Appendix C. Areas Potentially Vulnerable to Seepage Effects

This appendix provides an initial estimate of areas vulnerable to seepage effects associated with implementation of Restoration Flows on the basis of historical groundwater levels, anecdotal accounts, and other information. It also includes priority seepage parcel groups for implementation of seepage projects. Additional data used in these analyses are documented in Appendix B. This document focuses on the 150-mile portion of the San Joaquin River between Friant Dam and the confluence with the Merced River.

C.1 Historical Depth to the Water Table

The history of hydrologic and associated groundwater table changes in and around the Restoration Area helps define areas potentially vulnerable to seepage effects. Agricultural development began in the late 1800s, but accelerated rapidly post-World War II (Bertoldi and others, 1991). Through the 1960s, most of the water used for irrigation in areas surrounding the Exchange Contractors was groundwater. This use was reflected in a long-term decline of groundwater levels throughout most of the San Joaquin Valley (Belitz and Heimes, 1987).

Although groundwater levels declined over much of the valley, some areas near the San Joaquin River, particularly on the west side, continued to be shallow groundwater areas (Reclamation, 1962). Causes of this shallow groundwater may include fine-grained soils in the shallow subsurface and the primary use of surface water for irrigation in these areas. Landowners in this area had access to riparian water from the San Joaquin River before Friant Dam was constructed. In exchange for the loss of this source of irrigation water, Reclamation delivered surface water from the Sacramento-San Joaquin Delta via the Delta-Mendota Canal (DMC) to the San Joaquin River Water Authority Exchange Contractors, including the Central California Irrigation District (CCID), San Luis Canal Company (SLCC), and Columbia Canal Company (CCC) starting in 1951. Agricultural tile drains were installed in the 1950s and 1960s to help manage many of these areas (Joseph McGahan, Summers Engineering, written communication, 2002; Stuart Styles, Irrigation Training and Research Center, written communication, 2002)).

Available water level data prior to the 1980s is insufficient for mapping of depth to the groundwater table below land surface (DTW), but data from shallow wells during the 1960s indicate large areas where the DTW was less than 10 feet. These areas were predominantly west of the San Joaquin River.

Following is a series of DTW maps from 1981 through 2009, a subset of those presented in Appendix B, with accompanying descriptions of the associated hydrologic conditions.

Substantial deliveries of surface water to the area west of the SJRRP study area began during the early 1970s with the completion of the California Aqueduct. Accompanied by a large decrease in groundwater pumping, this caused a dramatic recovery of water levels over much of the west side of the valley (Belitz and Heimes, 1991). Due to sparse data availability, it is not clear if this recovery to the west had a significant effect on shallow water levels within the SJRRP study area. Water levels on the east side, however, continued to decline and by 1981 were much lower than on the west side (Figure C-1). 1981 was a normal precipitation year preceded by two normal years. Notably, the shallowest groundwater areas in 1981 are primarily directly below and west of the river, with the exception of areas east of the river in Reaches 4 and 5.

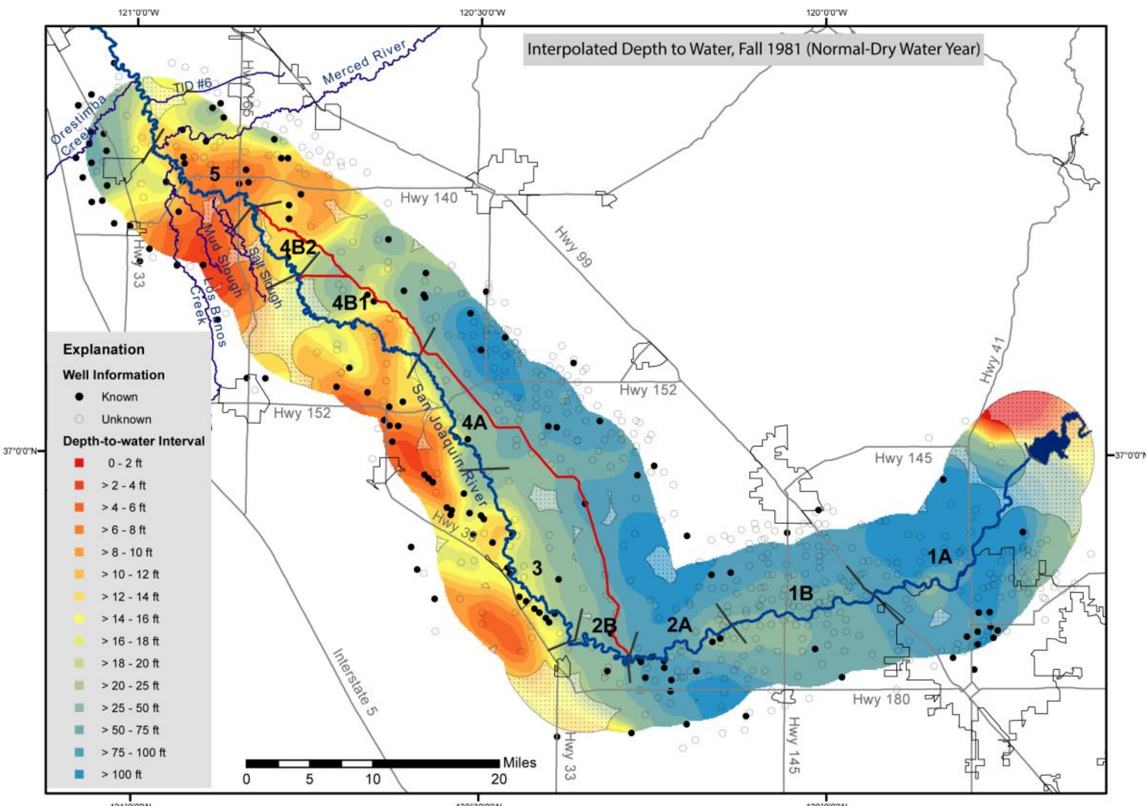


Figure C-1. Interpolated Depth to Water Table Map for Fall 1981 (Normal-Dry Water Year)

Note: Stippled areas are not within two miles of a well; interpolated values in these areas should be considered relatively poorly constrained.

Following 1981, two years of above-normal precipitation caused substantial increases in the groundwater table over most of the study area. Figure C-2 shows DTW in 1983, which indicates recovery of groundwater levels along the eastern margin of the study area towards Chowchilla and Madera, and considerable growth in the shallow groundwater areas along the west side and parts of the east side along the river and to the north.

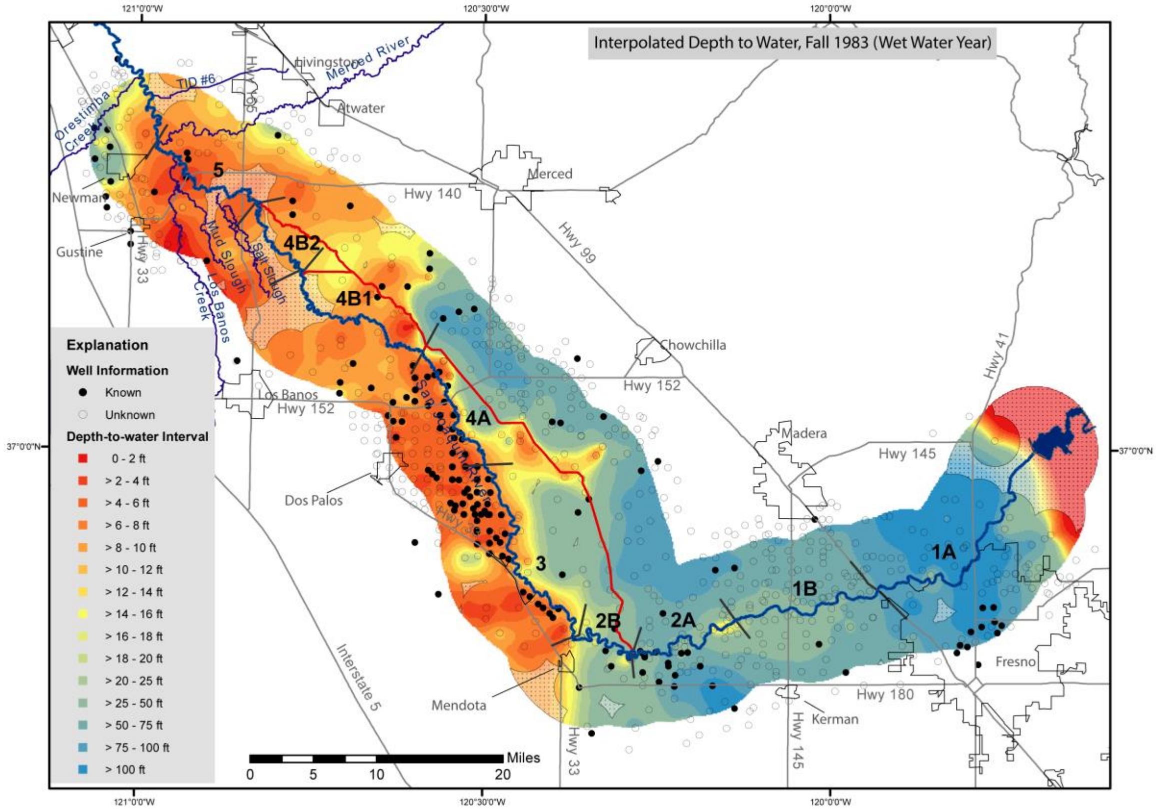


Figure C-2. Interpolated Depth to Water Table Map for Fall 1983 (Wet Water Year)

Note: Stippled areas are not within two miles of a well; interpolated values in these areas should be considered relatively poorly constrained.

Several years of normal to dry-normal precipitation followed 1983. By 1988 (dry), groundwater levels along the eastern margin of the study area had declined, and the area of shallow groundwater had retreated westward; however, the shallow groundwater area remained widespread on the west side (Figure C-3).

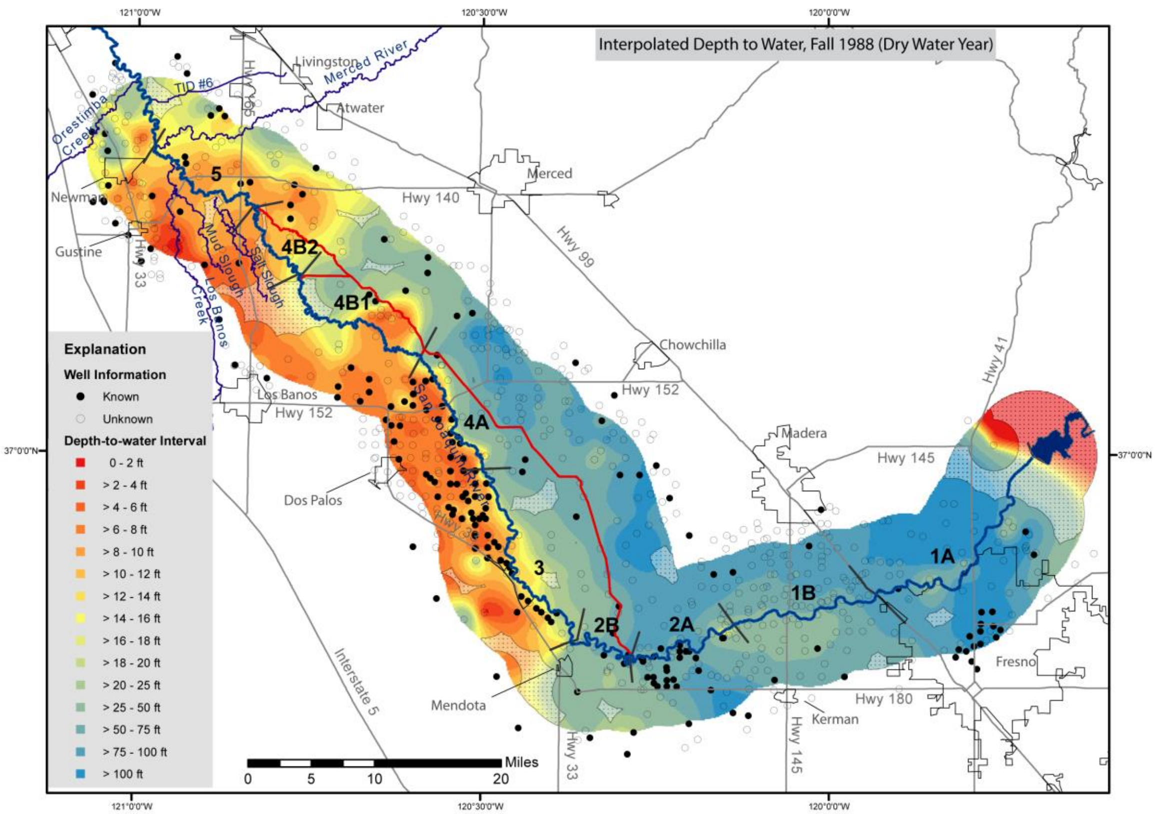


Figure C-3. Interpolated Depth to Water Table Map for Fall 1988 (Dry Water Year)

Note: Stippled areas are not within two miles of a well; interpolated values in these areas should be considered relatively poorly constrained

Data from 1991, the fifth year of a six-year drought, show a change in groundwater levels in response to the combination of reduced availability of surface water, increased groundwater pumping, and reduced recharge from precipitation. Figure C-4 shows that by 1991, groundwater levels had declined substantially along the eastern margin of the study area, and the areas of shallow groundwater had retreated compared to those prior to the drought.

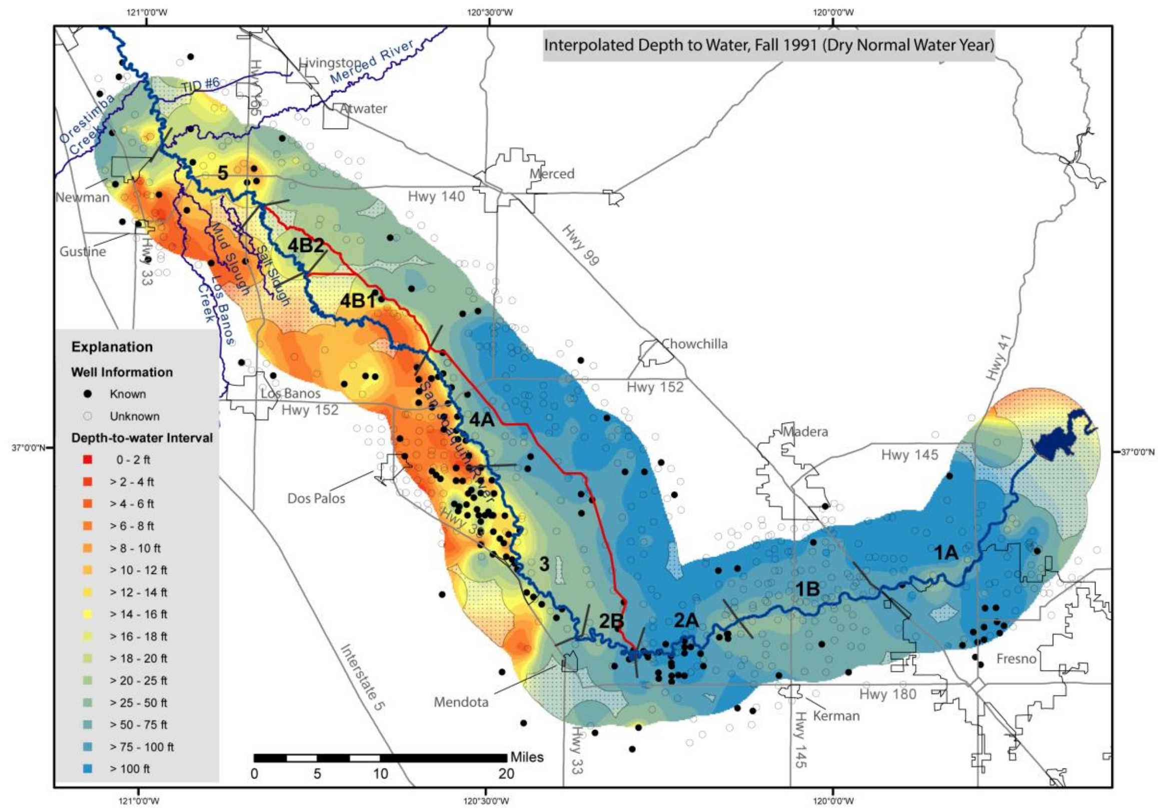


Figure C-4. Interpolated Depth to Water Table Map for Fall 1991 (Normal-Dry Water Year)

Note: Stippled areas are not within two miles of a well; interpolated values in these areas should be considered relatively poorly constrained

Figure C-5 shows DTW in 2006, a wet water year preceded by several normal years. Although groundwater levels along the eastern margin had remained low, the shallow groundwater areas west of the river and east of the river to the north were fully re-established.

