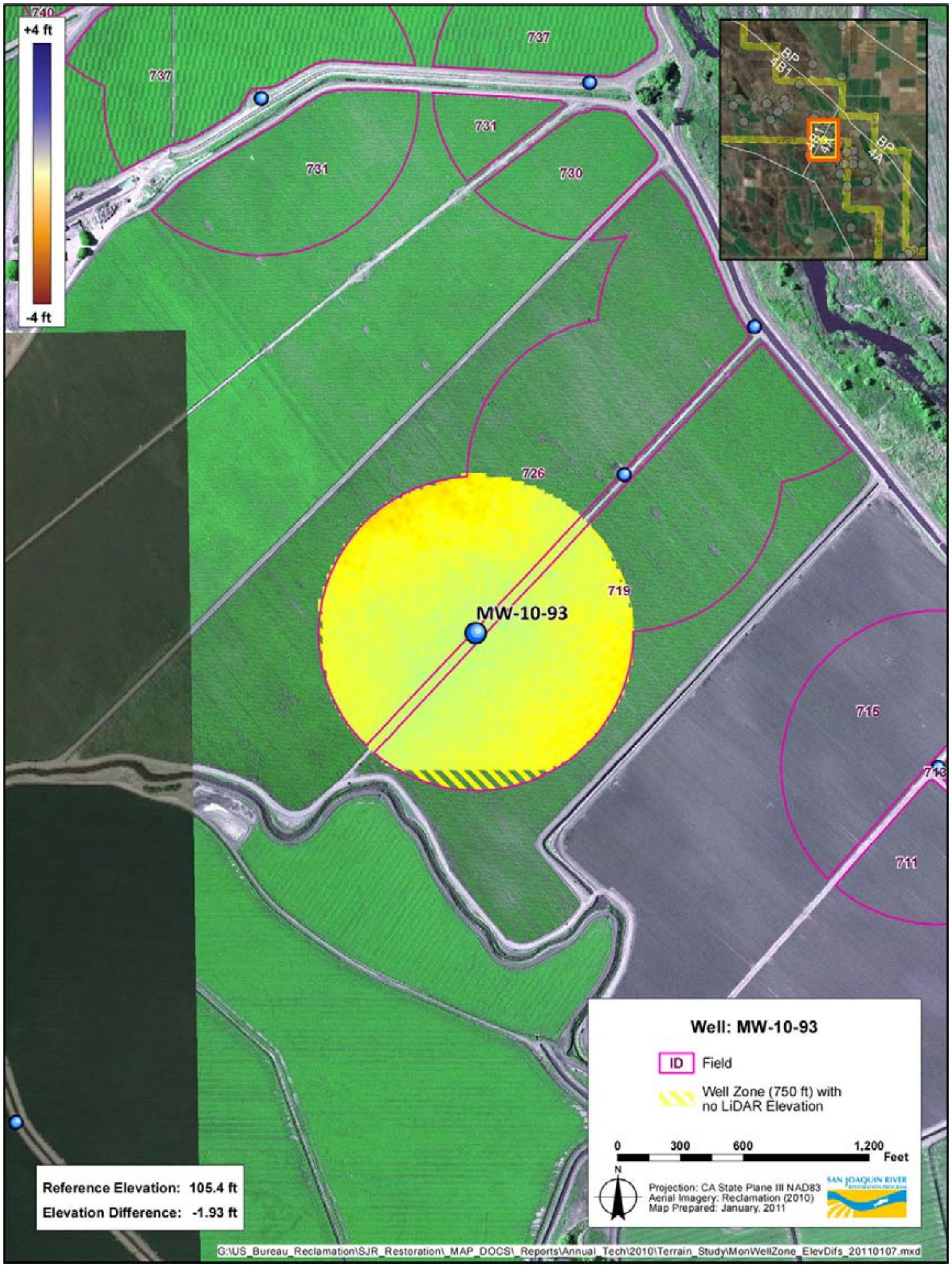

Figure 2-1
Monitoring Well MW-10-93

Thresholds assume a flat groundwater surface in the area they represent. Groundwater level measurements taken in a well only accurately represent nearby groundwater conditions. Further away fields may have canals, sloughs, ditches, changes in soil type, or other factors influencing groundwater levels that are not represented in the well or threshold.

The difference between the ground surface elevation at the well and the minimum field elevation within 750 feet of the well was used as the ground surface buffer. A negative ground surface buffer indicates that the well is located lower than the adjacent field, such as in the river channel. An example of this is shown in Figure 2-2 below.

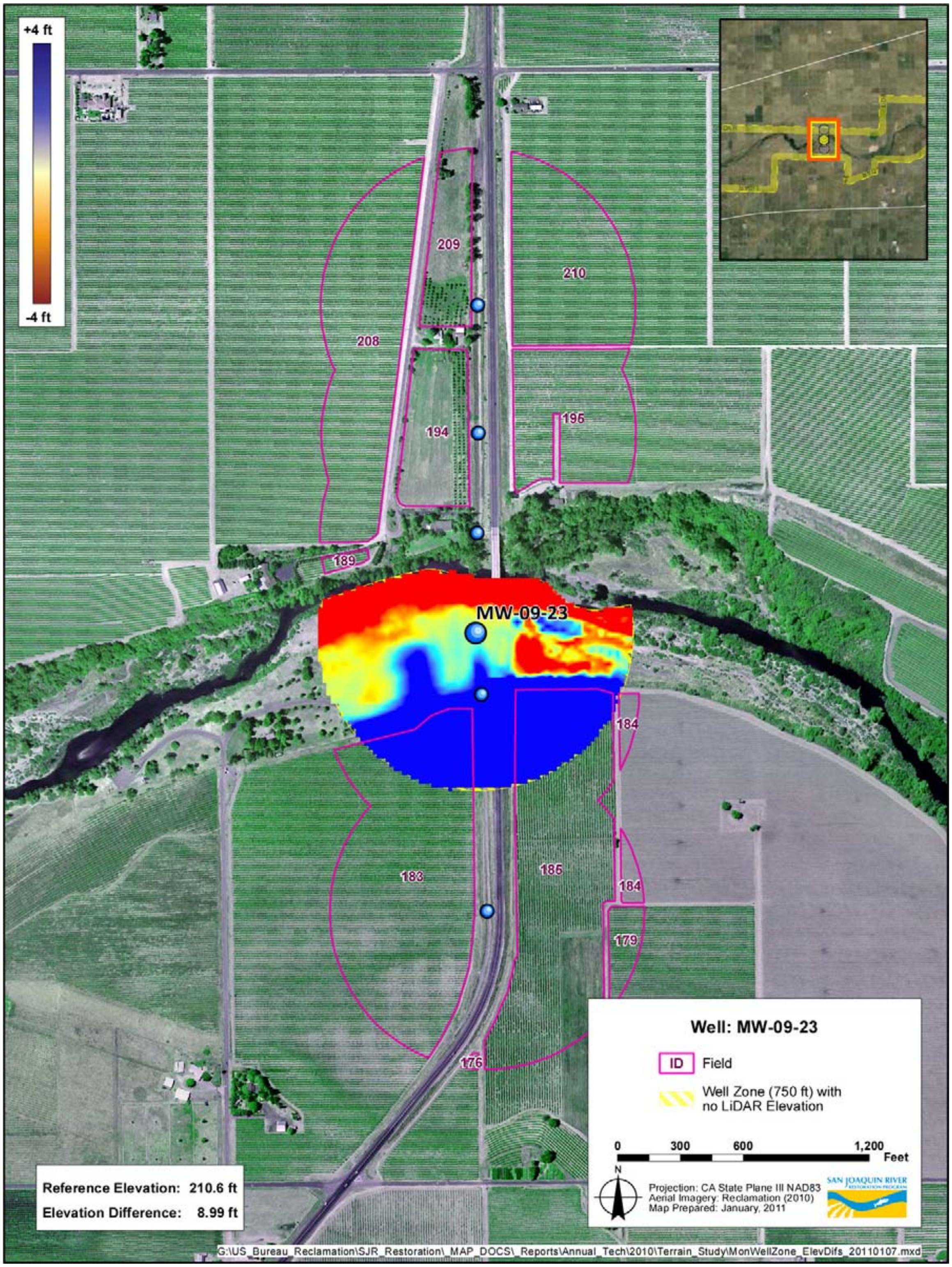

Figure 2-2
Monitoring Well MW-09-23

2.2.2 Results

Corrections made for changes in elevation range from 8 to -9.5 feet. Results are shown per well in Table 2-2 below.

Table 2-2
Ground Surface Buffer

Well	Ground Surface Elevation at Well (feet NAVD '88)	Minimum Adjacent Field Elevation (feet NAVD '88)	Ground Surface Buffer (feet)
131	116.7	113.2	3.4
132	118.6	115.9	2.6
145	124.2	122.5	1.7
151	130	124.8	5.2
154	130.7	129.2	1.5
156	138	133.0	5.0
157	136	134.7	1.3
158	139.5	135.5	4.0
191	110.9	108.0	2.8
144A	120	118.7	1.3
186A	108.1	106.1	2.0
FA-1	206.87	205.1	1.8
FA-2	207.17	204.9	2.2
FA-3	206.43	204.9	1.5
FA-4	179.84	184.4	-4.6
FA-5	179.45	184.2	-4.7
FA-6	180.86	176.1	4.8
FA-7	181.57	175.9	5.6
FA-8	172.7	170.9	1.7
FA-9	174.48	170.8	3.7
MA-1	206.65	204.9	1.7
MA-2	182.69	179.8	2.9
MA-3	179	178.1	0.9

Table 2-2
Ground Surface Buffer (cont.)

Well	Ground Surface Elevation at Well (feet NAVD ’88)	Minimum Adjacent Field Elevation (feet NAVD ’88)	Ground Surface Buffer (feet)
MA-4	174.45	168.4	6.1
MW-09-21	226.6	220.8	5.7
MW-09-22	222.8	219.4	3.4
MW-09-23	210.6	219.4	-8.8
MW-09-23B	210.6	219.4	-8.8
MW-09-25	224.9	234.5	-9.6
MW-09-26	228.6	234.5	-5.7
MW-09-27	236.8	243.5	-6.7
MW-09-36	191	186.5	4.5
MW-09-37	191.8	189.1	2.7
MW-09-37B	192.1	189.1	3.15
MW-09-39	184.9	184.4	0.5
MW-09-39B	184.9	184.4	0.5
MW-09-41	180.7	184.2	-3.5
MW-09-44	179.2	176.1	3.1
MW-09-46	173.5	170.9	2.5
MW-09-47	174.7	171.2	3.5
MW-09-49	171	169.2	1.8
MW-09-49B	170.9	169.2	1.7
MW-09-52	162.1	161.2	0.9
MW-09-53	162.8	161.4	1.3
MW-09-54	168	160.3	7.7
MW-09-54B	168.2	160.3	7.9
MW-09-55	166.1	162.0	4.1
MW-09-55B	165.7	162.0	3.7
MW-09-56	161.2	159.5	1.7
MW-09-57	163.1	161.5	1.6
MW-09-84	115.8	112.4	3.4
MW-09-85	120.8	113.7	7.1
MW-09-85B	120.6	113.7	6.9
MW-09-86	121	112.9	8.0
MW-09-86B	120.9	113.0	7.9
MW-09-87	115.03	113.1	1.9
MW-09-87B	115	113.1	1.9
MW-10-100	102.7	98.2	4.5
MW-10-102	95.7	93.3	2.4
MW-10-103	99.1	94.5	4.6
MW-10-105	96.7	95.3	1.4
MW-10-106	95.08	93.1	1.9
MW-10-107	96	93.3	2.7
MW-10-108	96.5	94.7	1.7
MW-10-109	98.09	96.5	1.5
MW-10-110	88.84	87.0	1.8
MW-10-111	90.64	88.9	1.8
MW-10-113	99.53	95.1	4.4

Table 2-2
Ground Surface Buffer (cont.)

Well	Ground Surface Elevation at Well (feet NAVD '88)	Minimum Adjacent Field Elevation (feet NAVD '88)	Ground Surface Buffer (feet)
MW-10-114	98.9	97.0	1.9
MW-10-118	138	135.6	2.4
MW-10-119	139.31	136.9	2.4
MW-10-124	154.07	153.4	0.6
MW-10-188	116.9	114.8	2.0
MW-10-74	136	131.8	4.2
MW-10-78	125.3	122.3	3.0
MW-10-80	124.9	119.8	5.1
MW-10-89	118.8	115.4	3.4
MW-10-91	107.2	103.5	3.7
MW-10-92	106	103.4	2.6
MW-10-93	105.4	103.2	2.2
MW-10-96	100.4	98.4	2.0
MW-10-97	101.2	97.8	3.4
MW-10-98	102.2	98.2	4.0
MW-10-99	104.3	99.6	4.7
PZ-09-R2B-1	155.16	153.9	1.2
PZ-09-R2B-2	153.17	149.3	3.9
PZ-09-R3-1	137.12	133.1	4.1
PZ-09-R3-2	138.39	136.8	1.5
PZ-09-R3-3	141.06	136.7	4.3
PZ-09-R3-4	140.24	136.7	3.5
PZ-09-R3-5	140.33	139.2	1.2
PZ-09-R3-6	141.56	140.1	1.5
PZ-09-R3-7	144.08	143.3	0.7
R1-1	216.85	215.3	1.5
R1-2	218.38	215.3	3.1
SJR W-1	100.17	98.4	1.8
SJR W-10	106.74	104.9	1.8
SJR W-11	108.23	106.4	1.8
SJR W-12	106.19	104.1	2.1
SJR W-2	103.19	98.9	4.2
SJR W-3	102.54	98.8	3.8
SJR W-4	106.35	105.2	1.1
SJR W-5	103.42	101.5	1.9
SJR W-6	105.65	101.3	4.4
SJR W-7	106.99	102.9	4.0
SJR W-8	108.88	105.5	3.3
SJR W-9	105.07	104.0	1.1

Key:
NAVD = North America Vertical Datum

2.2.3 Limitations

Limitations of this analysis include:

- This approach assumes the groundwater level measured at a monitoring well represents the groundwater level under the lowest point within 750 feet of the well in the adjacent field. It does not address ground slope away from the river and assumes there is no groundwater table gradient within 750 feet of each well.

- The lowest adjacent field elevation within 750 feet may not represent a large acreage of the actively growing adjacent crop. The adjacent field could have a small depression that would result in a large ground surface buffer.

2.3 Irrigation Buffer Objectives

Objectives of the irrigation buffer include:

- Address salinity buildup in the soil column

- Allow space for furrow irrigation

- Allow space for leaching irrigation

2.3.1 Approach

Irrigation depends on crop type, evapotranspiration, and a variety of other factors. For the purposes of this study irrigation is generally either by drip lines or furrow.

In crops irrigated by furrow, a portion of irrigation in excess of evapotranspiration[2] (ET) passes through and beyond the crop root zone. The lower portion of the root zone may have higher salinity than the upper portion due to the smaller volume of water that passes through it (Ayers, 1985). Buildup of salts from irrigation or poor drainage may require periodic leaching applications. The purpose of this excess irrigation is to remove some of the applied salts from the lower portion of the root zone. This leaching fraction, with salts in a reduced volume and proportionately increased concentration, could dissolve additional salts from the underlying soil. If this situation occurs and there is inadequate drainage, a perched water table could occur, bringing water and concentrated salts back into the root zone (Rhoades, 1999).

Drip irrigation is generally matched to evapotranspiration rates, and thus has no deep percolation (Burt, 2010). These draft thresholds assume that there is no excess irrigation that could raise the water table, and thus, there is no buffer needed for drip irrigation.

However, the efficiency of drip lines results in a buildup of salts. These salts may require leaching. Deep percolation from drip irrigation in orchards in California leaves substantial amounts of salt in the soil (Burt, 2003). A buffer is assumed during the month prior to planting to ensure the lowering of the groundwater level prior to leaching and space for the leachate.

[2] A combination of evaporation and plant transpiration of water from the soil to the atmosphere.

The irrigation buffer allows extra space for drainage following leaching of both furrow and drip irrigation to prevent a stagnant water table. This may be done pre-planting to address salt buildup in the root zone from salts that rose after the previous harvest. The lower water table avoids the waterlogging of roots and potential ‘subbing up’ of salts back into the root zone (Rhoades, 1999).

Reclamation gathered data and information from various sources for use in establishing a more locally based understanding of the irrigated agricultural practices. Table 2-3 presents information on irrigation practices per crop type.

Table 2-3
Irrigation Per Crop Type

Crop Type	Pre-Irrigation Time	Pre-Irrigation Amount	Planting Time	Irrigation Timing	Irrigation Amount(total)
Cotton and Corn (furrow)[1]	February / March	6” to 1’ of water	By May 1	June on, every 10 days	6” more than total ET, generally 3 to 3.5’
Tomatoes (drip)	Generally None[1]	Generally None[1]		Mid-May to September, every few days[3]	2.2’[2]
Wheat and small grains (furrow)				Every 7-18 days	4-8” each time[4]

Notes:
[1] C. White personal communication, 12/23/2010
[2] ITRC Report, November 2010
[3] San Juan Ranch irrigation records
[4] University of California Division of Agriculture and Natural Resources Publication 8168

Immediately following 6-inch furrow irrigation, the water can rise up to a couple of feet, however it should recede fairly rapidly with good natural drainage or artificial drains. On properties that do not have good natural drainage or artificial drains, extra space is allowed for excess furrow irrigation water to percolate. Reclamation has assumed an initial draft buffer during typical months of furrow irrigation, to allow groundwater levels to lower and excess irrigation to drain. This buffer may be applied as more information is obtained on properties with poor natural and no artificial drainage.

2.3.2 Results

The leaching buffer, presented in Table 2-4 represents a buffer added only in certain times of the year to thresholds in areas with poor natural and no artificial drainage. The purpose of the leaching buffer is to allow for leaching irrigation, if needed, to remove accumulated salts in the soil from irrigation or groundwater. Identification of additional areas with poor drainage may be aided by observation of inverted soil salinity profiles. (Rhoades, 1999)

Table 2-4
Irrigation Buffer

Type	Time of Year	Leaching Buffer
Poorly drained areas	Feb / March – planting	1’

2.3.3 Limitations

SJRRP groundwater thresholds would benefit from landowner input to determine timing and amounts of leaching. Limitations of the analysis include:

- For annual crops the timing of the water table fluctuations will be different than for semi-permanent crops such as orchards and vineyards. This approach does not take a crop-specific planting time into account.
- Crop rotations may influence the irrigation buffer zones each year. Planting of winter rotation crops may result in more irrigation in the spring. This approach uses values based on general irrigation per crop as recorded in Table 2-4.
- Existing management of salinity by leaching will likely continue.
- Monitoring wells located underneath irrigation header lines will show increases in groundwater levels above the adjacent field. This approach does not take this into account.

2.4 Capillary Fringe Objectives

Inclusion of a capillary fringe buffer intends to:

- Account for the more saturated portion of the capillary zone

2.4.1 Approach

The height of the capillary fringe depends on soil texture, depth to the water table, evaporative demand of the atmosphere, and land use (Belitz, 1993). Fine-grained soil texture with broad distribution of grain sizes contains small pores, which increases the capillary rise (Hackett, 1927; Carman, 1941). A deeper water table will often have a larger capillary fringe. In addition, crop roots transpire water, affecting capillary rise and concentrating salts.

Two related items that are a part of the monitoring of a shallow water table are the potential saturation of the crop root zone and the movement of dissolved salts and potential to increase the salinity of the soil root zone.

A water table and associated CR under actively growing crops can increase soil moisture and supply some of the crop water demand, reducing irrigation (Ramirez, 1996). If the water table is too deep, then groundwater is not able to move up far enough, or at a rate fast enough, to supply much of the crop demand. If the water table is too shallow and encroaches on the root zone then crop production will suffer due to lack of air in the root zone. Also, if the water table is too saline, the crop cannot utilize much of the ground water.

The following illustrations presented in Figures 2-3 and 2-4 (Sands, 2001) show the relationship of soil CR potential vs. the amount of saturation and air in the soil pore space. Capillary forces can conduct water many feet above a water table in medium and fine textured soils. A large portion of the CR above the water table contains air and water and is not detrimental to plant root growth from the water logging standpoint. Only the part of the CR that is immediately above the water table is the area of concern for water-logging and could be included in the monitoring threshold. For the purposes of this Technical Memorandum (TM) this will be called the capillary fringe. The capillary fringe is a zone above a water table that is nearly saturated near the base and just above field capacity at the top.

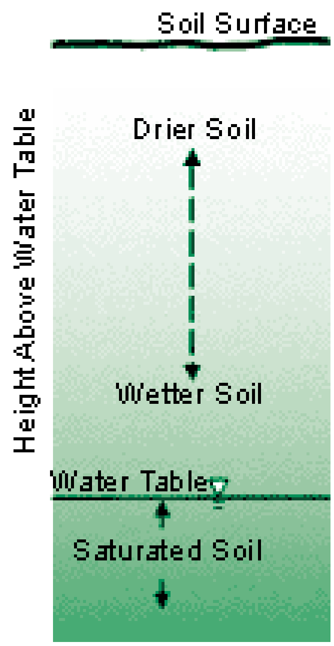

Figure 2-3
Soil Moisture Variation Between the Water Table

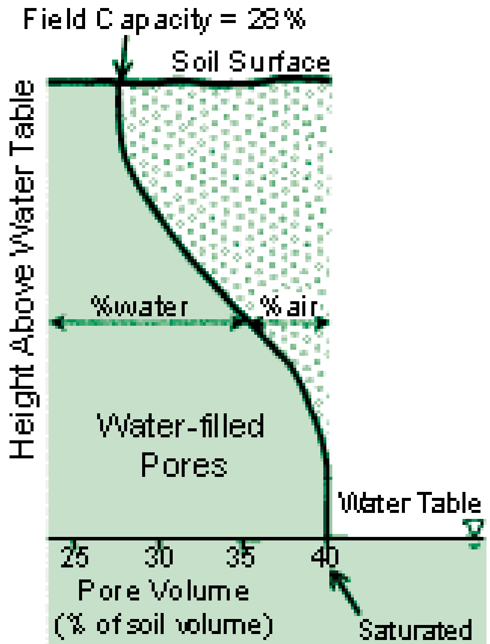

Figure 2-4
Proportion of Air- and Water-Filled Pores Between the Water Table and the Soil Surface After the Downward Flow of Water Ceases

Field Capacity is less than saturation, but is moist in terms of total soil moisture. Generally field capacity moisture content is representative of the condition when a fully saturated soil profile is allowed to drain for 12-24 hours. Field capacity is water held under slight tension, often defined as 1/3 bar or 1/3 atmospheric pressure for laboratory experiments or in-field monitoring instruments (Brady, 1974).