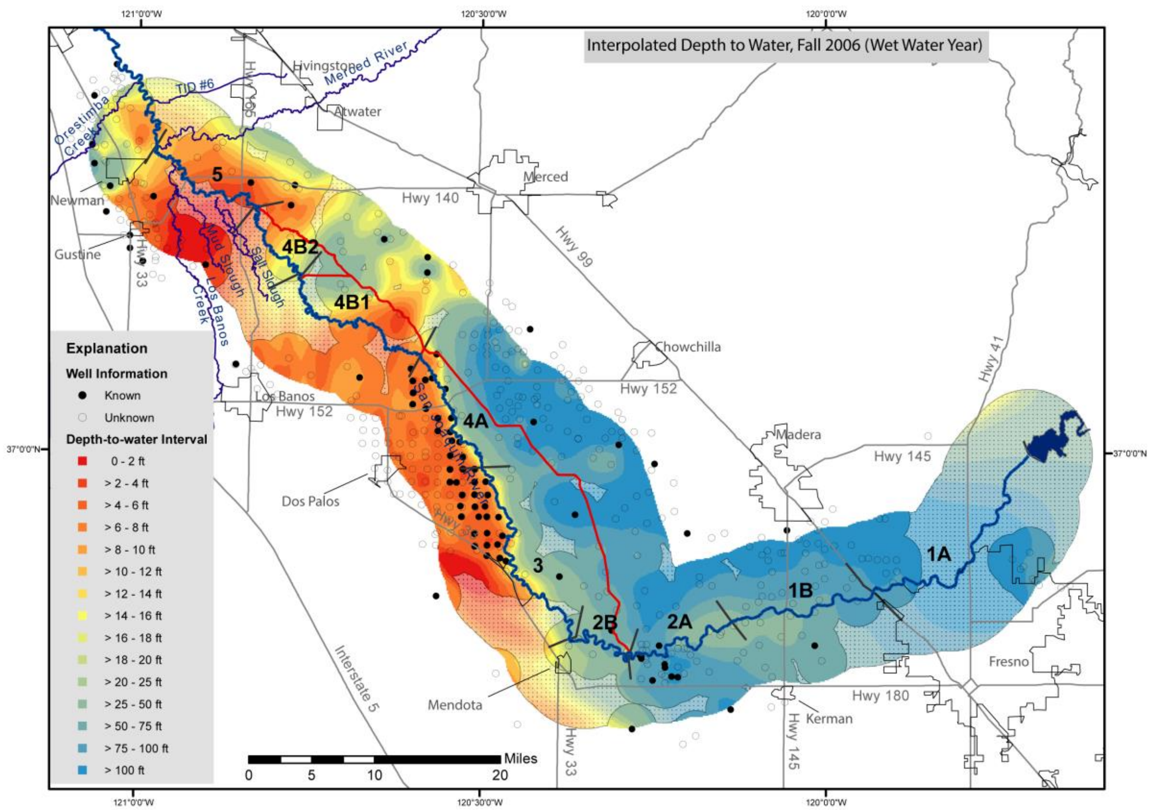


Figure C-5. Interpolated Depth to Water Table Map for Fall 2006 (Wet Water Year)

Note: Stippled areas are not within two miles of a well; interpolated values in these areas should be considered relatively poorly constrained

This brief historical review shows that there are shallow groundwater areas, particularly west of the San Joaquin River, and east of the river along Reaches 4 and 5, that have persisted through time with the exception of during drought conditions. Persistent shallow groundwater areas shown to be within the hydraulic influence of the San Joaquin River are potentially vulnerable to seepage effects from Restoration Flows.

The historic response of shallow groundwater areas to drought and other dry climatic conditions indicates that the shallow groundwater table is sensitive to reduced surface-water availability and associated groundwater pumping on both sides of the river, which is consistent with previous findings (Phillips and others, 1991; Belitz and others, 1993; Belitz and Phillips, 1994; K.D. Schmidt & Associates, reported in the McBain and Trush, Inc. Background Report, 2002, p. 4–26). This sensitivity has implications for year-to-year operations of the SJRRP and for groundwater pumping as a potential future response action.

C.2 Anecdotal Information

Stakeholders have identified agricultural land that they feel is currently vulnerable to seepage effects. These effects range from groundwater table rise that is currently manageable through the use of drainage wells, tile drains or other means, to seepage-related inundation causing crop damage or loss. Identification of these areas is important for the monitoring SJRRP program because these areas are known to be highly sensitive to river stage and associated seepage effects. Therefore, these areas may be useful locations for monitoring wells and associated monitoring thresholds used to avoid or minimize seepage impacts.

The vast majority of the landowner-identified agricultural land that is currently vulnerable to seepage effects is in two physical settings expected to be sensitive to high-stage events. The first setting is the interior of a river meander, or bend, where the land is surrounded on three sides by the river. The second is lands situated between two waterways, including the river, bypasses, and unlined canals.

In addition to vulnerable locations identified by landowners, the San Joaquin River Resources Management Coalition (RMC) mailed surveys to their members and provided the SJRRP with parcels that could be of concern regarding seepage impacts. The parcels identified by the RMC are generally large areas of land, some of them a mile or more from the San Joaquin River or bypass system.

Finally, at Seepage and Conveyance Technical Feedback Group (SCTFG) meetings in December 2010 and February 2011, irrigation district and canal company staff identified areas potentially vulnerable to seepage impacts as well as data gaps in the existing monitoring well network. Some of these areas overlap with previously identified vulnerabilities, and some are broad areas identified as data gaps in the monitoring well network (for example, the large area in Reach 4B1).

Figure C-6 through Figure C-11 show stakeholder-identified locations of concern.

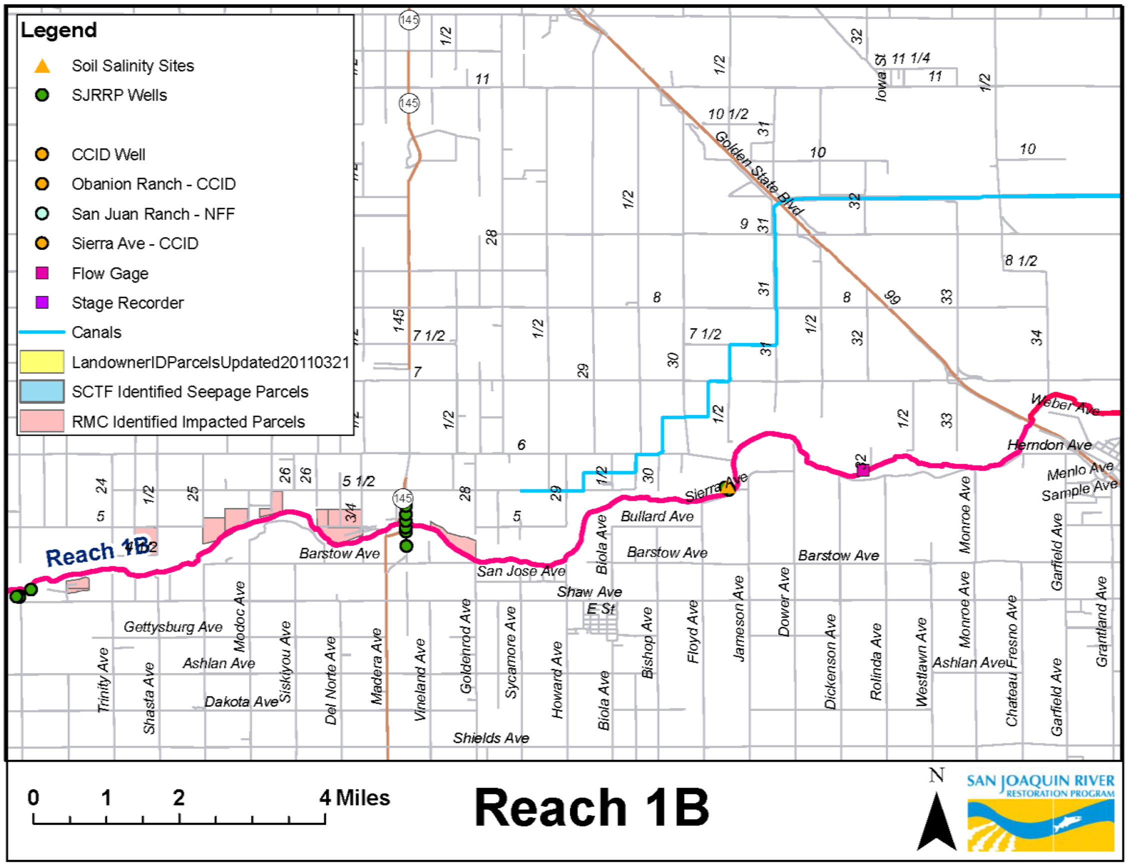


Figure C-6. Reach 1B Locations of Identified Risk

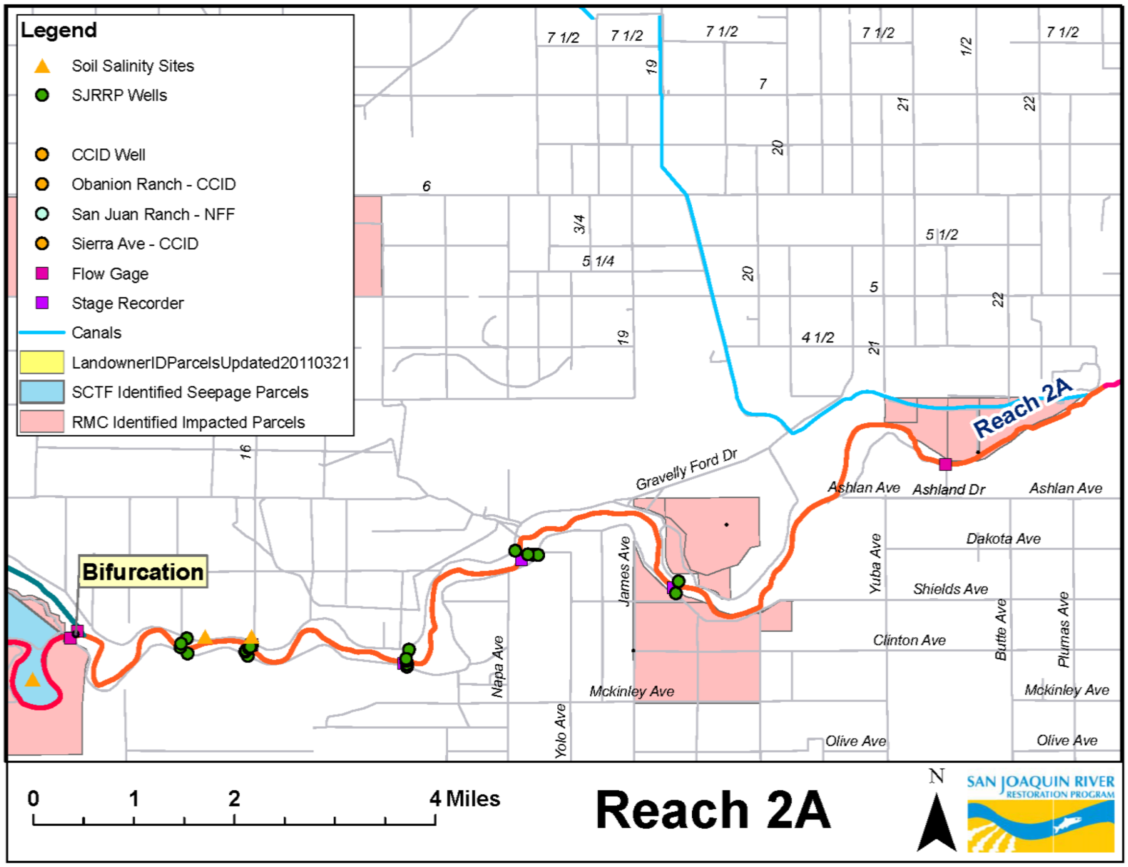


Figure C-7. Reach 2A Locations of Identified Risk

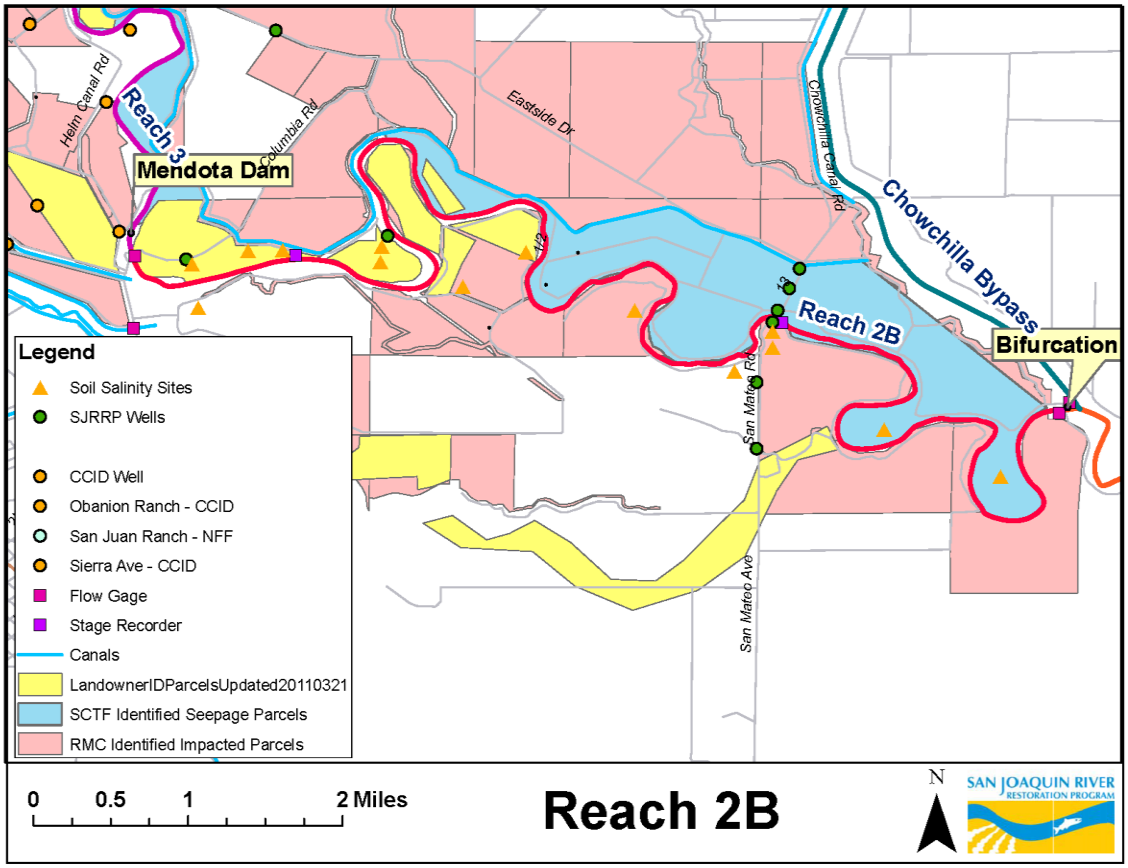


Figure C-8. Reach 2B Locations of Identified Risk

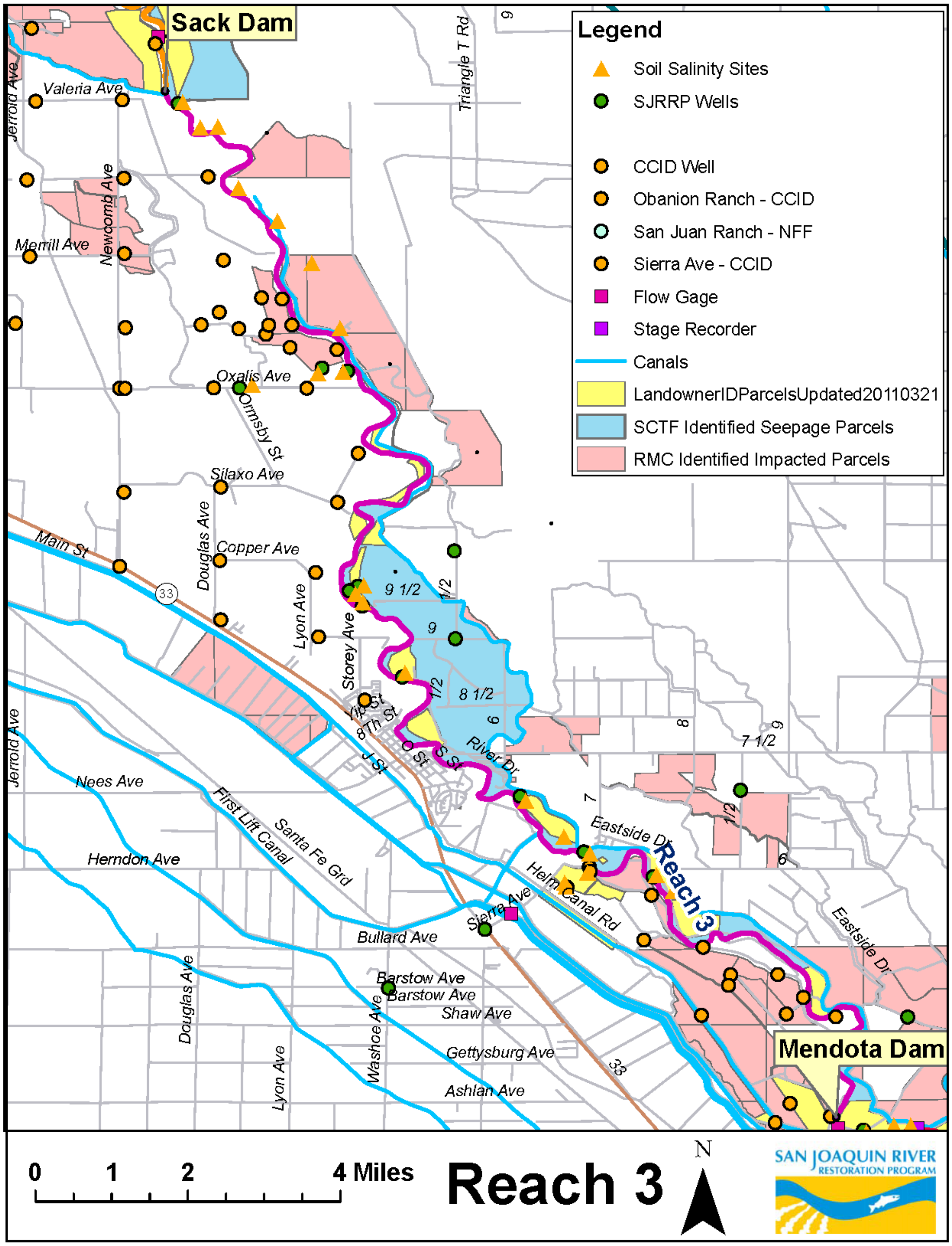
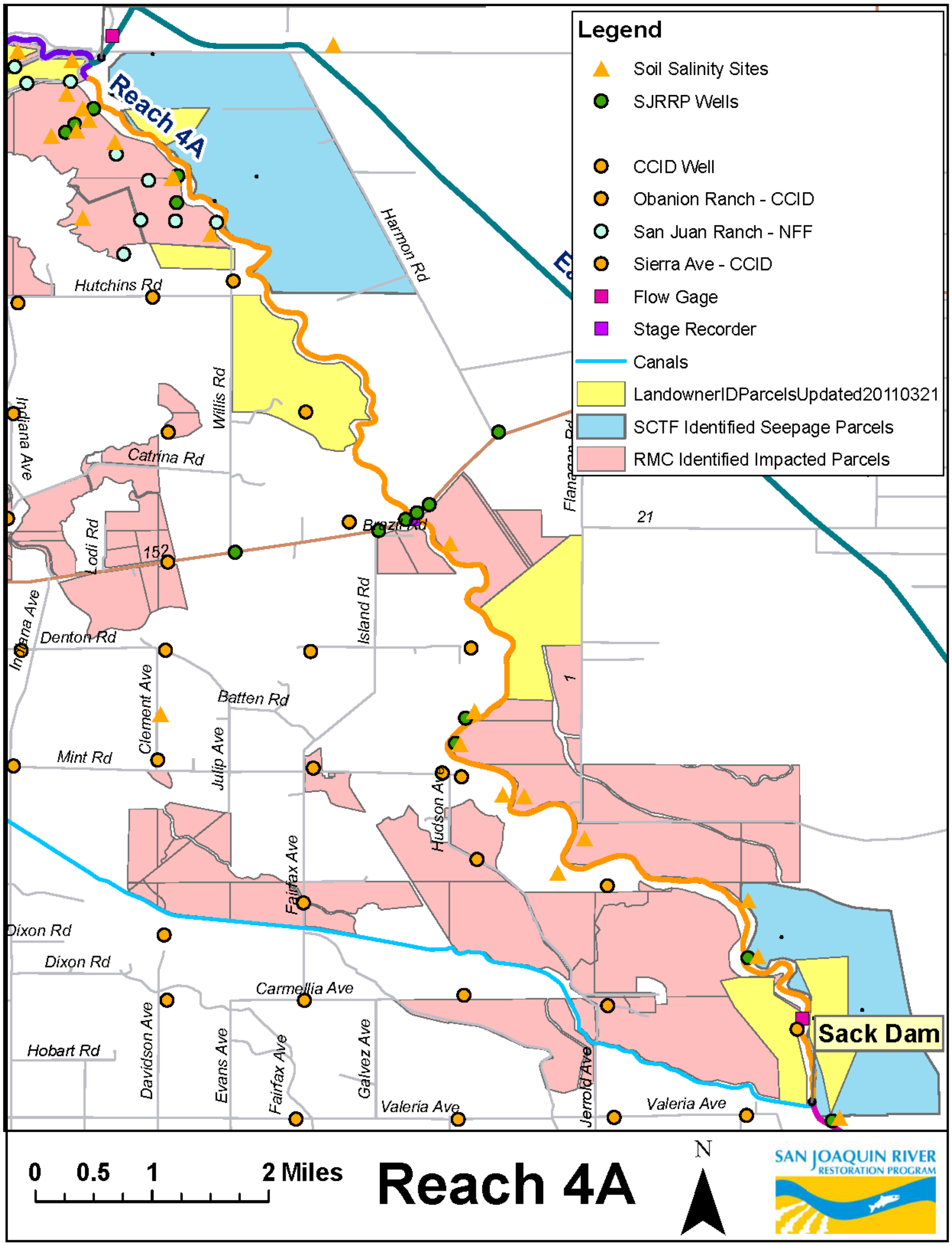


Figure C-9. Reach 3 Locations of Identified Risk



1

2 **Figure C-10. Reach 4A Locations of Identified Risk**

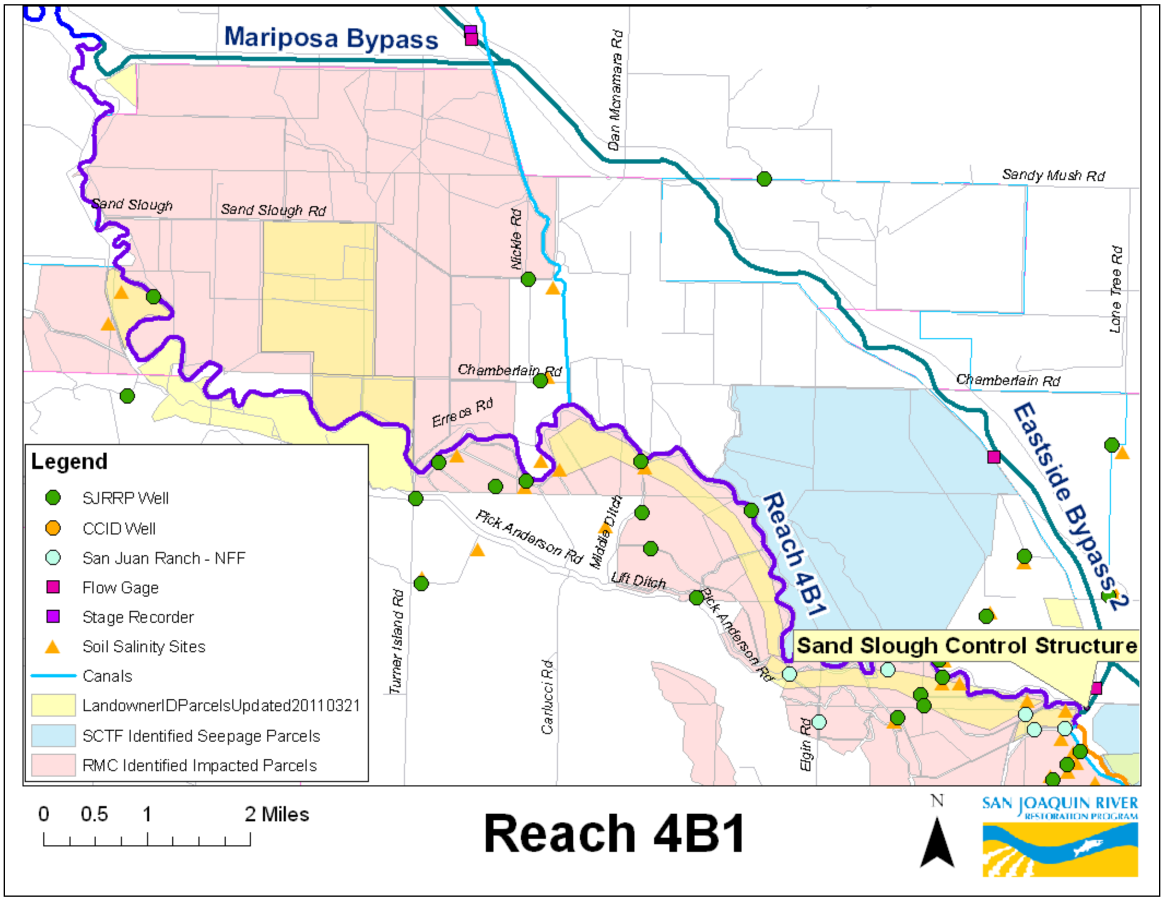


Figure C-11. Reach 4B1 Locations of Identified Risk

C.3 Elevation

This section includes analysis to screen for potential locations of seepage risk based on land elevation and predicted water surface up to 4,500 cubic feet per second (cfs), to allow full Restoration Flows. Seepage management includes real-time management of flows to reduce or avoid material adverse seepage impacts, as well as implementation of projects to increase capacity outside of site-specific projects, as part of Paragraph 12 in the Stipulation of Settlement (Settlement) in *NRDC et al., v. Rodgers, et al.* Locations will require a more detailed analysis to determine if seepage concerns exist and an evaluation to identify the type, advantages, and limitations of a potential project. This section screens out locations that do not require more detailed site evaluations for installation of seepage projects.

San Joaquin River water surface elevations taken from the HEC-RAS (Tetra Tech 2009) hydraulic model as well as surveys were compared with terrain. The analysis extended water surface elevations beneath the adjacent fields to obtain predicted depths below ground surface, as shown in Figure C-12.

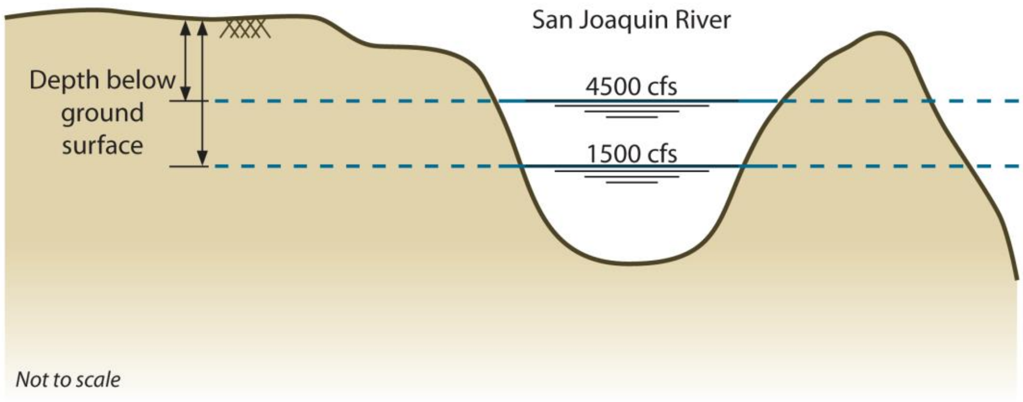


Figure C-12. Seepage Project Elevation Analysis Conceptual Model

The one-dimensional hydraulic model predicts water surface elevations at cross-sections. Analysis included local flows of 1,500 and 4,500 cfs. Reclamation subtracted the model-predicted water surface elevations from the 2008 LiDAR (ground surface elevation). This difference provides an estimate of the shallowest groundwater depth below ground surface. This estimate does not consider any groundwater gradient adjacent to the river.

A second analysis used surveyed water surface elevations. See Table C-1 below for a description of the surveys and hydraulic modeling runs used to conduct this elevation analysis.

Table C-1. Results by Reach

Reach	Type[1]	Date	Local Flow (cfs)
1B	HEC-RAS Results		1,500
1B	HEC-RAS Results		4,500
2A	HEC-RAS Results		1,500
2A	HEC-RAS Results		4,500
3	HEC-RAS Results		1,500
3	DWR Survey	January 5 – 11, 2011	1,880
3	HEC-RAS Results		4,500
4A	HEC-RAS Results		1,500
4A	HEC-RAS Results		4,500

1: HEC-RAS results from Tetra Tech 2009

Figures C-13 through C-23 show color-shaded results of the comparison between the water surface and ground surface elevations. As noted above, the results assume the water surface elevation in the river matches the groundwater elevation (no groundwater gradient). Areas that are shaded blue indicate that the water surface elevation in the river is above the ground surface. Assuming no groundwater gradient, surface ponding would be expected in those areas at the flow indicated. Areas shaded red indicate that the water surface elevation in the river and assumed groundwater level is between zero and three feet below the ground surface. Combined, the blue and red shaded areas indicate areas with a high potential for seepage.