The lower portion of the capillary fringe is considered too wet for crop health and few roots penetrate this zone. Crops do however use water from the top portion of this capillary fringe zone where there is more entrapped air. Capillary fringes may be thicker in the non crop season, under roads and other barren areas, and when water tables are deeper in the substrata.

Usually entrapped air, soil stratification and the discontinuity of soil pores and structural channels limit the thickness of a capillary fringe. The field setting can present a different capillary fringe than a theoretical or laboratory experiment under uniform controlled conditions. Thus, measurements made in the field are the basis for this analysis.

The capillary fringe is dependent on matric suction (or negative pressure head) to rise. During the furrow irrigation season, when infiltration from the ground surface adds a zone of near saturation at the top of the soil column, matric suction is reduced. If the matric suction within the pore spaces between the bottom of the irrigation zone and the capillary fringe is not great enough, capillary rise will be limited. In addition to the reduced capillary rise under irrigation, the capillary fringe and associated salinity may be pushed down depending on the leaching fraction of the applied irrigation (Rhoades, 1999). Between furrow irrigations, plants could pull up salts by transpiring water and capillary forces would then cause water and salt to rise above the water table and potentially into the root zone. These same crops could also limit the CR however, by transpiring water before it can rise further into the root zone.

Soil boring logs from 85 soil sampling sites collected in March and April of 2010 were reviewed to determine the potential thickness of capillary fringe zones in soils of various textures on lands near the San Joaquin River. These are presented in Table 2-5 below.

Drill logs or, when available, the logs from soil borings offset from the wells were examined to determine soil textures in the monitoring wells from 4-6 feet deep. Many soil sampling sites were offset from stakes that were planned for future monitoring well sites when wells had not yet been drilled. In some cases the drill logs had fill. Under these circumstances the texture evaluation was 4-6 feet below the fill / native soil boundary as noted on the logs for the subsurface profile. Each well was assigned a capillary fringe thickness based on this analysis. Capillary fringe thicknesses for each well are presented in Table 4-1.

2.4.2 Results

A summary of the findings from the review of soil logs is presented below in Table 2-5.

Table 2-5
Capillary Fringe Thickness (inches)

Category	Soil Texture	Number of Observations	Average Rise, Inches	95% Confidence Range, inches
1	Sand, loamy sand	15	6.9	4.1 – 9.1
2	Sandy loam, loamy fine sand	4	13.75	9.5 – 18.1
3	Fine sandy loam, loam, silt loam, very fine sandy loam	21	18.3	14.3 – 22.3
4	Clay loam, silty clay loam, clay	6	10.3	5.1 – 15.5
2 and 3	Loamy fine sand, silt loam	25	17.6	14.1 – 20.9

Based on the data presented above from soil sampling sites (mostly in Reaches 4a and 4b) a capillary fringe (CF) thickness of 1 foot for all soils except the loamy sand and sand soils was incorporated. A 0.5 foot CF thickness would be used for these soils. The reasons for this decision are listed below.

- The sites were evaluated based on spring conditions before the crop season. When an actively growing crop is present and is consuming water from the upper portion of the capillary fringe the thickness of the capillary fringe should be less.

- The upper portion of CF contains enough air to permit root establishment.

- Categories 2-4 were combined since the 95 percent confidence intervals overlapped. The clay loam and clay soils were added to the 1 foot CF category since the low macro pore space present in these soils makes field observations of capillary fringe difficult.

- Only hand augured holes were evaluated. Large drill rigs tend to advance flight augurs too rapidly to evaluate and estimate capillary fringe conditions.

- The thick capillary fringe observed in October by ITRC researchers (Burt, 2010) was partially due to being sited on a compacted road site. No crop roots were using water from the capillary fringe at the time, resulting in large observed capillary moisture content at some distance above the actual water table. The water table was about 7 to 8 feet deep rather than in the 4-5 action threshold range. Capillary fringe thickness should increase with a deeper water table that is farther away from the influences of evaporative and crop consumptive use forces near the soil surface.

2.4.3 Limitations

Timing of the capillary fringe vs. growing season or root development is not addressed in this approach.

Water quality of the groundwater is not included as part of this evaluation. The irrigation buffer discussed below allows for leaching of potentially saline groundwater from the root zone.

This approach does not address the degree of soil salinity existing at each site. Soil salinity is addressed through the irrigation buffer discussed in Section 2.3.

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3.0 Historical Groundwater Levels

The second method of analysis, historical groundwater levels also provide a check on thresholds and a basis for change comparison. Comparison with historical groundwater levels accounts for field conditions and historical practices.

3.1 Objectives

The objective of the historical groundwater level method is to:

- To compare thresholds to local conditions

3.2 Approach

Groundwater level data along the San Joaquin River does not exist in all areas and times of interest. Sources of historical groundwater data include CCID wells, the United States Geological Survey (USGS), and wells included in the California Department of Water Resources (DWR) database. Ninety percent of the available records represent the period from 1960 to the present, with some wells covering a longer time period. While some wells have monthly or weekly measurements for short periods of time the majority of wells have biannual spring and fall measurements.

The USGS has developed depth to water maps in certain historical years having the greatest number of measurements. These depth to water maps include both shallow and deep wells. There are few shallow wells outside of Reaches 3 and 4A. The depth to water maps cover a variety of year types. Three of these depths to water maps were chosen to use in this analysis, to represent average, or normal, conditions. Spring 2008 represents springtime conditions in normal-dry year. Fall 2008 represents fall conditions in a normal-dry year, and fall 1999 represents fall conditions in a normal-wet year. The water level database contains few spring groundwater level measurements, thus few spring depth to water maps were made and no map is available to represent normal-wet springtime conditions. This and the inclusion of deep wells may result in lower groundwater levels than a true average.

The approach described above best utilizes a database of mainly bi-annual measurements. However, CCID has an extensive well network in Reaches 3 and 4A of the San Joaquin River with a long historical period of data. These values were averaged, since these measurements are over an extensive period of time and at a set interval, which raises confidence that an average of these measurements best represents groundwater conditions in this area.

The final values for historical groundwater took the smallest depth to water calculated through these approaches. See figures 3-1 to 3-5.

3.2.1 Depth to Water Maps

USGS created maps presented in Figures 3-1 through 3-6 using DWR, USGS, and CCID well data interpolated using the inverse distance weighting (IDW) method. The IDW method averages the depth to water in adjacent wells while weighting closer wells more than measurements a greater distance away. A greater concentration of points represents a better interpolation. Interpolations in areas having few or no wells can only be considered an approximation of actual conditions. USGS created maps were used to find interpolated depths to water at SJRRP monitoring wells. In areas without data (for example, in Fall 2008 Reaches 1A through 2A - Figure 3-1 below), no depth to water was recorded.

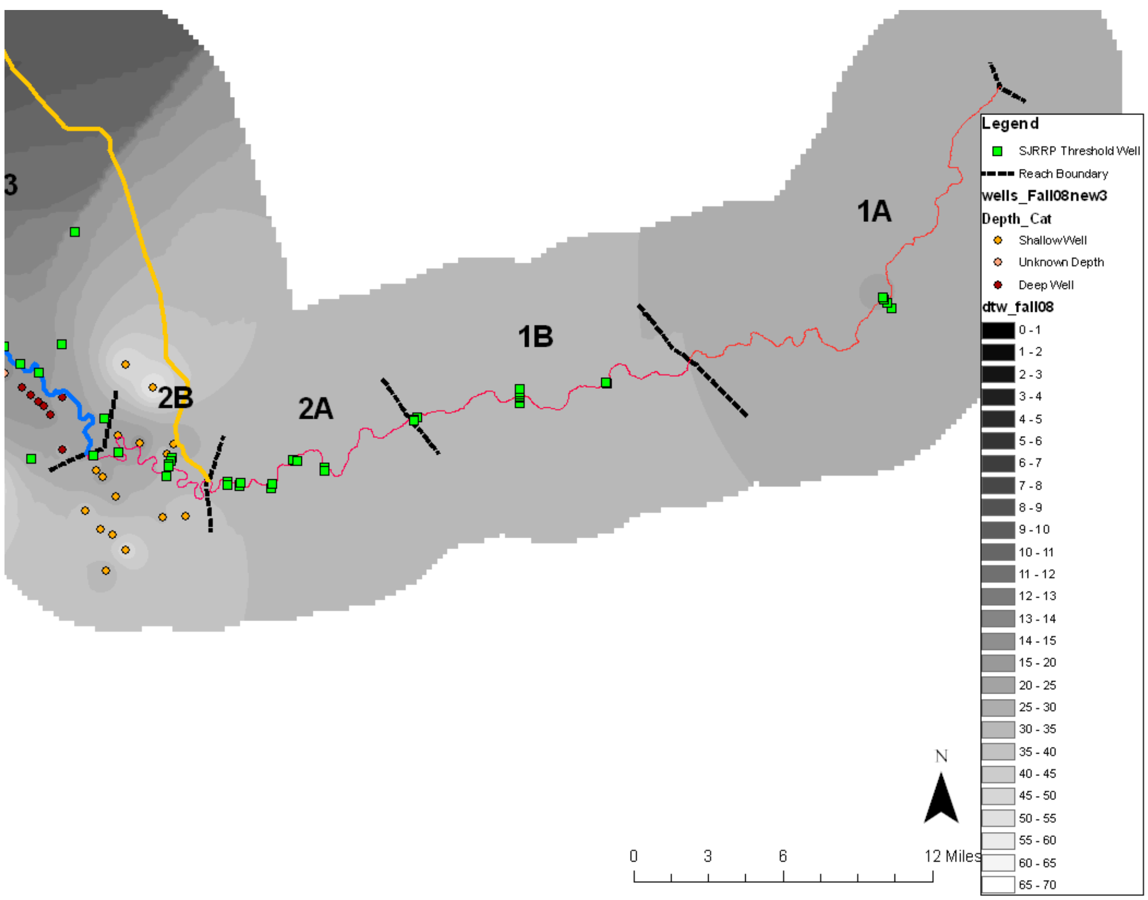

Figure 3-1
Fall 2008 Depth to Water in Reaches 1A through 2B

These maps contain deep water wells, which may often be representing a lower confined aquifer rather than the unconfined surface aquifer that influences groundwater levels. These wells include Mendota Pool Group production wells and other groundwater extraction wells. Because of this, low spots can be seen on the maps surrounding production wells. This can be seen especially well in Figure 3-6. These pumps do not run continuously and thus do not represent historical groundwater conditions at all times. When interpolated on depth to water maps with sparse data, these pumping centers affect groundwater levels very far away from the pumps. This, combined with the fact that they may represent a different aquifer, influences their effectiveness representing historical groundwater conditions. However, some deep water wells may accurately show water levels, especially those on the north and east sides of the San Joaquin Valley. To reduce the influence of deep water pumping on results, the minimum depth to water obtained at each well was chosen from these three maps.

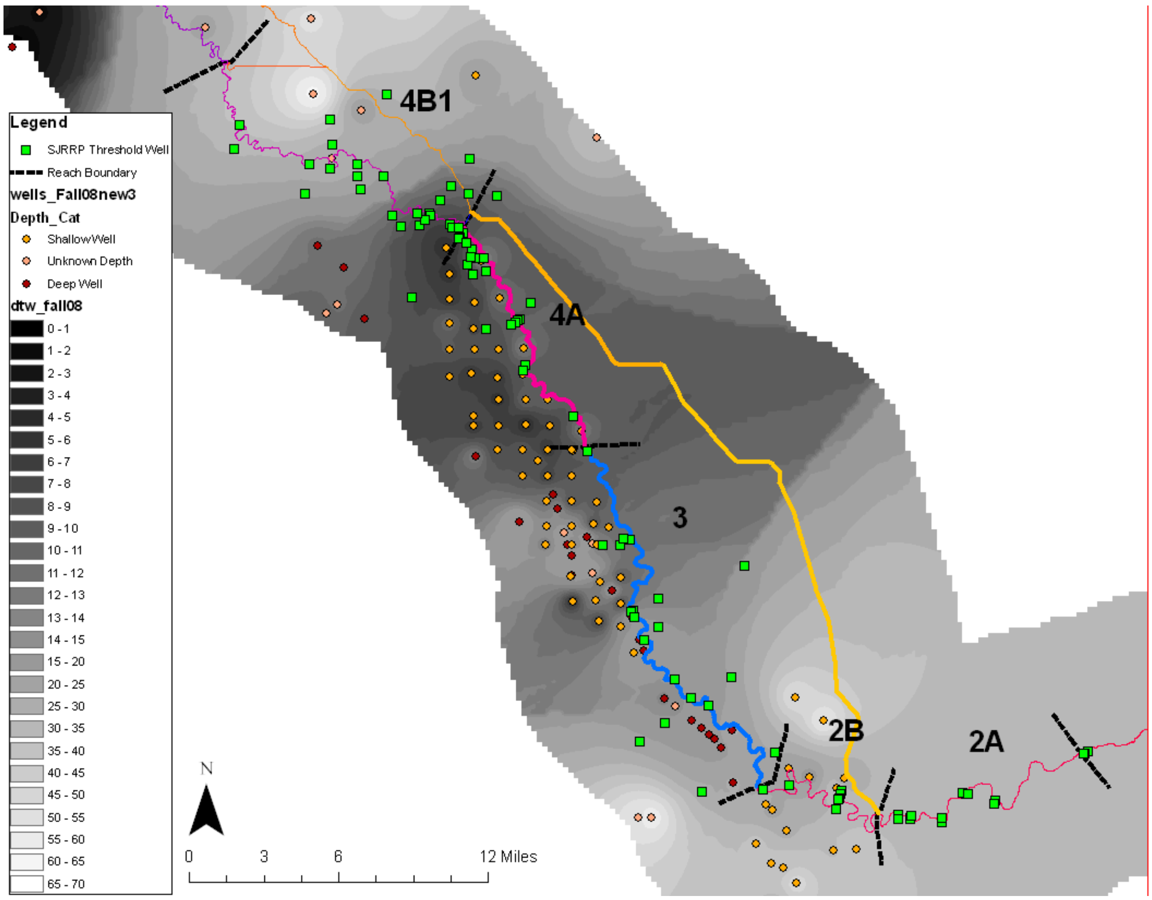

Figure 3-2
Fall 2008 Depth to Water in Reaches 2B through 4B1

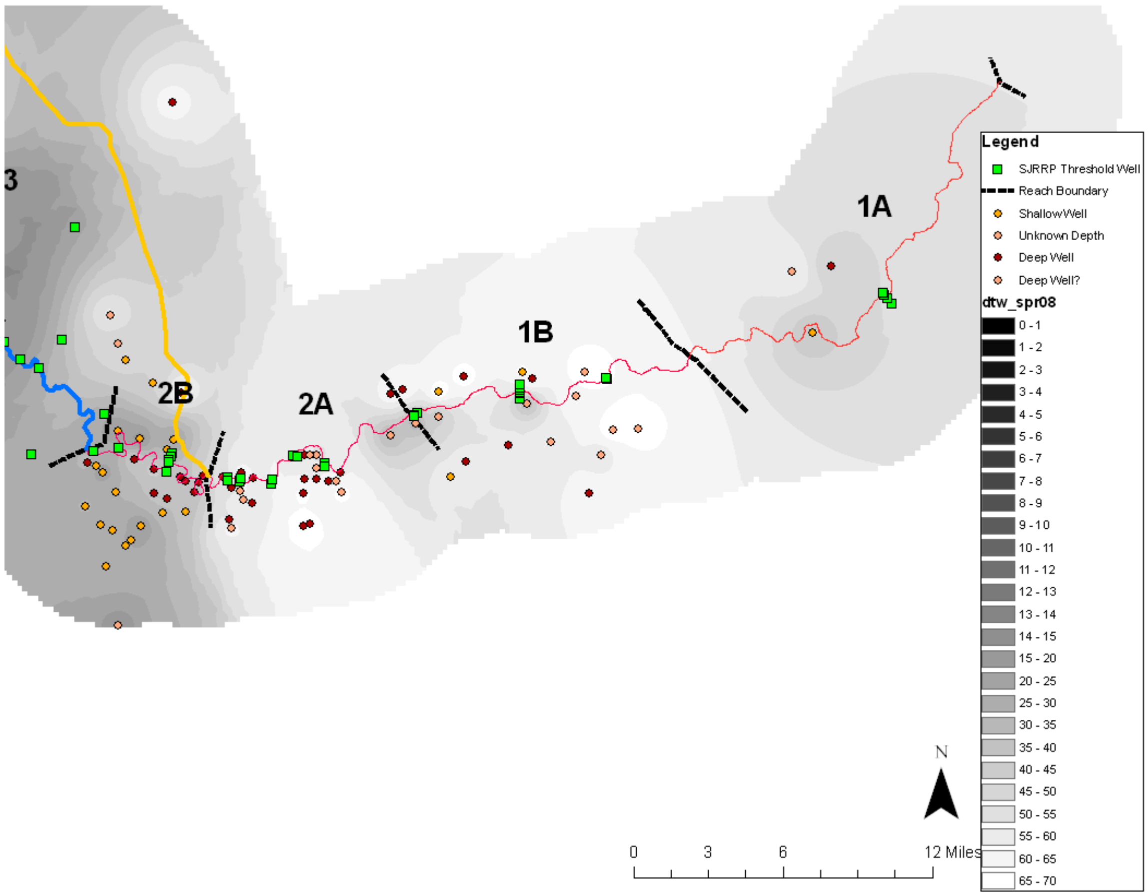

Figure 3-3
Spring 2008 Depth to Water in Reaches 1A through 2B

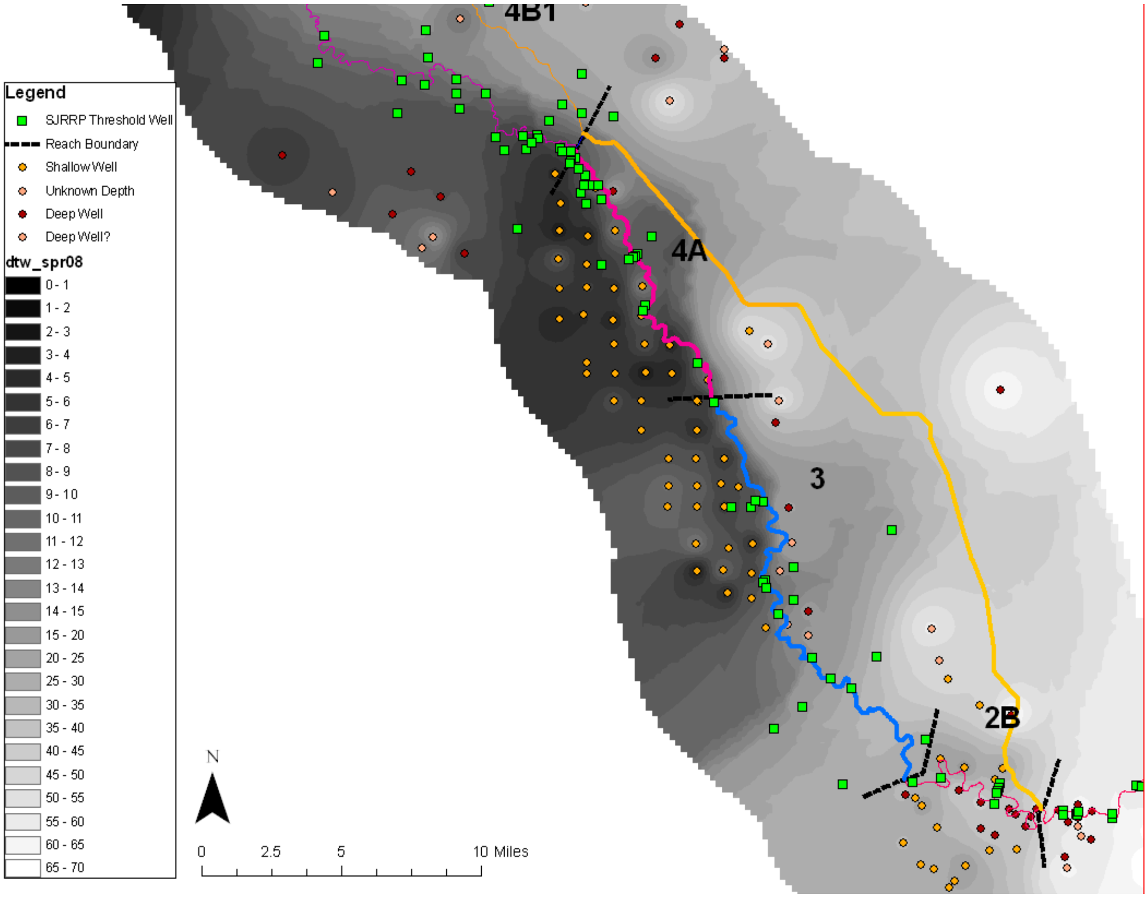

Figure 3-4
Spring 2008 Depth to Water in Reaches 2B through 4B1

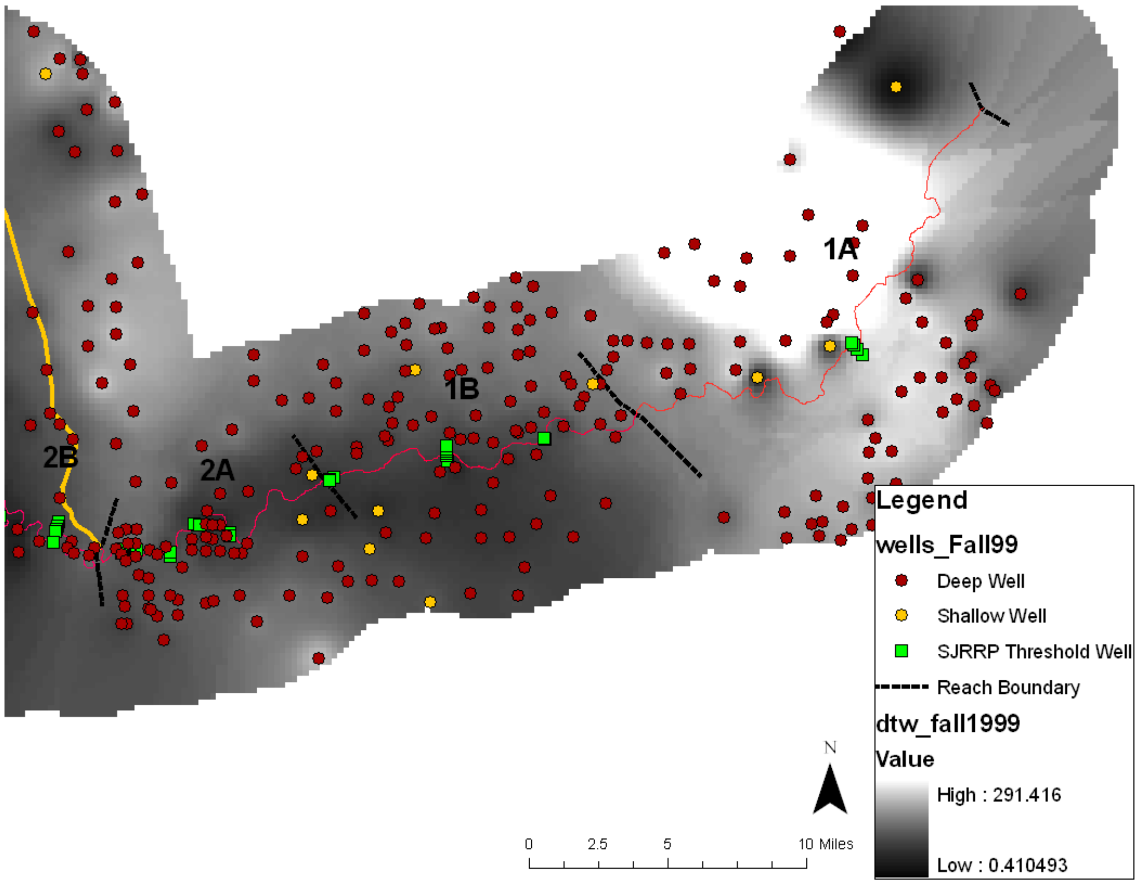

Figure 3-5
Fall 1999 Depth to Water in Reaches 1A through 2B

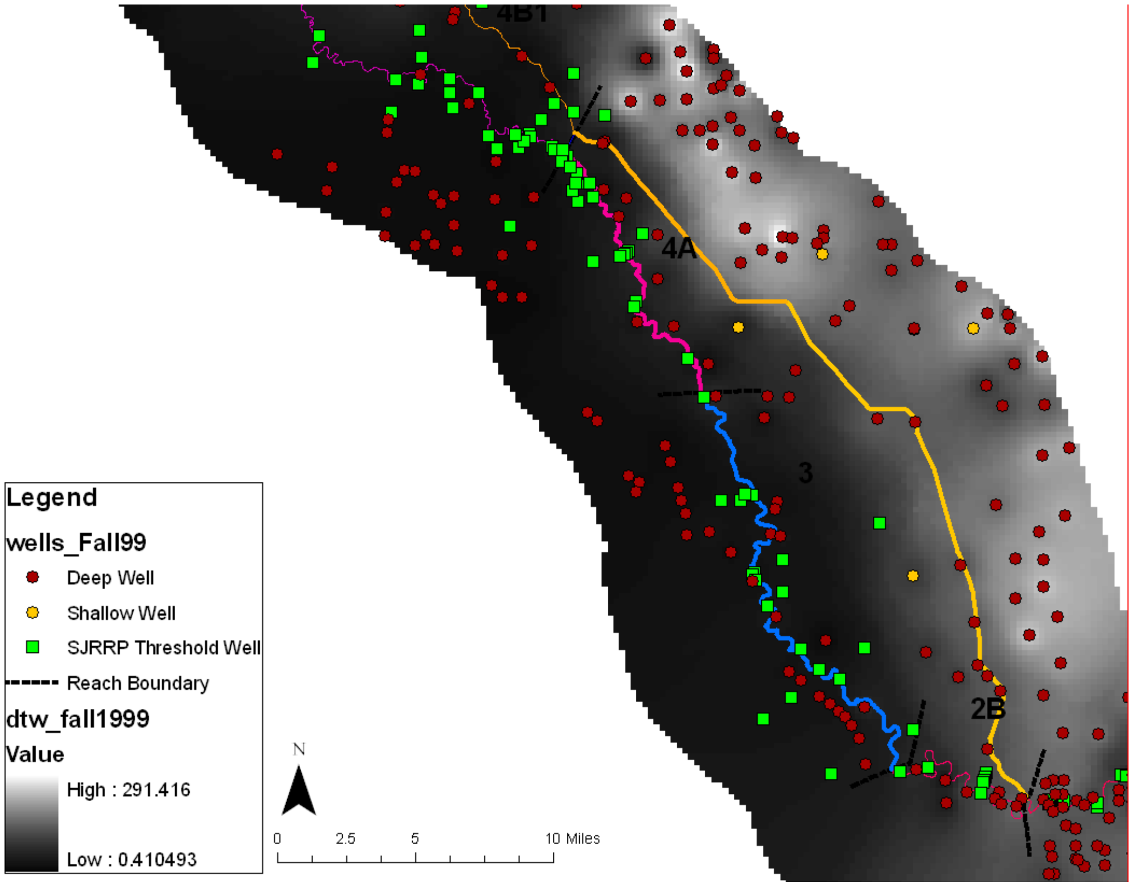

Figure 3-6.
Fall 1999 Depth to Water in Reaches 2B through 4B1

3.2.2 CCID Threshold Wells

The above approach does not fully utilize the CCID well data. Ground surface elevations are not always known for wells in the DWR database, and thus water level elevations are difficult to determine. However, CCID well data includes consistent records with ground surface elevation information available. CCID well data was used as a check on the above mapping approach. CCID well data was interpolated just in the reaches it applies to, providing localized average historic depth to groundwater. This approach also removes the potential influence of deep production wells.

The USGS previously created plots of the CCID well data. Many of these wells have records that look similar to Figure 3-7 below. Average values from the groundwater level records for these wells and wells similar to Figure 3-8 were used. The dotted line in these figures shows the average value chosen. Wells such as 144A (Figure 3-9) were not used in this analysis due to records that may show influences from pumping.