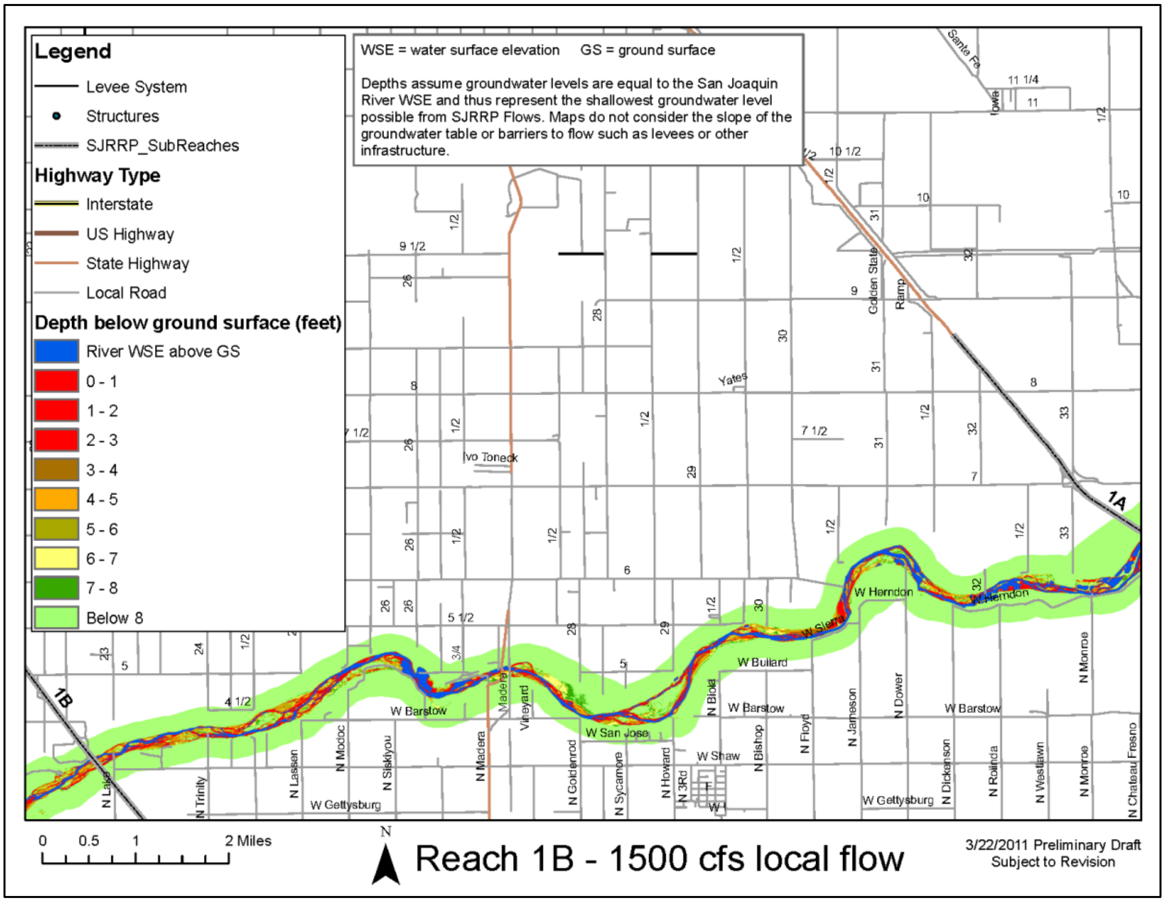


Figure C-13. Reach 1B: 1,500 cfs

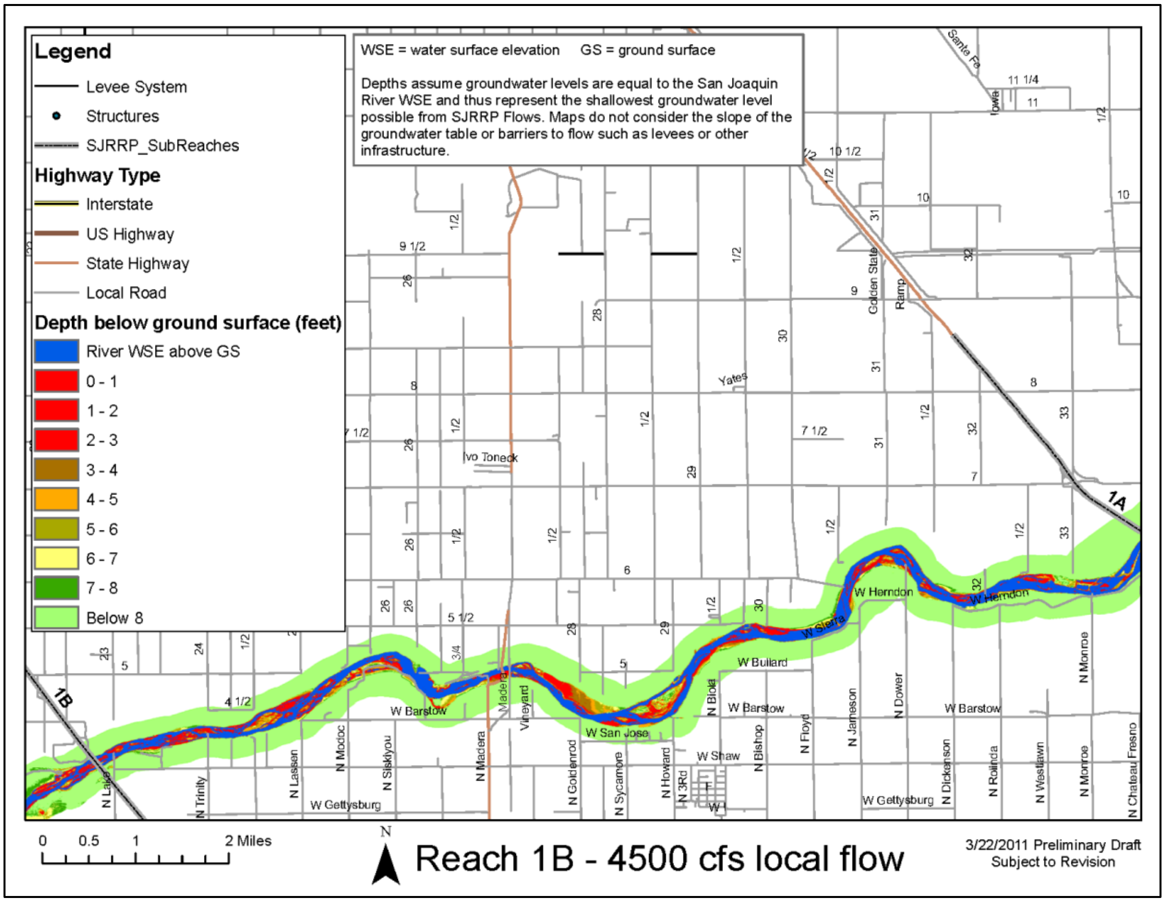
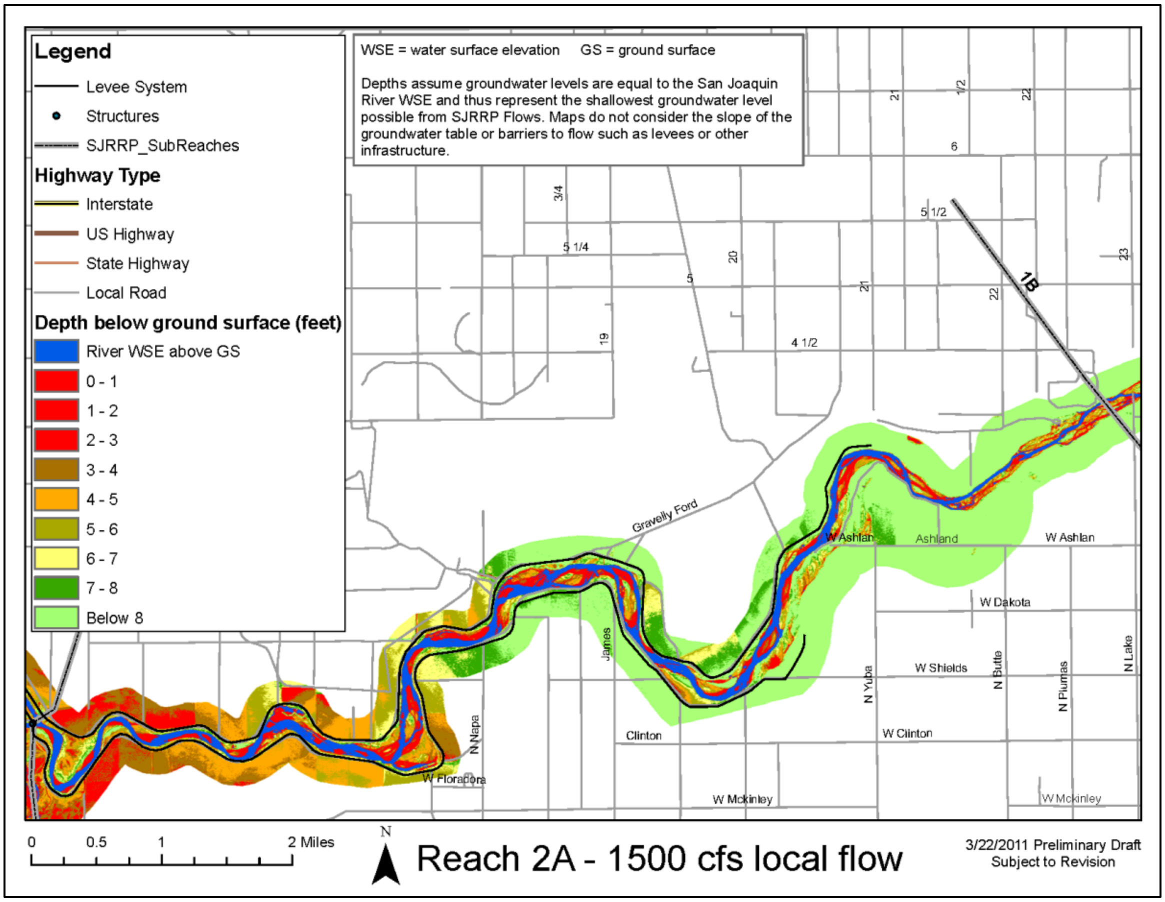