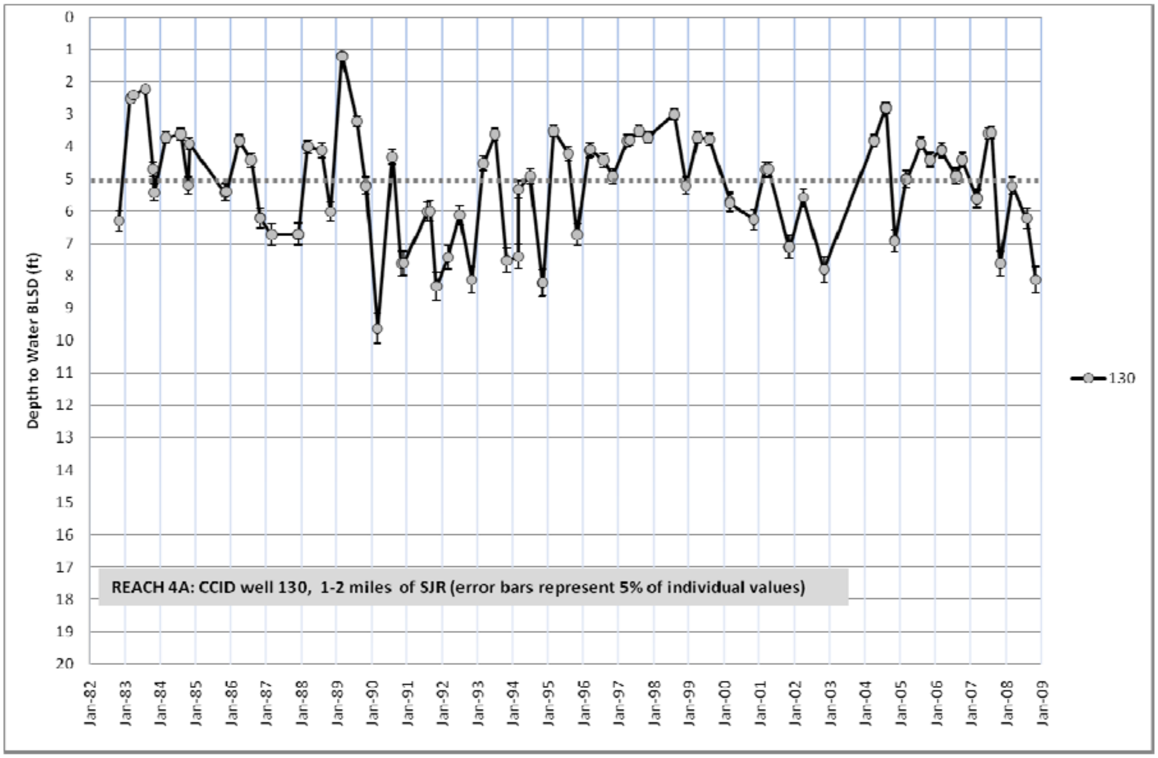

Figure 3-7
CCID Well 130

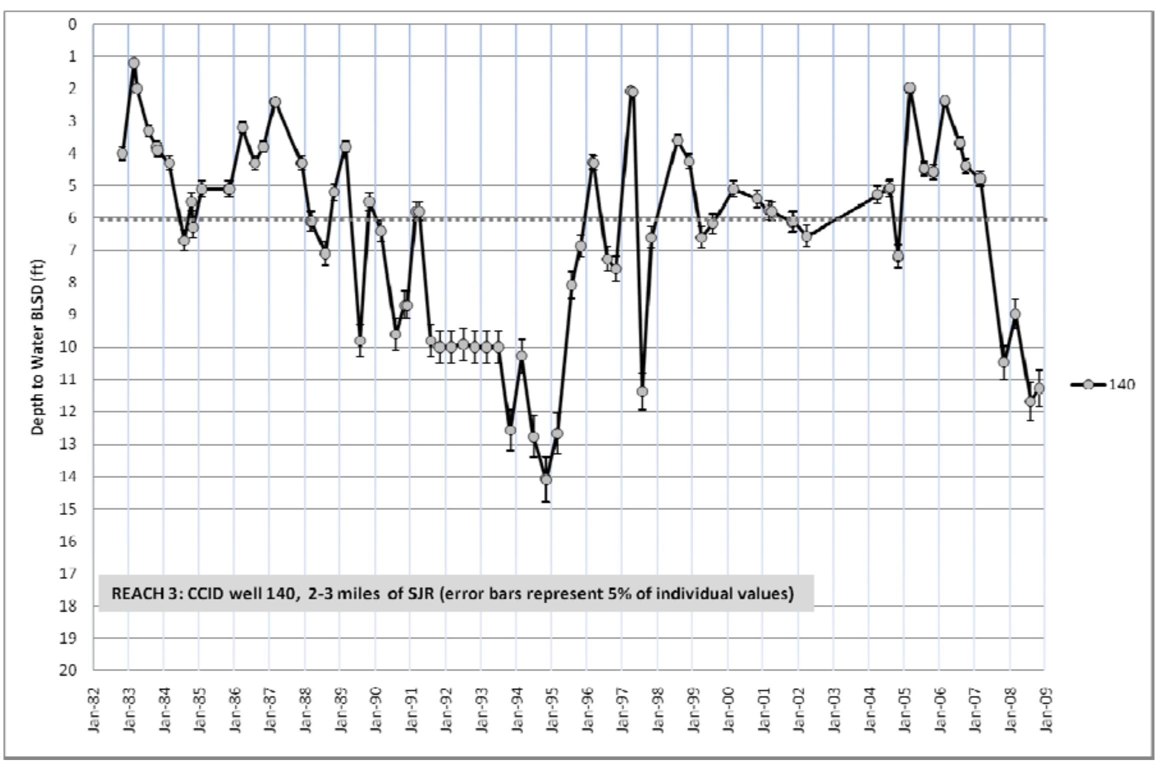

Figure 3-8
CCID Well 140

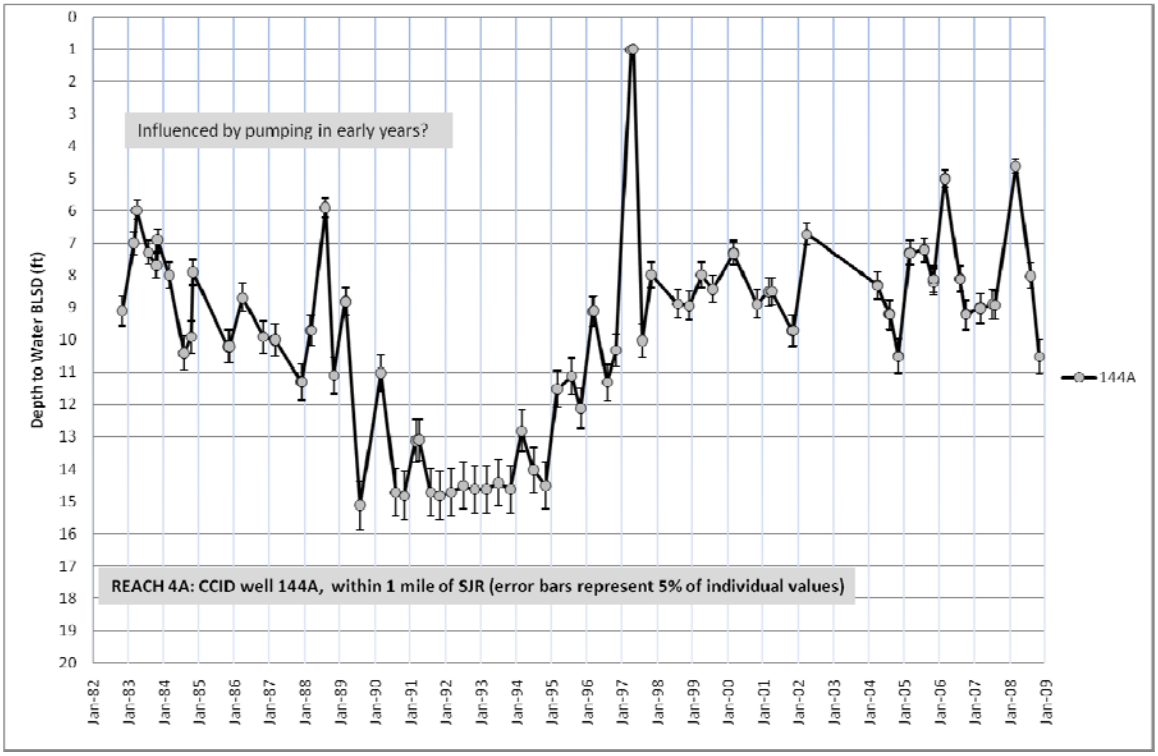

Figure 3-9
CCID Well 144A (Not Used in the Analysis)

As a first step, average groundwater levels below ground surface were converted to groundwater elevation using ground surface elevation of CCID wells and interpolated using IDW across Reaches 3 and 4A.

Figure 3-10 below shows the resultant water table elevation map. Green stars represent the subset of CCID wells with consistent data that the USGS created plots for. These represent data points used for interpolation. Thresholds were developed through this document for wells marked with a black square. An interpolated historical groundwater level based on CCID wells was chosen for SJRRP wells located on the colored interpolation surface in Figure 3-10. This ground surface elevation was converted back to depth to ground surface for each well. Converting to elevation and then back to depth to water below ground surface corrects for wells located on levee banks or otherwise at a different elevation.

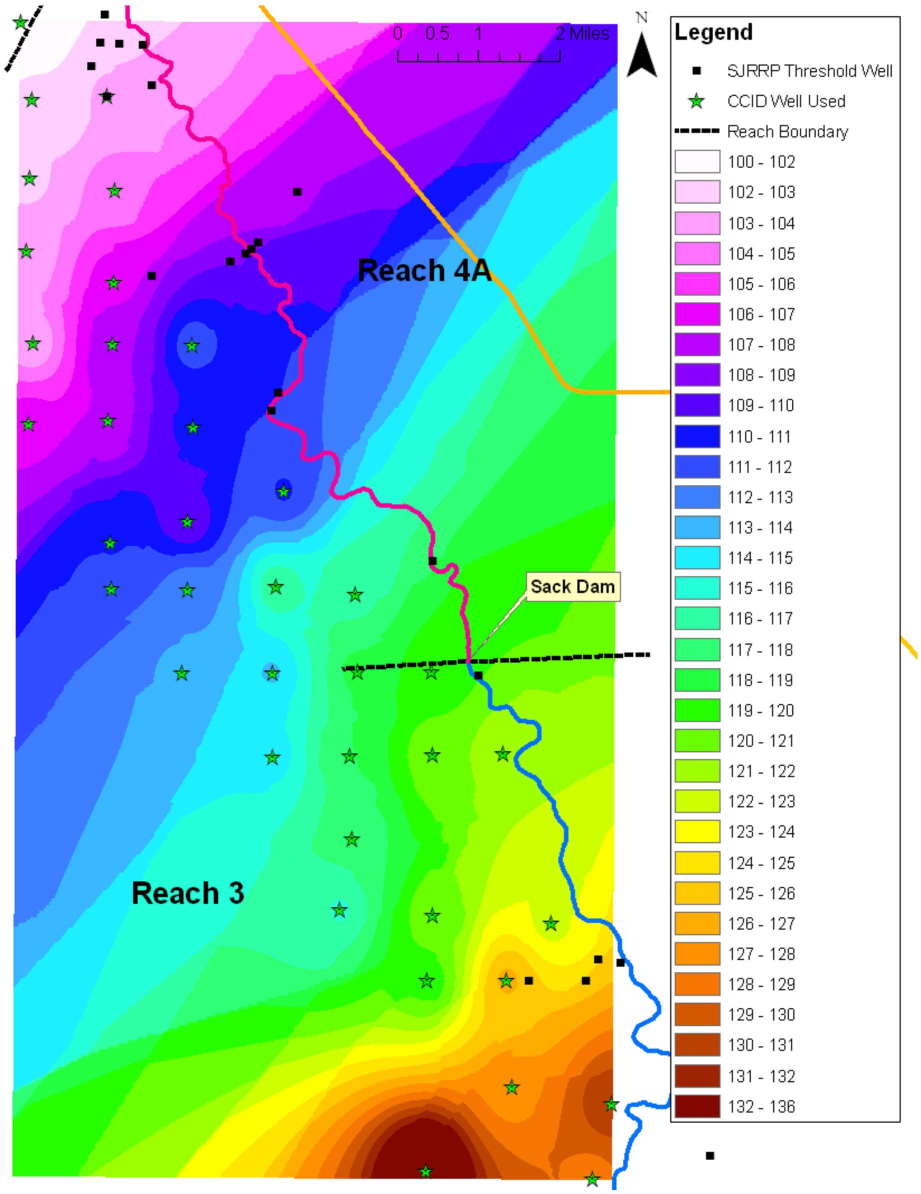

Figure 3-10
Map of Average Historical Water-Table Elevation in CCID wells

3.3 Results

Table 3-1 below shows historical groundwater level results of these analyses.

Table 3-1
Historical Groundwater Levels

Well ID	CCID Well Average Ground water Elevation (feet)	CCID Well Average Groundwater Depth (feet bgs)	Groundwater Depth Fall 1999 (feet bgs)	Groundwater Depth Spring 2008 (feet bgs)	Groundwater Depth Fall 2008 (feet bgs)	Historical Groundwater (feet bgs)
JR-1				50	50	
JR-2				50	50	
MW-09-1			112	51	51	
MW-09-2			101	51	51	
FA-1			48	44	44	
FA-2			46	36	36	
FA-3			46	36	36	
MA-1			46	36	36	
MW-09-21			45	48	45	
MW-09-22			47	54	47	
MW-09-23			50	54	50	
MW-09-23B			50	54	50	
MW-09-25			50	54	50	
MW-09-26			54	59	54	
MW-09-27			54	60	54	
R1-1			58	65	58	
R1-2			61	66	61	
FA-4			42	59	42	
FA-5			42	59	42	
FA-6			63	60	60	
FA-7			63	60	60	
FA-8			73	58	58	
FA-9			72	60	60	
MA-2			40	59	40	
MA-3			60	60	60	
MA-4			72	54	54	

Table 3-1
Historical Groundwater Levels (cont.)

Well ID	CCID Well Average Ground water Elevation (feet)	CCID Well Average Groundwater Depth (feet bgs)	Groundwater Depth Fall 1999 (feet bgs)	Groundwater Depth Spring 2008 (feet bgs)	Groundwater Depth Fall 2008 (feet bgs)	Historical Groundwater (feet bgs)
MW-09-36			49	56		
MW-09-37B			49	56		
MW-09-39B			34	59		
MW-09-47			72	60		
MW-09-49B			68	56		
MW-09-52			58	31	31	31
MW-09-53			59	33	34	33
MW-09-54B			59	33	33	33
MW-09-55B			60	33	32	32
MW-09-56			57	38	31	31
PZ-09-R2B-1			34	27	24	24
PZ-09-R2B-2			30	27	24	24
155	125.3	9		8	12	8
MW-10-117				24	16	16
MW-10-118			15	14	13	13
MW-10-119			15	13	15	13
MW-10-120				14	21	14
MW-10-121			15	16	16	15
MW-10-122				33	21	21
MW-10-123				29	27	27
MW-10-124				28	25	25
MW-10-74	125.6	10	13	11	12	10
MW-10-75	125.0	7		9	12	7
MW-10-76	125.3	5		7	13	5
MW-10-78	119.9	5	29	8	9	5
PZ-09-R3-1			12	10	14	10

Table 3-1
Historical Groundwater Levels (cont.)

Well ID	CCID Well Average Ground water Elevation (feet)	CCID Well Average Groundwater Depth (feet bgs)	Groundwater Depth Fall 1999 (feet bgs)	Groundwater Depth Spring 2008 (feet bgs)	Groundwater Depth Fall 2008 (feet bgs)	Historical Groundwater (feet bgs)
PZ-09-R3-2			12	10	14	10
PZ-09-R3-3			12	10	16	10
PZ-09-R3-4			17	12	17	12
PZ-09-R3-5			14	19	16	14
PZ-09-R3-6			13	15	15	13
PZ-09-R3-7			16	28	18	16
191	103.1	8	16	10	10	8
186A	103.1	5		6	8	5
MW-09-83	107.6	7	44	9	10	7
MW-09-83B	107.6	7		9	10	7
MW-09-84	108.3	8		9	10	8
MW-09-85	108.4	12		9	10	9
MW-09-85B	108.4	12		9	10	9
MW-09-86	108.4	13		9	10	9
MW-09-86B	108.4	13		9	10	9
MW-09-87	108.9	6		9	10	6
MW-09-87B	108.9	6		9	10	6
MW-09-88	107.6	4		6	8	4
MW-10-115				6	8	6
MW-10-116			55	22	11	11
MW-10-188	111.0	6	23	9	9	6
MW-10-80	117.6	7	18	9	9	7
MW-10-89	111.2	8	21	9	9	8
MW-10-91				8	8	8
MW-10-92				8	7	7
MW-10-93				7	7	7

Table 3-1
Historical Groundwater Levels (cont.)