Figure C-14. Reach 1B: 4,500 cfs

1


2
Figure C-15. Reach 2A: 1500 cfs

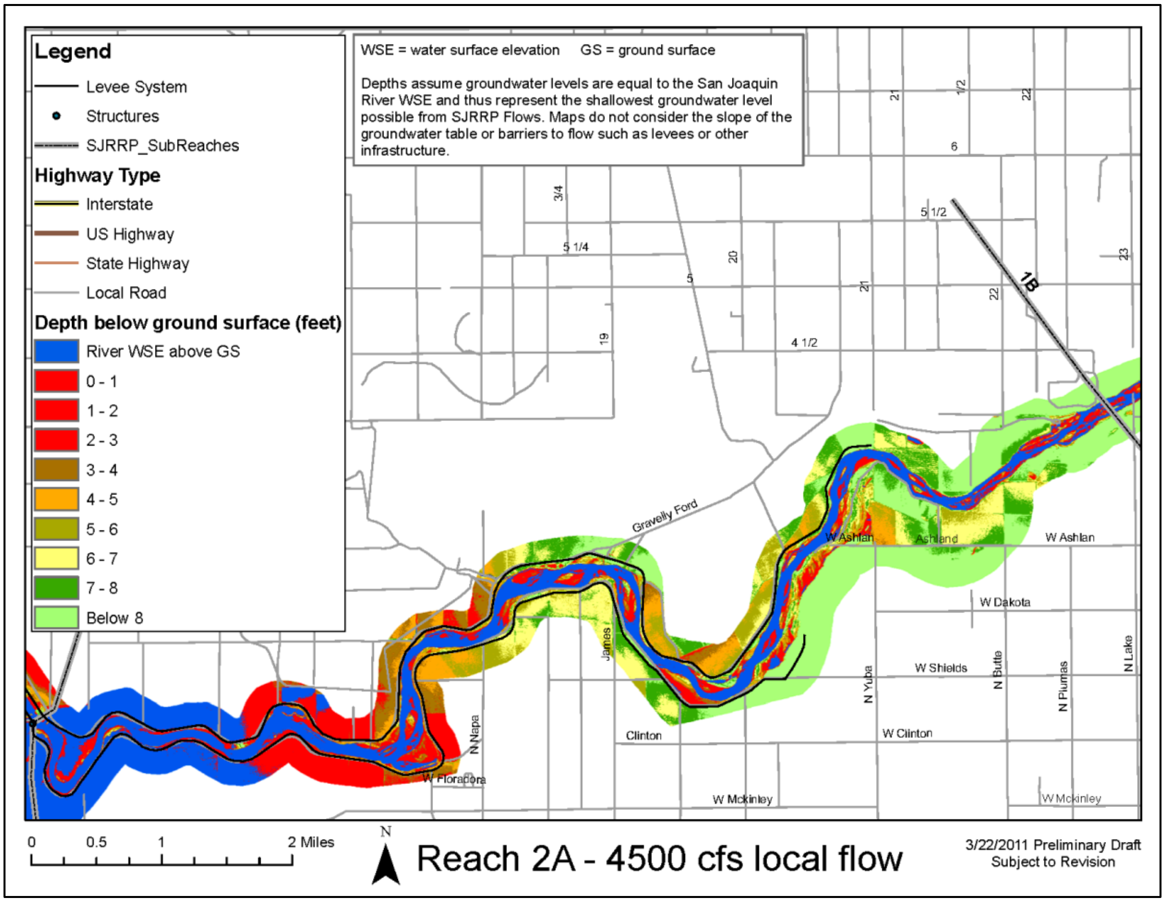


Figure C-16. Reach 2A: 4,500 cfs

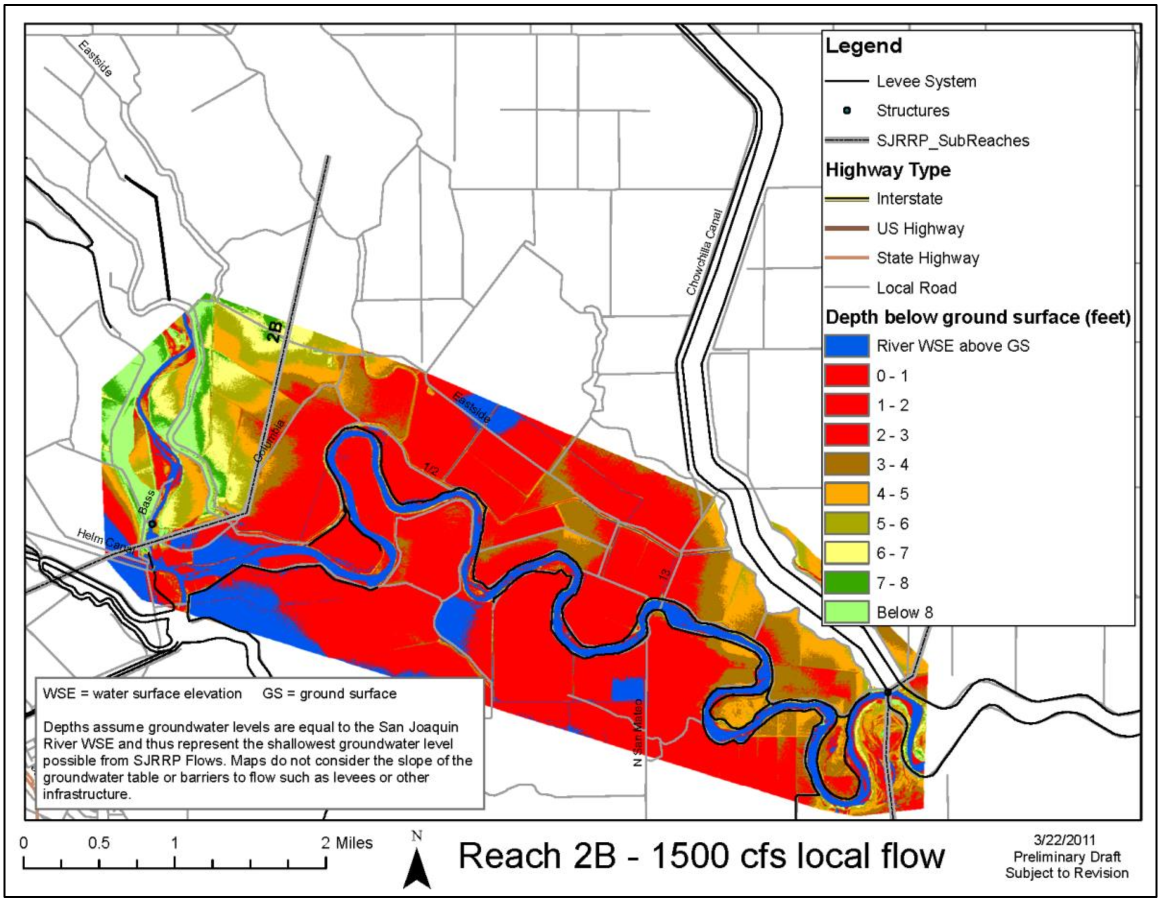


Figure C-17. Reach 2B: 1,500 cfs

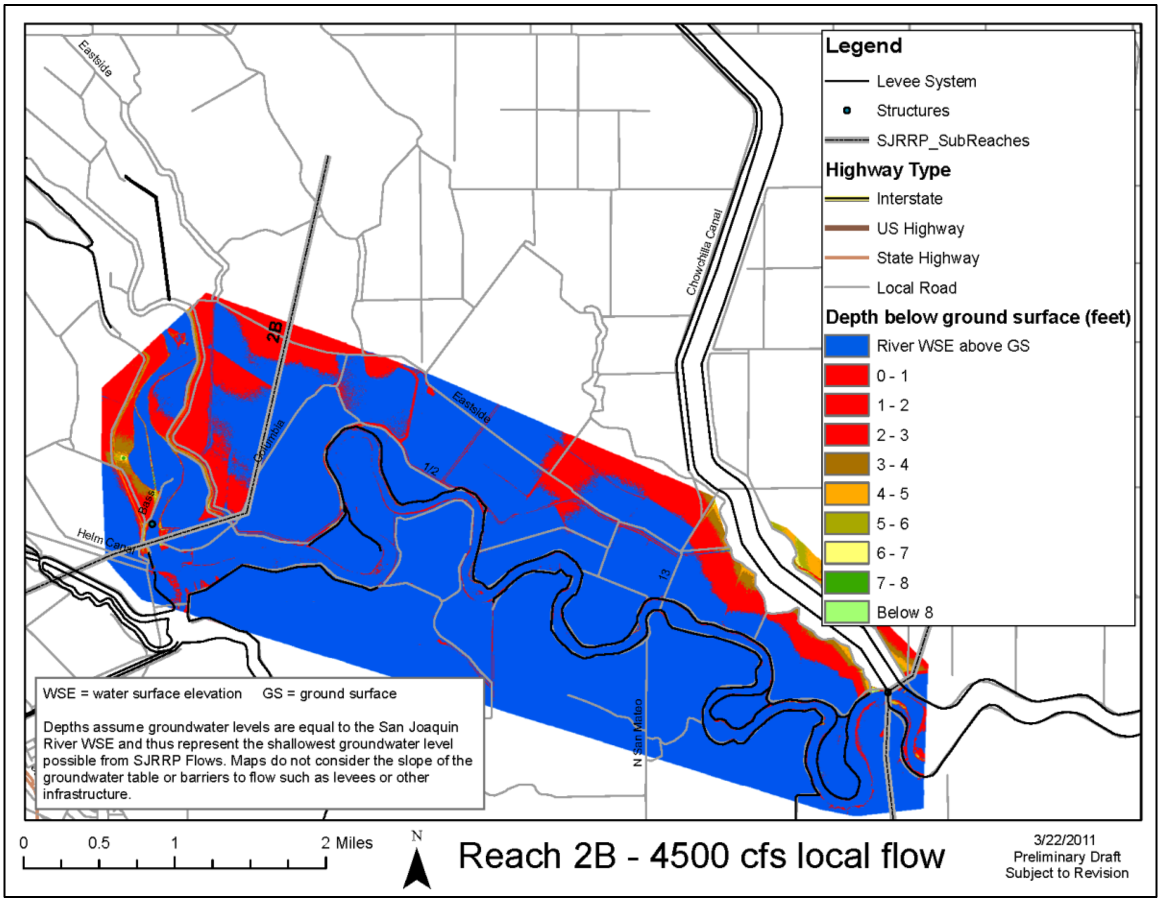


Figure C-18. Reach 2B: 4,500 cfs

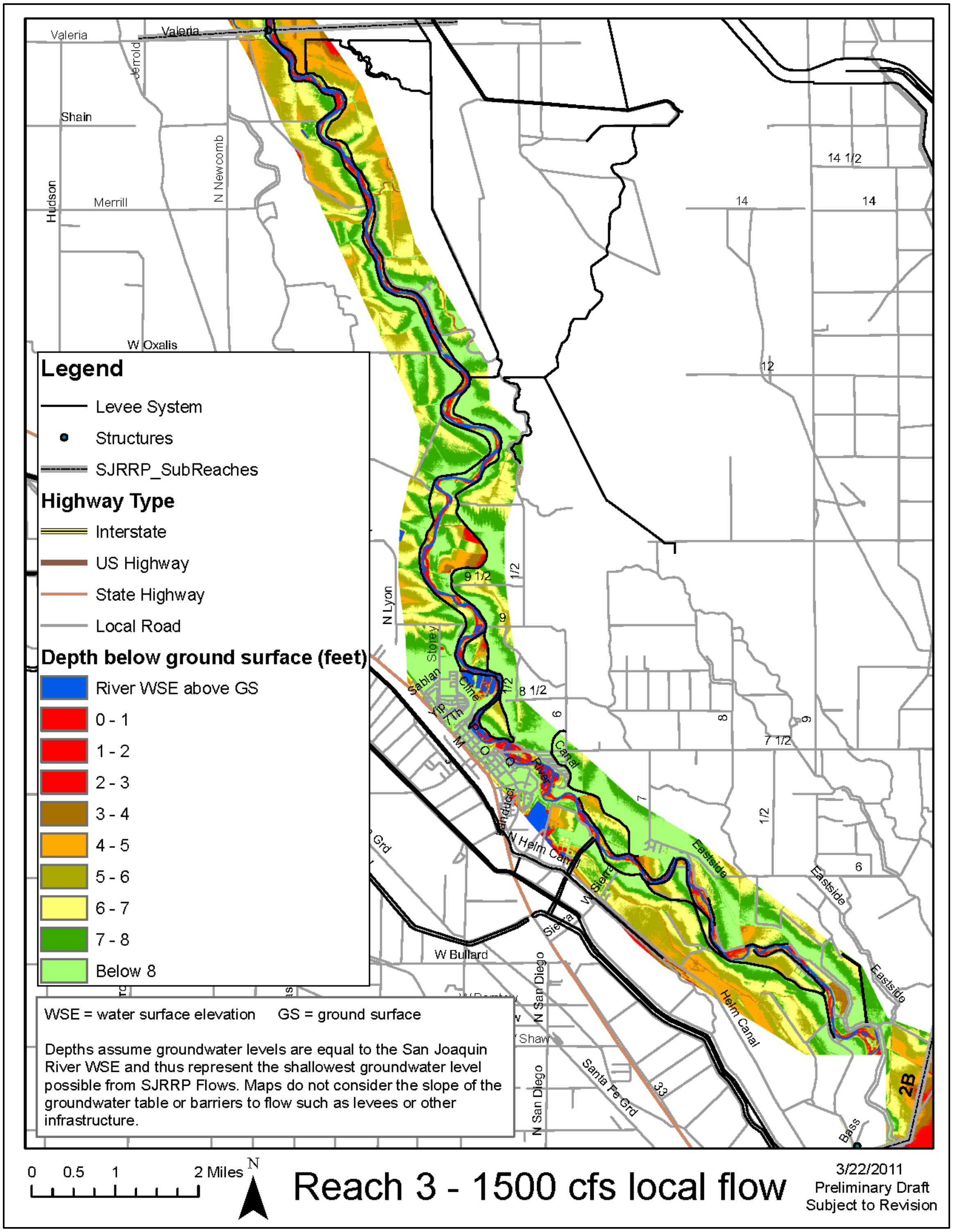


Figure C-19. Reach 3: 1,500 cfs

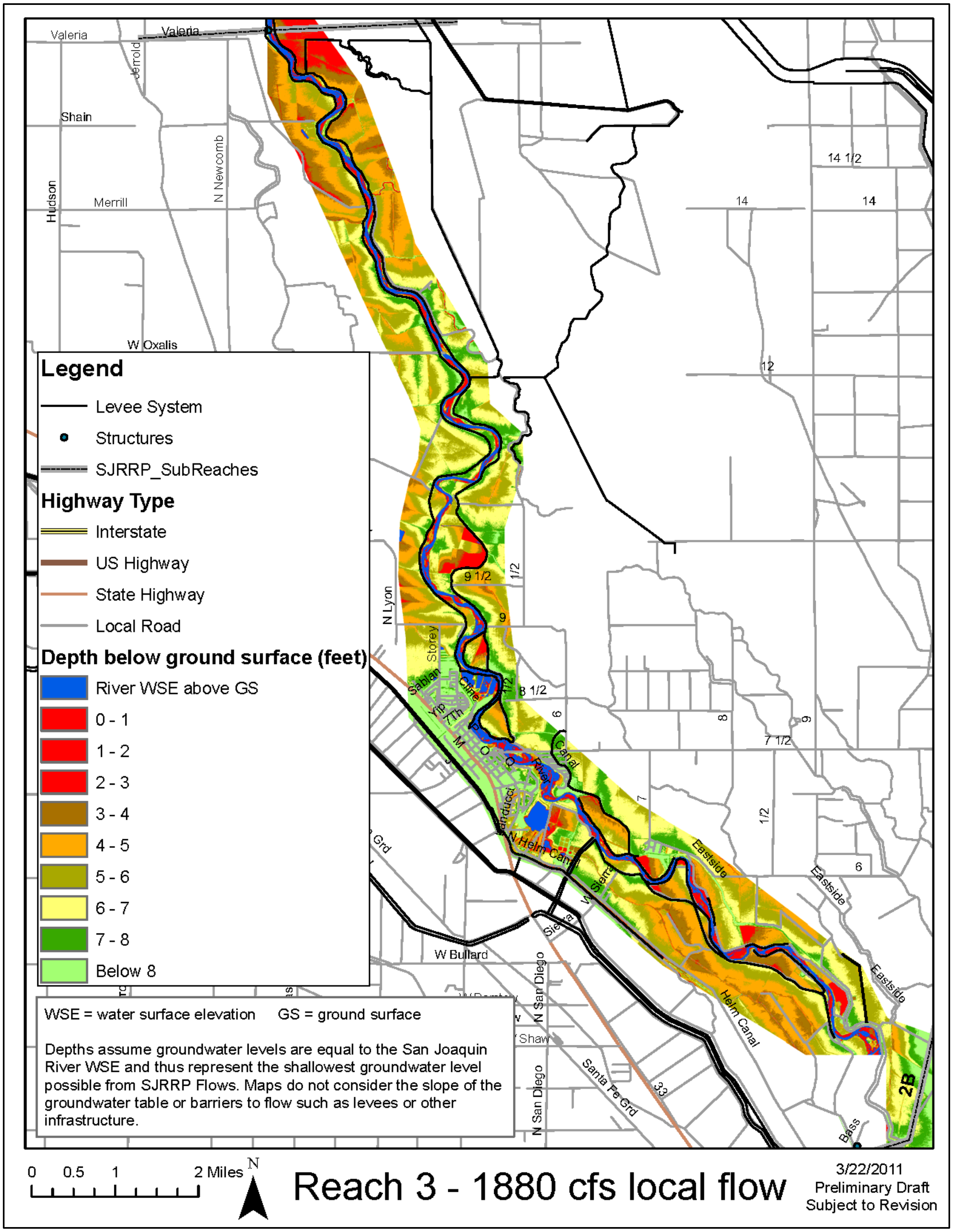


Figure C-20. Reach 3: 1,880 cfs

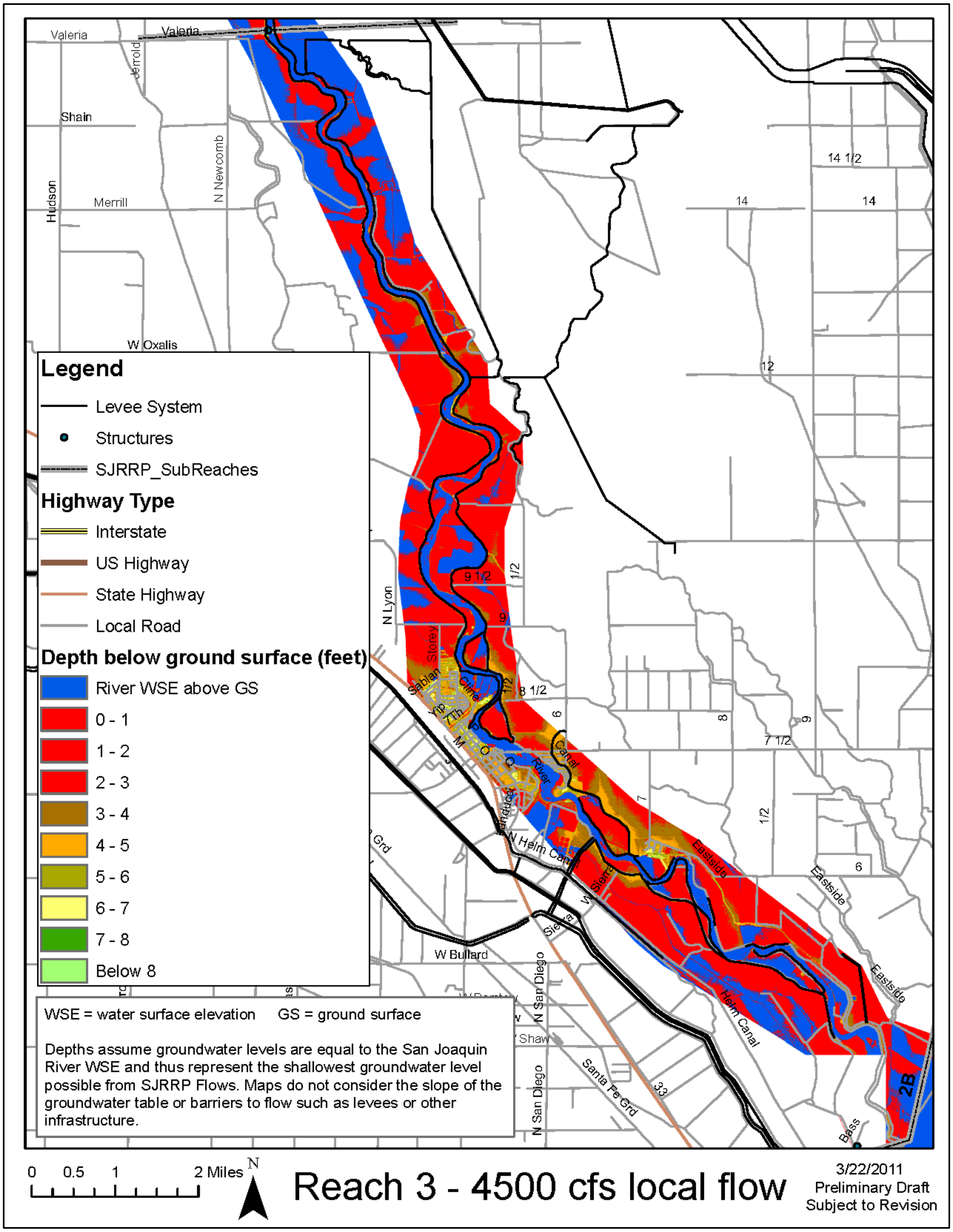


Figure C-21. Reach 3: 4,500 cfs

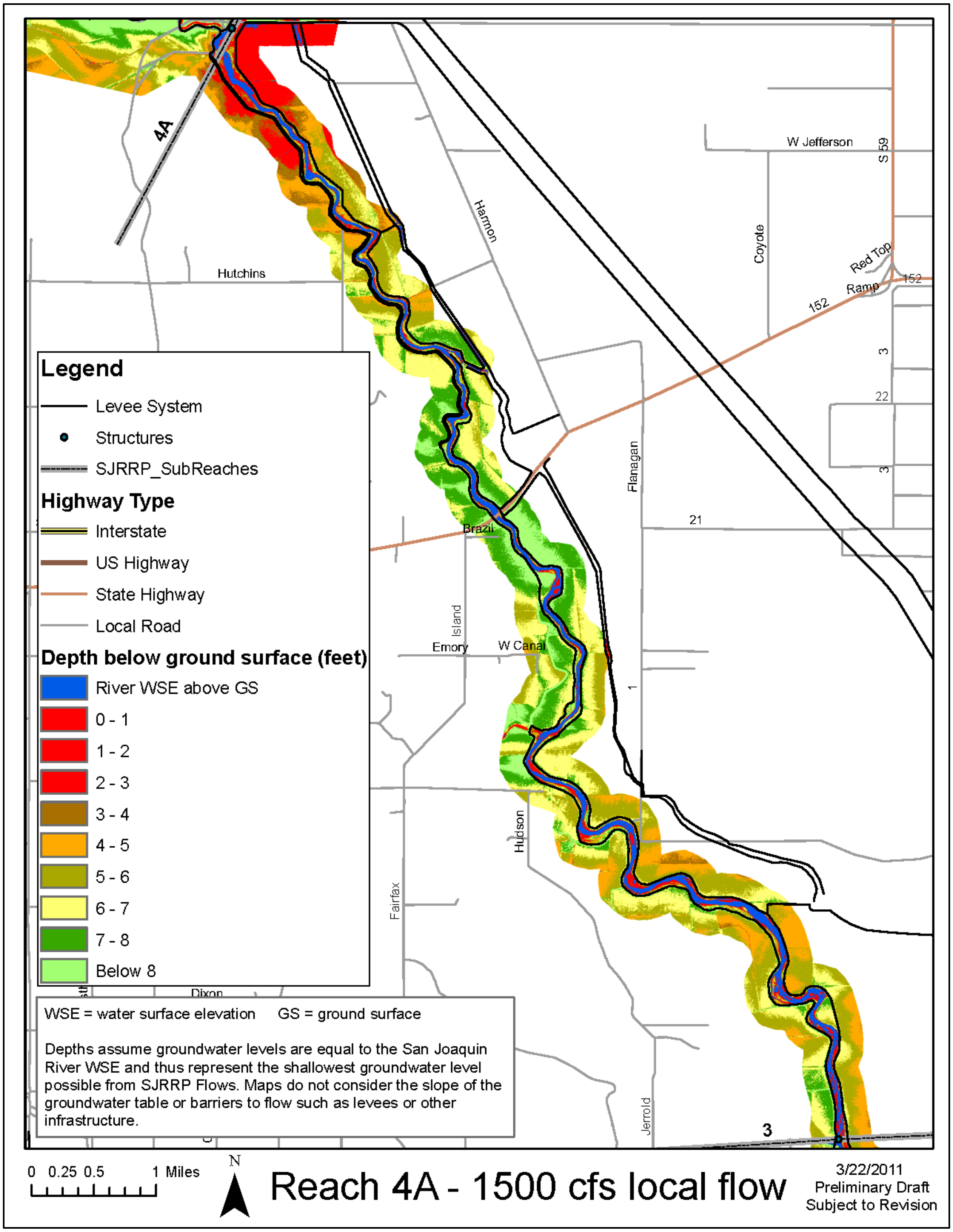


Figure C-22. Reach 4A: 1,500 cfs

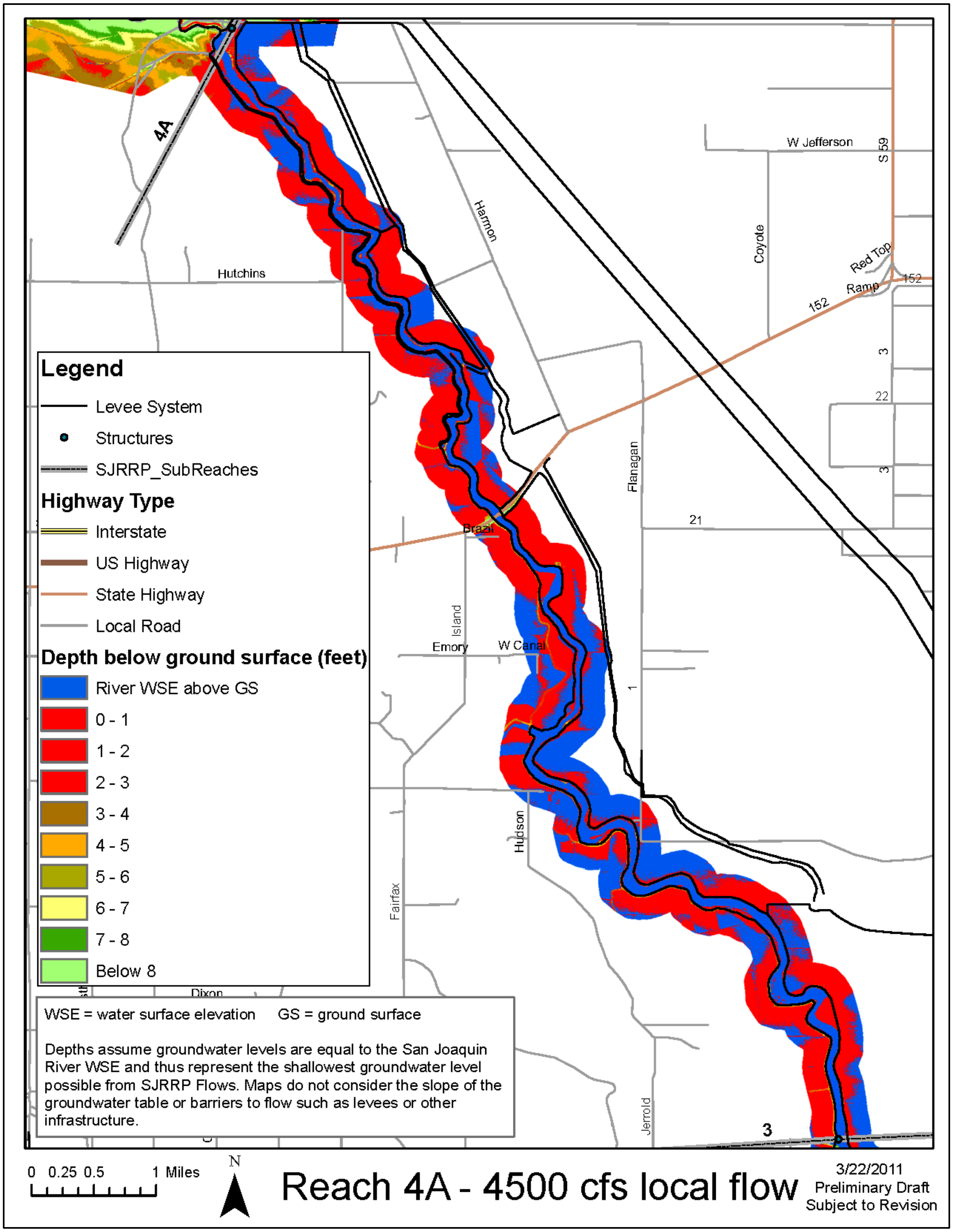


Figure C-23. Reach 4A: 4,500 cfs

While this analysis assumes a flat groundwater table with no gradient toward or away from the river, monitoring data collected by the SJRRP during the last two to three years indicates gradients exist in most locations. Assuming no gradient overestimates the effects of river stage on seepage. This approach results in more locations and larger areas identified as vulnerable to seepage. The key areas of concern for seepage projects include the downstream end of Reach 2A, portions of Reach 3, and the downstream end of Reach 4A.

C.4 Prioritization of Parcel Groups for Seepage Projects

C.4.1 Purpose

To allow Reclamation to proceed with analysis for potential seepage projects in an orderly fashion, Reclamation developed a prioritized list of parcels. This list prioritized parcels that may be impacted at the lowest flows in the San Joaquin River.

C.4.2 Introduction

Reclamation first divided the project area into parcel groups to create manageable sections for initiating and tracking projects. Existing information was collected on each parcel group. Parcel groups with observed flooding in 2011 or a minimum land surface elevation equal to water surface elevation at less than 2,000 cfs were prioritized for the first tier of seepage projects.

C.4.3 Parcel Groups

The following section shows the parcel groupings in the SJRRP project area. Reclamation chose parcel groups based on changes in the following criteria:

- Ownership,
- Infrastructure,
- Terrain, and
- Level of flow where impacts occur.

For example, a change in ownership at a canal would indicate the potential for a different hydrologic regime (due to canal) and different preferred seepage project (due to change in ownership). Therefore, parcel groups were defined accordingly.

Figures C-24 through C-30 below show the parcel group boundaries on aerial photos along with the existing monitoring well locations.

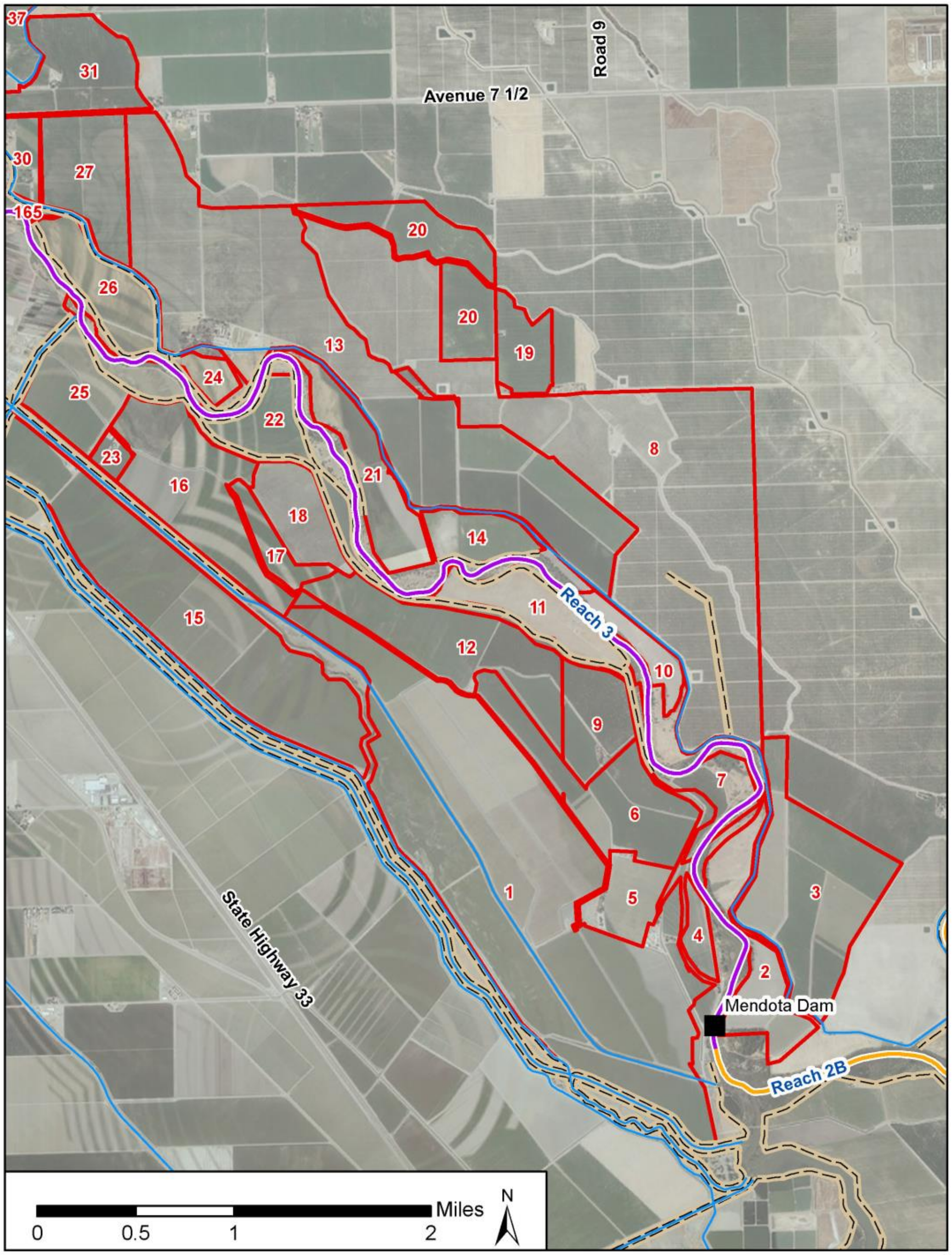


Figure C-24. Parcel Group Location Map (1 of 7)

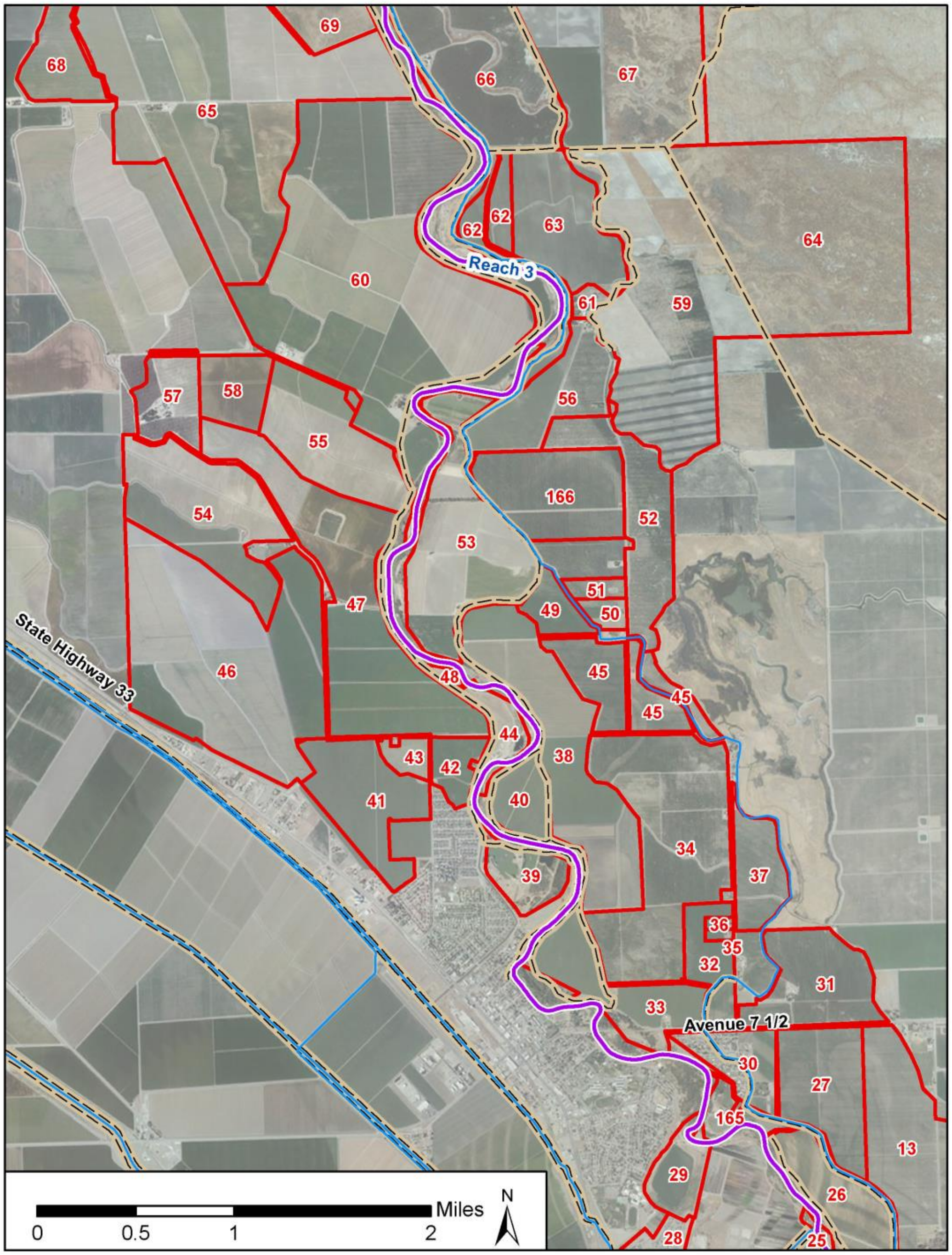


Figure C-25. Parcel Group Location Map (2 of 7)

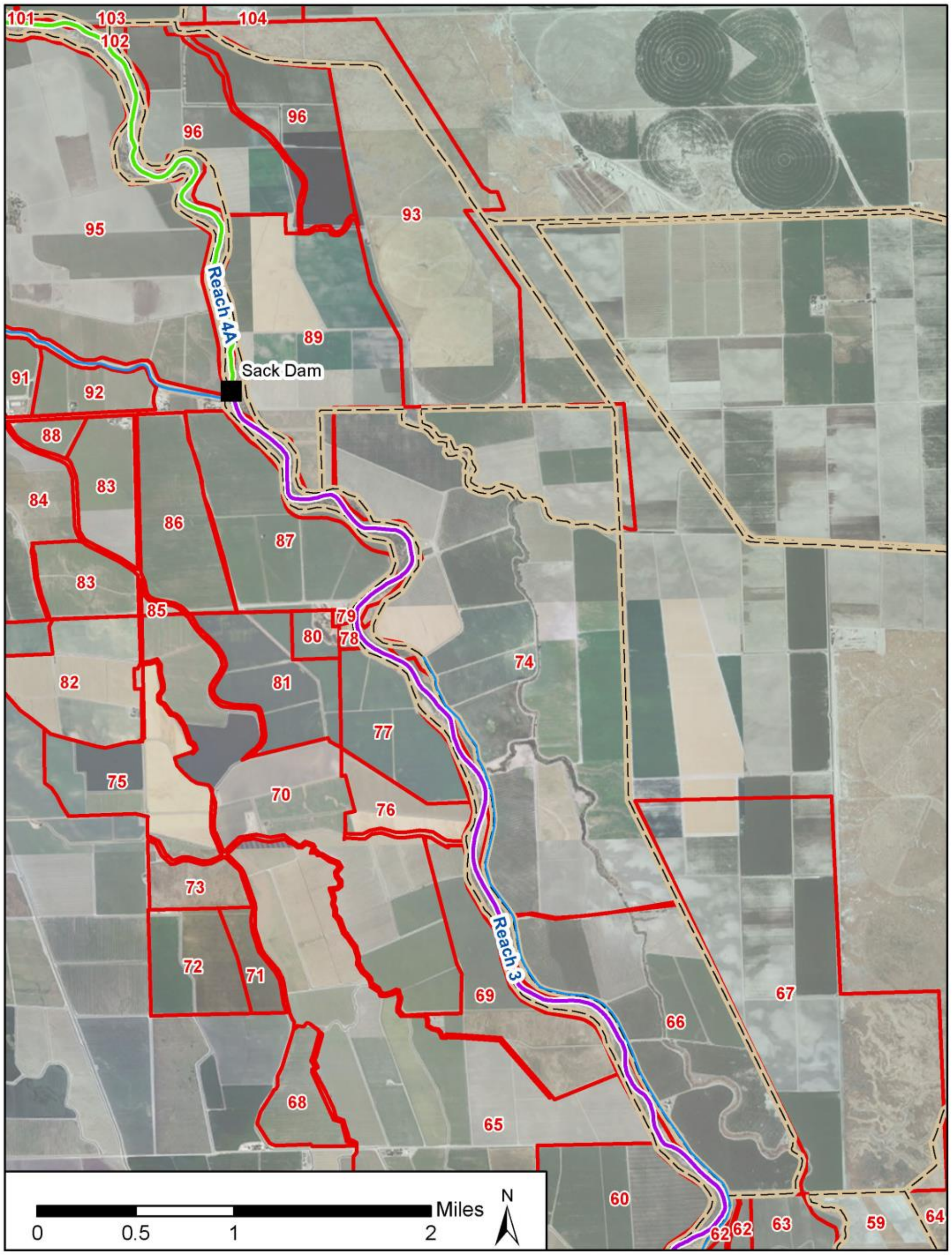


Figure C-26. Parcel Group Location Map (3 of 7)

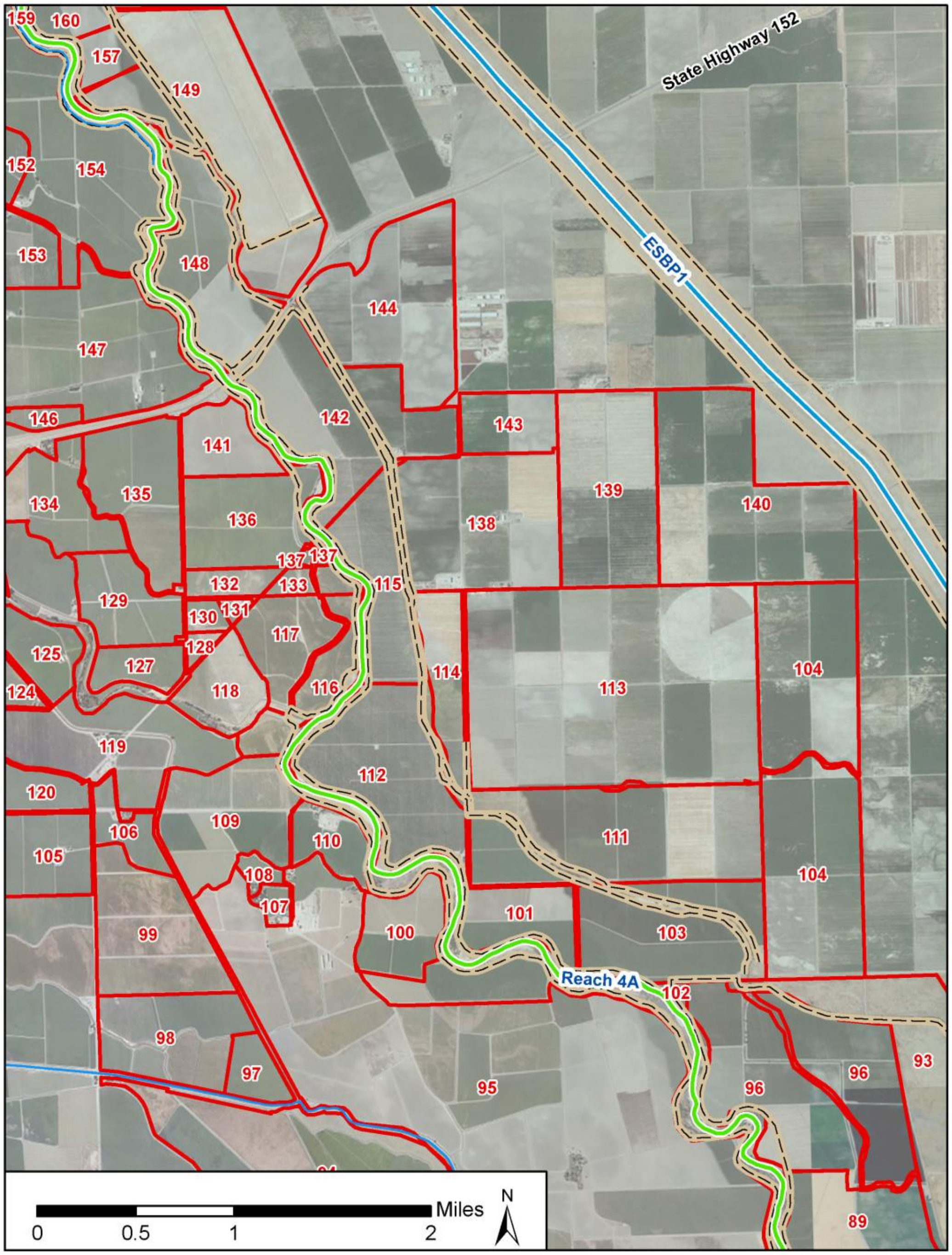


Figure C-27. Parcel Group Location Map (4 of 7)

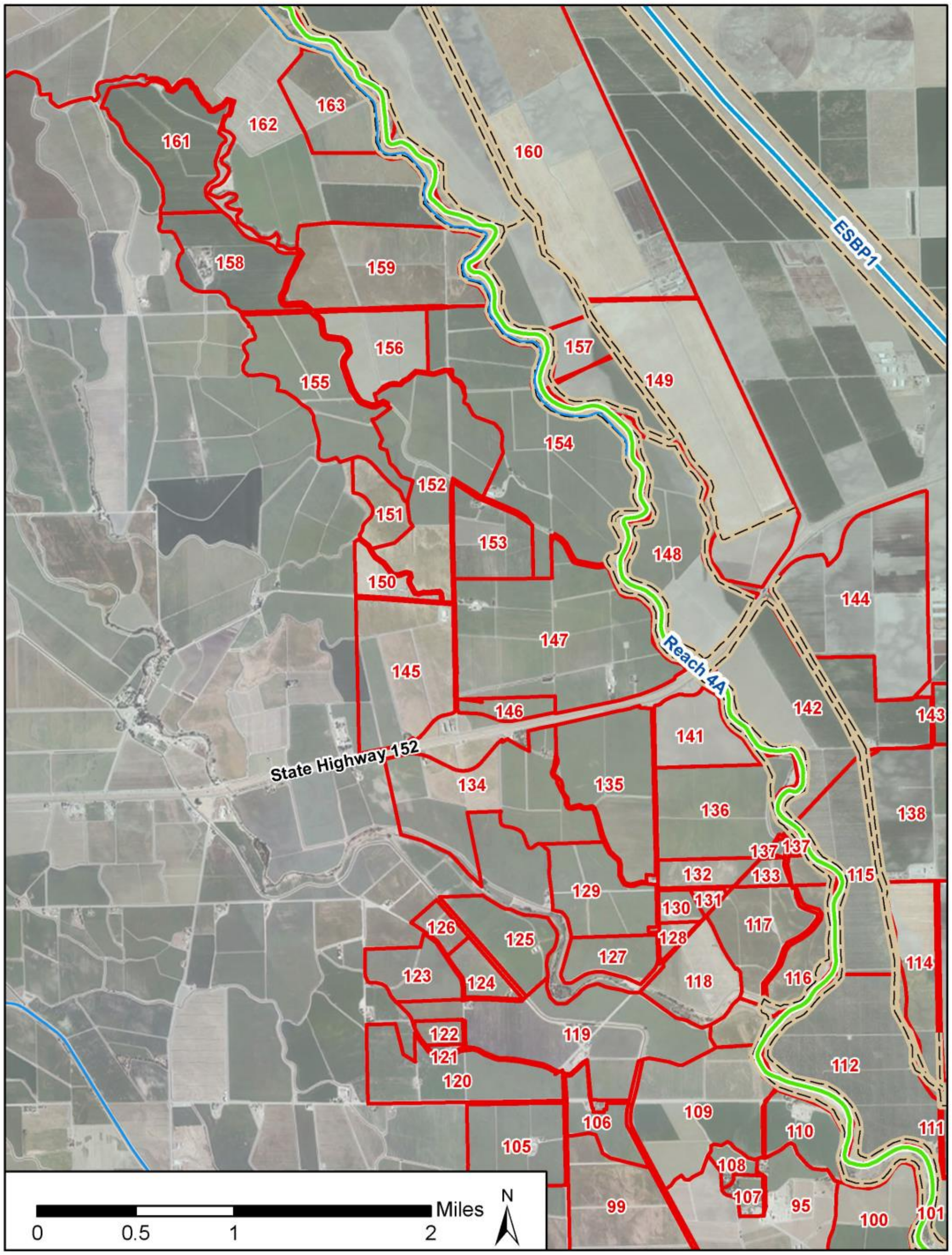


Figure C-28. Parcel Group Location Map (5 of 7)