Well ID	CCID Well Average Ground water Elevation (feet)	CCID Well Average Groundwater Depth (feet bgs)	Groundwater Depth Fall 1999 (feet bgs)	Groundwater Depth Spring 2008 (feet bgs)	Groundwater Depth Fall 2008 (feet bgs)	Historical Groundwater (feet bgs)
SJR W-10	102.8	4	18	11	13	4
SJR W-11	102.9	5	17	11	14	5
SJR W-12				9	10	9
SJR W-4				8	9	8
SJR W-5				8	7	7
SJR W-6				7	7	7
SJR W-7				9	7	7
SJR W-8	102.8	6		7	8	6
SJR W-9	102.5	3		9	9	3
MW-10-100			7	7	8	7
MW-10-102				14	36	14
MW-10-103			11	13	28	11
MW-10-105			7	10	28	7
MW-10-106			10	10	27	10
MW-10-107			7	9	21	7
MW-10-108			9	12	25	9
MW-10-109			8	11	22	8
MW-10-110				12	34	12
MW-10-111				10	30	10
MW-10-112			20	17	30	17
MW-10-113			8	11	20	8
MW-10-114			7	9	20	7
MW-10-90				15	11	11
MW-10-94			36	23	14	14
MW-10-95			13	15	11	11
MW-10-96				11	9	9

Table 3-1
Historical Groundwater Levels (cont.)

Well ID	CCID Well Average Ground water Elevation (feet)	CCID Well Average Groundwater Depth (feet bgs)	Groundwater Depth Fall 1999 (feet bgs)	Groundwater Depth Spring 2008 (feet bgs)	Groundwater Depth Fall 2008 (feet bgs)	Historical Groundwater (feet bgs)
MW-10-97				8	9	8
MW-10-98				8	8	8
MW-10-99				7	8	7
SJR W-1				7	10	7
SJR W-2			6	8	11	6
SJR W-3			6	7	9	6
MW-09-125				9	10	9

Key:
bgs =
CCID =

3.4 Limitations

- Depth to water mapping uses three seasonal maps with the greatest number well measurements to represent historical groundwater conditions.
- Depth to water mapping does not take into account elevation differences between wells and fields.
- Depth to water mapping includes deep production wells.
- CCID well interpolation simplifies years of data into one average.
- CCID well data only includes wells on one side of the river.

4.0 Threshold Results

Threshold results are presented in Table 4-1, with the results of each analysis.

Table 4-1
Thresholds for SJRRP Monitoring Wells

Well ID	Reach	Bank	Crop Type	Root Zone (feet)	Capillary Fringe (feet)	Ground Surface Buffer (feet)	Historical Groundwater (feet bgs)	Threshold (feet bgs)	Threshold Elevation (feet)
JR-1	1A	Left	Public Land	4	1.0	0.00[1]	50	5	
JR-2	1A	Left	Public Land	4	1.0	0.00[1]	50	5	
MW-09-1	1A	Right	Public Land	4	0.5	0.00[1]	51	5	266.2
MW-09-2	1A	Right	Public Land	4	0.5	0.00[1]	51	5	265.7
FA-1	1B	Left	Vineyard	4	1.0[1]	1.78	44	7	195.7
FA-2	1B	Left	Vineyard	4	1.0[1]	2.24	36	7	198.1
FA-3	1B	Left	Vineyard	4	1.0[1]	1.50	36	7	198.0
MA-1	1B	Left	Fallow	4	1.0[1]	1.72	36	7	199.9
MW-09-21	1B	Left	Public Land	4	1.0	5.75	45	11	215.8
MW-09-22	1B	Left	Public Land	4	1.0	3.37	47	8	214.4
MW-09-23	1B	Left	Public Land	4	0.5	-8.81	50	-4	214.9
MW-09-23B	1B	Left	Public Land	4	0.5	-8.81	50	-4	214.9
MW-09-25	1B	Right	Public Land	4	1.0	-9.58	50	-5	229.5
MW-09-26	1B	Right	Public Land	4	1.0	-5.88	54	-1	229.5
MW-09-27	1B	Right	Public Land	4	1.0	-6.67	54	-2	238.5
R1-1	1B	Right	Pomegranate	6	0.5[1]	1.55	58	8	2080.8
R1-2	1B	Right	Pomegranate	6	0.5	3.08	61	10	208.8
FA-4	2A	Left	River Channel	4	1.0[1]	-4.58	42	0	179.4
FA-5	2A	Left	River Channel	4	1.0[1]	-4.70	42	0	179.2
FA-6	2A	Left	River Channel	4	1.0[1]	4.80	60	10	168.6
FA-7	2A	Left	Almonds	6	1.0[1]	5.59	60	13	166.4
FA-8	2A	Left	River Channel	4	1.0[1]	1.74	58	7	166.0
FA-9	2A	Left	Alfalfa	4	1.0[1]	3.71	60	9	165.3
MA-2	2A	Right	Annual Crops	4	1.0[1]	2.87	40	8	174.8
MA-3	2A	Right	Annual Crops	4	1.0[1]	0.90	60	6	173.1

Table 4-1
Thresholds for SJRRP Monitoring Wells (cont.)

Well ID	Reach	Bank	Crop Type	Root Zone (feet)	Capillary Fringe (feet)	Ground Surface Buffer (feet)	Historical Groundwater (feet bgs)	Threshold (feet bgs)	Threshold Elevation (feet)
MA-4	2A	Right	Vineyard w Drains	4	1.0[1]	6.08	54	11	163.4
MW-09-36	2A	Right	Annual Crops	4	1.0	4.53	49	10	181.5
MW-09-37B	2A	Left	Vineyard	4	1.0	3.05	49	8	184.1
MW-09-39B	2A	Left	Almonds	6	0.5	0.48	34	7	177.9
MW-09-47	2A	Right	Vineyard w Drains	4	1.0	3.46	60	8	166.2
MW-09-49B	2A	Left	Annual Crops w Drains	4	0.5	1.66	56	6	164.7
MW-09-52	2B	Right	Almonds	6	1.0	0.94	31	8	154.2
MW-09-53	2B	Right	Almonds	6	1.0	1.35	33	8	154.4
MW-09-54B	2B	Right	Almonds	6	1.0	7.91	33	15	153.3
MW-09-55B	2B	Left	Palms	4	1.0	3.67	32	9	157.0
MW-09-56	2B	Left	Pistachios	4	1.0	1.73	31	7	154.5
PZ-09-R2B-1	2B	Right	Annual Crops	4	1.0	1.26	24	6	148.9
PZ-09-R2B-2	2B	Right	Annual Crops	4	0.5	3.88	24	8	144.8
155	3	Left	Almonds	6	1.0[1]	3.29	8	8	126.4
MW-10-117	3	Right		4[1]	1.0[1]	0.00[1]	16	5	
MW-10-118	3	Right		4[1]	1.0[1]	2.41	13	7	130.6
MW-10-119	3	Right		4[1]	1.0[1]	2.44	13	7	131.9
MW-10-120	3	Left		4[1]	1.0[1]	0.00[1]	14	5	
MW-10-121	3	Left		4[1]	1.0[1]	0.00[1]	15	5	
MW-10-122	3	Right		4[1]	1.0[1]	0.00[1]	21	5	
MW-10-123	3	Left		4[1]	1.0[1]	0.00[1]	27	5	

Table 4-1
Thresholds for SJRRP Monitoring Wells (cont.)

Well ID	Reach	Bank	Crop Type	Root Zone (feet)	Capillary Fringe (feet)	Ground Surface Buffer (feet)	Historical Groundwater (feet bgs)	Threshold (feet bgs)	Threshold Elevation (feet)
MW-10-124	3	Right		4[1]	1.0[1]	0.63	25	6	148.4
MW-10-74	3	Left	Almonds	6	0.5	4.23	10	10	125.6
MW-10-75	3	Left	Almonds	6	1.0	0.50	7	7	125.0
MW-10-76	3	Left	Annual Crops	4	1.0	2.74	5	5	125.3
MW-10-78	3	Right	Annual Crops	4	1.0	3.04	5	5	119.9
PZ-09-R3-1	3	Right		4[1]	0.5	4.06	10	9	128.6
PZ-09-R3-2	3	Right	Annual Crops	4	1.0	1.54	10	7	131.8
PZ-09-R3-3	3	Right	Annual Crops	4	1.0	4.34	10	9	131.7
PZ-09-R3-4	3	Right	Annual Crops	4	1.0	3.53	12	9	131.7
PZ-09-R3-5	3	Right	Annual Crops	4	1.0	1.15	14	6	134.2
PZ-09-R3-6	3	Right	Annual Crops	4	1.0	1.46	13	6	135.1
PZ-09-R3-7	3	Right	Annual Crops	4	0.5	0.74	16	5	138.8
191	4A	Left		4[1]	1.0[1]	2.85	8	8	103.1
186A	4A	Left		4[1]	1.0[1]	2.01	5	5	103.1
MW-09-83	4A	Right	Public Land	4	1.0	0.00[1]	7	5	109.8
MW-09-83B	4A	Right	Public Land	4	1.0	0.00[1]	7	5	110.0
MW-09-84	4A	Right	Public Land	4	1.0	3.42	8	8	108.3
MW-09-85	4A	Right	Public Land	4	1.0	7.12	9	9	111.8
MW-09-85B	4A	Right	Public Land	4	1.0	6.92	9	9	111.8
MW-09-86	4A	Left	Public Land	4	1.0	8.02	9	9	112.3
MW-09-86B	4A	Left	Public Land	4	1.0	7.90	9	9	112.2
MW-09-87	4A	Left	Public Land	4	0.5	1.96	6	6	108.9
MW-09-87B	4A	Left	Public Land	4	0.5	1.86	6	6	108.9
MW-09-88	4A	Left	Public Land	4	1.0	2.17	4	4	107.6
MW-10-115	4A	Left		4[1]	1.0[1]	0.00[1]	6	5	
MW-10-116	4A	Right		4[1]	1.0[1]	0.00[1]	11	5	

Table 4-1
Thresholds for SJRRP Monitoring Wells (cont.)

Well ID	Reach	Bank	Crop Type	Root Zone (feet)	Capillary Fringe (feet)	Ground Surface Buffer (feet)	Historical Groundwater (feet bgs)	Threshold (feet bgs)	Threshold Elevation (feet)
MW-10-188	4A	Left	Annual Crops	4	1.0	2.07	6	6	111.0
MW-10-80	4A	Right	Annual Crops	4	1.0	5.13	7	7	117.6
MW-10-89	4A	Right	Almonds	6	0.5	3.44	8	8	111.2
MW-10-91	4A	Left	Tomatoes	3	1.0	3.67	8	8	99.7
MW-10-92	4A	Left	Tomatoes	3	1.0	2.58	7	7	99.4
MW-10-93	4A	Left	Tomatoes	3	1.0	2.21	7	6	99.2
SJR W-10	4A	Left	Tomatoes	3	1.0[1]	1.84	4	4	102.8
SJR W-11	4A	Left	Tomatoes	3	1.0[1]	1.83	5	5	102.9
SJR W-12	4A	Left	Tomatoes	3	1.0[1]	2.14	9	6	100.1
SJR W-4	4A	Left	Corn	3	1.0[1]	1.14	8	5	101.2
SJR W-5	4A	Left	Tomatoes	3	1.0[1]	1.89	7	6	97.5
SJR W-6	4A	Left	Tomatoes	3	1.0[1]	4.38	7	7	98.9
SJR W-7	4A	Left	Tomatoes	3	1.0[1]	4.00	7	7	99.8
SJR W-8	4A	Left	Alfalfa	4	1.0[1]	3.35	6	6	102.8
SJR W-9	4A	Left	Tomatoes	3	1.0[1]	1.09	3	3	102.5
MW-10-100	4B1	Left	Annual Crops	4	1.0	4.55	7	7	96.2
MW-10-102	4B1	Right	Annual Crops	4	1.0	2.36	14	7	88.3
MW-10-103	4B1	Right	Annual Crops	4	1.0	4.61	11	10	89.5
MW-10-105	4B1	Left		4[1]	1.0	1.44	7	6	90.3
MW-10-106	4B1	Left		4[1]	1.0[1]	1.96	10	7	88.1
MW-10-107	4B1	Left		4[1]	1.0	2.68	7	7	89.1
MW-10-108	4B1	Left		4[1]	1.0[1]	1.72	9	7	89.8
MW-10-109	4B1	Left		4[1]	1.0[1]	1.55	8	7	91.5
MW-10-110	4B1	Left		4[1]	1.0[1]	1.82	12	7	82.0
MW-10-111	4B1	Left		4[1]	1.0[1]	1.76	10	7	83.9
MW-10-112	4B1	Right		4[1]	1.0[1]	0.00[1]	17	5	

Table 4-1
Thresholds for SJRRP Monitoring Wells (cont.)