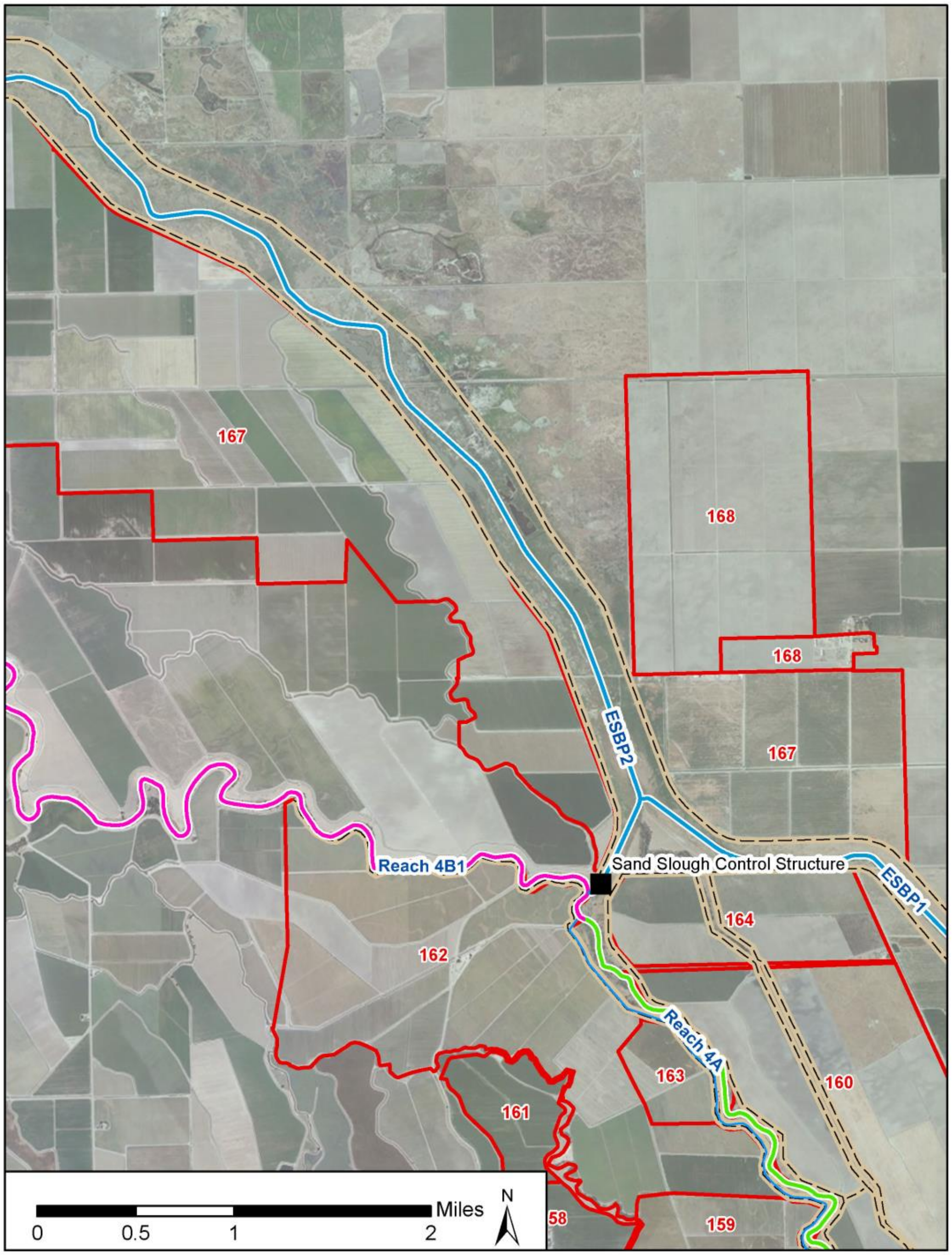


Figure C-29. Parcel Group Location Map (6 of 7)

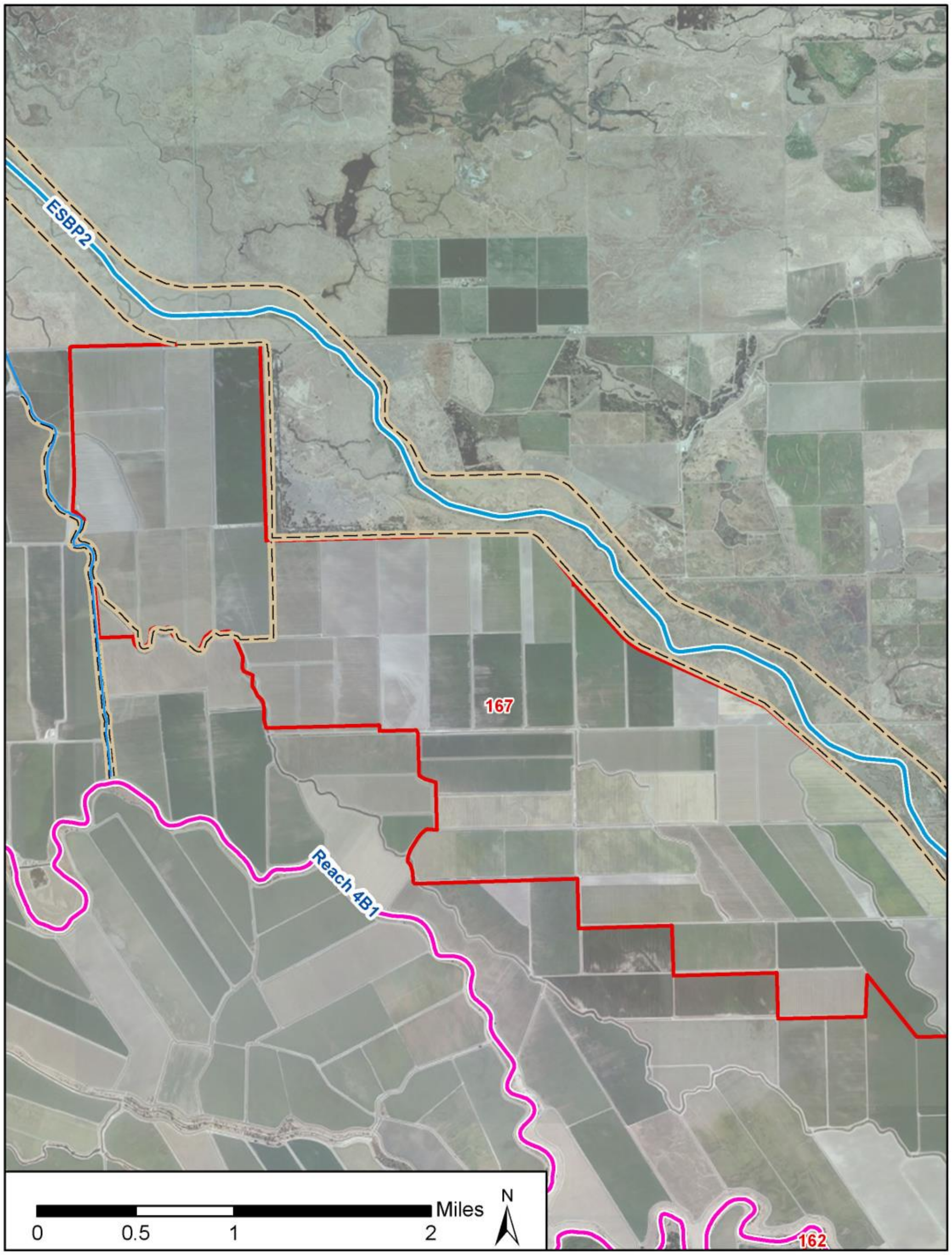


Figure C-30. Parcel Group Location Map (7 of 7)

C.4.4 Parcel Groups Existing Data Collection

Initial existing data collection can help prioritize parcel groups and rule out other parcel groups if they clearly do not need further evaluation. In addition to the parcel location maps shown in Section C.4.3, Attachment 1 to Appendix C contains existing information for each seepage parcel group. This information includes:

- 2011 Aerials Map
- 1937 Aerials Map
  - Current aerials transparent in the background to provide field references
- Inundation Map
  - Landowner observed historical flooding
  - RMC observed historical flooding
  - Water district observed historical or 2011 flooding
  - Reclamation observed 2011 flooding
- Profile and Cross-Section
  - Surveyed river water surface elevation (if available)
  - Modeled river water surface elevation (if surveyed is unavailable)
  - Measured groundwater level elevations
  - Threshold elevation

Reclamation will also include additional text and data for each parcel group as available.

C.4.5 First Tier Priority Parcel Groups

Figures C-31 through C-37 below show the priority parcel groups for the first round of seepage project implementation. These parcel groups were prioritized because surface ponding was observed in 2011 or the minimum land surface elevation in the field was equal to a water surface elevation at less than 2,000 cfs in the San Joaquin River or Eastside Bypass channel. Once projects are complete for this first tier, additional parcel groups will be prioritized, in the order that they restrict flows. All projects will be completed to allow Restoration flow of 4,500 cfs.

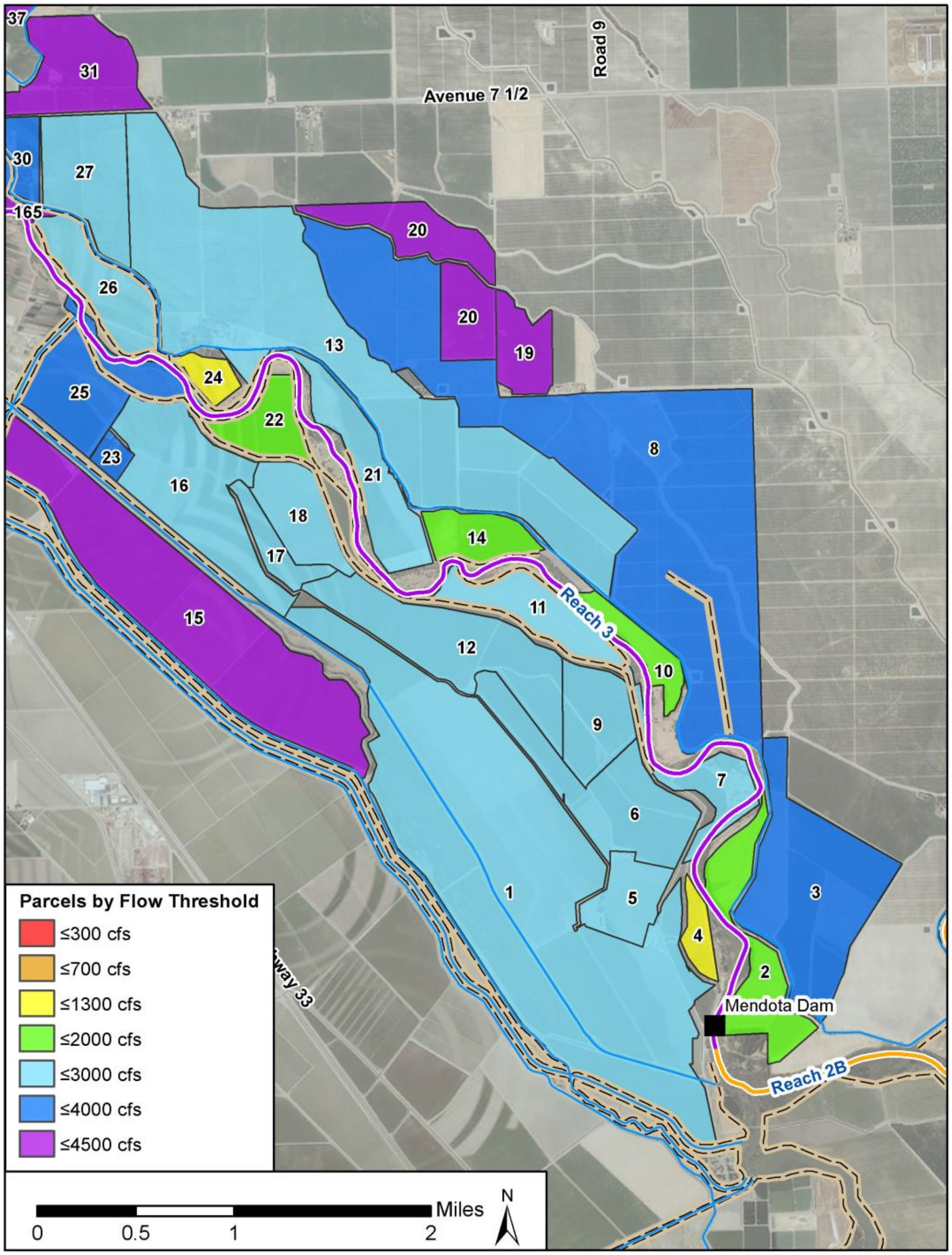


Figure C-31. Parcel Group Prioritization Map (1 of 7)

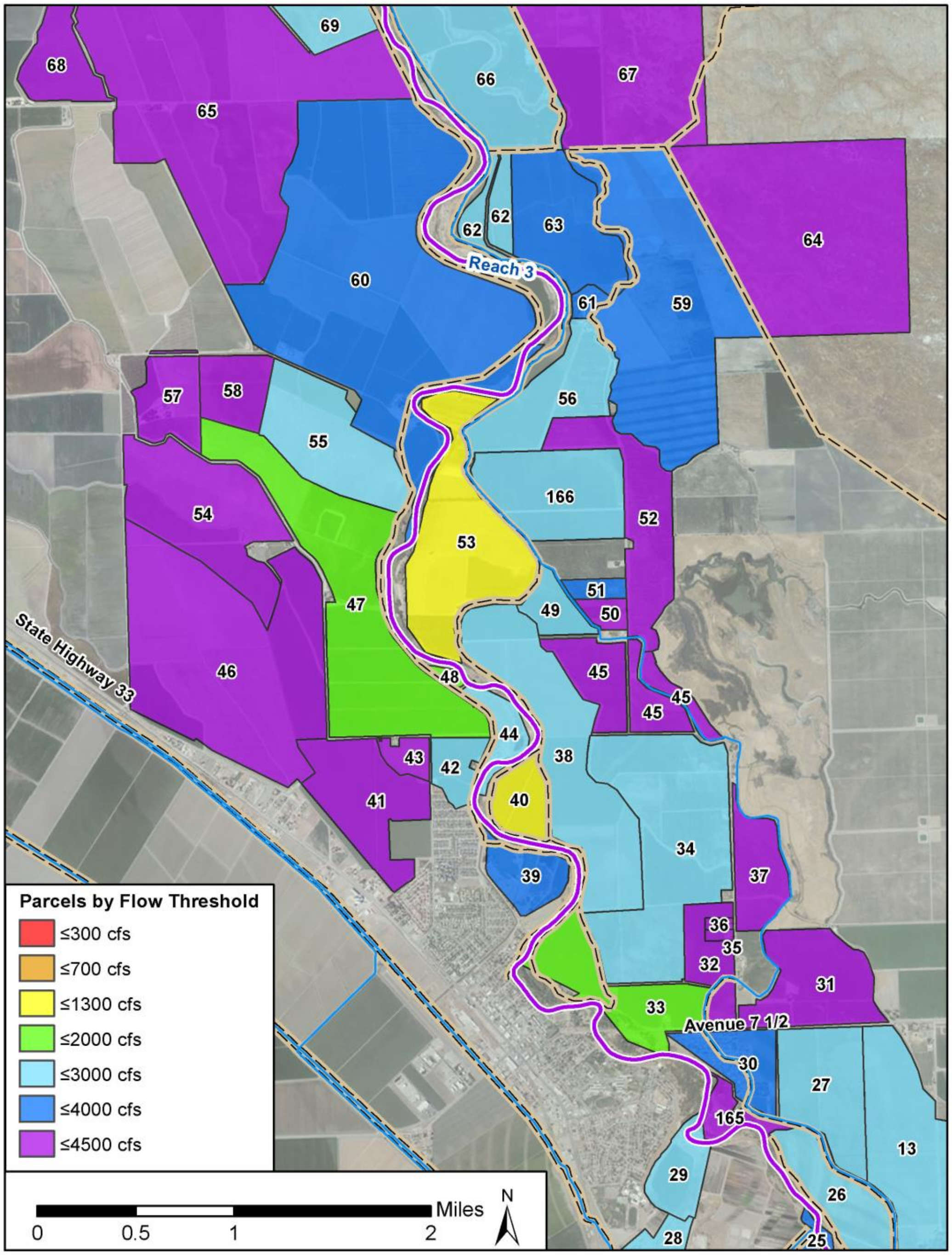


Figure C-32. Parcel Group Prioritization Map (2 of 7)

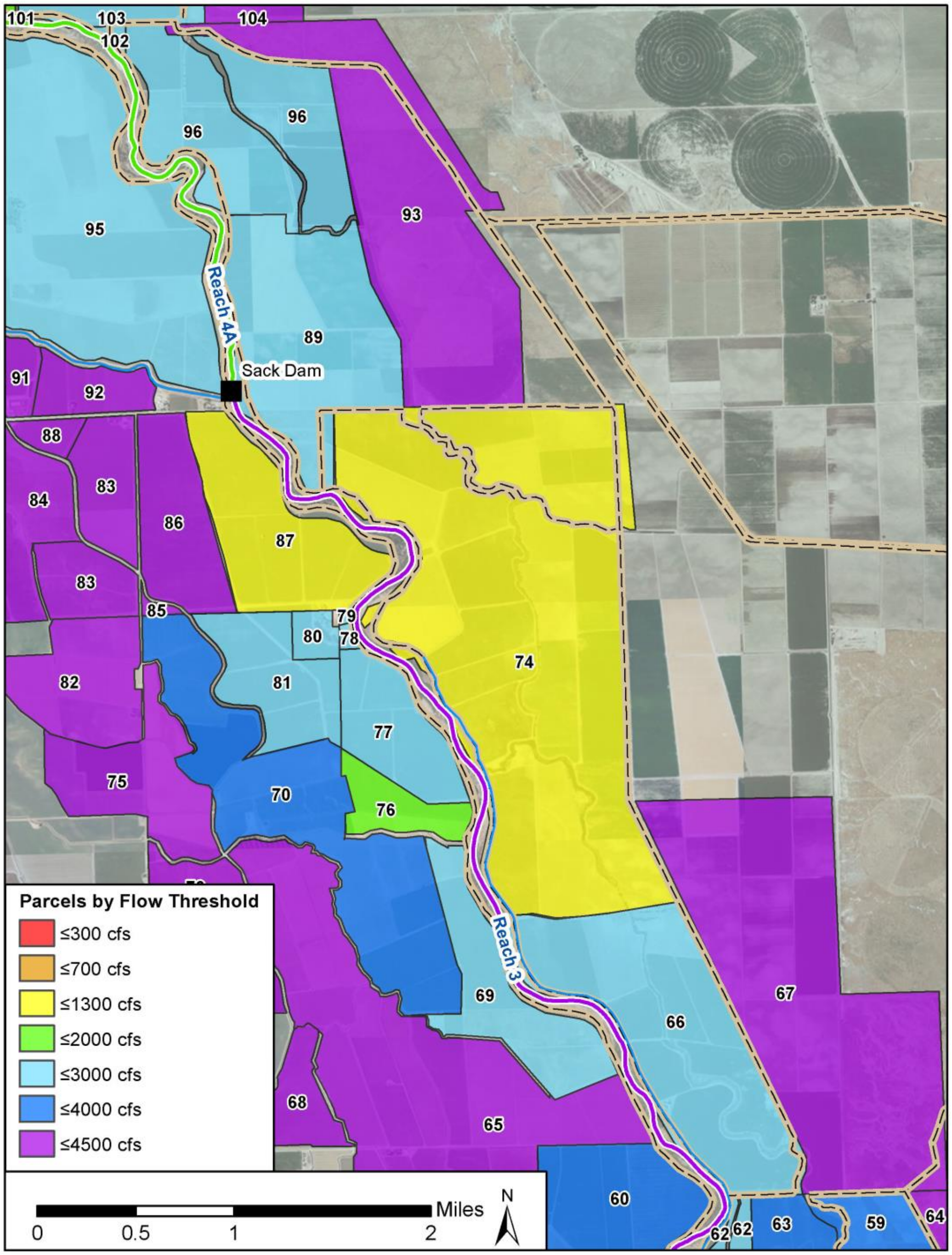


Figure C-33. Parcel Group Prioritization Map (3 of 7)

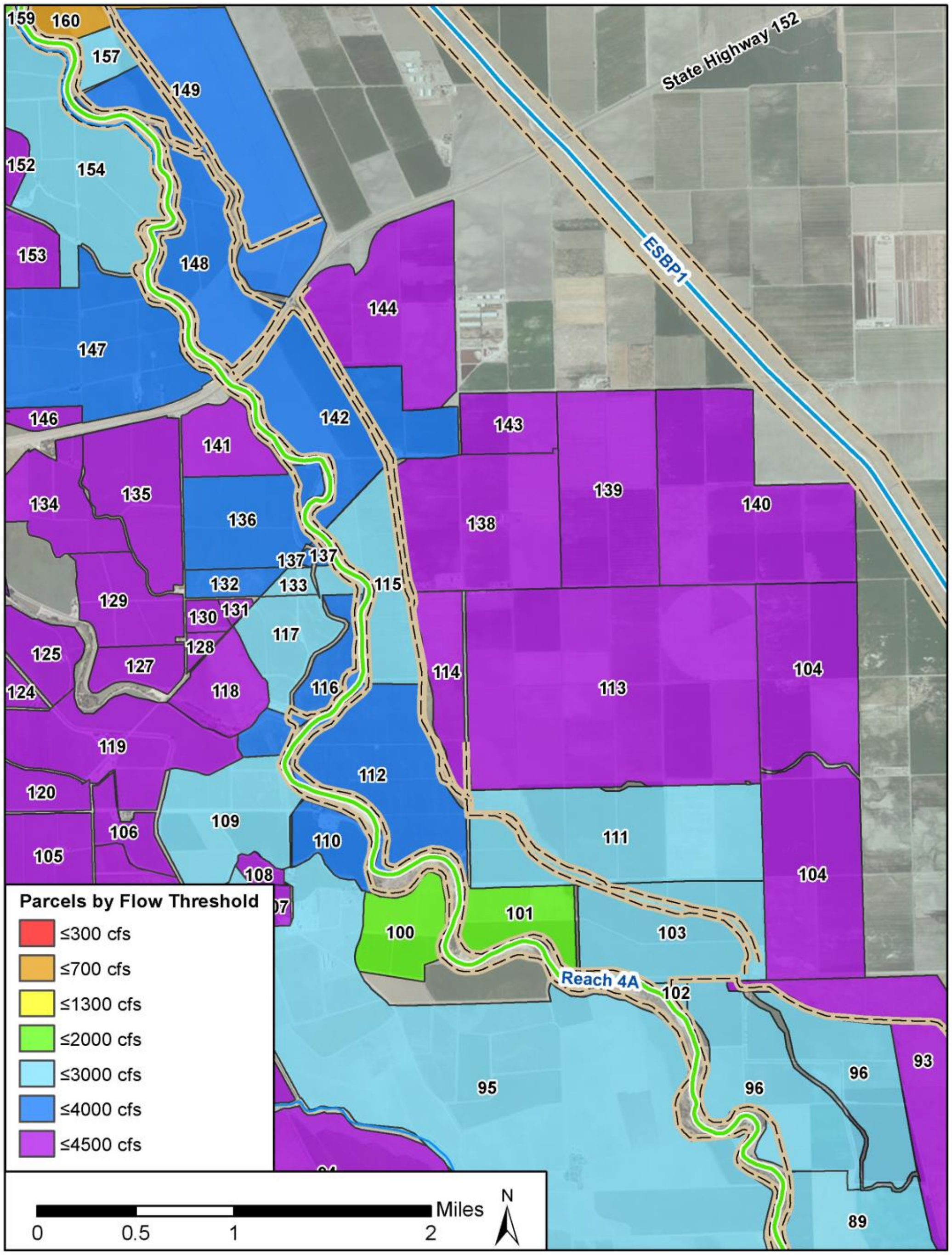


Figure C-34. Parcel Group Prioritization Map (4 of 7)

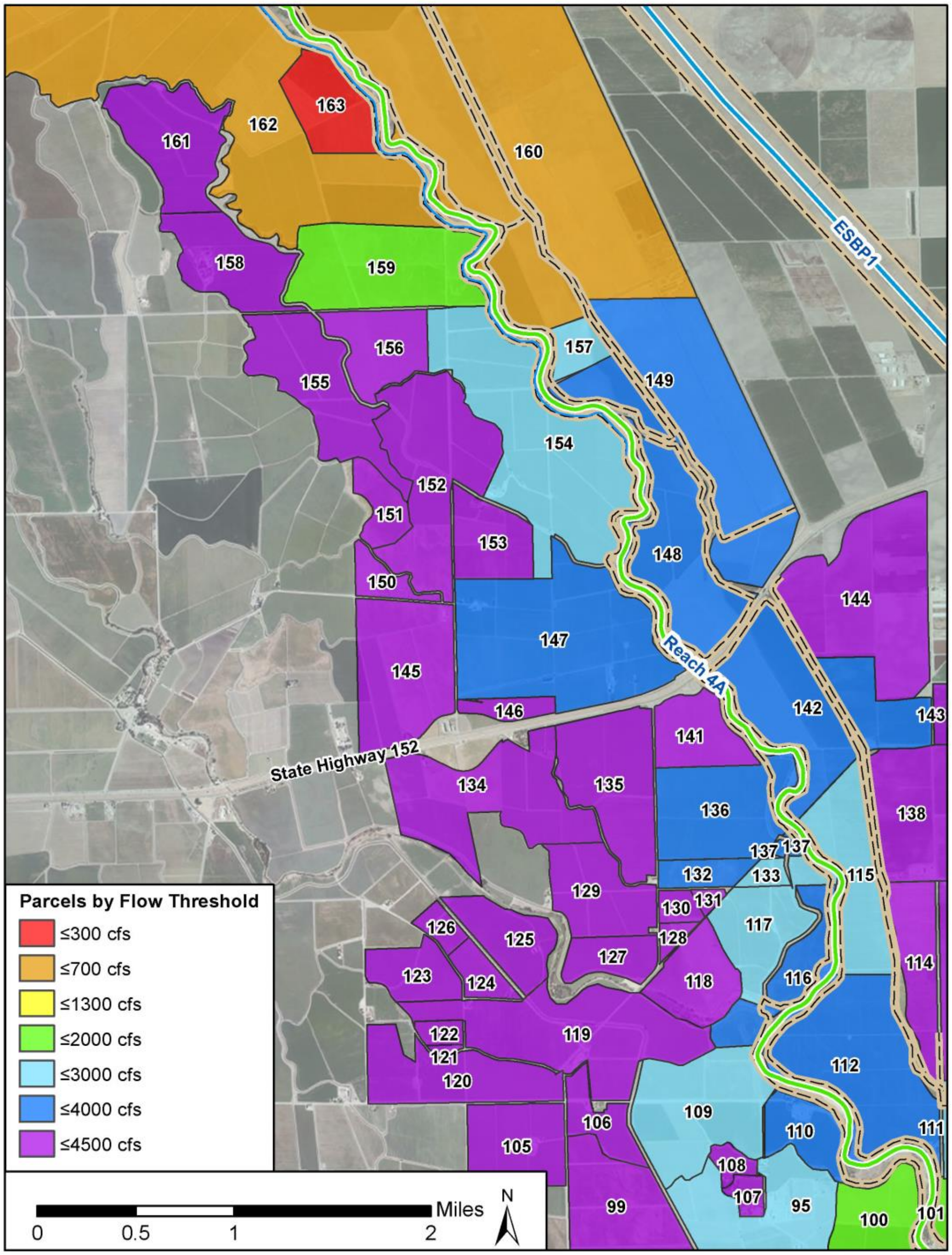


Figure C-35. Parcel Group Prioritization Map (5 of 7)

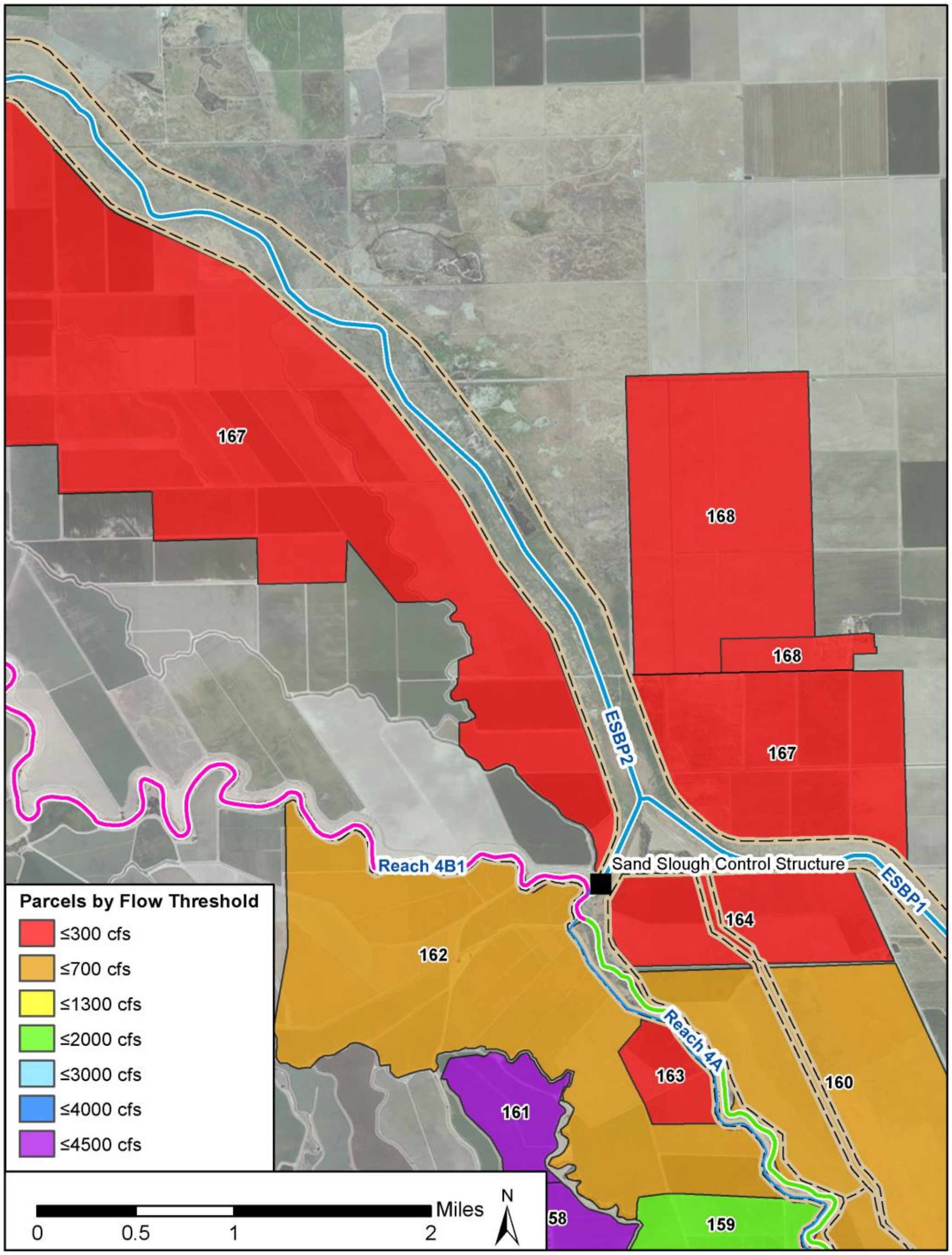


Figure C-36. Parcel Group Prioritization Map (6 of 7)

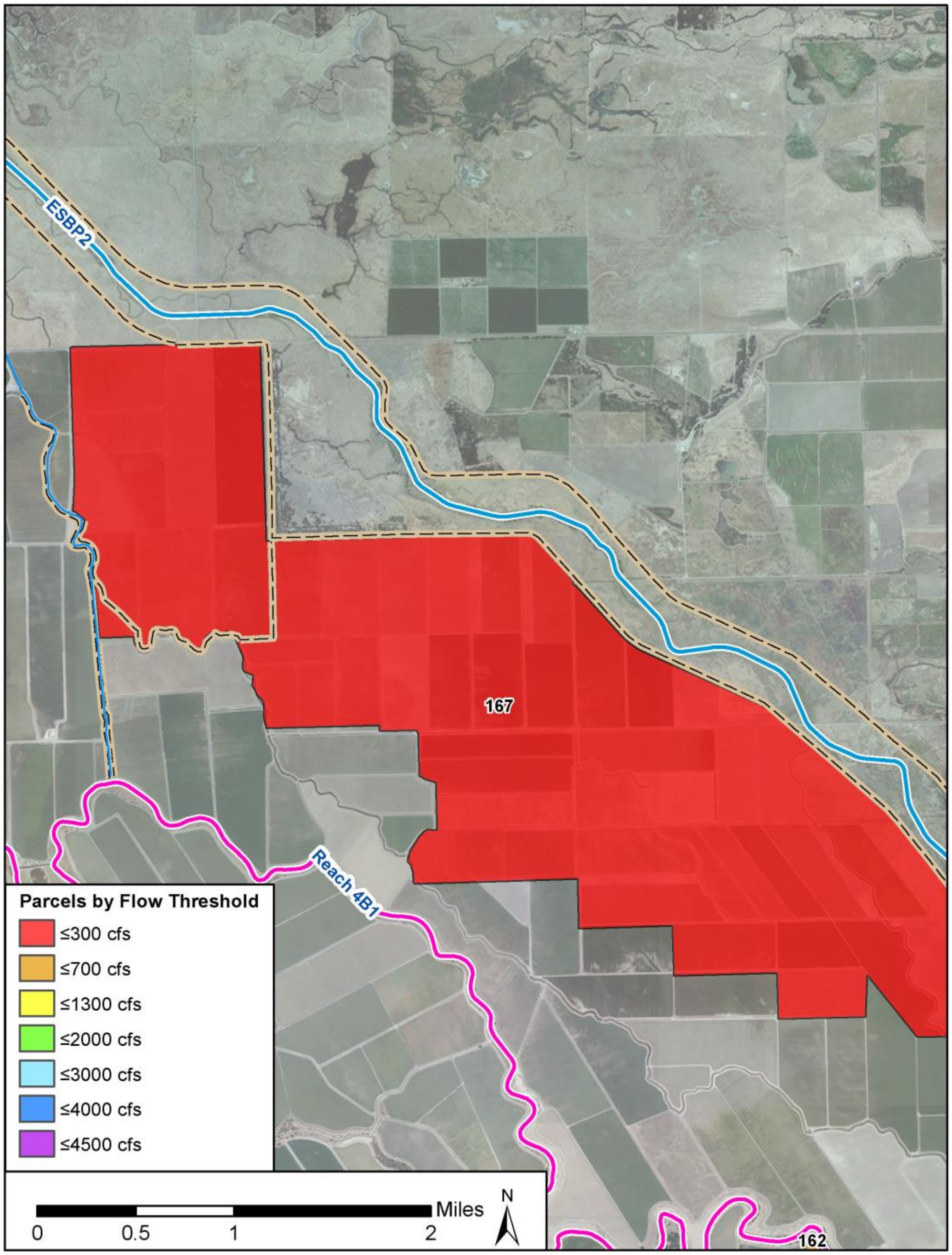


Figure C-37. Parcel Group Prioritization Map (7 of 7)