Well ID	Reach	Bank	Crop Type	Root Zone (feet)	Capillary Fringe (feet)	Ground Surface Buffer (feet)	Historical Groundwater (feet bgs)	Threshold (feet bgs)	Threshold Elevation (feet)
MW-10-113	4B1	Left		4[1]	1.0[1]	4.45	8	8	91.8
MW-10-114	4B1	Left		4[1]	1.0[1]	1.92	7	7	92.0
MW-10-90	4B1	Right	Pistachios	4	1.0	4.67	11	10	91.6
MW-10-94	4B1	Right	Pistachios	4	1.0	0.00[1]	14	5	96.6
MW-10-95	4B1	Right	Alfalfa	4	1.0	2.21	11	7	91.8
MW-10-96	4B1	Right	Alfalfa	4	1.0	2.03	9	7	93.4
MW-10-97	4B1	Right	Annual Crops	4	0.5	3.43	8	8	93.3
MW-10-98	4B1	Left	Annual Crops	4	1.0	4.04	8	8	94.2
MW-10-99	4B1	Left	Annual Crops	4	1.0	4.70	7	7	97.7
SJR W-1	4B1	Left		4[1]	1.0[1]	1.78	7	7	93.4
SJR W-2	4B1	Left		4[1]	1.0[1]	4.22	6	6	97.0
SJR W-3	4B1	Left		4[1]	1.0[1]	3.79	6	6	97.0
MW-09-125	5	Right	Alfalfa	4	1.0	0.00[1]	9	5	69.4

Note:
[1] Assumed Value

Key:
bgs =

- Three CCID wells are measured frequently by Reclamation. Thresholds for these wells were developed. All other CCID wells are not measured by Reclamation and thus no thresholds have been developed for the rest of the CCID wells.
- Several SJRRP monitoring wells are deeper wells, intended to monitor groundwater flow across a transect rather than shallow groundwater seepage. Thresholds were not developed for these wells.
- A negative threshold indicates the well is in the river channel and thereby does not monitor groundwater levels up to the threshold below the adjacent field.
- Wells without a threshold elevation have not yet been surveyed and were outside of the LiDAR survey range. Thus, the ground surface elevation for these wells is unknown.
- Thresholds will continue to be revised as additional monitoring and data collection results in modification to assumptions.

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5.0 Validation of Thresholds

The following sources were used to validate the chosen thresholds, and to determine if they are conservative or non-conservative.

5.1 Reclamation Drainage Manual

The Reclamation Drainage Manual was first printed in 1978 and revised in 1993. The drainage manual states: “All the methods and techniques covered in the manual have proven to be very satisfactory through observed field conditions on irrigated lands throughout the world. Some methods have a more elegant development and basis in science than others, but all have been designed to solve practical problems in the field. The manual contains techniques developed over the last 50 years by personnel in the Bureau of Reclamation.”

According to the Drainage manual, a depth-to-water table of 3 to 5 feet is generally satisfactory, depending on local conditions including type of crops grown (Reclamation, 1993; pg 132). Many thresholds established above are deeper than 3 to 5 feet, indicating thresholds may be conservative in terms of depth.

5.2 2010 Monitoring Data

Monitoring data at groundwater transects during the 2010 Interim Flows shows the horizontal groundwater gradient away from the river (Figure 5-1). This third method addresses drainage. As is shown by this data, the groundwater surface is not flat as assumed in idealized threshold method ground surface buffer section above.

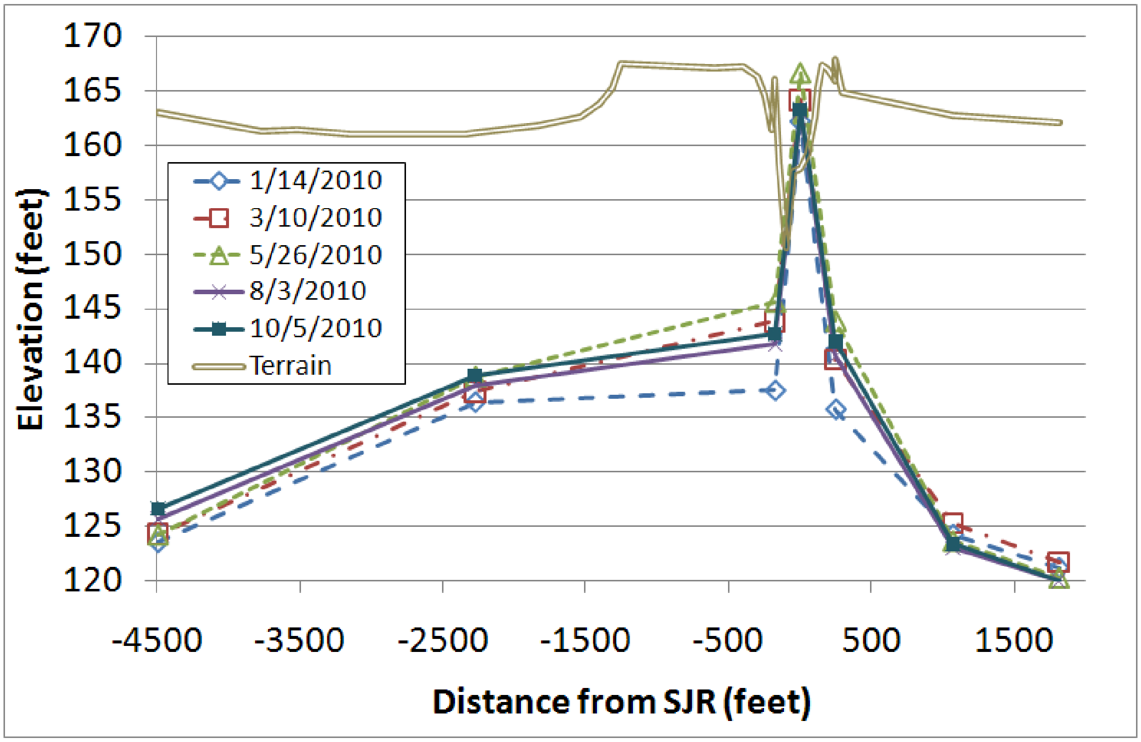

Figure 5-1
San Mateo Avenue Cross-section (MW-09-52 through MW-09-57)

Baseline groundwater levels in Reach 2B appear to be around an elevation of 125 feet (approximately 40 feet below ground surface). A threshold below this would indicate it is too conservative. The chosen threshold is above these levels.

Baseline groundwater levels at the end of Reach 4A appear to be around an elevation of 98 feet (approximately 7 to 9 feet below ground surface). A threshold below this would indicate it is too conservative. The chosen thresholds in these wells are 8, 7, and 6 feet below the ground surface respectively. This is just above the equilibrium water table as monitored in 2010 and shown in Figure 5-2.

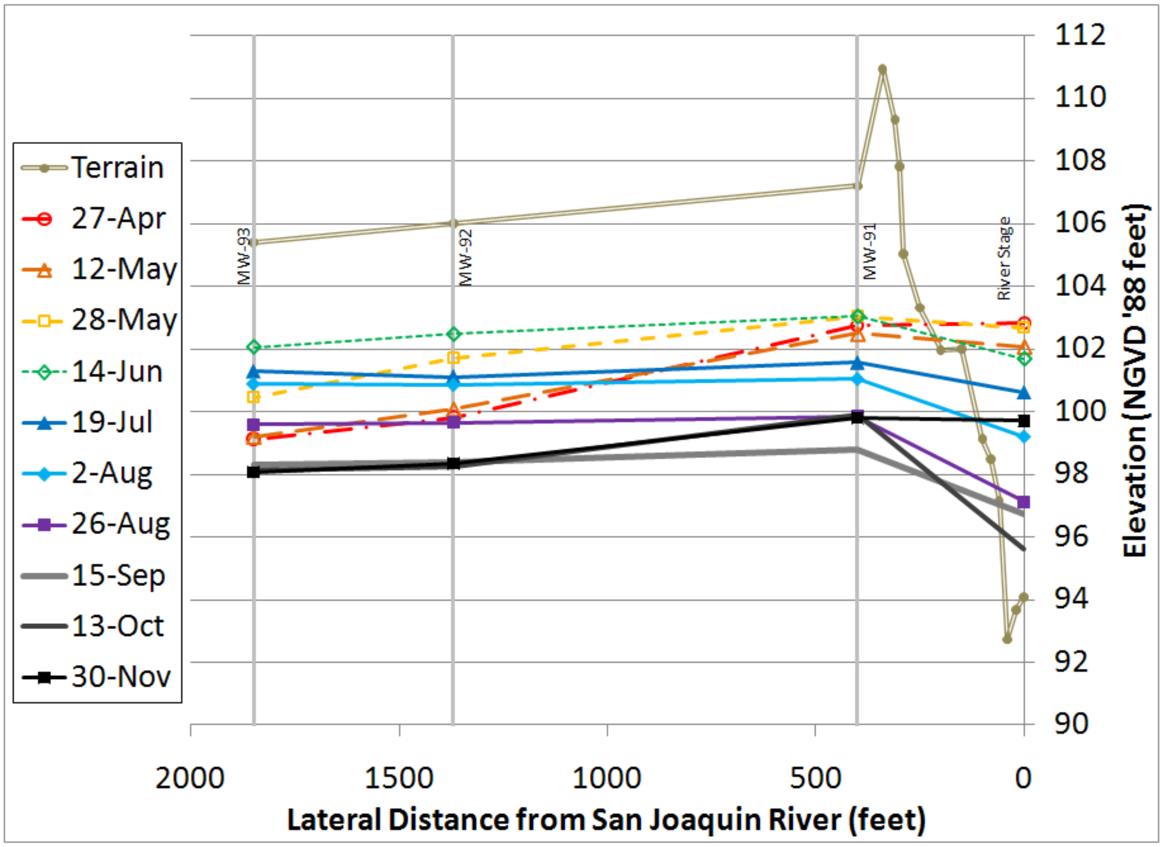

Figure 5-2

Nickel Family Farms Cross-section (MW-10-91, MW-10-92, and MW-10-93)

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6.0 References

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